Evaluation of Work Zone Safety Using the SHRP 2 Naturalistic Driving Study Data

Phase I Final Report and Phase II Proposal

SHRP 2 Implementation Assistance Program

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Table of Contents

1. PHASE I- - SUMMARY OF RESEARCH AND FINDINGS

1.1 Background

Over 1,000 fatalities and 40,000 injuries occur annually in work zones in the US. Work zone crashes are not only a problem for the traveling public, they are a serious concern for highway workers who are injured or killed by errant vehicles. Between 106 to 133 worker fatalities per year occurred in work zones from 2010 to 2013 (1).

A number of factors are believed to contribute to work zone crashes. Several researchers have noted that work zone crashes are more likely to occur during the daytime (2, 3). Harb et al (4) did find night-time or conditions with low visibility increased the likelihood of a work zone crash. The time of day relationship may be due to traffic volumes and whether the work zone is active at night. Multi vehicle crashes were more predominant than single vehicle crashes with 42.7% being rear-end crashes (2).

Middle age drivers were primarily involved (64%) with 24% young drivers and 4% older drivers. Men were more likely to be involved (58.2%) (2). Type of work zone has also been evaluated. Akepati and Dissanayake (2) determined that 37% occurred within the work zone, 37% occurred with a lane closure, 18% with work on shoulder or median, 15% occurred with lane shift/crossover/head-to-head traffic, and 8.7% intermittent or moving work zone.

1.2 Rationale

A number of factors have been noted in the research as contributing to work zone crashes. Driver factors have not been as well studied since they are difficult to determine from crash data but it is largely believed that the main contributors are inattentive driving, speeding, and other unsafe driver behaviors, such as following too closely. A number of countermeasures have been utilized by agencies to get driver's attention and encourage safe work zone driving. However, there is limited information about which countermeasures are the most effective since driver behavior in work zones is not well understood for several reasons.

First, the most common method to evaluate crash causation is to analyze crash data. Crash data only include reported crashes and the level of detail provided is dependent on the attending officer. As a result, whether a crash is coded as work zone-related depends the on the officer's interpretation. In some cases, work zone traffic control may be present but the work zone is not active during the time the crash occurred and the traffic control is unrelated to the crash. In other cases, the impact of the work zone extends well beyond the extent of the work zone (i.e. queuing or congestion) but since the crash does not happen within the confines of the work zone, it is not reported as such.

The second issue is that little information can be gleaned from crash reports as to what the driver was doing which resulted in the work zone crash. It is commonly believed that the driver is the major factor but information such as distraction or speeding are only estimates.

The naturalistic driving study data (NDS) collected by the SHRP 2 offers a rare opportunity for a first-hand view of work zone safety critical events. Using these data, actual driver behavior can be observed. Additionally, using forward roadway views, a researcher can make a determination as to whether the event was actually work zone related or not.

1.3 Project Organization and Scope

A technical advisory committee (TAC) was formed at the beginning of the project as required by the Minnesota Department of Transportation (MnDOT). The TAC provided guidance and input on project tasks and served as a technical resource. Additionally, issues of interest were identified with the TAC which guided project scope:

- What is the relationship between work zone speed limit and driving speed?
- How to get drivers attention in advance of a work zone?
- How does work zone signing and configuration affect driver expectation and speed?
- How effective are ITS strategies in getting driver attention?
- Are work zone crashes more likely during recurring versus non-recurring queuing?

The goal of this research was to more fully investigate work zone safety using the unique data available in the SHRP 2 data as a proof of concept. In particular, the analyses addressed the role of speed and distraction in work zone crashes and near crashes. To accomplish this goal, work zone safety was explored from different perspectives and different analyses were conducted. First, work zone crash and near-crashes were used to identify related characteristics. A model to predict where a driver begins reacting to the work zone was also developed. Finally, a model was developed which predicts speed within the work zone based on work zone configuration and driver characteristics. Speed was used as a surrogate safety measure.

2. DATA SOURCES AND DATA REDUCTION

Several datasets were utilized in the analyses described in this report as noted below.

2.1 Events

The Virginia Tech Transportation Institute (VTTI) reduced a set of crashes and near-crashes from the SHRP 2 NDS data (4,246 total). Crashes/near-crashes can be viewed in an Event Detail Table available on the InSight website. Over 70 variables are provided including crash type, severity, driver actions, etc. A brief video clip of the forward roadway is included along with graphical display of select vehicle kinematics (i.e. speed, acceleration, distance into trip, wiper status). High level roadway and traffic characteristics are also included such as intersection type, traffic control, alignment, and level of service.

A total of 256 work zone related safety critical events (crash, near-crash, and crash relevant) were coded as “construction” in the Event Detail Table. A review using the forward roadway video indicated that many were coded as “construction” due to barrels or other work zone paraphernalia being present but the work zone was not relevant to the event. Each event was reviewed to determine whether they were actually work zone related which included a lane closure, presence of barrels or cones near the lane edge, presence of construction equipment or workers, dynamic message signs, or other characteristics which suggest the work zone may have contributed to the safety critical events. This resulted in 148 events.

Around 32,586 baseline events are also available. Similar information is provided as for the safety critical events except that a forward video clip is not available on the InSight website.

Baselines were randomly selected by VTTI with the goal of having at least 1 baseline per driver and the number of baselines for each driver proportional to the total driving time. A total of 1,171 baseline that are potentially work zone related were identified from InSight. The team had budgeted for a total of 600 to 700 total events (crash/near crash and baseline), so 443 baseline events were selected and data requested from VTTI. A total of 420 baseline events were received. Baseline events are typically 21 seconds long

Since data cannot be downloaded from the website, a download of attributes for safety critical and baseline events from the Event Detail Table was requested along with GPS coordinates, raw time series data (i.e. speed, acceleration, pedal position), and a video clip of the forward roadway. GPS coordinates could not be provided for any crashes due to privacy concerns.

2.2 Roadway Information Database (RID)

The RID contains detailed roadway data for around 12,500 centerline miles in the SHRP 2 NDS study states. This roadway data attributes collected include curve radius and length, rumble strips, lane width, and grade. The RID also combined data from several sources including state DOTs, HPMS, and other supplemental data which covered most roadways for each study state.

2.3 Description of Data and Data Reduction

The following summarizes general data reduction. If additional data reduction was necessary for a particular analysis, it is detailed within the corresponding summary. When GPS data were available, events were geocoded and matched against the roadway information database (RID). Roadway characteristics of interest (i.e. number of lanes, medians, roadway width) were extracted for each event. When roadway characteristics could not be obtained from the RID data, they were extracted from Google earth, the forward video view, or aerial images. Time of day (daytime, nighttime with no lights, nighttime with lights), ambient conditions (i.e. foggy), and pavement surface condition (i.e. wet, dry) were coded in the Event Detail Table.

