Intrusion Prevention Technology Evaluations



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Work Zone Intrusion Prediction and Prevention

(NCHRP 17-107)

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NCHRP NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Oregon State University

Texas A&M Transportation Institute



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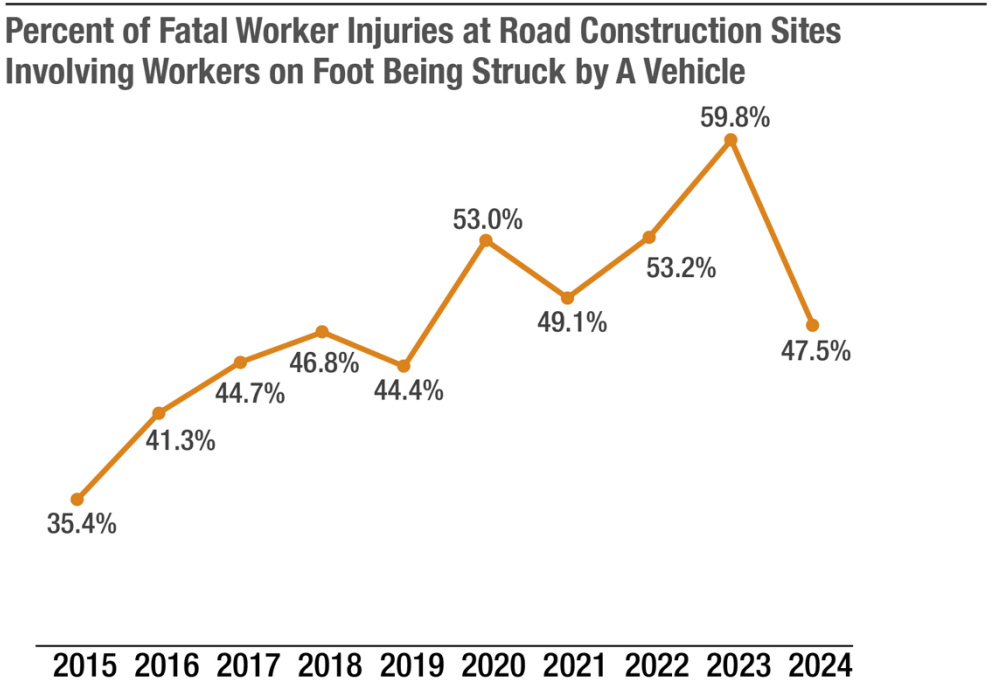
Research Study Overview

Goal:

Prevent vehicle intrusions into roadway work zones through improved work zone safety management and decision-making.

Objectives:

1. Determine the frequency and characteristics of work zone intrusions and resulting crashes, fatalities, and injuries.
2. Develop a tool to estimate the likelihood of work zone intrusions.



(Graphic source: https://workzonesafety.org/work-zone-data/worker-fatalities-and-injuries-at-road-construction-sites/)



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Research Study Overview

Study Scope

"Guide for Work Zone Intrusion Prediction and Prevention" (NCHRP Project 17-107)

GOAL:
Prevent injuries/fatalities due to work zone intrusions

INPUTS

Work zone intrusion data and knowledge

OUTPUTS

Work zone intrusion prediction models

Decision-support tool and Implementation Guide

IMPLEMENTATION OUTCOME:
Work zone designs and planning that minimize the likelihood of intrusions

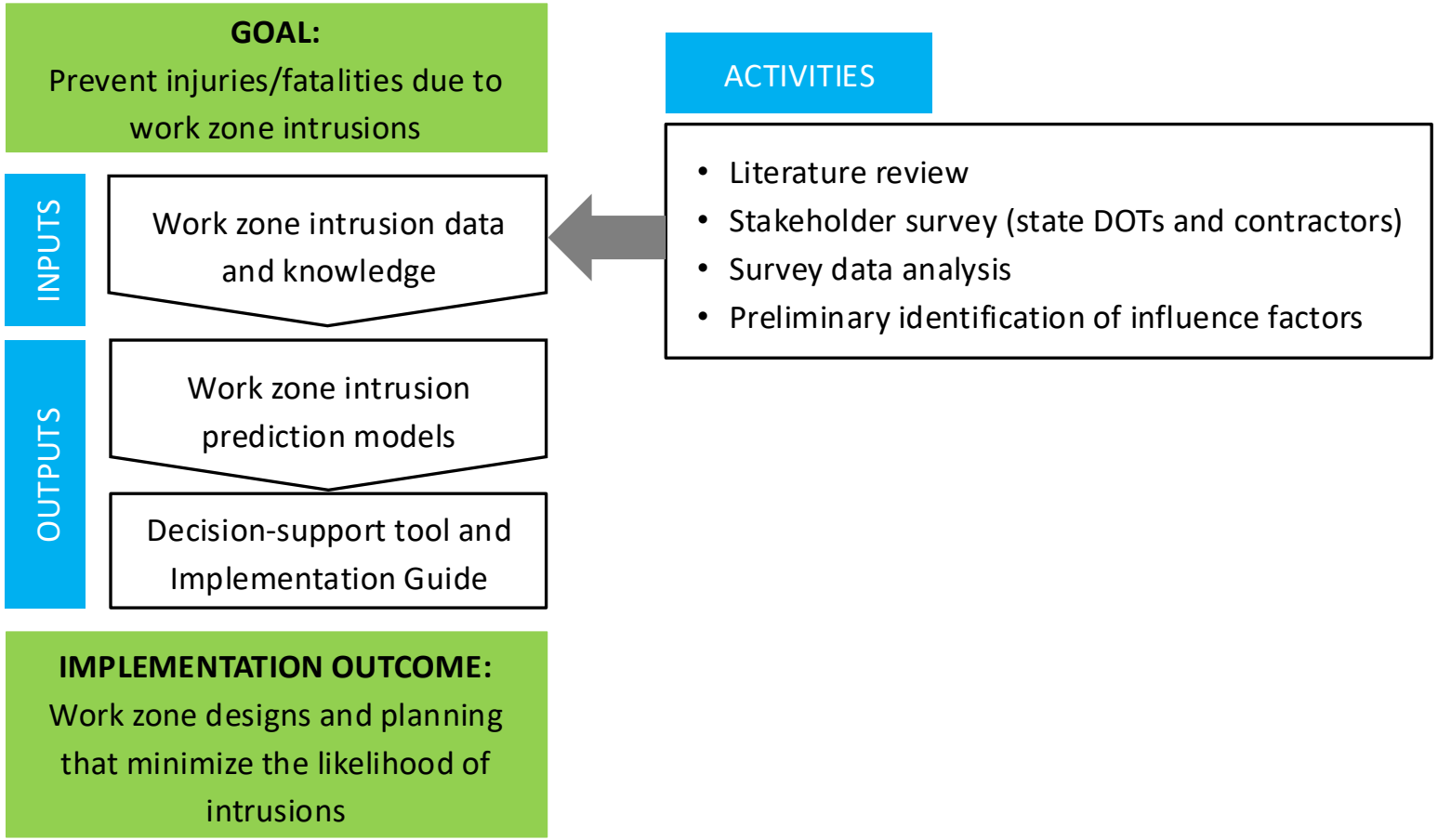
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Research Study Overview

Study Scope

"Guide for Work Zone Intrusion Prediction and Prevention" (NCHRP Project 17-107)





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Stakeholder Survey

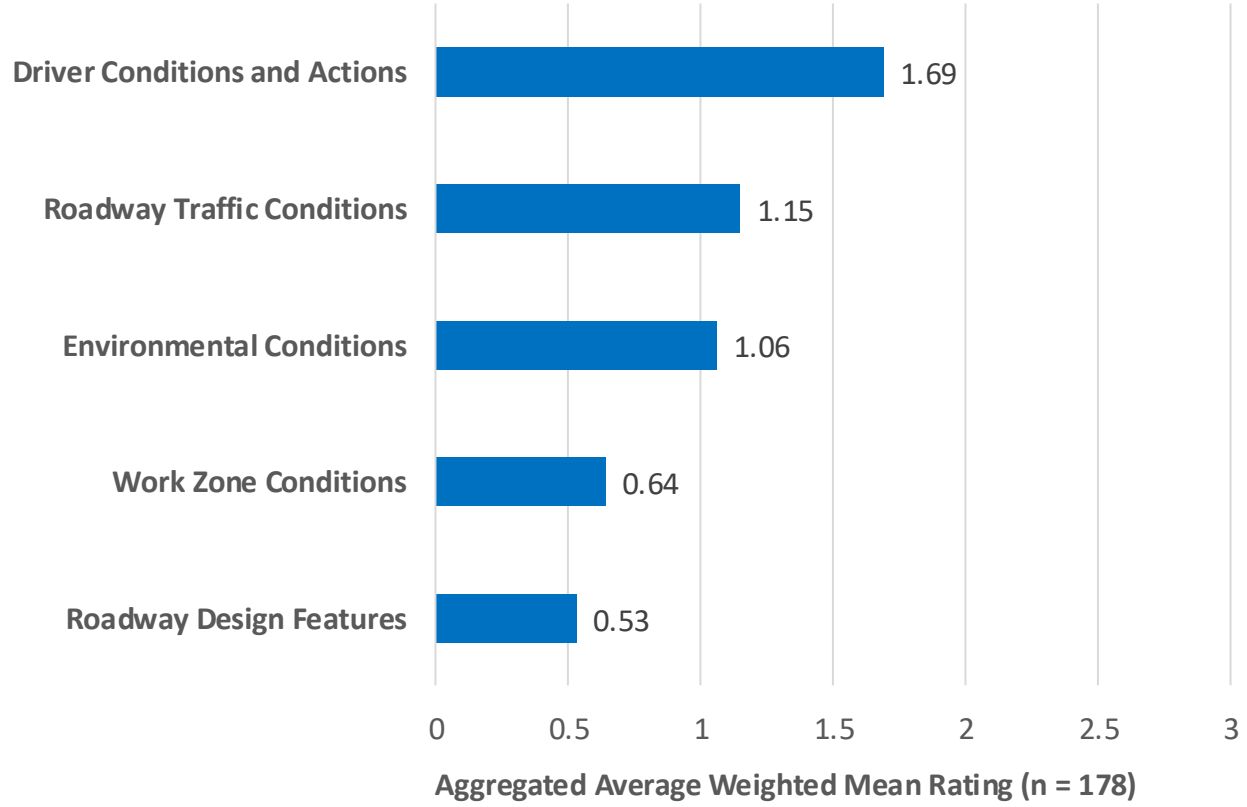
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Survey Results – Intrusion Influence Factors

