IOWA STATE UNIVERSITY
Civil, Construction and Environmental Engineering

Modeling driver work-zone speed on 4 lane divided highways

7th International Symposium on Naturalistic Driving Research

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Problem Statement

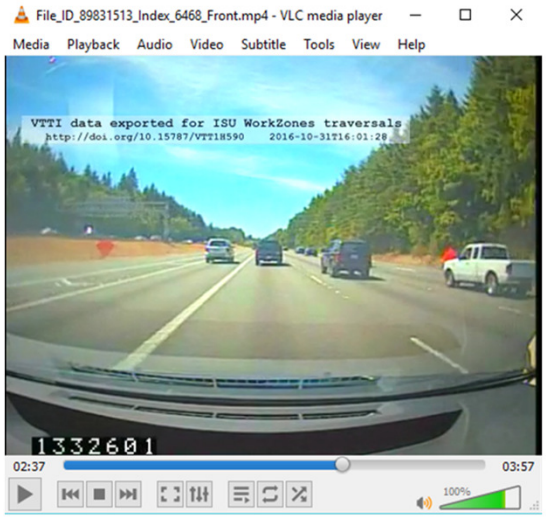
- Around 48000 injuries were estimated to have occurred in work-zones crashes during 2013.
- Work zone crashes are also a serious concern for highway workers. More than 20,000 workers are injured each year.
- Previous studies have shown that work-zone crashes were more severe than other crashes (rouphail et. Al., 1988; pigman et al., 1990, and aashto 1987).
- Transportation agencies and contractors have used numerous countermeasures to get drivers' attention in work zones.
- However, limited information about which countermeasures are the most effective since driver behavior in work zones is not well understood for several reasons.
- The availability of Naturalistic Driving Study (NDS) data by the Second Strategic Highway Research (SHRP2) offers an opportunity for first-hand observation of driver behavior in work-zones.

Data Sources

- The second Strategic Highway Research Program (SHRP2) Naturalistic Driving Study (NDS) data.
- Roadway Information Database (RID) Supplemental 5-1-1 data.
- 5-1-1 is a transportation and traffic information telephone hotline to inform drivers regarding road conditions and traffic. Currently 35 states participates in the 511 system.
- The 5-1-1 data served as the main source of data for finding out construction and maintenance events for this study.

Some Identities

- **Trace:** A trace is one time series file with driver speed along a particular work zone.
- **Forward Videos:** Driver front videos captured by the Data Acquisition System.
- **Work Zone ID:** Work Zone at a given location at given date duration.
- **Event ID:** Unique IDs for each trace.
- **Anonymous Driver ID:** Unique ID for Each Driver
- **Timestamp:** Random number in sequential increasing order given to every incremental 0.1 seconds along a trace.



Data Collection

511 data (mined for construction and maintenance)

