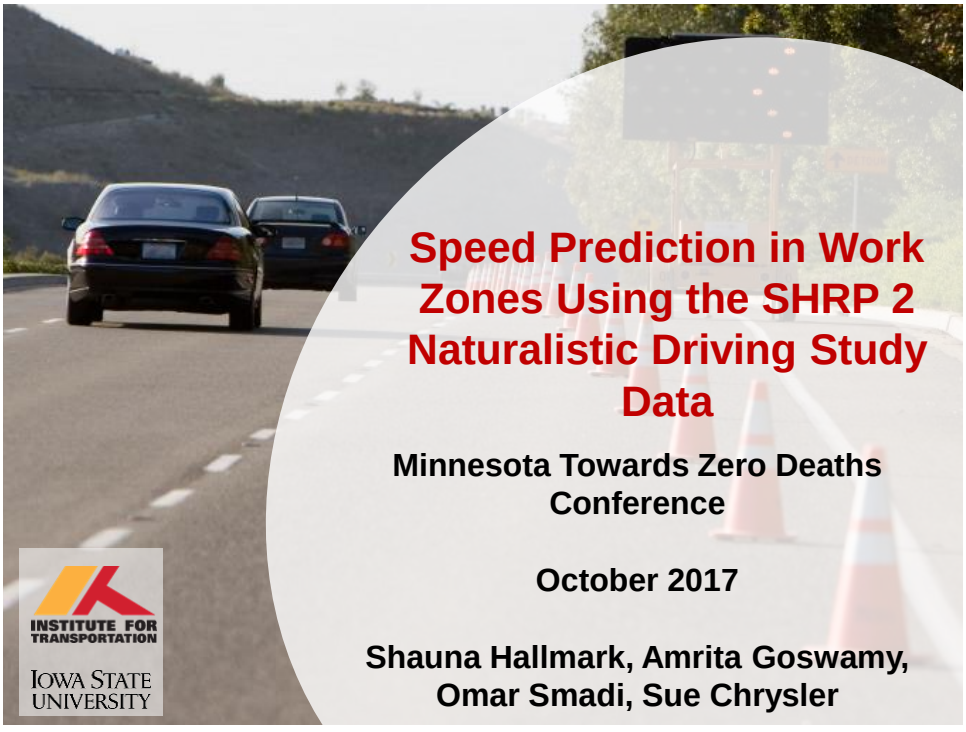

Speed Prediction in Work Zones Using the SHRP 2 Naturalistic Driving Study Data

Minnesota Towards Zero Deaths Conference

October 2017

Shauna Hallmark, Amrita Goswamy, Omar Smadi, Sue Chrysler

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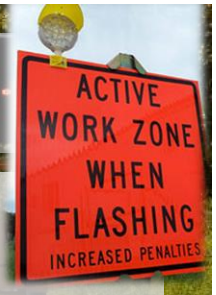
IOWA STATE UNIVERSITY

Background

- Over 96,000 US work zones crashes (2015)
- 700 fatalities (2.0% of all roadway fatalities)
- 120 worker fatalities annually
  - ✓ 46% are struck by vehicle
- Most common type is rear end
- Common causes: following too closely, FTY, driver inattention, too fast for condition, improper lane change

Background



- Work zone crashes not well understood
- NDS data collected by SHRP2 Program offers a rare opportunity for a first-hand view of work-zone safety critical and base events

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SHRP 2 Naturalistic Driving Study

- Largest naturalistic driving study ever undertaken
- 2,900 drivers, all age/gender groups
  - ✓ Most participants 1 to 2 years
- 3,900 data years; 5 M trip files; 32 M vehicle miles
- 2 years of data collection
- Vehicle Types: All light vehicles
- Six data collection sites
- Integration w/ detailed roadway information

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Data Acquisition System

- Video cameras
  - ✓ Forward roadway
  - ✓ Rear
  - ✓ Driver face
  - ✓ Over shoulder
- Accelerometers
- GPS
- Vehicle network information