Work zone configuration was coded using the forward view and included: number of closed lanes, type and location of barriers, presence of DMS or other ITS countermeasures, presence of workers, presence of equipment, lane shifts, and temporary pavement markings. Driver characteristics, such as age, gender, years driving, number of violations, etc. were provided for each driver. Driver behavior included: hands on wheel, impairments (i.e. drowsy, intoxicated), seat belt use, driving action (i.e. failure to yield), and speeding (exceeded speed limit or too fast for conditions).

Driver distraction was also coded in the form of secondary tasks. However, one of the limitations noted with the data in how secondary tasks were coded. First secondary tasks were only coded in safety critical events if they occurred within a 5 seconds window prior to start of the event. As a result, distractions that occurred upstream of the conflict were not included. For baseline events, secondary tasks were only coded for the last 6 seconds of the baseline epoch. As a result, engagement in secondary tasks is not necessarily comparable between crashes/near-crashes and baseline events. Additionally secondary tasks in all cases were coded when they involved non-driving related glances away from the driving task. As a result, duration of glances away from the forward view should correspond to length of secondary tasks but this does not appear to be the case since a number of tasks were recorded > 6 seconds and it is unlikely drivers were looking away for amount of time.

Studies have indicated that visually distracting tasks, such as dialing a hand held device, were much riskier than secondary tasks that did not involve glancing away from the driving task, such as talking or listening on a hand-held device (5, 6). Others have found longer eyes-off-road glances were positively correlated with safety risk (7, 8). Since duration of glances away from the driving task has been correlated to safety risk, one major limitations to the datasets used is inconsistency glance duration coding.

2.4 Limitations

Another limitation to the data is that baseline events did not include a full driving trace through the work zone. Baseline events were sampled for a random 21 second interval. As a result, the event typically included one of the following: 1) segment upstream of the work zone; 2) short segment upstream followed by a short section of driving with the work zone; or 3) segment within a work zone but did not include driving throughout the entire work zone.

As a result, many baseline did not include any within work zone driving and no data were available that represented a driver entering and traversing the entire work zone. The change point model and speed prediction model described in Sections 3.3 and 3.4, required this type of data and had to be adjusted as noted.

The main limitations noted are summarized below. Section 4 of this report describes how limitation will be addressed in Phase II.

- Sample size for crashes – was addressed in the Phase I analysis by using additional analyses and crash surrogates
- Baseline events do not include full driving trace upstream and through work zone
- Glance location and duration not consistently coded
- Secondary tasks coded only for short segments in safety critical and baseline events
- Steering wheel position is not widely available
- Alcohol sensor was not specific to the driver so intoxication is difficult to detect

2.4 Crash Surrogates

As noted above, only 110 safety critical events were available on multi-lane roadways were available. This is not a sufficient sample size to fully explore the relationship between work zone safety and driver and work zone characteristics. A number of researchers have employed crash surrogates to model safety impacts of countermeasures.

A number of crash surrogates have been proposed and each was examined to determine feasibility. Lane position offset, standard deviation of lane position, and encroachments are widely used in simulator studies as measures of safety risk (10, 11, 12, 14) and can be extracted with a moderate amount of success in general from the SHPR 2 time series data. However, the lane tracker utilized for collection in SHRP 2 depends on presence of lane lines or contrast between roadway surfaces. In many cases within a work zone, lane lines are discontinuous or obscured, lane shifts are present which are difficult to detect, and temporary lane markings may be overlain with permanent markings making it difficult to establish the actual vehicle path. As a result, lane position could only be established for a subset of the baseline events which were examined and was determined not feasible as a crash surrogate in this application.

Speed is considered to be a marker for unsafe driving. Around 31% of fatalities nationally are speeding-related (13). Related behavior such as braking or deviation in speed have also been utilized. Given the above information, speed was the only feasible crash surrogate.

3. METHODOLOGY AND RESULTS

Even with the full NDS dataset, work zone crashes and near-crashes were still rare events. As a result, the impact of driver speed and distraction on work zone safety was evaluated from several different perspectives. First, logistic regression was used to model characteristics present in safety critical events against corresponding baseline data. Next, speed, acceleration, and pedal position were used as indicators of where drivers began reacting to the presence of a work zone. Finally, speed was used a safety surrogate to assess driving behavior within work zones.

The majority of safety critical events occurred on multi-lane roadways (110 of 148 total events). As a result, due to time and resource constraints, only **multi-lane facilities** were included in the three analyses in Phase I to demonstrate proof of concept. Additionally although a number of different methodologies were considered and evaluated, only those which the team felt could be successfully incorporated into Phase II are included due to space limitations.

3.1 Summary of Safety Critical Event Characteristics

A descriptive analysis of the characteristics of safety critical and baseline events was completed and the results are presented below:

- 62% of safety critical events were rear-end, 25% were sideswipes, 5% collided with construction equipment, and 5% were roadway departures;
- 81% of events were "going straight", 10% were merging and 7% were changing lanes;
- Presence of equipment was noted in 66% and presence of equipment/workers (19%);
- 61% of safety critical events involved drivers 16 to 24 compared to 55% of baseline;
- 15% of safety critical events involved cell phone use compared to 11% of baseline;
- 23% of drivers in safety critical events were speeding compared to 8% for baseline;
- 13% of safety critical events were on wet roadways compared to 6% for baseline;
- 77% occurred during the daytime compared to 75% of baselines;
- 75% of crashes/near-crashes had no passengers compared to 65% of baseline.