Comparison of work zone intrusion factor categories with respect to their influence on work zone intrusions

Rating: -3 = extensive decrease in intrusions, 0 = no increase or decrease, +3 = extensive increase in intrusions



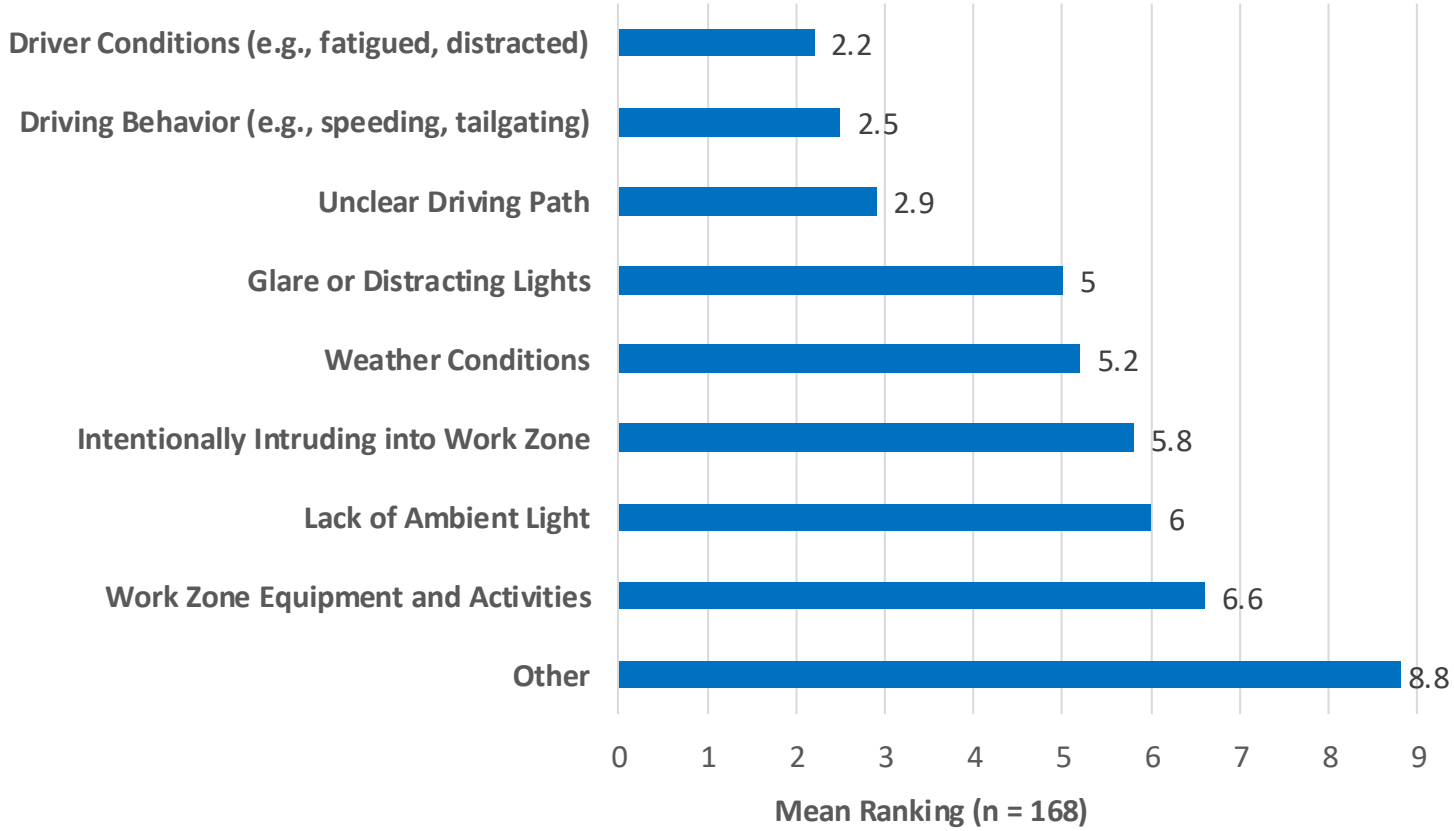
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Survey Results – Causes of Intrusions

Ranking of conditions as a cause of work zone intrusions

1 = greatest cause, 2 = second greatest cause, etc. (**a lower value indicates a higher ranking**)



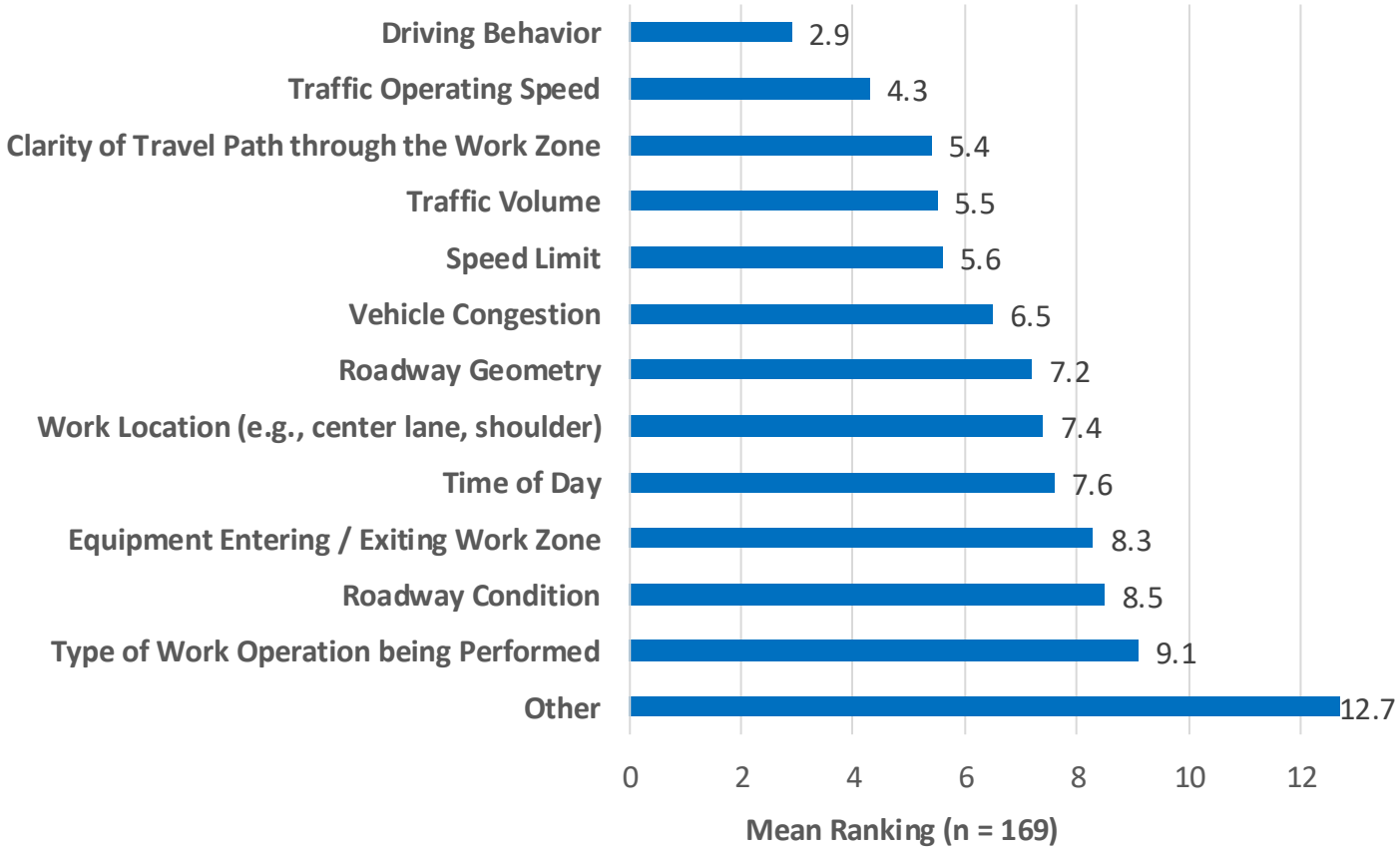
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Survey Results – Intrusion Predictors

Ranking of conditions as a predictor of work zone intrusions

1 = greatest cause, 2 = second greatest cause, etc. (**a lower value indicates a higher ranking**)



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Predicting Intrusions

Balancing multiple criteria



Influence on intrusions:
- Work zone features
- Causes and predictors
- Traffic control measures

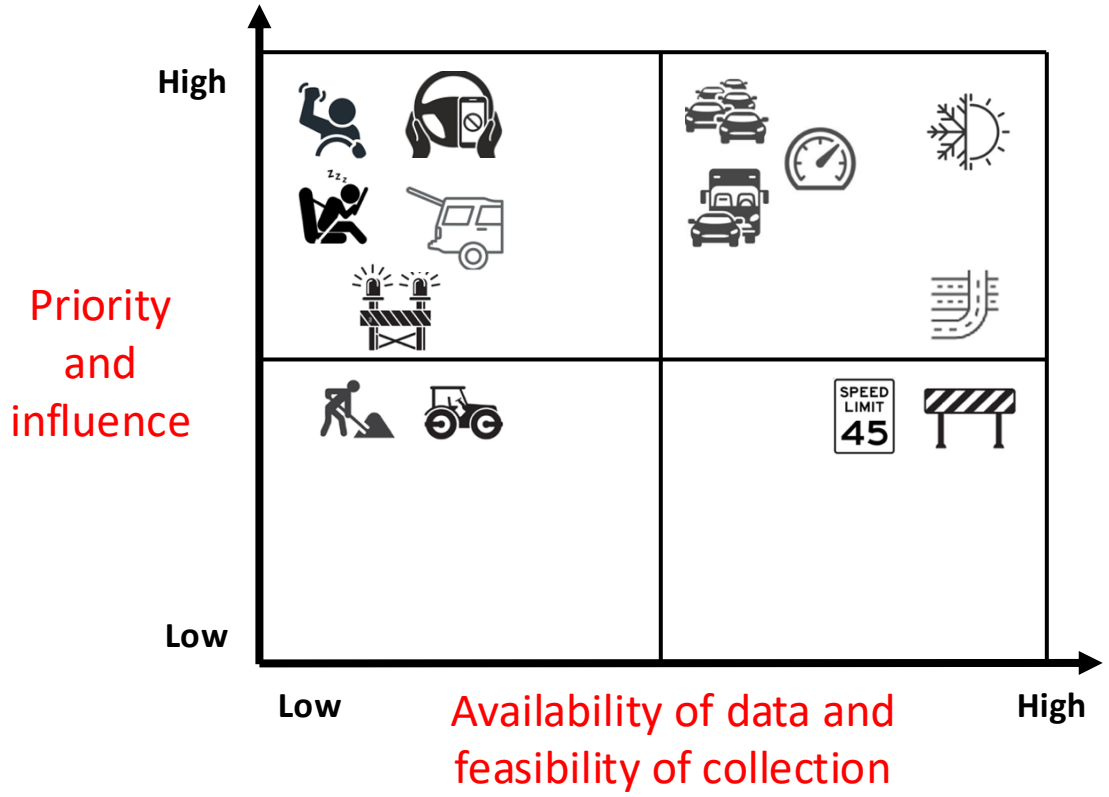
Development of prediction models:
- Factor priority
- Availability of data
- Quality of data
- Feasibility of implementation