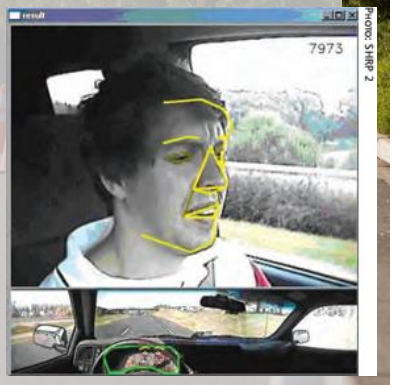

Photo Source: SHRP 2

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Vehicle Kinematic Data

- Represents vehicle position at 0.1 sec increments

System.Time	vtti.accel_x	vtti.accel_y	vtti.accel_z	vtti.pedal_gas_position	vtti.gyro_y	vtti.gyro_x	vtti.wiper	vtti.gyro_z	speed
205	0.0116	-0.0087	-1.0063	12.54902	0	-0.3252		-0.3252	23.33335
206	0.0174	-0.0174	-0.9976	12.54902	0	-0.3252		-0.3252	23.33335
207	0.0203	-0.0058	-0.9947	12.54902	-0.3252	0		-0.3252	23.33335
208	0.0319	-0.0174	-1.0092	12.54902	0.325195	0		-0.3252	23.05557
209	0.0029	-0.0174	-0.9976	12.54902	0	-0.3252		-0.3252	22.7778
210	0.0261	-0.0029	-0.9918	12.54902	0	-0.65039		0	22.7778
211	0.0145	0.0029	-0.9947	12.54902					22.7778
212	0.0058	0.0029	-0.9976	12.81046	0	0		0	22.7778
213	0.0203	-0.0232	-0.9715	13.46406	-0.65039	0		-0.3252	22.7778
214	0.0029	-0.0232	-0.9831	13.92157	0	0		0	22.7778
215	0.0145	-0.0116	-0.9831	14.31373	0	0		-0.3252	22.7778
216	0.0145	-0.029	-1.0034	15.09804	0	-0.65039		-0.3	
217	0.0232	-0.0203	-1.0005	15.55556	0.650391	-0.65039		-0.3	
218	0.029	-0.0145	-0.9802	16.33987	-0.65039	0		-0.3	
219	0.0174	-0.0116	-0.9715	16.60131	-0.97559	0		-0.3	
220	0.0058	-0.0261	-1.0034	16.86275	0	0		-0.65	
221	0.0261	-0.0261	-1.0063	17.12419					
222	0.0145	-0.0116	-1.0295	17.25491	0.650391	-0.3252		-0.65	
223	0.0348	-0.0116	-0.9947	17.25491	0	0		-0.3	
224	0.0377	-0.0232	-0.9686	17.25491	-0.65039	0		-0.3	

- ABS activation
- Acceleration, z-axis
- Cruise control
  - Time into trip
  - Elevation, GPS
  - Head position y
  - Ambient light
- Lane marking, probability, right
- Lane markings, probability, left
- Wiper setting
- Pitch rate, y-axis
- Roll rate, x-axis
- Seatbelt, driver
- Acceleration, x-axis
- Airbag, driver
- De-identified date
- Driver button flag
- Head confidence
- Head position z
- Lane marking, distance, left
- Lane marking, type, left
- Lane position offset
- Lane width
- Accelerator position
- Speed, vehicle network
- Accelerator position
- Radar range rate forward x
- Seatbelt, driver
- Acceleration, y-axis
- Alcohol
- Dilution of precision, position
- Electronic stability control
- Head position x
- Headlight setting
- Lane marking, distance, right
- Lane marking, type, right
- Timestamp
- Spatial position (Lat/Long)
- Steering wheel position
- Yaw rate, z-axis
- Pedal, brake
- Radar range rate forward y

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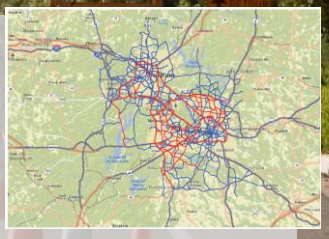
Roadway Information Database

- 4 different data sources
  - ✓ ESRI: baseline data for entire country
  - ✓ State roadway inventory data: from 6 study states; data vary by state; about 200,000 miles
  - ✓ Mobile van data: very detailed, 12,542 centerline miles; 43,195 intersections, 518,570 signs; includes forward video
  - ✓ Supplemental data: from 6 study states, data vary by state



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Objectives

- Project funded under FHWA Implementation Assistance Program in conjunction with the Minnesota DOT
- Develop relationship between speed and work zone and driver characteristics
  - ✓ Identify driver/work zone characteristics associate with safety critical events in work zone
  - ✓ Speed is used as a surrogate for crashes
    - ❖ Few crashes
    - ❖ Other surrogates such as lane position not reliable
  - ✓ One of several analyses (also evaluating reaction point, merge behavior, and back of queue)