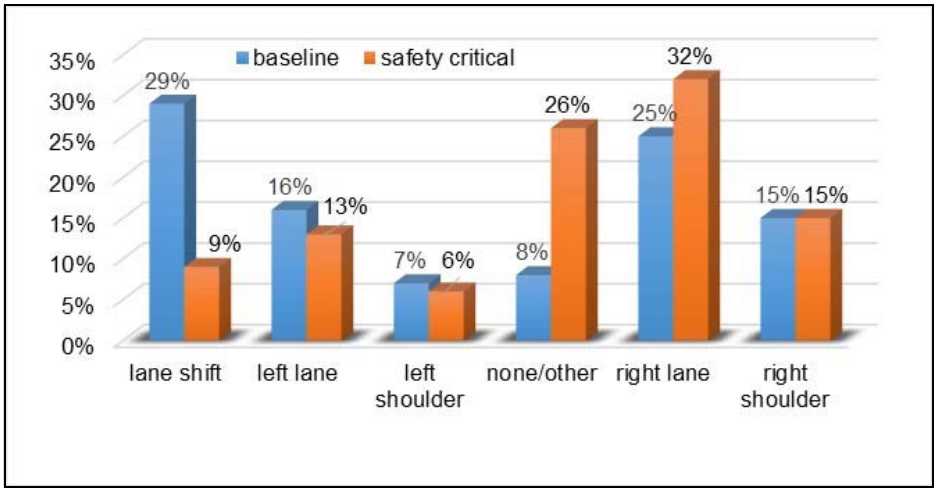

Figure 1: Lane closure Type and Location by Event Type

Type of work zone was summarized as shown in Figure 1. Right lane closure was the predominant work zone configuration (32%) for safety critical events compared to 25% for baseline. Lane shift with no shoulder accounted for 29% of baseline events compared to 9% for safety critical events. The number of left lane closures was higher for baselines (16% vs.13%) while right lane closures were over-represented for safety critical events (32% vs. 25%).

3.2 Modeling Crash Risk in Work Zones

The first analysis modeled risk factors related to safety critical events for multi-lane roadways. Data were compared against similar baseline events.

3.2.1 Description of Data: 110 of the safety critical events occurred on multi-lane roadways (4 or more lanes) which were primarily interstates or expressways and 89 baseline events were determined to be similar and were used as a measure of exposure. Each event was modeled as one observation. In addition to the characteristics included in Table 1. If the driver was engaged in a secondary task at some point an indicator for distraction was coded.

Standard deviation of speed was calculated using the times series data for each event. In some cases, the Event Detail Table indicated speeding. In other cases, speed was determined by comparing time series speed against the speed limit (when known). Speeding was defined as traveling 10 or more mph over the speed limit.

3.2.2 Description of Model: A logistic regression model was used to investigate the statistical relationship between safety critical events and roadway, driver, and work zone characteristics. Logistic regression or logit model was used to model work zone event type outcome. In the logit model, the log odds of the outcome is modeled as a linear combination of predictor variables. Odds is defined as ratio of the probability of the occurrence of safety critical event versus normal work zone driving condition (baseline).

3.2.3 Results and Benefits: Modeling results are presented in Table 1. The effect of all continuous and categorical variables were tested and those which were significant at 90% used to develop the best model. When a driver is speeding (10 mi/hr over posted speed), the odds of a crash/near-crash is 11.7 times higher than when a driver is not speeding. The odds are 3.27 times greater if driver is distracted and 3.4 times more likely to be female drivers. The odds of a work zone crash/near crash are 2.5 higher standard deviation of speed than for baseline events.

3.2.4 Discussion and Limitations: This preliminary analysis indicates that relationships can be derived between driver characteristics including distraction and speeding and work zone safety risk. It also provides some insight that work zone characteristics present in safety critical events.

This was a preliminary analysis using the data which could reasonably be obtained during Phase I. Limitations which can be addressed in Phase II include sample size, the inability to match baseline event to safety critical events, and inconsistencies in how secondary tasks and glance duration were coded.

Table 1: Logistic regression model parameter estimate for work zone event outcome

Variable	Coefficient Estimate	Std Error	Chi Square	Prob > ChiSq	Odds ratio (95% interval)
intercept	-7.437	1.382	28.95	<.0001	
speeding	2.463	0.907	7.37	0.0066	11.7 (2.2, 80.2)
distraction	1.186	0.639	3.44	0.0636	3.3 (1.0, 12.5)
speed variation	0.928	0.176	27.7	<.0001	2.5 (1.9, 3.8)
interchange/ intersection	1.751	0.822	4.54	0.0331	5.8 (1.235, 33.3)
urban area	2.434	0.673	13.09	0.0003	11.4 (3.3, 48.7)
gender	1.227	0.682	3.24	0.0721	3.4 (1.0, 14.6)

3.3 Identifying Work Zone Reaction Point

One of the questions posed by the TAC was how to get driver attention in advance of a work zone. Serious crashes have resulted when driver do not realize a work zone is imminent and unexpectedly encounter the back of a queue. Drivers react to the presence of work zones at some distance upstream of the start of the work zone. Factors such as traffic conditions, roadway geometry, speed limits and sign positions are all expected to affect this reaction distance. Understanding where drivers begin reacting to work zones provides important information on signing placement and work zone configuration. A change point analysis was utilized to assess driver reaction to presence of a work zone.

3.3.1 Description of Data: Speed, forward acceleration, and pedal position are available in the time series data (usually reported at 0.1 second intervals) with a reasonable amount of fidelity and were used to determine work zone reaction point. Steering wheel position was also available for a subset of those events. As noted in the limitation section, most events did not include a full trace through a work zone so only 13 baseline events had sufficient data upstream of a work zone to include the times series data.

The location of work zone signs and work zone start were extracted from the forward video and linked to the corresponding time stamp in the times series data. Distance was calculated using speed and time 300 meters upstream of the work zone.

3.3.2 Description of Model: Change point models were used to identify driver reaction point to upcoming work zones. Change point models can detect changes in the data by providing confidence levels. Additionally they can be used to detect more than one change in the data. The test is also reasonably robust to outliers. It's also suited to large datasets.

Individual models were developed for each time series trace using the dependent variables of speed, longitudinal acceleration, pedal position and steering position. Not all of the variables were available or had sufficient fidelity to include so the sample size varied by model as noted in Table 2. The R statistical package of R was utilized for the analysis, the model follows the form: $y = \beta_0 + \beta_1 D + \beta_2 (D - D^*)$ where: Y is the dependent variable for each model; D is distance upstream from beginning of work zone (negative value); and D* is change point (the distance at which the driver reacts to the curve).