2 million records

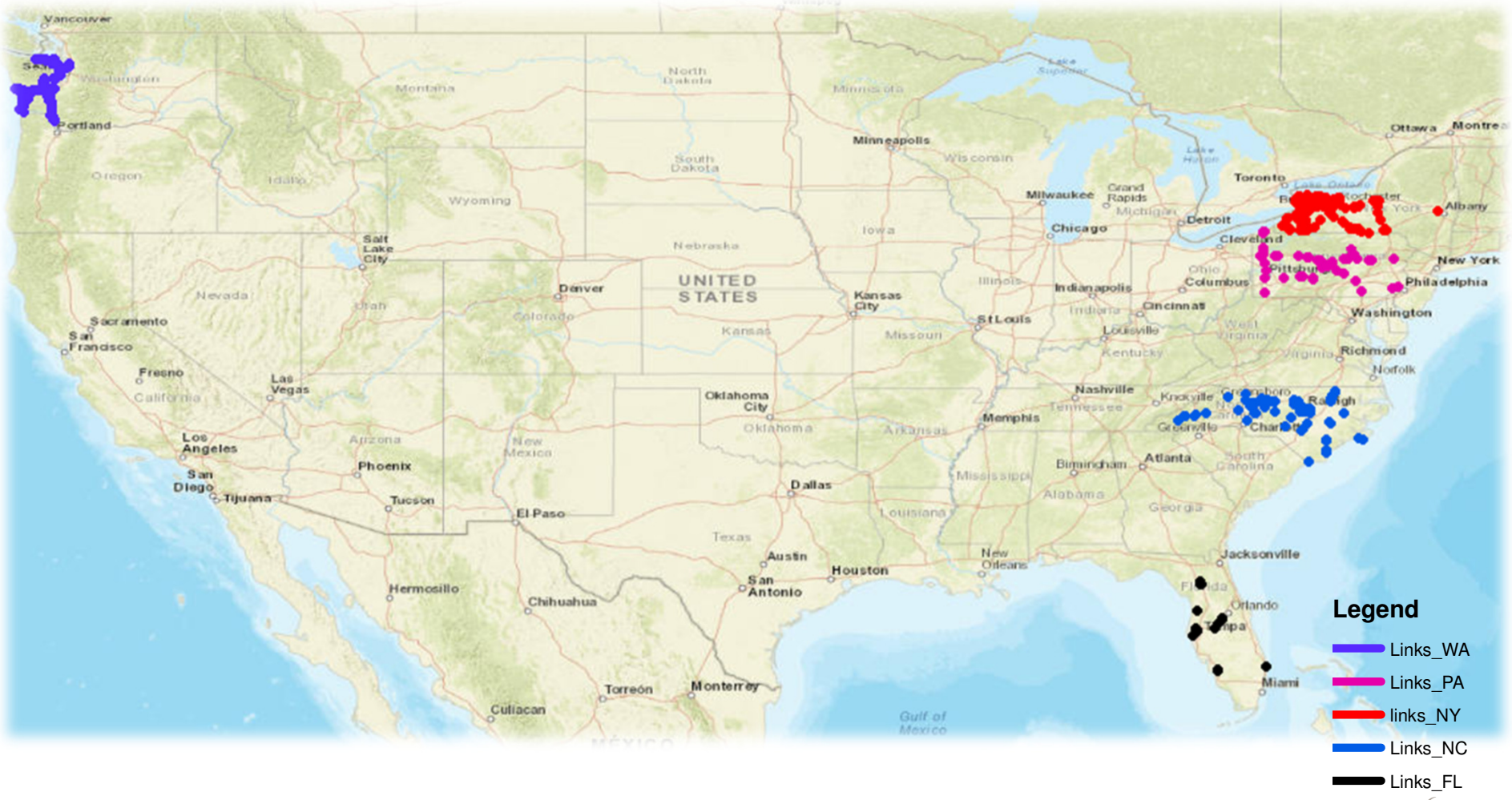
Longer duration work zones selected for NDS study period

9290 Work Zones

Vttl provided trip density

Work zones with > 15 trips selected: 1680

Identified Work Zones From 5 states



Data Collection

Dynamic segmentation method in ArcGIS

Work Zone Extents were detected

VTTI provided 2 to 3 time series traces from each work zone

Forward videos manually checked: only active work zones were selected: 118 work zone

Previously determined Extents of work zones adjusted based on videos

Using spatial location from time series data

Data Collection

VTTI provided 50-100 traces for each work zone

4800 time series traces were obtained

Traces were filtered

90% more speed data available, distribution of driver demographics, day/night , etc.

Driver face video reduced at the enclave

Reduced glance and distraction of driver

Data Reduction

- Even though multiple time series traces were available for each work zone, characteristics within a work zone can change from day to day.
- Information starting from First Work Zone Sign to the End of Work Zone Using time stamps from the front video was coded for each individual time series files.
- Work Zone Signs: Static, VMS, Speed limit, lane merge , enforcement, etc. were coded manually.