Application of intrusion prediction models:
- Who, when, how
  - During TCP design
  - Before TCP implementation

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Data Collection

Target data



Factor categories	Priority / Influence	Availability of data and feasibility of collection
Driver conditions and actions	High	Low
Roadway traffic conditions	High	Moderate/High
Environmental conditions	High	High
Roadway design features	Moderate	High
Traffic control practices and work operations	Moderate/ High	Low
Traffic control technologies and devices	Moderate/ High	Low



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Research Study Overview

Study Scope

"Guide for Work Zone Intrusion Prediction and Prevention" (NCHRP Project 17-107)

GOAL:
Prevent injuries/fatalities due to work zone intrusions

INPUTS
- Work zone intrusion data and knowledge

OUTPUTS
- Work zone intrusion prediction models
- Decision-support tool and Implementation Guide

IMPLEMENTATION OUTCOME:
Work zone designs and planning that minimize the likelihood of intrusions

ACTIVITIES
- Intrusion data collection:
  - Work zone intrusion reports
  - State DOT near-miss reports
  - State DOT crash reports
- Data cleaning, formatting, and aggregating
- Prediction model development



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Work Zone Intrusion Data



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Data Collected

Datasets:

1. Work zone intrusion reports
2. State DOT near-miss reports
3. State DOT crash reports



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Data Collected

Datasets:

1. Work zone intrusion reports
2. State DOT near-miss reports
3. State DOT crash reports

- Collected via online (Qualtrics) reporting form
- ~2,200 email requests, plus multiple reminder emails
  - State DOTs, contractors, professional associations, stakeholder survey respondents
  - All 50 states
- 37 complete responses
  - 13 states (all US regions)
  - Variety of respondent organizations (mostly state DOTs)
  - Range of respondent titles/positions



Data Collected

Datasets:

1. Work zone intrusion reports
2. State DOT near-miss reports
3. State DOT crash reports

- Voluntary reporting programs in Oregon and Minnesota
- Oregon DOT:
  - 670 reports of near misses
  - August 2022 – December 2024
- Minnesota DOT
  - 80 intrusion reports
  - Limited information available
  - Information available did not match well with the variables targeted



Data Collected

Datasets:

1. Work zone intrusion reports
2. State DOT near-miss reports
3. State DOT crash reports

- Crash data received:
  - 16 states: AZ, CA, IL, IN, ME, MI, MN, MS, NY, NC, ND, OH, PA, TX
  - Most recent 5 – 10 years of data
  - All crashes or just work zone crashes
- Data evaluation and cleansing:
  - Required data content:
    - Work zone marker
    - Type of event marker as proxy for intrusion
    - 15 most impactful roadway and work zone characteristics
- Final dataset data: MI, NC, OH, TX



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Data Collected – Final Datasets

Datasets:

1. Work zone intrusion reports
2. State DOT near-miss reports
3. State DOT crash reports

Data Source	Number of Intrusion Records
National work zone intrusion report form	37
Oregon DOT near-miss reports	670
State crash reports (work zone intrusion incidents only):	
Michigan	4,036
North Carolina	339
Ohio	3,222
Texas	18,752
Total	27,056

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Work Zone Intrusion Frequency

Interviewee: “An intrusion occurs every day.”

- Most intrusions go unreported
  - Near misses
- Unable to calculate a rate from the data collected



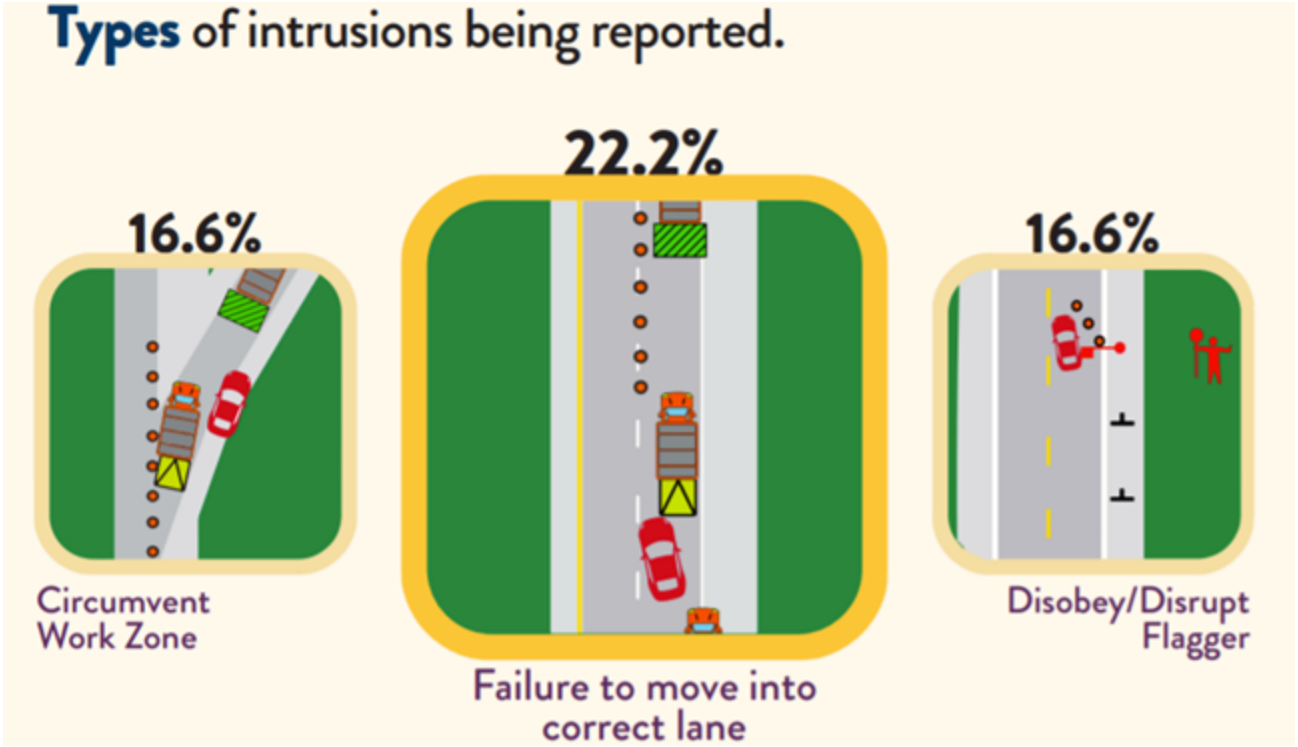
Work Zone Intrusion Characteristics

Intrusion crashes as a % of all work zone crashes:

- Daytime: 5.07%
- Nighttime: 10.77%

Result of intrusion crashes:

- Injury and/or fatality: 27.9%
- Property damage only: 72.1%



Graphic source: https://mntransportationresearch.org/2024/02/13/a-mobile-app-to-report-driver-intrusions-into-work-zones/



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Work Zone Intrusion Characteristics

Weather

Category	Intrusion crashes	Non-intrusion crashes
Clear	70.3%	75.4%
Cloudy	15.2%	16.1%
Rain	**12.6%**	7.5%
Other (fog, snow, etc.)	**1.9%**	0.9%

Rain, curves and speed limits above 45 mph make up a larger share of intrusion crashes than of non-intrusion crashes.

Road alignment

Category	Intrusion crashes	Non-intrusion crashes
Straight or other	85.1%	93.1%
Curve	**14.9%**	6.9%

Posted speed limit

Category	Intrusion crashes	Non-intrusion crashes
45 mph or less	27.4%	43.4%
More than 45 mph	**72.6%**	56.6%



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Work Zone Intrusion Characteristics

Work zone incidents:

* Intrusions/near misses voluntarily reported

Dataset	Work Zone Intrusions (% of reports)	Intrusion Outcome (% of intrusions)		
		Near miss	Property damage only	Injury and/or fatality
National work zone intrusion report form (n = 37)*	37 (100%)	16 (43.2%)	17 (46.0%)	4 (10.8%)
Oregon DOT near-miss reports (n = 670)*	158 (23.6%)	109 (69.0%)	42 (26.6%)	7 (4.4%)
State crash reports, 4 states (n = 350,358)	26,349 (7.52%)	--	18,976 (72.1%)	7,350 (27.9%)