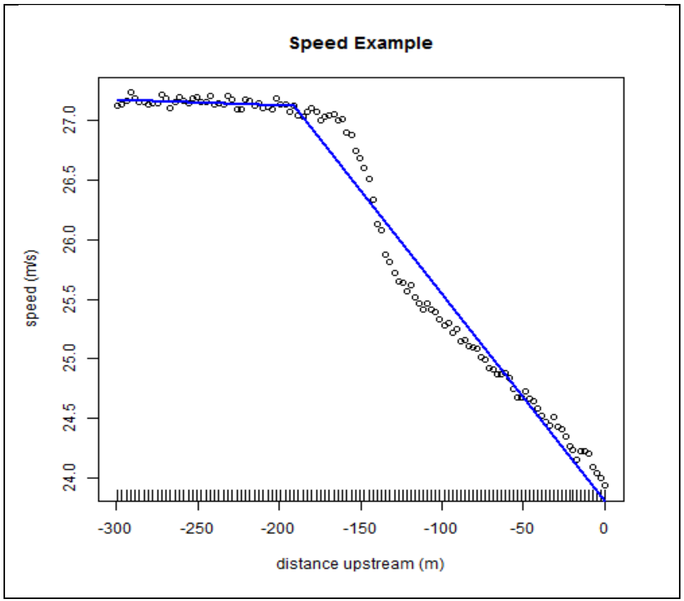

Figure 3: Example speed change point model

Figure 3 shows example output of the fitted change point models. The solid line shows the fitted model and the scattered points are actual observations.

3.3.3 Results and Benefits: After evaluating the time series data and model outcome, it was determined that longitudinal acceleration was not reliable enough to determine change point as there was significant noise in the data.

Speed models were developed for all 13 traces and all had statistically significant results. As noted in Table 2, the average driver adjusted their speed 140.8 meters upstream of the work zone with a standard deviation of 42.1 m. Pedal position was missing for several traces and in some cases a statistically significant difference could not be identified resulting in a sample size of only 5 traces. As noted, the average reaction point was 151.4 m upstream of the work zone. Steering wheel position was missing for approximately half of the traces and this model noted an average point of 128.1 meters. The change point detected between the 3 models was reasonably consistent. Average reaction point only varied by 23 meters (128.1 m to 151.4 m).

3.3.4 Discussion and Limitations: These results successfully demonstrated proof of concept that upstream change point can be determined. Speed appears to be the most reliable indicator of reaction distance. The main limitation was sample size. In Phase II, if a large sample of reaction points can be determined, it is expected that models can be developed to show reaction point based on different work zone characteristics such as upstream signing. Although not included in this model, the point at which drivers merge can also be extracted.

Another limitation is noise within the variables utilized to detect change point which is expected with field collected NDS data. In some cases, it is due to a malfunctioning sensor in which case the data are invalid. In most cases, variability in the data are present which are not true representations of vehicle activity. For instance, note the amount of variation in pedal position as shown in Table 2. Noise can be addressed in Phase II by filtering out traces where variables of interest are not reliable. Smoothing algorithms can also be applied.

Table 2: Change point model results (shown in feet)

	average distance	minimum distance	maximum distance	standard deviation	sample size
speed (m/s)	140.8	76.8	200.6	42.1	13
gas pedal position	151.4	100.6	273.6	70.7	5
steering wheel position	128.1	250.2	59.3	76.1	6

3.5 Speed Prediction Model

How drivers speed changes throughout a work zone as well as what elements affect their speed all play a role in the safety of the work zone. Understanding the relationship between speed and work zone characteristics can provide agencies with additional information to address speed management and safety in work zones. For instance, understanding the effect of countermeasures, such as the presence of an arrow board or dynamic message sign (DMS), on slowing drivers down can allow for better usage of these countermeasures.

The objective of this analysis was to evaluate the relationship between speed and driver and work zone characteristics using speed as a safety surrogate. To accomplish this, a speed prediction model was created which evaluated speed at various points throughout work zones based on driver, environmental and roadway factors.

3.5.1 Description of Data: Baseline time series data for rural multi-lane and interstate roadways were examined to determine feasibility for use in this analysis. The objective of this task was to assess how driver speed choice changed through the work zone based on changing work zone characteristics. This requires a full time series trace that includes travel upstream and then through the work zone. Due to time and resource constraints it was not possible to request additional data. As a result, the relationship through the work zone could not be fully incorporated in the model for Phase I. Baseline time series data were used to demonstrate whether the model was feasible and demonstrate proof of concept.

The analysis only included rural multilane work zones. A total of 87 baseline events had sufficient data within the work zone to be included in the analysis. Location within the work zone was determined using the forward view and correlated to the time series data via time stamp.

Data were sampled at multiple points were selected sampled sequentially upstream and within the work zones. In most cases 2 or 3 points per time series traces was sampled but only one was included in a few. Each point was modeled as one observation. A 1.5 second timestamp was marked around each point and speed was averaged for this interval. Driver distraction, if present, for the specified interval was extracted. Corresponding roadway, environmental, driver and work characteristics, as described in Section 2.3, were included for each point.

3.5.2 Description of Model: A linear mixed effects (LME) was used to model the relationship between speed and work zone, roadway, environmental, and driver characteristics. This methodology was chosen since it can account for repeated sampling of a variable using a random effect. In this case, multiple samples were taken for each EventID. Additionally the model allows for 2nd order autocorrelation correction which was necessary as the data were correlated due to their close proximity in time. The best fit model was determined using the statistical package “R” and minimizing statistics such as the AIC.

Speed (mph) was the dependent variable. A total of 87 work zones were sampled resulting in 226 data points. Covariates included number of drivers, work zones, roadway, and environmental characteristics.

3.5.3 Results and Benefits: The results for the best fit model are shown in Table 3. Since data were sampled at varying locations within the same work zone, a categorical variable was used to indicate sequential order of the repeated samples (i.e. entrance, midpoint 1). Although not statistically significant but they were included to show order within the work zone).

Table 3: Best Fit Speed Model

Variable		Estimate	Std Error	p-value
intercept		27.383340	11.492183	0.01868
point in work zone	entrance	-0.551395	0.782294	0.4821
	midpoint 1	-1.216261	1.099864	0.2708
	midpoint 2	-0.642614	1.211712	0.5968
	midpoint 3	-0.059670	1.408128	0.9663
	midpoint 4	-2.216483	1.894261	0.2441
curve (1=Y, 0=N)		-7.165752	4.067046	0.0817
speed limit (mph)		0.585144	0.178884	0.0016
number of closed lanes (no DMS)		-6.002645	1.857361	0.0016
number of closed lanes with DMS present		-7.611817	2.409343	0.0020
Phi 1 = 1.4823897		Phi 2 = -0.5683737		
random effect for Event ID		0.008943856	10.63758 (residual)	

When a curve was present speeds were slower (7.2 mph). Higher speed limit on the corresponding segment also increase the expected speed. Speeds were also lower when more lanes within the work zone were closed. Speed is expected to be 6.0 mph lower for each additional lane that is closed if a DMS is not present and 7.2 mph if a DMS is present. The presence of a DMS decreases speed by approximately 1.6 mph. The sample of work zones with DMS was small, but was found to be statistically significant.