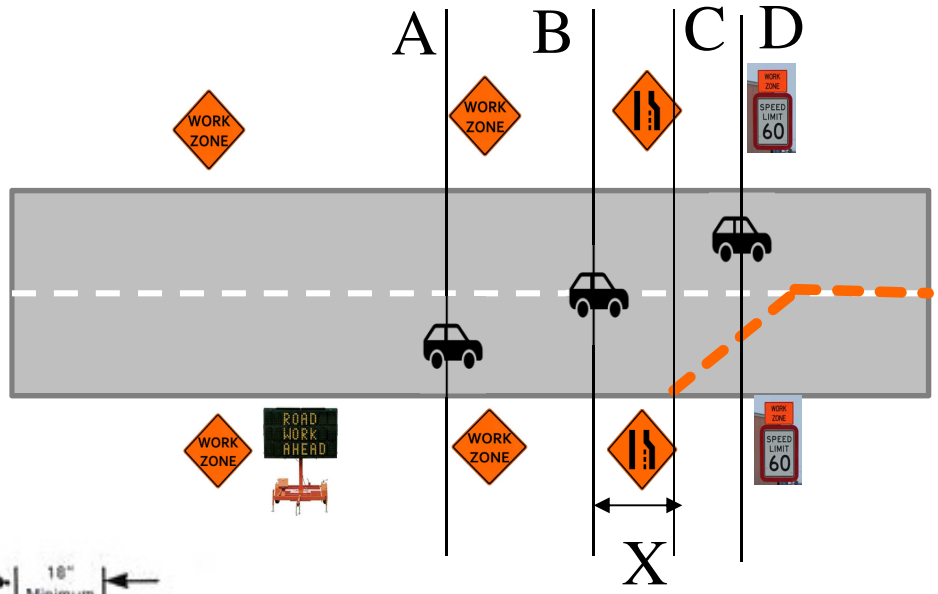
Data Reduction

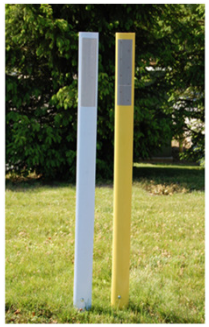
List of variables reduced from each traces:

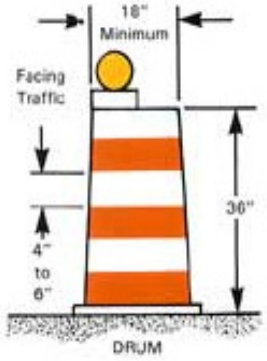
- Road Configuration prior to Work Zone
- Median Type
- Type of Barrier
- Presence of glare screen
- Work Zone Configuration
- Number of lane closed
- Channelizing device (cones, barrels, or concrete barrier, vertical panels)
- Location of Channelization
- Presence of equipment and type of exposure
- Presence of barrier
- Presence of Workers and type of exposure

Data Reduction (continued)

- Weather Condition
- Lighting Condition
- Presence of ramp
- Start of lane change
- Crossed Center line
- Completely merged to other lane