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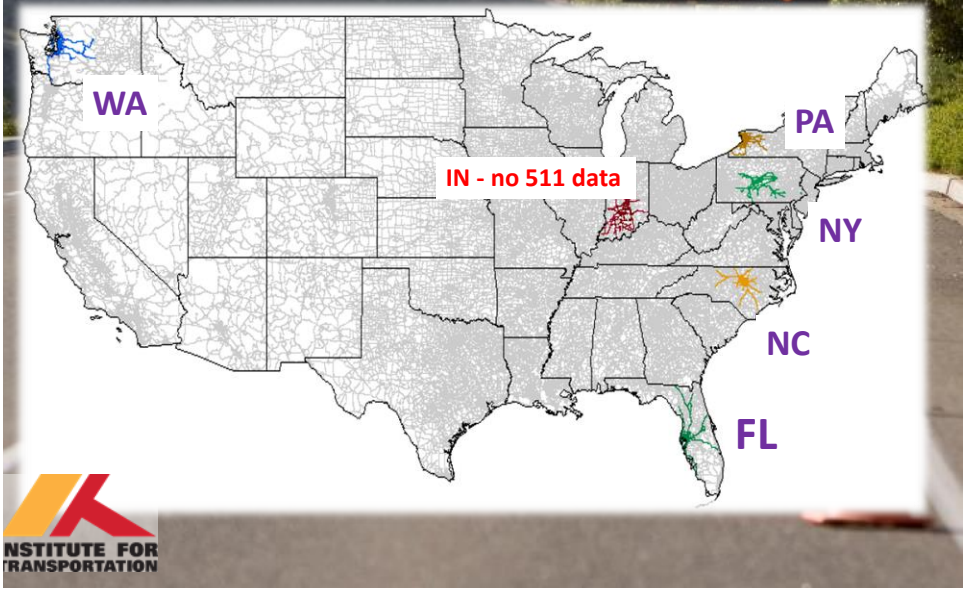
Identification of Work Zones



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Identification of Work Zones

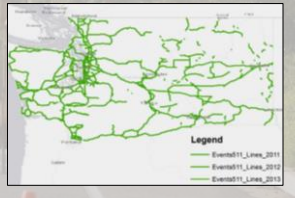
Identified potential WZ using 511 data (e.g. "construction", "lane closure")
> 2 million records

* Linked 511 events to RID; select WZ > 3 days
*Requested # potential trips **(9,290 work zones)**

* Selected WZ ≥ 15 trips **(1,680)**
* Reviewed forward video for (~ 700) to ensure active work zone was present

* Requested time series/forward video for subset (118 work zones)
* Received ~ 4,800 time series traces (multi-lane, 4-lane, 2-lane)

* Identified additional 145 work zones (2 and 4-lane)
* 2nd data request in progress



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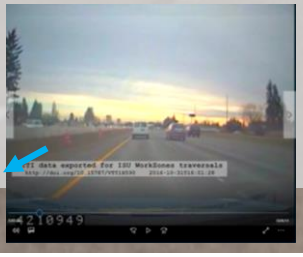
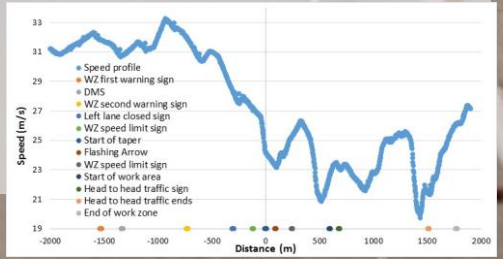
Data Utilized

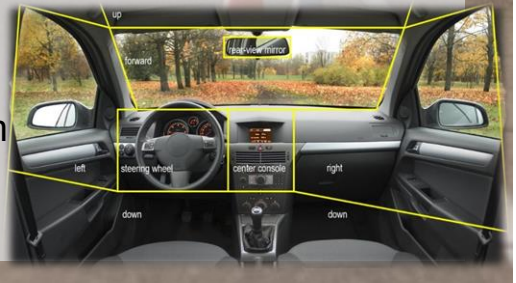
- 4-lane divided roadways (speed limit 45 to 55 mph)
- 82 time series traces
- 14 unique work zones with lane closures
- 60 unique drivers
- Location (GPS) provided at 1 second interval
- Times series traces (0.1 second interval)
- Related vehicle position to work zone features