The model could not definitively determine a statistically significant decrease in speed due to presence of workers and equipment. It was significant at a 75% confidence level and was found to decrease speeds by 2.9 mph. However co-variates were only included in the model if there were statistically significant at the 90% confidence level. With additional data, a correlation may be able to be determined within the model.

3.5.4 Discussion and Limitations: Results indicate the data can be obtained and the model is feasible. The main limitations are that complete traces through the work zone were not available. Another limitation is that secondary tasks were only coded by VTTI for the last 6 seconds of each baseline so distraction was not available for a number of the observations.

4. PHASE II RESEARCH PLAN AND FUTURE DIRECTION

Phase I provided preliminary results which demonstrated the feasibility of assessing work zone safety using the SHRP 2 NDS and RID data. Tasks were updated according to known limitations and a research plan outlined for Phase II.

4.1 Objective and Background

The goal for Phase II is to determine how drivers negotiate work zones and determine the factors present when safety critical situations arise as compared to normal work zone driving. Results from Phase I suggest that the impact of speed, driver distraction, work zone configuration and roadway characteristics can successfully be included in the analyses suggested.

After Phase I, the team coordinated with TAC to reestablish priorities based on initial findings. The analyses in Phase I demonstrated that the data and methodologies needed to address four of the TAC's issues of interest can be accomplished in Phase II through 3 main tasks:

1) Analysis of safety critical events: addresses the relationship between driver and work zone characteristic and safety;
2) Development of a model to identify reaction point: addresses the question of what gets a driver's attention in advance of a work zone and the effectiveness of ITS strategies;
3) Development of a speed prediction model: addresses the relationship between speed limit (and other work zone characteristics) and driving speeds. The last issue of interest was whether work zone crashes were more likely with non-recurring queuing than for recurring queuing. This task will include queuing but it will be difficult to determine whether the queuing is recurring.

All work zone types and roadway types present will be included in the analysis of safety critical events (Task 3) since there are only 148 events. However, it was necessary to focus resources for the other two analyses. Severe crashes are more likely on rural high-speed roadways and a large number of safety critical events occurred on multi-lane roadways. As a result rural multi-lane roadways will be one focus. Additionally the TAC was interested in rural 2-lane operations which will also be included.

Additionally, only longer term work zones will be included. Akepati and Dissanayake (2) determined 8.7% of work zone crashes occurred in intermittent or moving work zones. Short-term and maintenance work zones may be a significant safety hazard since they are unexpected. However, identifying work zones where subject drivers were present is not a trivial task and it would be difficult to sufficient data in work zones that only last a few days.

The role of driver distraction and reaction is an important component of the proposed research. As a result, the team is joined by Dr. Susan Chrysler, a human factors consultant who specializes in improving the roadway users' experience through optimizing roadway design, traffic control device, and traffic operations. Dr. Chrysler is currently a Senior Research Scientist at the Texas A&M Transportation Institute and is the former Director of Research at the National Advanced Driving Simulator at the University of Iowa. Dr. Chrysler's areas of expertise include human factors, driving simulation, driver behavior, driver distraction, traffic operations, and visibility. She has led or participated in numerous projects on work zone safety, driver distraction and human factors in-vehicle research on test tracks and open road.

Although including three analyses in the scope seems ambitious, it should be noted that a large share of project time and cost are in data acquisition and reduction. Once data are processed and available, conducting multiple analyses can be done reasonably efficiently.

The tasks proposed to complete the research are summarized below. The proposed solutions to limitations raised in Phase I are noted as they are addressed.

4.2 Outcomes and Benefits of the Research

Three different analyses will be utilized to assess work zone safety from a different perspective. The first will determine which factors are associated with increased or decreased odds of a safety critical event given relevant roadway, driver, or environmental characteristics. Results can be used directly by stakeholders to assess the impact of different strategies or countermeasures. For instance, in Phase I the preliminary model indicated that both speeding and increased variation in standard deviation of speed was associated with higher odds of a safety critical event in a work zone. This information suggests the importance of speed management in work zones.

The second analysis will identify driver reaction point which can be used to detect the point at which drivers react (or do not react) to upstream signing, presence of a queue, and beginning of a work zone. This information can be used to assess work zone signing placement and to determine which factors are more likely to get drivers attention before entering the work zone. Similarly, the analysis may provide insight as to why drivers miss cues. For instance drivers who are texting or have longer glances away from the driving task may have shorter reaction distances.

The third analysis will develop a model to predict driver speed. The output will be change in expected speed due to presence of a particular roadway or driver characteristic. Results from Phase I indicated that presence of a DMS sign was associated with lower speeds. This type of information can help practioners assess the impact of different work zone configurations on driver speed.

Task 1: Update IRB and Management Plan with MnDOT

The first task will be to develop a new IRB which will be required for a second phase of the project. The current team has all needed IRB training. Additionally Dr. Chrysler has completed all of the necessary IRB requirements and will obtain IRB approval as needed.

A TAC was required for Phase I since the funds were associated with the Minnesota DOT. This will no longer be the case in Phase II but the team will work with AASHTO and FHWA to retain the TAC in order to provide overall perspective to the project. The team will review planned tasks with the TAC and obtain feedback.

Task 2: Data Needs, Data Request, Data Reduction

Two different types of data are necessary for the analyses proposed for Phase II as described below. Specifications for the data required will be determined in Task 2 and a data sharing agreement developed. The DSA will also include permission to continue using in-house data.

Crash/Near-Crash Event: 148 crashes/near-crashes were identified in Phase I which were work zone related. A number of different roadway types were included. Driver and environmental characteristics were extracted for all safety critical events. Some roadway characteristics were available for all events but GPS location could not be provided for crashes so some roadway characteristics, such as speed limit, could only be reduced for crashes. Crashes can be viewed at the VTTI secure data enclave so roadway characteristics will be reduced during a data reduction visit for time series traces in Phase II.

Additionally, the concern with glance duration as discussed earlier will first be discussed with VTTI. If glance location was not coded, duration of glances associated with secondary tasks will also be extracted during a data reduction visit to the secure data enclave.

Time Series Traces: Tasks 3 and 4 require time series traces which traverse the entire work zone. The number of observations needed to accomplish Tasks 4 and 5 was estimated by assuming around 50 observations are necessary for each factor to be included in a model. Approximately, 21 co-variates will be tested for Task 5. As a result, around 1050 time series traces will be requested for each roadway type included in the analysis. The limitation of sample size and baseline coverage noted in Section 2.3 are addressed in this task,

Three different strategies will be used to identify work zones in the NDS.