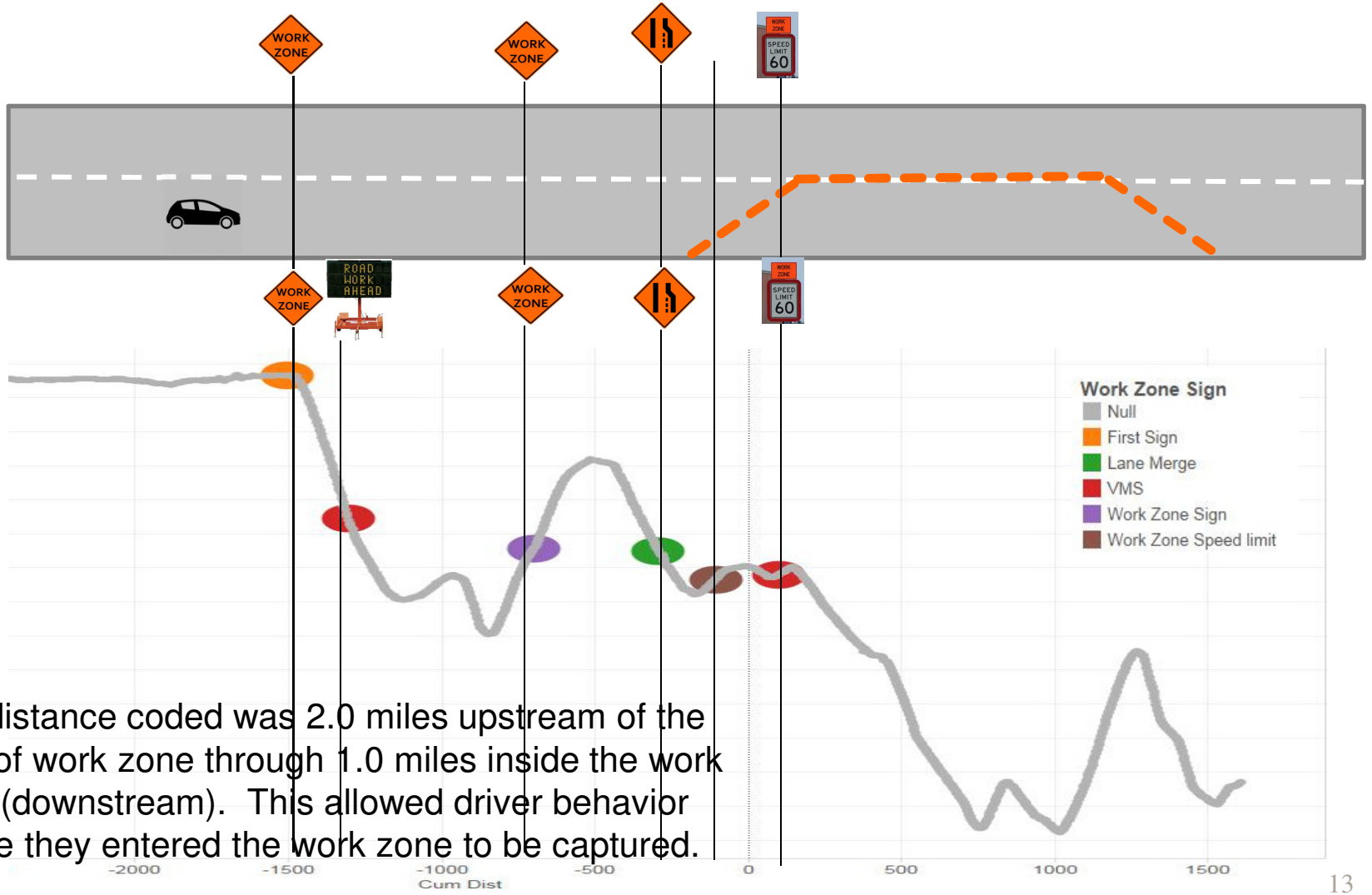




Speed prediction model- Preliminary model

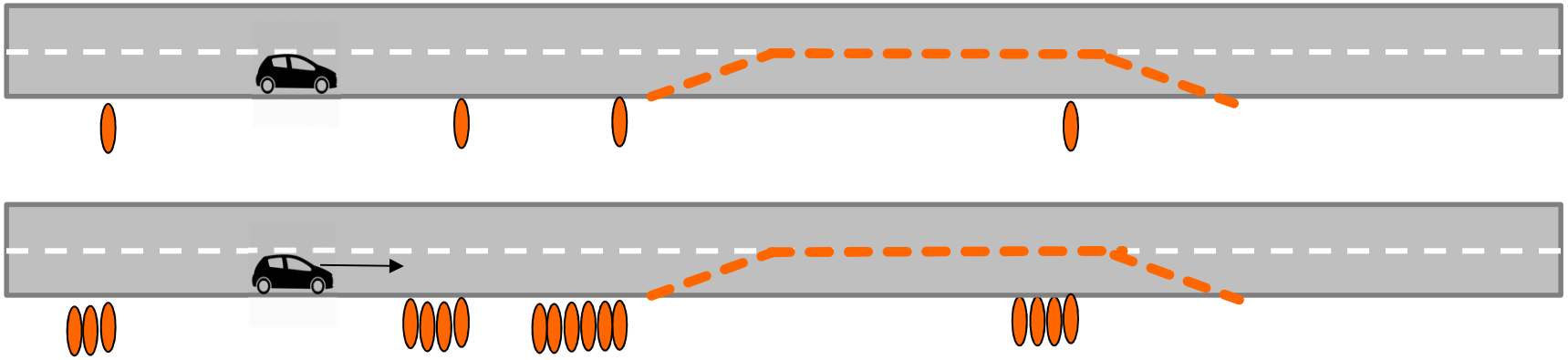
- Various factors affect the speed of vehicles passing through a work zone.
- The main purpose was to model drivers' speed along a work zone as well as to identify Infrastructure and operational elements intended to control speed and their effect on driver behavior. This information can be used by agencies to decide work zone strategies to maintain desired speeds within a work zone.
- The model uses estimates at a point to assess driver speed. The model only included time series traces where the driver was in free-flow conditions. The dataset represents Speed in m/s as dependent variable.
- The dense time series data (0.1 secs apart) for 82 traces of work-zones on 4 lane divided roadways were stacked together and the dataset represented a combined file of multiple time series files with other variables associated to the time stamps.
- The position points were treated as indicators of the locations 100 m apart along a trace.

Speed Profile along Work Zone



The distance coded was 2.0 miles upstream of the start of work zone through 1.0 miles inside the work zone (downstream). This allowed driver behavior before they entered the work zone to be captured.

Legibility distances

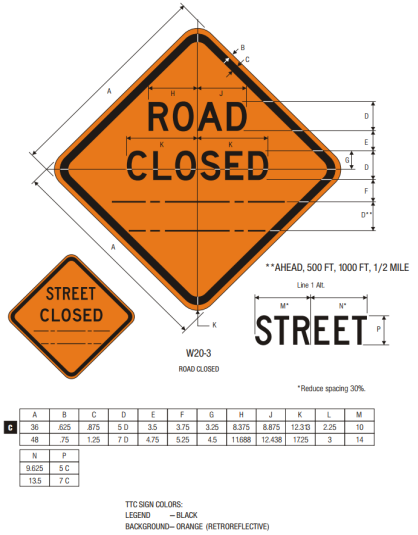


Static Work Zone Warning Signs:

General guidance: 1 inch of letter height per 30 feet legibility distance.