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Intrusion Prediction Models

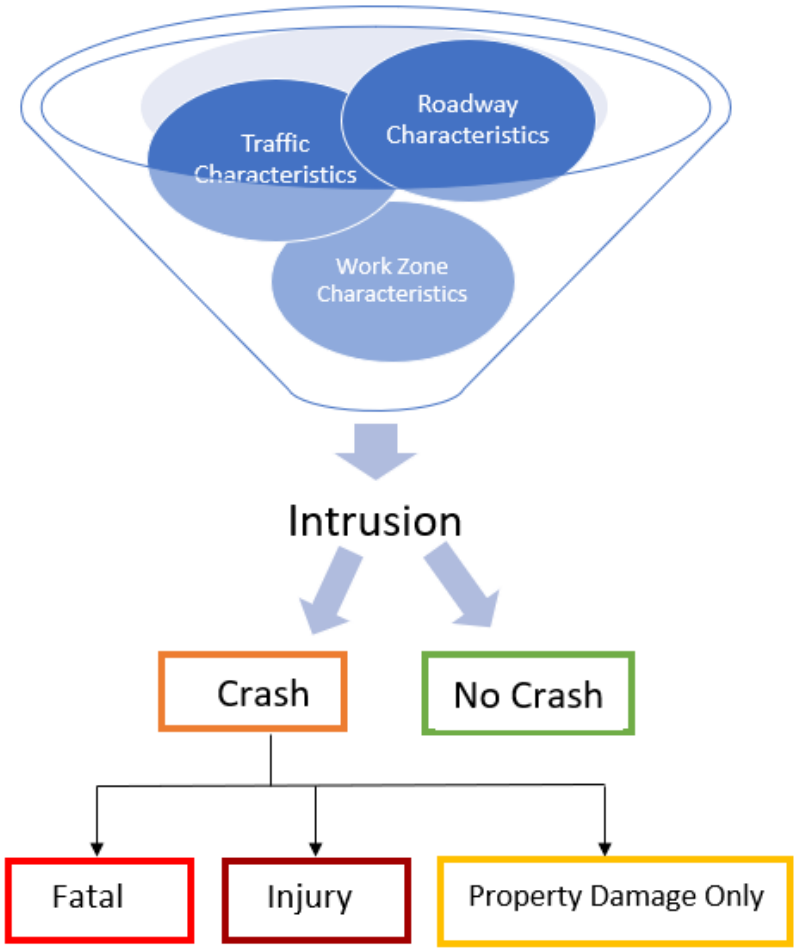
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Prediction Models

Prediction models developed:

1. Work zone intrusion occurrence
2. Intrusion-related crash occurrence
3. Intrusion-related crash severity





Prediction Models

Logistic regression:

- Conditional probability of a binary outcome occurring
- Coefficients transformed into odds ratios

$$Logit(P) = \beta_0 + \sum(\beta_k X_k)$$

$$P(Y = 1) = \frac{1}{1 + e^{(-Logit)}}$$

Where:

- *Logit(P)* = natural logarithm of the odds
- *P(Y=1)* = conditional probability of outcome Y occurring
- β_0 = intercept
- β_k = regression coefficients
- X_k = explanatory variables



Prediction Models

Prediction models developed:

1. Work zone intrusion occurrence
2. Intrusion-related crash occurrence
3. Intrusion-related crash severity

- Datasets used:
  - National work zone intrusion reports
  - Oregon DOT near-miss reports



Prediction Model 1: Intrusion Occurrence

Variable	Coefficient	Std Err	P-value
Nighttime or low light conditions	0.619	0.255	0.015
Roadway with 4 or more lanes	0.228	0.316	0.472
Presence of horizontal curve	1.348	0.446	0.003
Divided roadway	-0.179	0.350	0.608
Freeway facility	0.744	0.284	0.006
Worker present	1.238	0.225	< 0.0001
Lane closure activity	-0.146	0.249	0.557
Work on shoulder	-0.109	0.283	0.700



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Prediction Models

Prediction models developed:

1. Work zone intrusion occurrence
2. Intrusion-related crash occurrence
3. Intrusion-related crash severity

- Datasets used:
  - National work zone intrusion reports
  - Oregon DOT near-miss reports
  - 100 randomly selected crashes from 4 state crash reports



Prediction Model 2: Intrusion Crash Occurrence

Variable	Coefficient	Std Err	P-value
Nighttime or low light conditions	1.544	0.446	0.0005
Roadway with 4 or more lanes	-0.280	0.406	0.491
Presence of horizontal curve	-0.034	0.533	0.949
Divided roadway	-0.553	0.458	0.228
Freeway facility	1.000	0.408	0.014
Congestion	2.006	0.598	0.0008
Speed variability high	0.928	0.176	< 0.0001
Worker present	-0.208	0.320	0.515
Lane closure activity	0.264	0.385	0.492
Work on shoulder	0.427	0.407	0.295
Work area location	0.513	0.292	0.079



Prediction Models

Prediction models developed:

1. Work zone intrusion occurrence
2. Intrusion-related crash occurrence
3. Intrusion-related crash severity

- Datasets used:
  - National work zone intrusion reports
  - Oregon DOT near-miss reports
  - Crashes reports from four states



Prediction Model 3: Intrusion Crash Severity

Variable	Coefficient	Std Err	P-value
Driver distraction present	0.078	0.018	0.559
Aggressive driving behavior	0.345	0.014	0.0089
Tailgating observed	0.225	0.013	0.0012
Rain	-0.159	0.016	0.881
Snow/Ice	-0.298	0.059	0.658
Fog	-0.066	0.052	0.204
Nighttime or low light conditions	0.293	0.091	0.0012
Roadway with 4 or more lanes	1.067	0.092	< 0.0001
Presence of horizontal curve	1.003	0.151	< 0.0001
Divided roadway	0.455	0.100	< 0.0001
Freeway facility	0.235	0.116	0.0432
Speed limit ≥ 30 mph	0.848	0.259	0.0011
Traffic volume > 50,000 vehicles/day	-0.370	0.084	< 0.0001
Worker present	0.064	0.105	0.544
Lane closure activity	-0.915	0.098	< 0.0001
Work on shoulder	-0.998	0.139	< 0.0001



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Research Study Overview

Study Scope

"Guide for Work Zone Intrusion Prediction and Prevention" (NCHRP Project 17-107)

GOAL:
Prevent injuries/fatalities due to work zone intrusions

INPUTS

Work zone intrusion data and knowledge

OUTPUTS

Work zone intrusion prediction models

Decision-support tool and Implementation Guide

IMPLEMENTATION OUTCOME:
Work zone designs and planning that minimize the likelihood of intrusions

ACTIVITIES

- Develop, test, and evaluate tool and guide
- Obtain feedback regarding content and application



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Decision-support Tool



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Decision-support Tool

Functionality and Value:

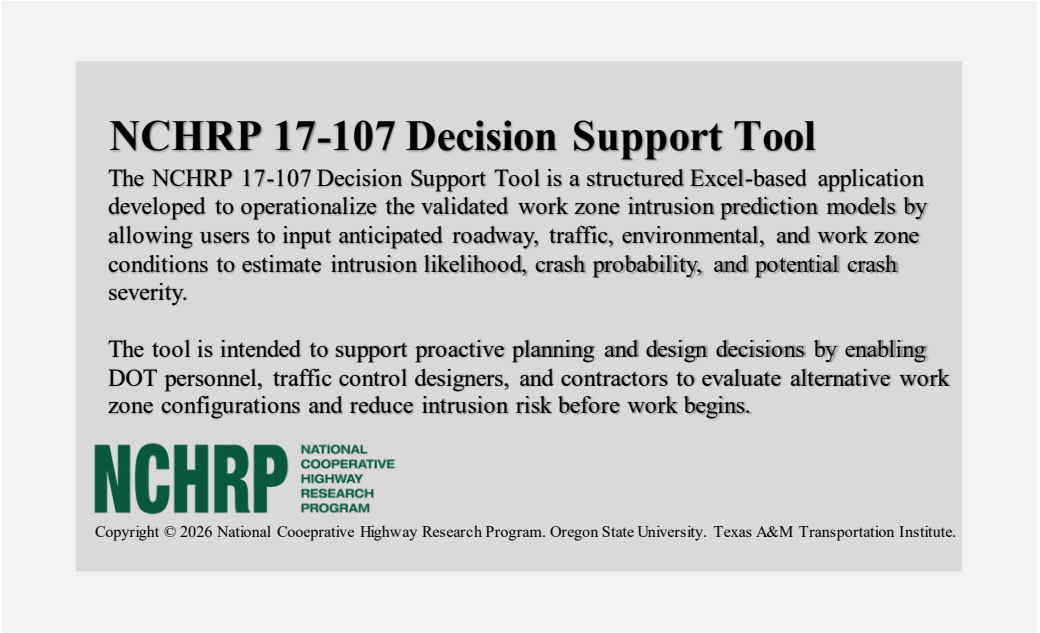
- Evaluate alternative work zone configurations and timing
  - Compute estimated intrusion likelihood
  - Estimate probability of a crash following an intrusion
  - Predict the likely severity of an intrusion-related crash
- Reduce intrusion risk before work begins

Users:

- DOT and contractor personnel involved in the design and implementation of work zone traffic control and work operations

Implementation:

- During traffic control design prior to the start of the work
- Immediately prior to the start of the work





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Decision-support Tool

Definitions (excerpt)

Term	Abbreviation	Definition
NCHRP Project 17-107	**NCHRP 17-107**	National Cooperative Highway Research Program project to develop predictive models and guidance for work zone intrusion prediction and prevention.
Decision Support Tool	**DST**	Excel-based tool that operationalizes intrusion prediction models for proactive work zone risk evaluation.
Work Zone Intrusion	**WZI**	Unauthorized vehicle encroachment into the work activity area or buffer space.
Intrusion Occurrence	—	Binary outcome indicating whether a work zone intrusion occurred (1 = Yes, 0 = No).
Intrusion-Related Crash	**IRC**	Crash resulting from a work zone intrusion event.
Crash Severity	—	Level of outcome from intrusion-related crash (injury, fatality, or property damage only).
Logit Function	**Logit(P)**	Natural logarithm of the odds of an event occurring, used in logistic regression.
Probability	**P(Y=1)**	Estimated likelihood that the modeled outcome occurs.
Intercept	β_0	Constant term in logistic regression equation.
Regression Coefficient	β_i	Parameter estimate representing effect of independent variable on log-odds of outcome.
Explanatory Variable	X_i	Independent variable included in prediction models.
Driver Distraction Present	$X_{distraction}$	Distraction is evident among approaching drivers, such as mobile phone use, looking away from roadway/work zone, and inattentive scanning (1 = drivers distracted; 0 = drivers not distracted).
Aggressive Driving Behavior	$X_{aggressive}$	Aggressive maneuvers are observed at or near the planned work zone, such as abrupt lane changes, unsafe passing, and hostile driving behavior (1 = aggressive driving observed; 0 = no aggressive driving observed).
Tailgating Observed	$X_{tailgating}$	Vehicles are observed following at unsafe headways and allow for insufficient following distance (1 = tailgating observed; 0 = no tailgating observed).
Rain	X_{rain}	Rain is occurring and potentially affecting visibility/traction (1 = raining; 0 = not raining).