Existing Baselines: 1,171 baseline events indicated as work zone related were present in the Event Detail Table (InSight website). Of those 443 events corresponded to multi-lane facilities and were reduced for Phase I. The team will review the remaining baseline events to determine those on rural 2-lane roadways. The location of work zones which were included in near-crash were also geocoded and catalogued. A matrix of work zone characteristics represented by these known work zones will be evaluated against the range of desired characteristics and gaps identified. Table 4 shows characteristics to be included. All are known to be present in the SHRP 2.

Table 4: Work Zone Configurations

	DMS	Other ITS	1-lane closure	2-lane closure	2+ lanes closed	head to head	left merge (vs right)	barrels/ cones	jersey barrier	free-flow	queuing
multi-lane	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
rural 2-lane with flagger	**X**	**X**	**NA**	**NA**	**NA**	**NA**	**NA**	**X**	**X**	**X**	**X**

511 Data: Next the 511 data which was included as a supplementary database to the RID will be used to identify work zones. There is no specific field in 511 data which can identify work zone types, but the event description field describes type of construction activity and possible closure for work zone sites. A text search will be conducted over this field looking for words such as “lane closures” or “head-to-head”. The event description field for New York was examined by

applying text search procedure to identify various work zone types. Table 5 shows the number of work zones types identified for New York. The categories on not mutually exclusive.

Table 5: NY Work Zones by Type

lane closure	45
alternating direction	13
reduced to 1 lane	70
reduced to 2 lanes	38
right lane closed	85
left lane closed	55
right shoulder closed	41
left shoulder closed	7

<u>*Image Processing*</u>: Since ITS strategies are of interest, image processing on high resolution RID videos will also be utilized. The automatic extraction of presence of work zone and identification of ITS devices will be achieved by using “deep convolutional neural networks” (CNN) based robust computer vision system (Figure 4). The architecture of a CNN is designed to take advantage of the 2D spatial structure of an input image. CNN has led to several breakthrough results especially in the area of computer vision and pattern recognition. CNN based vision technique has shown promising preliminary results for identifying traffic signals i a current project being conducted by the research team. For this project, a large image inventory of ITS infrastructure, work zone equipment will be prepared using manually verified images. This dataset will be used to train and validate a deep neural network. Once the model is validated, it will be used to automate the processing RID video feed to automatically find the work zones and classify ITS devices.

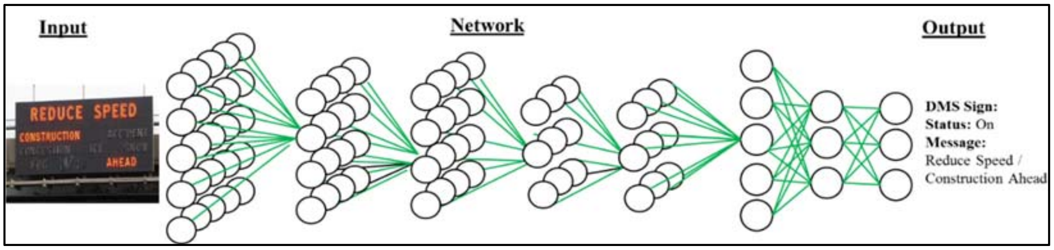

Figure 4: Deep Convolutional Neural Network

<u>*Final selection of work zones*</u>: Work zones identified using the 3 methods described above will be overlain with a trip density map to ensure the corresponding roadway segment is likely to have additional trips. Work zones characteristics will be mapped in a matrix to ensure sufficient work zones with the characteristics desired (see Table 4) are included.

Data Request: A buffer will be created around each identified work zone. A review of work zone plans in the MUTCD indicates that the maximum distance upstream that work zone signs would be located is 2,640 feet. Allowing another 0.5 mile to ensure normal driving is captured a total upstream distance of 5,280 feet will be included. This will allows us to establish normal driver behavior before encountering the work zone and then assess driver response as they receive work zone indicators upstream and how driver behavior changes as they enter and proceed through a work zone. The buffer will also include the length of the work zone to a distance 100 feet downstream.

Depending on the number of trips that are likely to be available, 20—30 time series traces will be requested from VTTI for each work zone. A trace is 1 trip for 1 driver through a roadway segment. Baseline event may be included but it will be necessary to request data for the entire buffered segment. Trips requested will be balanced across driver age and gender. Ideally driver impairment would be known so that fatigue and alcohol/drug impairment can be included. As noted in Section 2.3, an alcohol sensor was present but is not a robust indicator of driver impairment. Other impairments are only available after coding the driver face video so it is not possible to intentionally include a pre-determined number of samples with a particular impairment.

Times series data includes variables such as speed, acceleration, pedal position and all are typically available. However, in some cases a variable is reported at less than 0.1 seconds intervals (i.e. every 8th interval). Since this does not have sufficient resolution to detect a change, the team will work with VTTI to set a filter to ensure traces utilized for this task have continuous speed and pedal position. Steering wheel position was only collected in a subset of vehicles since the code for extracting steering wheel could not be obtained from all manufacturers. As a result, time series traces will not be intentionally selected to include steering wheel position since this would bias the sample to a certain vehicle type. Steering wheel position will be included when available. This addresses the limitation of steering wheel position as noted in Section 2.3. A forward video clip will also be requested for the duration of each trace. Driver (i.e. age, gender, violations) and vehicle characteristics will also be requested.

Reduction of Roadway/Environmental/Work Zone Factors: The forward video will first be checked to ensure a work zone is still present. Although we have some indication of dates from the 511 data, they are unlikely to be exact. Data reduction protocols will be developed to ensure data collectors are consistently coding various variables. The main characteristics to be reduced are shown in Table 6.

Roadway factors for near-crash and baseline data are already available. New time series traces will be overlain with the RID and roadway factors extracted. When not available, the forward video view, Google Earth and other data sources will be utilized. Some work zone characteristics will be available from the 511 data. Others will be reduced from the forward view. Location of advance signing, start of work zone, location of changes within work zone, etc. will be also be reduced from the forward view and correlated to the time series data using the video time stamp. Examples of various work zone configurations are shown in Figure 5. Time of day can be extracted from the time series data. Ambient conditions (i.e. raining) can be obtained from a review of the forward view or inferred from wiper/headlight use. Roadway surface condition will also need to be extracted from the forward view.