Data Reduction

- Environmental characteristics (forward video)
- Regular roadway characteristics (RID)
  - ✓ i.e. # lanes, median type, traffic control, speed limit, shoulder type
- Driver characteristics
  - ✓ Static from NDS database (i.e. age)
  - ✓ Reduced distraction and glance location



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Data Reduction

- Work zone characteristics
- Reduced from NDS forward video
  - ✓ VMS
  - ✓ WZ speed limit
  - ✓ Shoulder/lane closures
  - ✓ Start/end work zone
  - ✓ work zone signs (static and dynamic)
  - ✓ Presence/location of workers/equipment
  - ✓ Location and type of barriers
  - √ # lanes closed
  - √ type of lane shift
  - √ lane shift
  - √ head to head traffic

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Signs

- Assumed legibility distance for signs
  - ✓ 600 ft. for VMS, DSFS
  - ✓ 450 ft. for work zone speed limit
  - ✓ 180 ft. for static
  - ✓ Based on expected sign size and letter height
  - ✓ Worked with human factors expert
- Still need to account for impact of multiple signs

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Speed Prediction Model

- Linear mixed effects model (LME)
- Used lme4 in R
- Used time series intervals as observations
- Accounted for multiple observations
  - ✓ Driver
  - ✓ Work zone
- Accounted for distance in relationship to work zone
- Goodness of fit evaluated using AIC and BIC
- Model included variables significant at 95%
- Modeled speed as a function of
  - ✓ Location within work zone
  - ✓ Driver characteristics
  - ✓ Work zone characteristics

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	Description of variables	Estimate	Std Err	T value	p value
		28.681	1.185	24.212	**0.000**
β1	driver age	-0.049	0.019	-2.636	**0.008**
signs within legibility distance					
β3	first WZ sign	0.533	0.106	5.030	**0.000**
β4	lane merge sign	-1.546	0.112	-13.816	**0.000**
β5	WZ speed limit sign	-0.192	0.059	-3.247	**0.001**
β6	VMS	-0.887	0.152	-5.824	**0.000**
β7	static WZ sign	-0.510	0.072	-7.096	**0.000**
β8	start of WZ	-0.188	0.492	-0.382	0.703
Type of median prior to work zone					
β13	concrete median	2.827	0.034	82.970	**0.000**
β14	depressed median	0.106	0.033	3.199	**0.001**
β15	guard rail	-1.042	0.197	-5.278	**0.000**
Work zone configuration					
β16	head to head	-2.072	0.081	-25.732	**0.000**
β17	right shoulder closure	2.121	0.117	18.121	**0.000**
β18	left shoulder closure	2.892	0.093	31.021	**0.000**
β19	right lane/shoulder closure	-3.063	0.069	-44.266	**0.000**
β20	left lane/shoulder closure	-0.151	0.059	-2.541	**0.011**
Channelizing devices					
β21	cones	-3.284	0.168	-19.578	**0.000**
β22	concrete & cones	-4.609	0.320	-14.405	**0.000**
β23	guardrail & concrete	-7.629	0.153	-49.978	**0.000**
β24	barrels	-3.591	0.050	-72.176	**0.000**
β25	vertical panels	-4.101	0.072	-56.918	**0.000**
β26	channelizing concrete barrier	-4.563	0.069	-66.272	**0.000**
β27	concrete barrier and barrels	-4.184	0.137	-30.495	**0.000**
Construction equipment					
β28	equipment	-1.227	0.268	-4.572	**0.000**
Distraction/glance location					
β30	forward glance	-0.263	0.025	-10.681	**0.000**
β31	cell phone	0.307	0.120	2.554	**0.011**
β32	in-vehicle controls/moving or dropped object	-1.207	0.175	-6.897	**0.000**
β33	eating/smoking/personal hygiene	-4.193	0.130	-32.349	**0.000**
β34	interacting with passenger	-0.552	0.142	-3.883	**0.000**
location					
β35	-500 m	-0.915	0.517	-1.769	**0.077**
β36	-400 m	-1.167	0.516	-2.263	**0.024**
β37	-300 m	-1.555	0.517	-3.007	**0.003**
β38	-200 m	-1.955	0.517	-3.780	**0.000**
β39	-100 m	-2.191	0.517	-4.238	**0.000**
β40	100 m	-2.566	0.461	-5.572	**0.000**
β41	200 m	-3.369	0.516	-6.533	**0.000**
β42	300 m	-3.589	0.516	-6.961	**0.000**
β43	400 m	-3.833	0.516	-7.434	**0.000**
β44	500 m	-4.340	0.516	-8.416	**0.000**