Thus assuming **6 inch letter height** the legibility distance is **180ft.**

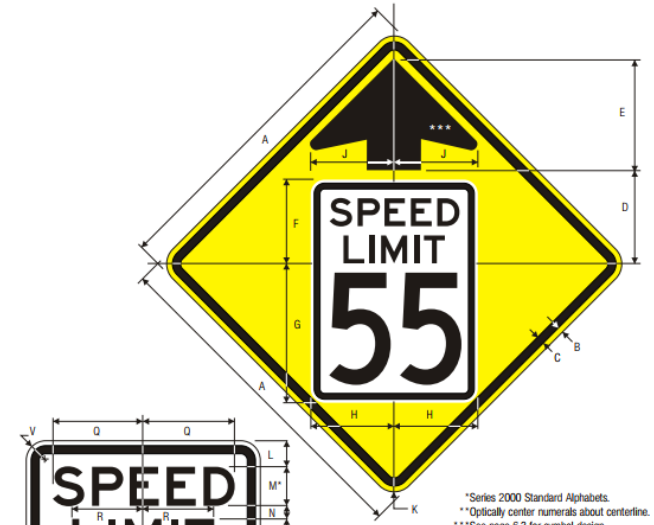
Source: MUTCD 2009



Legibility distances

Work Zone Speed Limit Sign : Assuming the letter height of speed limit letters to be **15 inches for 36'' by 36''** plaque size of **speed reduction sign** to be on the conservative side, the legibility distance was calculated as: **30X15= 450ft.**

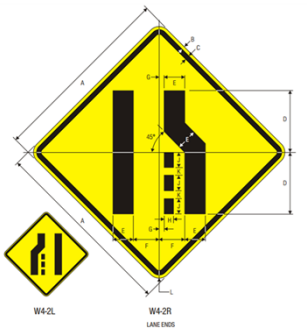
Changeable message sign and Lane Merge Sign: used on roadways with speed limits of 55 mph or higher should be visible from ½ mile under both day and night conditions. The message should be designed to be legible from a minimum of 600 ft. for nighttime conditions and 800ft. for normal daylight conditions. Source: MUTCD 2009. Lane Merge Sign was close to letter



C	A	B	C	D	E	F	G
	36	.625	.875	10	12	9	15
	48	.75	1.25	11.75	18	10.75	19.25

H	J	K	L	M	N	P
9	9	2.25	2	3 E	1	12 C
12	12	3	2.25	4 E	1.25	15 C

Q	R	S	T	U	V
7	5.46	7.126	.375	.625	2.25
9.327	7.279	9.258	.375	.625	3



4 lane divided work zones

Variables	Number	
Total number of traces	82	
Total Number of Observations in dataset	230866	
Average number of observation in each trace	2827	
Number of WorkZones	14	
Number of drivers	60	
Driver age	Min	19
	Max	86
Total number of traces VMS Sign was present	65	
Total number of traces among 65 where VMS was Active	53	
Total number of traces with Head To Head Traffic	29	
Left Lane Closure	45	
Right Lane Closure	22	
Total number of traces where equipment presence were noted	29	
Total number of traces where cell phone usage were noted	11	

Glance and Distraction

Glance

Forward
Right
Left
Down
Rear view Mirror
Steering Wheel
Center Console
Passenger
Missing
Over the shoulder
Up

Distraction

Passenger
Cell Phone
In vehicle Controls
Other Task
Drinking/Eating
Moving/Dropped Object
Personal Hygiene

Glance	
Eyes Forward	If Eye glance remained Forward
Distraction	**Base: Not Distracted**
Cell Phone	Cell Phone
In Vehicle Distraction	In Vehicle controls or moving or dropped object Distraction
DrinkEatSmokeOtherTaskPersonalHygiene	Drinking, Eating, Smoking, performing Other Tasks and Personal Hygiene
Passenger	Passenger