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Decision-support Tool

Assessment:

Input fields

1. Driver Conditions and Actions	Enter responses using drop-down lists
a. Is driver distraction a documented or known concern at or near the planned work zone?	
b. Is aggressive driving a documented or known concern at or near the planned work zone?	
c. Is close-following or tailgating a documented or known concern at or near the planned work zone?	
2. Environmental Conditions	**Enter responses using drop-down lists**
a. Is rainfall reasonably likely during the planned work period?	
b. Are snow or icy roadway conditions reasonably likely during the planned work period?	
c. Are fog or other weather-related conditions that reduce visibility reasonably likely during the planned work period?	
d. Will any work operations occur during nighttime or other low-light conditions?	
3. Roadway Design Features	**Enter responses using drop-down lists**
a. Does the roadway have four or more travel lanes at or approaching the work zone?	
b. Is a horizontal curve located within or on the approach to the planned work zone?	
c. Is the roadway divided by a median or other physical separation?	
d. Is the roadway classified as a freeway or other controlled-access facility?	
e. Is the posted speed limit at the work-zone location 30 mph or greater?	
4. Roadway Traffic Conditions	**Enter responses using drop-down lists**
a. Is the roadway AADT at the planned work-zone location greater than 50,000 vehicles per day?	
b. Is traffic congestion expected during the planned work period?	
c. Are substantial differences in vehicle speeds expected within or approaching the work zone?	
5. Work Operations and Conditions	**Enter responses using drop-down lists**
a. Will workers be located within or immediately adjacent to active travel lanes during planned operations?	
b. Will the planned temporary traffic control include closure of one or more active travel lanes?	
c. Will work activities be performed on or immediately adjacent to the roadway shoulder?	
d. What is the target location within the work zone, e.g., transition area, buffer area, activity area, or termination area?	



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Decision-support Tool

Assessment Results:

Output fields

*Risk levels:

- Low risk: P < 30%
- Moderate risk: 30% ≤ P < 60%
- High risk: P ≥ 60%

Prediction Models	Logit	Probability (P)	Risk Level*
Work Zone Intrusion Occurrence	-1.388		
Intrusion-related Crash Occurrence	-0.613		
Intrusion-related Crash Severity High (injury/fatality)	-2.055		

Categories	Variables	Input Value	Model 1 - Work Zone Intrusion Occurrence (β * X)	Model 2 - Intrusion-related Crash Occurrence (β * X)	Model 3 - Intrusion-related Crash Severity (β * X)
1. Driver Conditions and Actions	a. Driver distraction present				
	b. Aggressive driving behavior				
	c. Tailgating observed				
2. Environmental Conditions	a. Rain				
	b. Snow/Ice				
	c. Fog				
	d. Nighttime conditions				
3. Roadway Design Features	a. Four or more lanes				
	b. Horizontal curve				
	c. Divided roadway				
	d. Freeway facility				
	e. Speed limit ≥ 30 mph				
4. Roadway Traffic Conditions	a. Traffic volume				
	b. Congestion present				
	c. Speed variance high				
5. Work Operations and Conditions	a. Worker presence				
	b. Lane closure activity				
	c. Shoulder work				
	d. Work area location				



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Decision-support Tool

Logit model coefficients

NOTES:

Color coding:

= Variable is statistically significant

= Variable is impactful but not statistically significant

Coefficient values:

0 (zero) = Insufficient data available to calculate a coefficient

Categories	Variables	Model 1 - Coefficients (β)	Model 2 - Coefficients (β)	Model 3 - Coefficients (β)
1. Driver Conditions and Actions	a. Driver distraction present	0.000	0.000	0.078
	b. Aggressive driving behavior	0.000	0.000	0.345
	c. Tailgating observed	0.000	0.000	0.225
2. Environmental Conditions	a. Rain	0.000	0.000	-0.159
	b. Snow/Ice	0.000	0.000	-0.298
	c. Fog	0.000	0.000	-0.066
	d. Nighttime conditions	0.619	1.544	0.293
3. Roadway Design Features	a. Four or more lanes	0.228	-0.280	1.067
	b. Horizontal curve	1.348	-0.034	1.003
	c. Divided roadway	-0.179	-0.553	0.455
	d. Freeway facility	0.744	1.000	0.235
	e. Speed limit ≥30 mph	0.000	0.000	0.848
4. Roadway Traffic Conditions	a. Traffic volume	0.000	0.000	-0.370
	b. Congestion present	0.000	2.006	0.000
	c. Speed variance high	0.000	0.928	0.000
5. Work Operations and Conditions	a. Worker presence	1.238	-0.208	0.064
	b. Lane closure activity	-0.146	0.264	-0.915
	c. Shoulder work	-0.109	0.427	-0.998
	d. Work area location	0.000	0.513	0.000



NATIONAL WORKZONE SAFETY INFORMATION CLEARINGHOUSE

Implementation Guide



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Implementation Guide

Purpose:

- Translate the research results, predictive models, and decision-support framework into a clear, practical, operational resource for practical implementation

Users:

- DOT and contractor personnel involved in the design and implementation of work zone traffic control and work operations

Implementation:

- During traffic control design prior to the start of the work
- Immediately prior to the start of the work

IMPLEMENTATION GUIDE

NCHRP PROJECT 17-107

GUIDE FOR WORK ZONE INTRUSION PREDICTION AND PREVENTION

Prepared by:
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September 2026

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TRANSPORTATION RESEARCH BOARD
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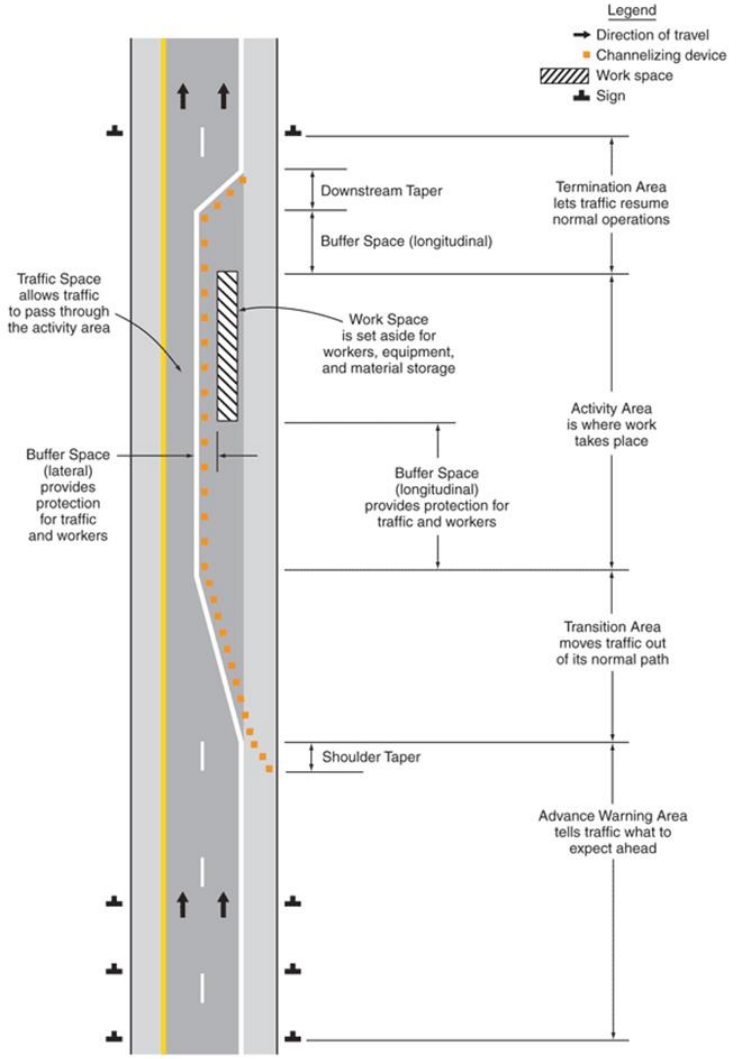
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Implementation Guide

Contents:

1. Purpose of the Implementation Guide
2. Core Inputs Required for Implementation
3. Structure of the Prediction and Decision-Support Process
4. Implementation Example:
    a. Application of the models and decision-support tool to a work zone intrusion case
5. Limitations and Recommendations for Application
6. References





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Key Findings and Recommendations



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Key Findings and Recommendations

Findings

Intrusion data:

- Limited amount
- Limited type
- Inconsistent quality

Intrusion prediction:

- Specific to site conditions, work operations, traffic conditions, driver behavior
- Real-time data needs

Prediction resources:

- Models, guide, and tool
- Further research and development

Recommendations

Practice:

- Application to selected work zones
- Tracking work zone intrusions
- Data collection

Research and development:

- Prediction model development
- Prediction calibration
- Site-specific evaluation



NATIONAL WORKZONE SAFETY INFORMATION CLEARINGHOUSE

Work Zone Intrusion Prediction and Prevention

Thank you for your interest!

Questions? Comments?

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WORK ZONE INTRUSIONS UNFOLD IN SECONDS. CAN WE ACT BEFORE THEY HAPPEN?