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Summary of Findings

- Signing
  - ✓ No impact of first work zone sign
  - ✓ -2.0 mph for VMS
  - ✓ Decrease at static lane merge (-3.5 mph)
- Driver Characteristics
  - ✓ Speed negatively correlated with age
  - ✓ -0.6 mph lower when driver glance is on roadway task
  - ✓ 0.7 m/s higher when interacting with cell phone
  - ✓ Lower for other types of distraction (interacting with in-vehicle controls, eating/smoking, interacting with passenger

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Summary of Findings

- Work zone configuration (compared to shoulder closure)
  - ✓ Head to head: -10.2 mph slower
  - ✓ Right lane/shoulder closer: -12.5 mph slower
  - ✓ Left lane/shoulder closer: -0.2 mph slower

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Summary of Findings

- Channelizing device (compared to cones)
  - ✓ Concrete + cones: -3.0 mph
  - ✓ Barrels: -0.7 mph
  - ✓ Vertical panels: -1.8 mph
  - ✓ Concrete barrier + barrels: -2.0 mph
- Location
  - ✓ Begins to decrease ~500 m upstream
  - ✓ Levels out ~500 m downstream

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Limitations/Challenges

- Significant data reduction
- Difficult to read work zone signs from video
- Work zones are complex environments
- Need to account for impact of multiple work zone devices
- Sample size (results are from interim model)
- Develop machine visioning techniques to identify and extract work zone features

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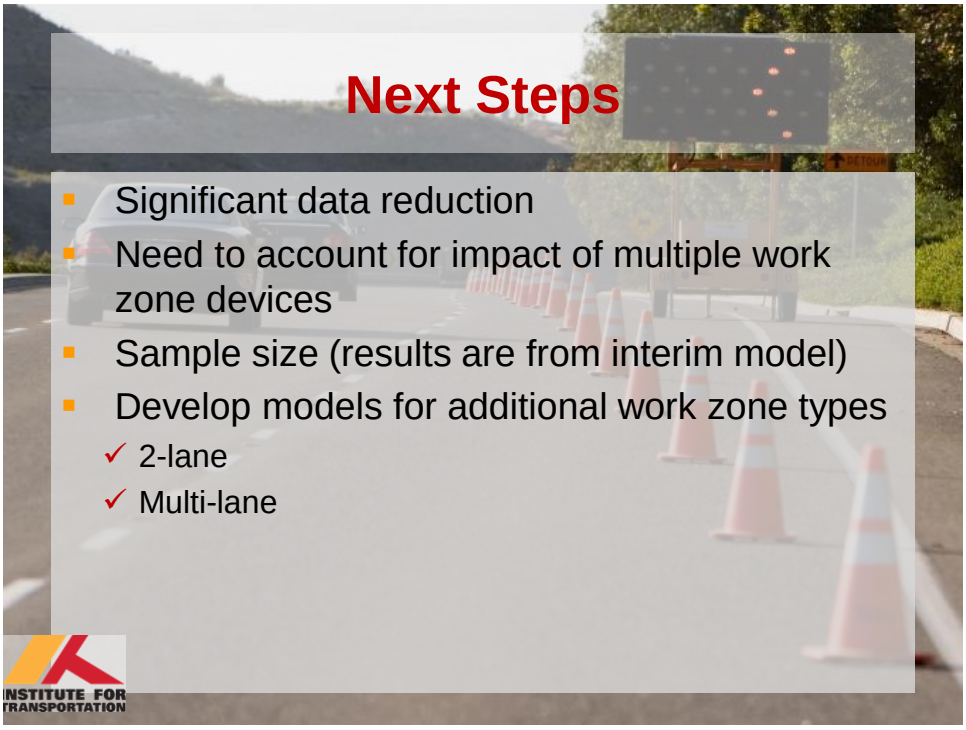
Next Steps
Significant data reduction
Need to account for impact of multiple work zone devices
Sample size (results are from interim model)
Develop models for additional work zone types
✓ 2-lane
✓ Multi-lane
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