Variables	Mean	Standard Deviation
Speed in meter per second	24.39	6.42
Age of Driver When Driving	48	17.75
Female Driver	0.554	0.50
First Sign within Legibility distance of 180ft	0.008	0.09
Lane Merge Sign within Legibility Influence	0.007	0.08
Work-zone Speed Limit Sign Along Legibility distance of 450 feet	0.028	0.16
Changeable message sign Along Legibility of 600 feet	0.034	0.18
Static Work-zone Sign Along Legibility of 180 feet	0.018	0.13
Concrete Median	0.279	0.45
Depressed Median	0.171	0.38
Raised Median	0.005	0.07
Guard Rail	0.008	0.09
Head to Head Traffic Work-zone Configuration	0.037	0.19
Right Shoulder Closure	0.008	0.09
Both Shoulder Closure	0.024	0.15
Left Lane Closure	0.097	0.30
Left Shoulder Closure	0.014	0.12
Right Lane Closure	0.133	0.34
Channelizing Guardrail	0.006	0.08
Cones	0.004	0.06
Concrete And Cones	0.001	0.03
Guardrail And Concrete	0.005	0.07
Barrels	0.116	0.32
Vertical Panels	0.052	0.22
Concrete And Vertical Panels	0.001	0.03
Channelizing Concrete Barrier	0.130	0.34
Concrete Barrier And Barrels	0.013	0.11
Equipment	0.005	0.07
If Eye glance remained Forward	0.621	0.49
Cell Phone	0.009	0.09
In Vehicle controls or moving or dropped object Distraction	0.003	0.05
Drinking, Eating, Smoking, performing Other Tasks and Personal Hygiene	0.006	0.07
Passenger	0.004	0.07

Linear mixed effects models:

- This study involved multiple observations from a same subject driver.
- Positive estimate value indicates drivers speed was higher than average due to the presence of that variable and vice versa.
- The speed prediction model can be written as: $Speed = \beta 0 + \beta 1x1 + \beta 2x2 + \beta 3x3 + \cdots \ldots \ldots \ldots + \gamma i \ , \gamma i \sim Normal(0, variance)$

  Where, $\beta 0$ is the intercept term and $\beta 1, \beta 2, \ldots .$ are values of parameter estimates (or coefficients) of variables shown in Table-3.

  $x1, x2, \ldots .$ are the values of the fixed effects variables shown in Table-3 above for each observation.

  γi = random effect terms
- The lme4 package in R was used to estimate the model. Models were fit including variables which were significant at the 95% confidence level. P-values for mixed models were calculated by normal approximation method.

Random effects:					
Groups	**Variance**	**Std. Dev.**			
FILE_ID	3.461	1.868			
Work-zone ID	5.950	2.439			
Anonymous Driver ID	3.773	1.942			
Residual	19.515	4.418			
Description of variables		**Estimate**	**Std. Err**	**T value**	**p values**
(Intercept)		28.681	1.185	24.212	**0.000**
Age of Driver When Driving		-0.049	0.019	-2.636	**0.008**
Signs within Legibility Distance	**Base: Compared to no sign present**				
First Sign within Legibility distance of 180ft		0.533	0.106	5.030	**0.000**
Lane Merge Sign within Legibility Influence		-1.546	0.112	-13.816	**0.000**
Work-zone Speed Limit Sign Along Legibility distance of 450 feet		-0.192	0.059	-3.247	**0.001**
Changeable message sign Along Legibility of 600 feet		-0.887	0.152	-5.824	**0.000**
Static Work-zone Sign Along Legibility of 180 feet		-0.510	0.072	-7.096	**0.000**
CMS Sign Type	**Base: No CMS Sign**				
Overhead CMS		2.224	0.207	10.745	**0.000**
Post Mounted CMS		1.480	0.534	2.773	**0.006**
Trailer Mounted CMS		-0.338	0.162	-2.091	**0.037**