Safer Workers | Safer Drivers | Smarter & connected Work Zones

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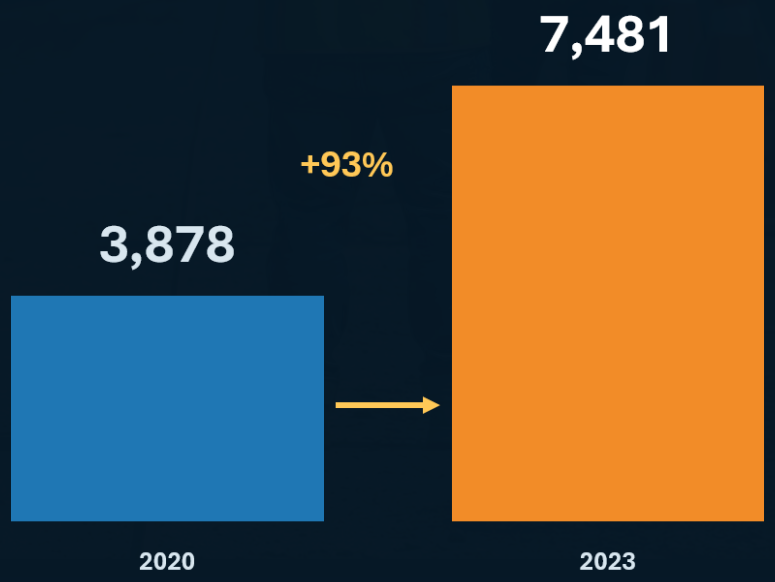


Work Zone Safety Remains a National Transportation Challenge

818
fatal work zone crashes
U.S., 2023

899+
people killed
U.S., 2023

2+
deaths each day
average burden



Speeding

Speeding is the most significant contributor to work-zone crashes; nearly 300 speeding-related work-zone deaths occurred in 2020.

Distracted Driving

Distraction is underreported but repeatedly identified as a leading source of driver inattention and work-zone risk.

National Work Zone Safety Information Clearinghouse/FARS; Indiana work zone crash data; AGC of America; National Safety Council.

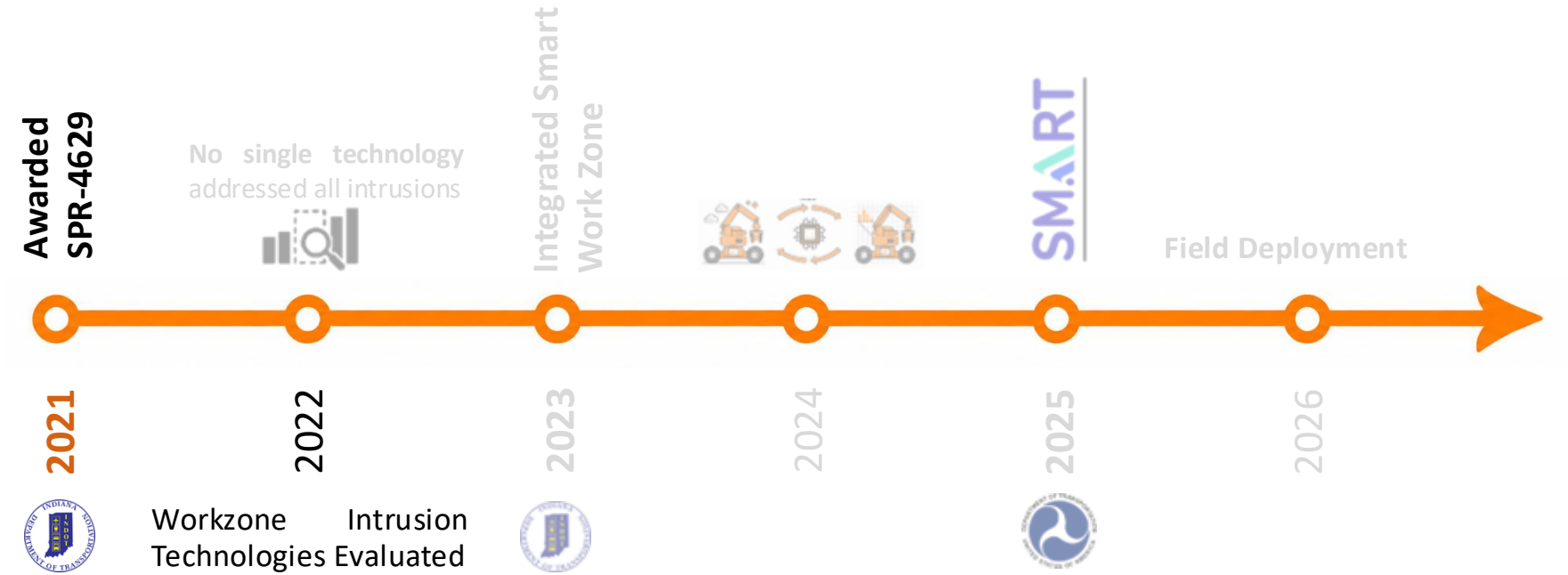
Evolution toward a proactive & predicted work zone intrusion system

Smarter and Safer Work Zone Through Multimodal Intrusion Detection

US Department of Transportation (USDOT) SMART

Integrated Smart Work Zone

Indiana Department of Transportation (INDOT)




65
mph

Year – 2021 Implementation and Assessment of Highway Intrusion Technologies

- To accomplish the overall goal, this research consisted following tasks:

01

Document current state of knowledge

- Literature review of the previous studies
- Research methodology and implementation strategies
- Reported best practices

02

Preliminary and pilot-controlled testing

- Sound levels, duration, work zone coverage
- To assess the functional characteristics in operation
- Feasibility and reliability of systems

03

Synthesize current practices and challenges

- Familiarity, perceived effectiveness, and associated challenges
- Functionality evaluation, false alarm concerns, durability and challenges in deployment

04

Examine drivers' risk perception and responses

- To assess drivers' perception, and reactions Examine effectiveness of technologies in creating a sense of urgency

05

Develop decision-making matrix

- Selecting the most suitable intrusion technology
- Address the work zone related issues based on criteria ranking and rating

Existing Intrusion Technologies

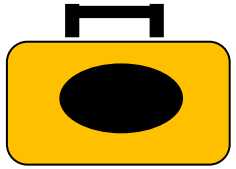
- Existing solutions can be classified as either **reactive** (impact-triggered) or **proactive** (Sensor-based)

Reactive



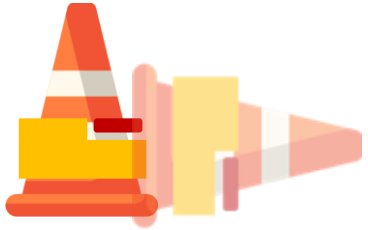
Intellicone systems

- Unit is triggered via internal shock sensor, transmits a radio signal, reaches the auditory-visual alarm



Traffic Guard Worker Alert System (WAS)

- Pneumatic hoses attached to a pressure sensor which acts as a transmitter device
- Siren and strobe lights are activated when a vehicle passes over the hoses



SonoBlaster

- Impact driven attached to a traffic control device
- Vehicle strikes the device, workers are alerted through a warning sound

Proactive

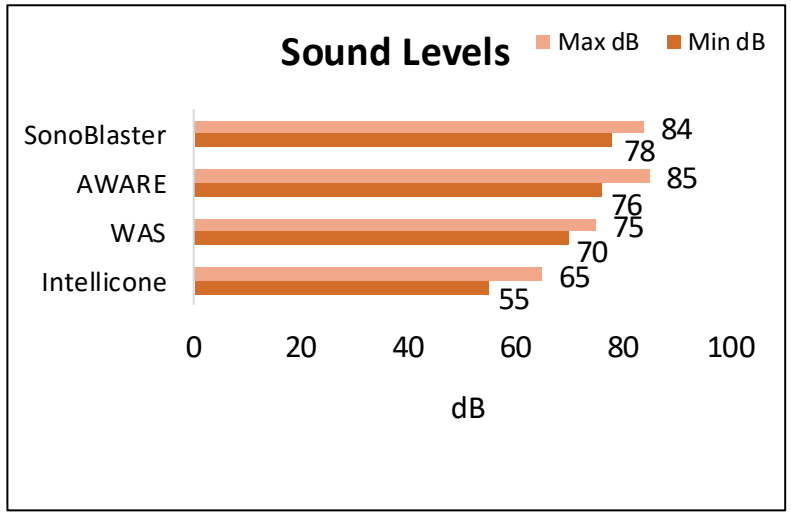


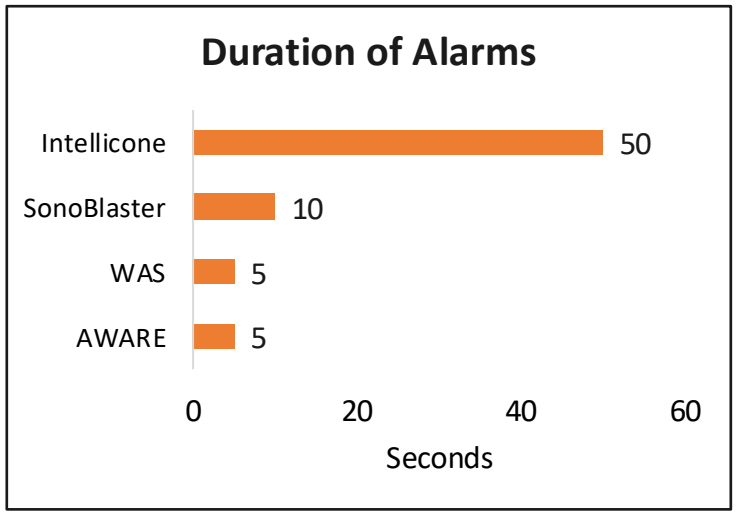
AWARE System

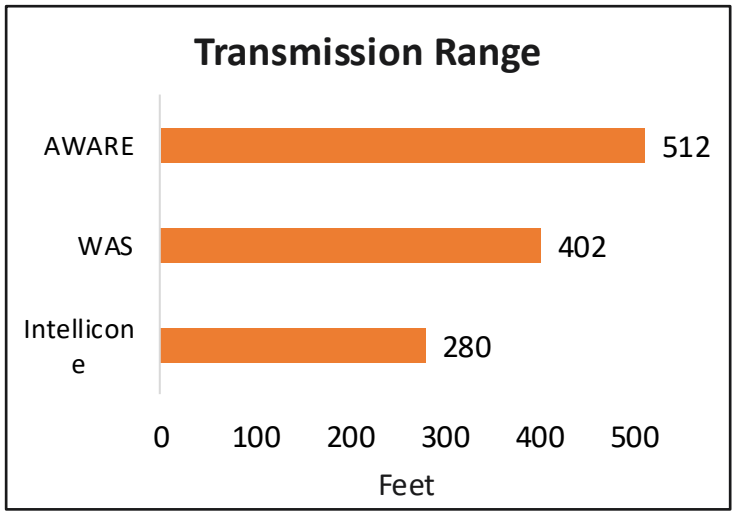
- Uses electronically scanned radar sensor
- Detects potential work zone intrusion from multiple vehicles
- Warn both driver and workers in danger zones