Reduction of Driver Factors: Studies have indicated that visually distracting tasks, such as dialing a hand held device, were much riskier than secondary tasks that did not involve glancing away from the driving task, such as talking or listening on a hand-held device (5; 6;) and longer eyes-off-road glances were positively correlated with higher roadway departure risks (7; 8).

Distractions and secondary tasks in the event detail table were described as being associated with a glance away the driving task. As noted in Section 2.3, it will be necessary to confirm accuracy of glance location coded in crash and near-crash events. If the issue cannot be resolved we will explore whether glance location should be coded in a visit to the secure data enclave. Glance and secondary tasks data are available for some of the times series traces that the team already has access to as indicated in Table 6. Driver glance and engagement in secondary tasks will be

Figure 5: Various Work Zone Configurations in Baseline Events

reduced for additional traces as needed. The team developed a methodology to reduce driver glance location and distraction associated with glances away from the driving task in SHPR 2 S08. We will utilize the same methodology for Phase II (9). Glance and secondary tasks will be coded by time stamp so that when data within the segment are sampled, the corresponding driver behaviors can be included.

Many of the same variables will be included in all three of the analyses as listed in Table 6.

Table 6: Characteristics to be Included in Various Analyses

static driver	age	gender	number of violations	number of crashes
	miles driven/yr	years driving		
dynamic driver	glance location and duration	secondary tasks	hands on wheel	impairment (i.e. sleepy)
	seat belt use	num. of passengers		
roadway	speed limit	num. of lanes	shoulder type	lane width
	median type	alignment (tangent, curve)	grade	
environmental	time of day (i.e. daytime, night/no lights)	ambient (i.e. raining)	surface condition (i.e. wet)	LOS
work zone	number of closed/open lanes	DMS	other ITS	type and location of barriers
	equipment/workers	advance signing	length	lane shift

Data Security Plan: all team members and staff who have access to the data have IRB training and will be included in the DSA. InTrans hosts and manages several servers on-site. For IRB-protected data we have an isolated backup routine on separate media that is always within control of either IT staff (in the locked server room) or the project PI. When not in the locked server room, media is located off-site at a locked location within a locked fireproof safe with only IT staff and the project PI having access to the keys.

Task 3: Analysis of Safety Critical Events

The objective of this task is to assess the factors associated with safety critical events which will include crashes and near-crashes of all severity levels. Several limitations were raised during Phase I which will be addressed in Phase II.

Data Needs: A total of 148 safety critical events were determined to be work zone related in Phase I. The definition of work zone related was described in Section 2.1 and included events which occurred within an active work zone or upstream but were a result of the work zone. As time series traces are evaluated for Tasks 3, 4, and 5 instances of conflicts will be flagged and coded as near-crashes to be included in the analysis. This would include hard braking, swerving, encroachment into the work zone, etc.

Baseline events used in Phase I were determined to not be feasible for Phase II since they do not include complete work zones, do not necessarily represent the same work zone configurations, and driver data were only reduced for the last 6 seconds. As a result, baseline events are not adequate for use as measures of exposure.

Spatial location of work zone corresponding to safety critical events are either available or will be available as described in Task 2. They will be included in the list of work zones for which time series data will be extracted. Time series data will be requested for these locations as described in Task 2. If a sufficient number of traces cannot be identified for a particular work zone, similar work zones will be identified from the data utilized from Tasks 3 and 4.

Data will be requested and reduced as described in Task 2. Data will be modeled at the event level (one observation per safety critical event or time series trace). As a result, roadway, work zone, driver, and environmental factors will be aggregated to that level. The amount over the speed limit immediately before the event will be extracted as well as average speed.

Analysis: Logistic regression was selected as the appropriate statistical model in Phase I. Additional information about model function is described in Section 3.2.2. The probability of a safety critical event is the dependent variable. Ideally, severity could be included as the dependent variable but given only 148 crashes and near-crashes are available, it is unlikely statistical significance can be determined. The co-variates listed in Table 5 will be included in the model.

Expected Outcome and Application for Stakeholder: Model outcome is the odds of a safety critical work zone event given a specific roadway, driver, or environmental factor. For instance, results in Phase I suggested that drivers who were speeding were 12 times more likely to be involved in a safety critical event. Odd ratios are easily understood by stake holders and can be used in a similar manner as crash modification factors. The odds ratio and confidence interval can be provided so that the confidence of a particular result can be assessed.

Odds ratio also provide information that can be used quantitatively in making decisions about selection of countermeasures. For instance, understanding crashes are ‘XX’ times less likely when DMS are used provides information that can be used in cost/benefit analyses. Products which are expected from this Task are summarized in Task 6.

Task 4: Modeling Driver Reaction to Work Zone

The objective of this task is to determine where drivers begin reacting to the work zone. Task results will provide information about the interaction between drivers and work zone configurations.

Data Needs: Time series traces will be utilized for this task. Speed, pedal position, and steering wheel position were the metrics identified in Phase I to identify reaction point.

Driver, roadway, and environmental characteristics will be reduced as described in Task 2. Additionally, location of work zone elements (i.e. advance warning, merge point) will be coded at the appropriate time stamp. This allows distance upstream from various features to be determined so that reaction point can be calculated in relationship to advance signing or start of work zone.

Analysis: Change point models can detect changes in the data by providing confidence levels. Additionally they can be used to detect more than one change. As a result, reaction to upstream signing as well as reaction to the merge point can be included in the same model. The test is also reasonably robust to outliers and is suited to large datasets.

Due to the nature of the change point models, one will be developed for each time series trace for each dependent variable (i.e. speed, pedal position, or steering wheel position). Model output will be averaged across traces for similar work zone configurations. Change point for the different dependent variables will be compared for the time series trace and similar work zones.

Expected Outcome and Application for Stakeholder: The outcome of the change point model is the upstream point at which a change in the metric of interest (i.e. speed changes) occurs. This serves as an indicator of driver reaction. As a result, the point at which a driver begins reacting to the presence of an advance work zone warning sign, intermediate warning sign, or actual begin of work zone can be modeled. Instances of queueing can be included, when available, so that driver reaction to back of queue can be included.

Outcome can be used to assess placement of signing, assess which factors get drivers attention, and the role of distraction in driver reaction. For instance, model output may show that drivers who are texting or engaged are likely to miss the back of a queue.

Task 5: Predicting Speed as a Function of Speed and Driver Characteristics

The objective of this task is develop a relationship between speed and driver, roadway, and work zone characteristics. Speed is used as a safety surrogate and speed prediction models will be created which evaluate speed at various points throughout work zones based on corresponding factors.