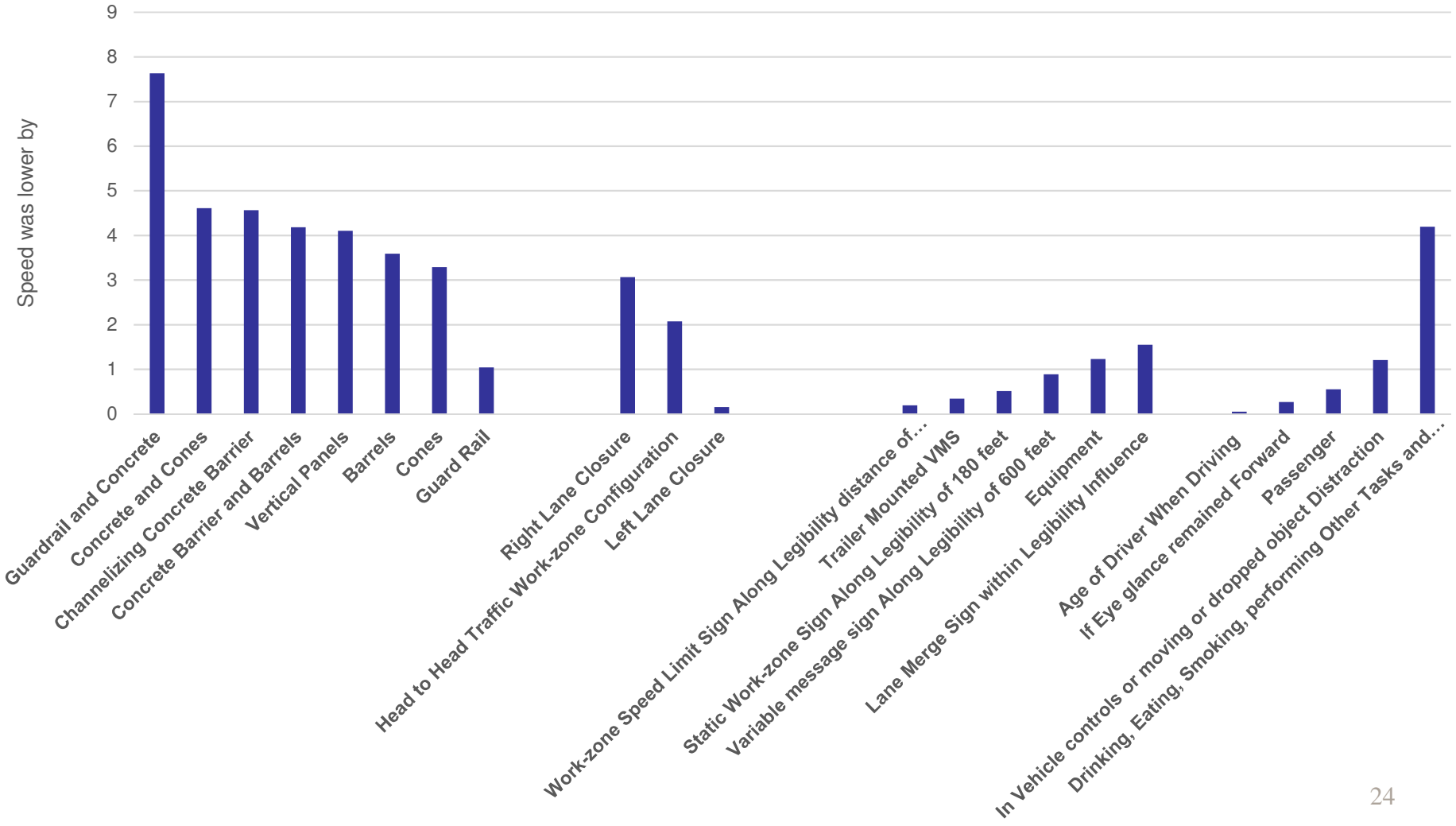
Type of median Prior to Work-zone					
Concrete Median	**Base: Raised Median**	2.827	0.034	82.970	**0.000**
Depressed Median		0.106	0.033	3.199	**0.001**
Guard Rail		-1.042	0.197	-5.278	**0.000**
Work-zone Configuration					
Head to Head Traffic Work-zone Configuration	**Base: Non Work-zone Area**	-2.072	0.081	-25.732	**0.000**
Right Shoulder Closure		2.121	0.117	18.121	**0.000**
Left Shoulder Closure		2.892	0.093	31.021	**0.000**
Right Lane Closure		-3.063	0.069	-44.266	**0.000**
Left Lane Closure		-0.151	0.059	-2.541	**0.011**
Work-zone Channelizing Devices					
Cones	**Base: No channelizing Devices used**	-3.284	0.168	-19.578	**0.000**
Concrete and Cones		-4.609	0.320	-14.405	**0.000**
Guardrail and Concrete		-7.629	0.153	-49.978	**0.000**
Barrels		-3.591	0.050	-72.176	**0.000**
Vertical Panels		-4.101	0.072	-56.918	**0.000**
Channelizing Concrete Barrier		-4.563	0.069	-66.272	**0.000**
Concrete Barrier and Barrels		-4.184	0.137	-30.495	**0.000**

Presence of Construction Equipment					
Equipment		-1.227	0.268	-4.572	**0.000**
If Eye glance remained Forward		-0.263	0.025	-10.681	**0.000**
Distraction	**Base: Not Distracted**				
Cell Phone		0.307	0.120	2.554	**0.011**
In Vehicle controls or moving or dropped object Distraction		-1.207	0.175	-6.897	**0.000**
Drinking, Eating, Smoking, performing Other Tasks and Personal Hygiene		-4.193	0.130	-32.349	**0.000**
Passenger		-0.552	0.142	-3.883	**0.000**
Position points 100 m apart before and inside work-zone	**Base: Other position Points**				
Position point at 500 m upstream of start of work-zone		-0.915	0.517	-1.769	**0.077**
Position point at 400 m upstream of start of work-zone		-1.167	0.516	-2.263	**0.024**
Position point at 300 m upstream of start of work-zone		-1.555	0.517	-3.007	**0.003**
Position point at 200 m upstream of start of work-zone		-1.955	0.517	-3.780	**0.000**
Position point at 100 m upstream of start of work-zone		-2.191	0.517	-4.238	**0.000**
Position point at 100 m inside of start of work-zone		-2.566	0.461	-5.572	**0.000**
Position point at 200 m inside of start of work-zone		-3.369	0.516	-6.533	**0.000**
Position point at 300 m inside of start of work-zone		-3.589	0.516	-6.961	**0.000**
Position point at 400 m inside of start of work-zone		-3.833	0.516	-7.434	**0.000**
Position point at 500 m inside of start of work-zone		-4.340	0.516	-8.416	**0.000**