Preliminary and Pilot Tests

- **3 trials** for each observation and each technology was activated manually



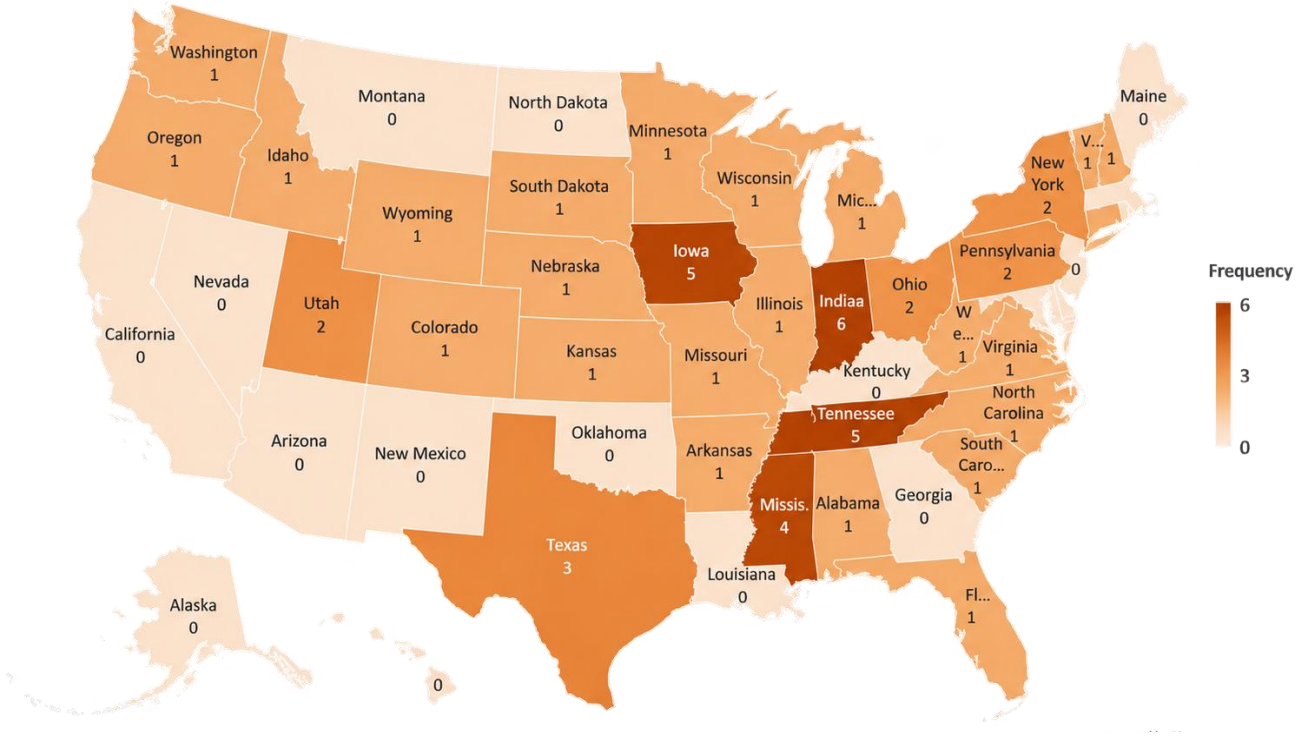




Pilot findings

- SonoBlaster had the loudest alarm. Its duration varied across tests.
- Intellicone's PSA lasted 50 seconds.
- WAS produced longer stopping distances and durations.

Survey Findings: Limited Adoption and Familiarity



Responses from **32** different states

65%

Not familiar with any of the four technologies

54 responses

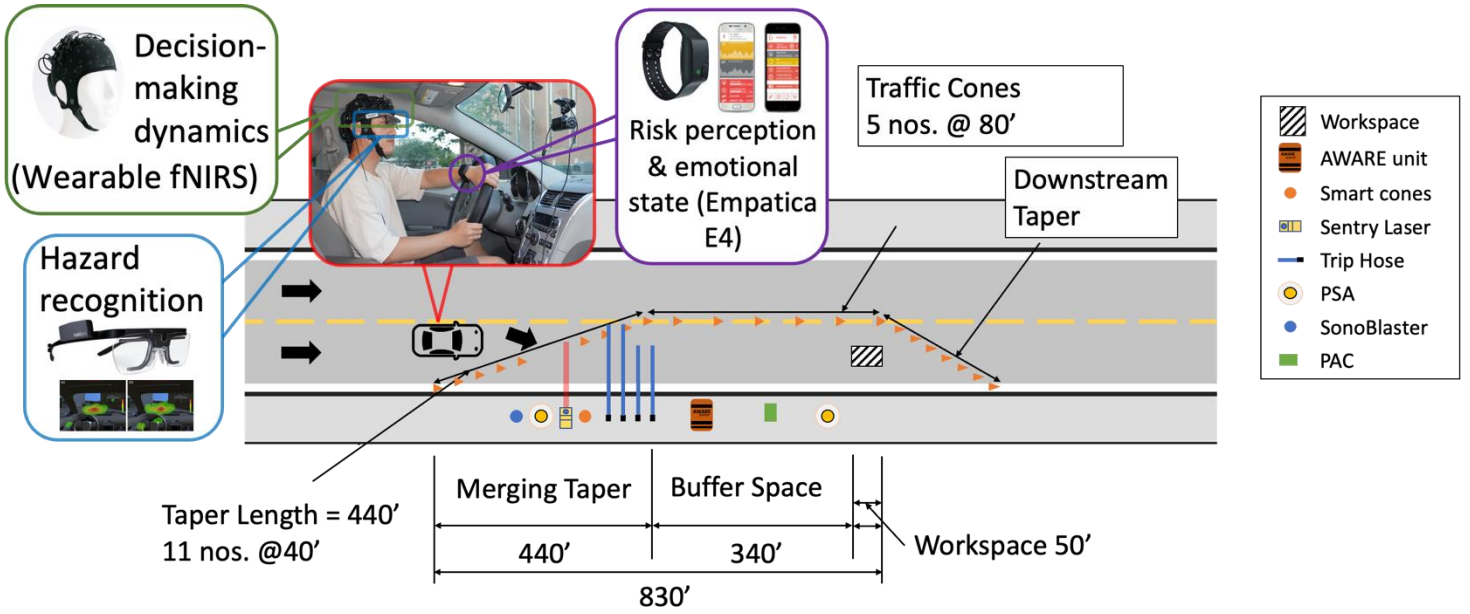
AWARE was the most used system at 28% of respondents

Adoption barriers

Coverage, adequate reaction time and identifying intrusion direction

Driver Risk Perception and Responses

Experimental layout of the field test:



- 9 trials for each participant with two vehicle speeds (35 & 45 MPH)

Visual attention

Drivers showed similar search patterns. Most attention stayed on the road and work site ahead.

Risk perception

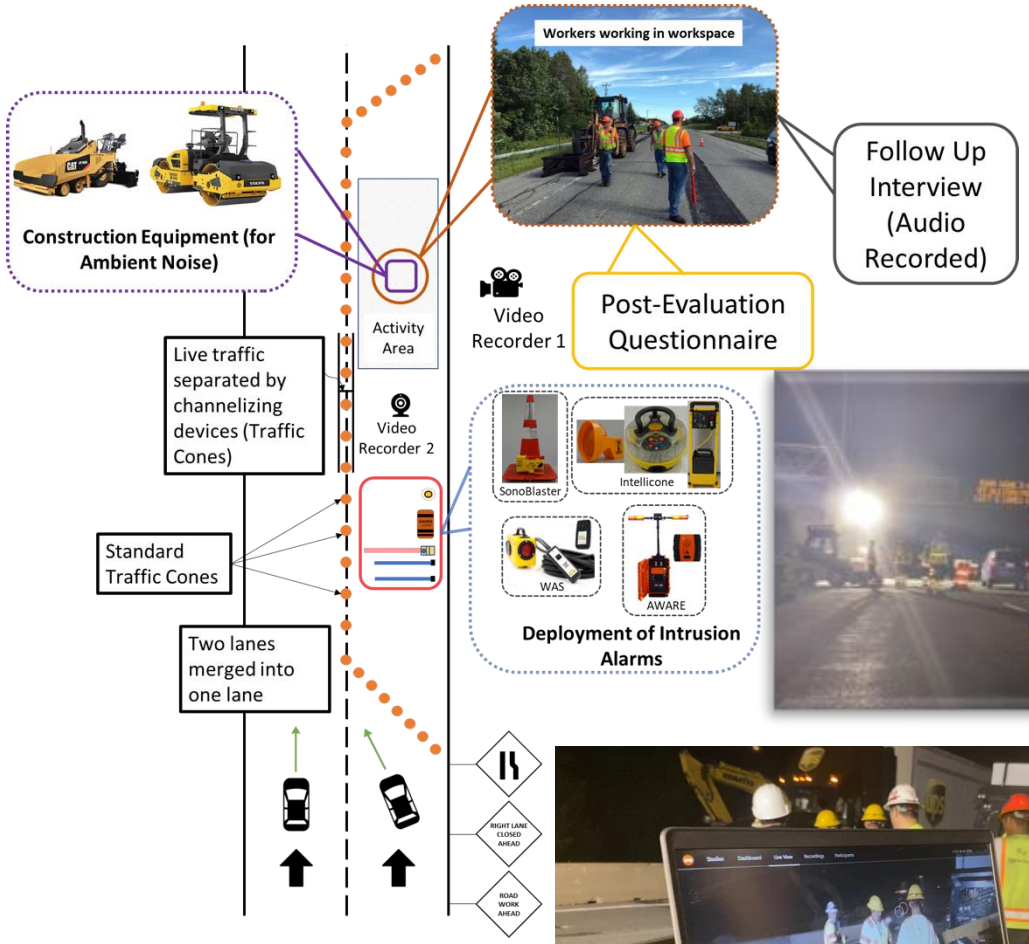
The analysis did not indicate significant perceived danger across the technologies.