Data Needs: The roadway type and work zone configurations are the same as those modeled in Task 4. As a result, much of the time series data reduced and utilized in Task 4 can also be used in this task. Data will be selected at points upstream and within the work zone as illustrated in Figure 6. Static roadway, environmental, work zone and driver characteristics will be extracted as noted in Task 2.

Dynamic characteristics will be collected at each point. For instance data extracted at point 2 would show 2 open lanes, no workers or equipment, and no distractions. Point 4 would show 1 lane closed, barrels on right lane line, driver is texting, and no workers or equipment while point 5 would show the same thing but workers/equipment would be present. Speed will be averaged for a 1 second interval around each point to avoid outliers. Secondary tasks, glance location and duration, and driver state (i.e. sleepy, impaired) will be coded at the VTTI secure data enclave as noted in Task 2.

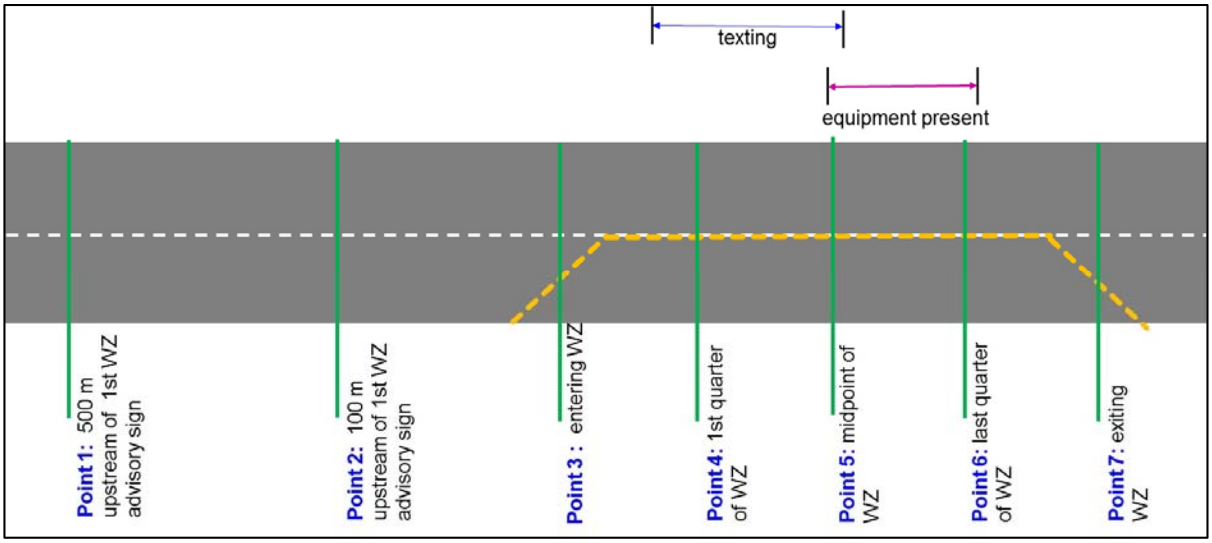

Figure 6: Schematic of Data Collection Points for Task II-5

Analysis: A linear mixed effects (LME) model will be used to assess the relationship between speed and work zone, roadway, environmental, and driver characteristics. LME can account for repeated sampling of a variable using a random effect and can account the proximity in time between samples for the same time series trace. Speed is the dependent variable and the model can predict speed as a function of driver, roadway, and environmental characteristics. Additionally the relationship to speed at upstream data points for the same times series can be accounted for using a categorical variable to indicate sequential order of the repeated samples.

Speed is the dependent variable and will be modeled as a function of the roadway, work zone, and driver characteristics including those shown in Table 5.

Expected Outcome and Application for Stakeholder: Prediction of speed given prevailing characteristics is the model outcome. For instance, in Phase I, presence of a DMS was shown to decrease work zone speeds by 1.6 mph for each lane that is closed. This type of information can be easily interpreted and applied in decisions about countermeasure selection.

The model will include driver characteristics (i.e. glance duration, secondary tasks), roadway, environmental (i.e. time of day), and work zone characteristics. As a result, we expect that model outcome will provide information such as the impact of different merge configurations or ITS strategies such as flashing beacons on work zone speed.

Information about the relationship between speed and work zone characteristics can be used to assess work zone configurations and determine what aspects are the most likely to get drivers to comply with work zone speeds. The relationship between speed and driver attention (glance location, distraction) can be used to better understand why drivers fail to notice work zones. Products from Task 5 are described in the following task.

Task 6: Final Report and Outreach

The final task is to summarize project results. A final report will be developed which will detail data collection and reduction, methodology and results by tasks, limitation, lessons learned, and recommendations.

Since one of the main goals of this research is to develop products that can be directly used by stakeholders, we propose developing the following products in addition to the final report. One technical brief (2 to 4 pages) will be created for each major task. It will summarize the background and methodology that can be understood by transportation agencies. The major feature of the tech briefs will be charts/figures/tables that will display key findings in a format that can be easily used. Additionally results will be interpreted in the context of how stakeholders use the information and recommendations based on task findings will be made. Stakeholders also include policy makers so the impact of findings such as texting or cell phone use increase the likelihood of a work zone crash will also be presented for this audience.

For example, odds ratios will be developed for Task 3. They can be displayed in a chart organized by factors of interest (i.e. work zone configuration) so the results are easily accessed. A finding such as: *glance durations away from the roadway task of more than 2 seconds increase the odds of a safety critical work zone event by 2.5 times* might be interpreted as: *countermeasures which focus driver attention to the forward roadway are likely to be most effective in reducing crashes in work zones.*

The team will also meet with the TAC to review project results and ensure products are useful. Additionally, the team will develop an implementation plan with the TAC and other interested stakeholders. This may include development of additional outreach material, webinars, and presentations at county and state organizations such as the National Association of County Engineers.

APPENDIX

A.1 Schedule

The estimated duration of Phase II is 28 months. This will provide sufficient time to procure additional data from VTTI, complete project tasks, and summarize results.

Table A-1: Summary of Task Milestones

Task	Month								
	1-3	6 - 8	9 - 12	11 -13	14- 16	17 - 19	20 - 23	24- 26	27- 28
1. Update IRB	🟩								
2. Data request and reduction		🟩	🟩	🟩	🟩				
3. Analysis of safety critical events				🟩	🟩	🟩	🟩		
4. Develop driver reaction model					🟩	🟩	🟩	🟩	
5. Develop speed prediction model					🟩	🟩	🟩	🟩	
6. Final report, outreach									🟩

Quarterly or other reports will be provided as requested.

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