Conclusion

- For each one-year increase in age, speed was 0.05 meter per second(mps) or 0.11 miles per hour(mph) lower.
- Under the influence of a lane merge sign, speed was lower by 1.55mps(3.50mph). The presence of an active CMS sign showed that speed was lower by 0.89mps(1.98mph).
- When median guardrails were present outside of the active work zone, speed was 1.04mps(2.33mph) lower as compared to raised median type.
- Speed was lower by 3.06mps(6.85mph) when the work-zone had right lane closures.
- The presence of channelizing devices lowered speed from more than 3.28mps(7.34mph) to 7.63mps(17.07mph).
- When work-zone equipment was present, speed was lower by more than 1.23 mps(2.75mph).

Speed was lower with these variables

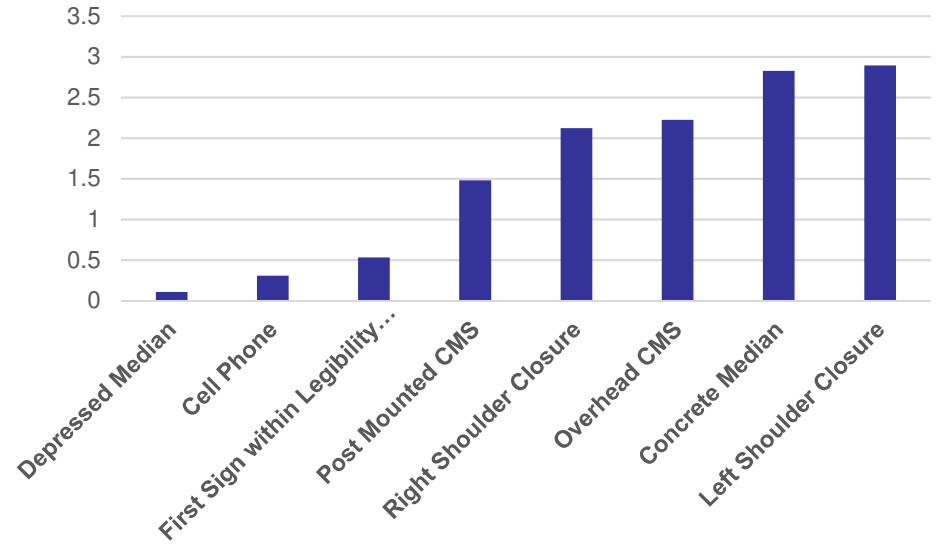


Speed was higher with these variables

- **Results also indicate that driver speeds were higher under the influence of the first work-zone sign they encountered when compared to sections where no sign was visible . This may be since first signs were placed about 2 miles upstream for majority of lane closure work-zones.**

- **When drivers were engaged in a cell-phone distraction, speed was higher by about 0.31mps(0.69mph) compared to no distraction.**

- **All of the above results are statistically significant at 0.10 alpha levels except for cell phone use.**



Few Takeaways

The study demonstrated that work-zones can be successfully located in the SHPR 2 RID data using the 511 data and then matched to work-zones identified in the SHRP 2 NDS data.

Taken together, the study evaluated the impact of various temporary traffic control signs along with presence of equipment on driver's speed.

Lane merge sign, CMS, channelizing devices influenced the drivers to choose lower speed in a work zone.

Drivers tends to choose lower speed consistently starting from 500m upstream until 500m inside the work zones. But speed reductions become somewhat static after that when drivers become familiar with the work zone.

Limitations and ongoing future work

- 260 more reduced work zone traces in 4 lane roads will be added in future.
- This study investigated 4 lane divided roads only, in the future the research team wishes to expand this method to other multilane roads.
- This study is based on only free flow condition, information on level of service is being collected on non-free flow traces of the same work zones to assess driver behavior before lane drop.
- This model uses estimates at a point to assess driver speed. The model cannot indicate whether drivers slowed down for a particular work zone feature. That will be addressed in another difference in speed model.
- Spatial correlation will be addressed.

Thank You.

Questions?