Responses

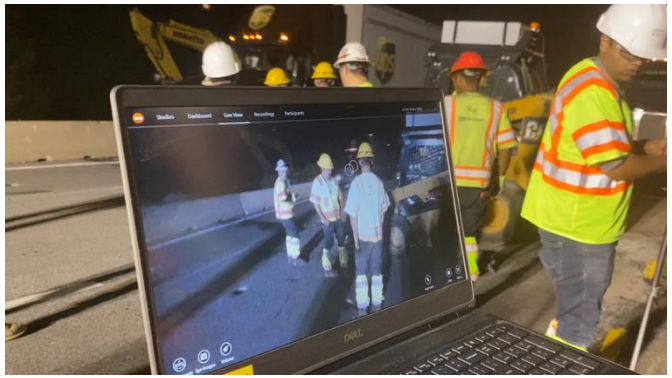
Higher concentration of oxyhemoglobin (brain activation) within auditory cortices during reaction time when **SonoBlaster** was triggered

Drivers could not detect the stimulus, perceive the potential risks, or have a sense of urgency because alerting mechanisms were **insufficient regarding sound level, duration, and frequency**.

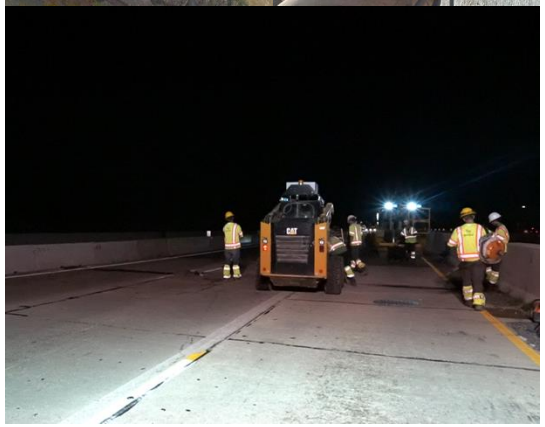
Worker Risk Perception and Responses



- 7 active work zones
- 4-6 workers as participants on each work zone.
- The participants will also be asked to fill up a short post-evaluation survey.
- Follow-up interview (audio-recorded).
- Total number of participants: 29 participants including 6 primary participant







Post-evaluation Survey

Name: _____ Age: _____

Date: 11/01/2022 Gender: _____ Technology Name: AWARE

Job Title: _____ Years of experience in construction: _____

Please rate the following information on a scale of 1 – 5, with 5 being "strongly agree" and 1 being "strongly disagree".

	Strongly Disagree				Strongly Agree
You were familiar with this technology before testing.	1	2	3	4	5
The alarm caused you to feel a sense of urgency after its activation.	1	2	3	4	5
This technology was effective in improving the work zone safety.	1	2	3	4	5
This system was helpful in figuring out the direction of intrusion.	1	2	3	4	5
In the presence of ambient noise environment, the alarm sound was distinguishable.	1	2	3	4	5
The alarm allowed sufficient lead time to find the escape path.	1	2	3	4	5
The sound of the alarm felt annoying while working.	1	2	3	4	5
The flashing lights of the alarm were effective to grab your attention.	1	2	3	4	5

For what type/s of operation duration would you like to recommend this technology?

(Please select all that apply)

- ☐ Short duration highway work zones operation
- ☐ Moderate duration highway work zones operation
- ☐ Long duration highway work zones operation
- ☐ None
- ☐ Other _____

Decision matrix for selecting technology

- Nine key criteria were identified regarding functionality of the technologies:

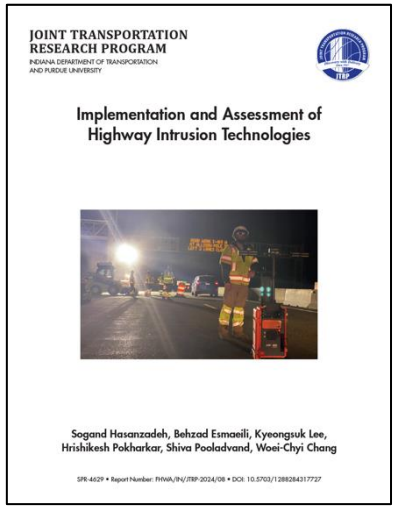
  - Frequency of false alarms
  - Effectiveness of driver
  - Sound distinctiveness
  - Deployment
  - Cost
  - Alert level and type
  - Incident database
  - Transportation
  - Coverage

Evaluation Criterion	SonoBlaster	AWARE	Intellicone	WAS
Deployment (Easy, straightforward, and less time-consuming)	Takes time to set up and mount units to traffic cones. Once attached, then very easy to deploy and replace cartridges	Very straightforward deployment, easy to set up, and getting connected to servers	Takes time to insert batteries in smart cones. Easy to get connected to servers. (As the number of cones increases, more time it will take to setup)	Simple to deploy hoses and alarm units in a work zone
Work zone coverage (Area that can be covered once deployed)	Not applicable	It can be extended up to 510 feet (Between Sentry and PSDs)	Unlimited coverage with more smart cones	Up to 400 feet (Between alarm unit and pressure sensor)
Transportation and storage after use	Very difficult to transport as traffic cone cannot be stacked on each other. Requires larger storage space.	Very easy to transport and store	Requires larger space to store and transport due to many smart cones. Batteries are required to be removed after each use. Difficult to move the sentry laser unit due to its weight	Hoses get entangled if placed together. Batteries need to be removed while transporting.
Alert level and type (Visual, Audio, and Haptic)	Loud audio alert only	Somewhat loud, with visual, audio, and haptic alerts	Somewhat loud, with visual and audio alerts	Somewhat loud, with visual (not very effective), audio, and haptic alerts

Color coding based on the effectiveness

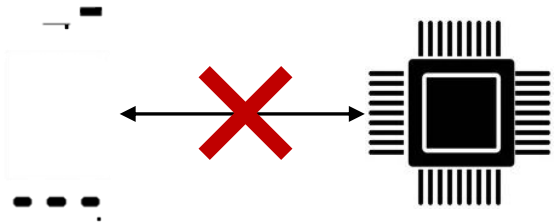
Most preferable | Preferable | Somewhat preferable | Not preferable at all | Not applicable

Current Limitations in Intrusion Technology

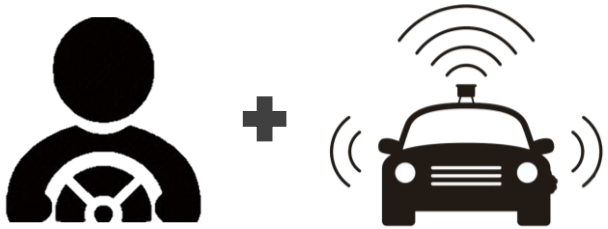


No single system addressed every work-zone safety need [3]

1. **No communication** among different technologies



2. No integrated solutions for **current** and **future** traffic conditions.



3. No solutions for **static** and **mobile** work zone



[3] Hasanzadeh, S., Esmaeili, B., Lee, K., Pokharkar, H., Poolavand, S., & Chang, W. C. (2023). Implementation and assessment of highway intrusion technologies.

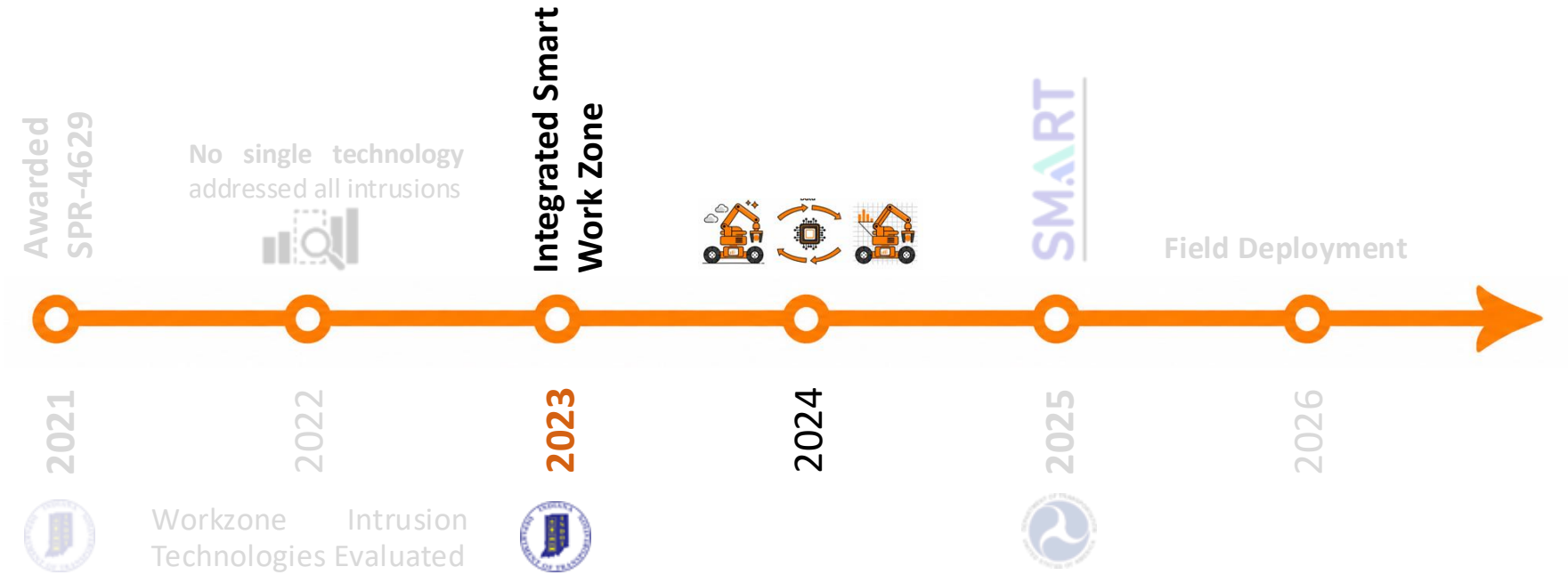
Year – 2023 Integrated Smart Work Zone

Smarter and Safer Work Zone Through Multimodal Intrusion Detection

US Department of Transportation (USDOT) SMART

Integrated Smart Work Zone

Indiana Department of Transportation (INDOT)



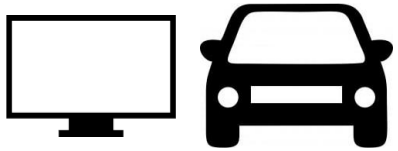
Integrated Smart Work Zone Scope

Phase I



Regular vehicles

Phase II



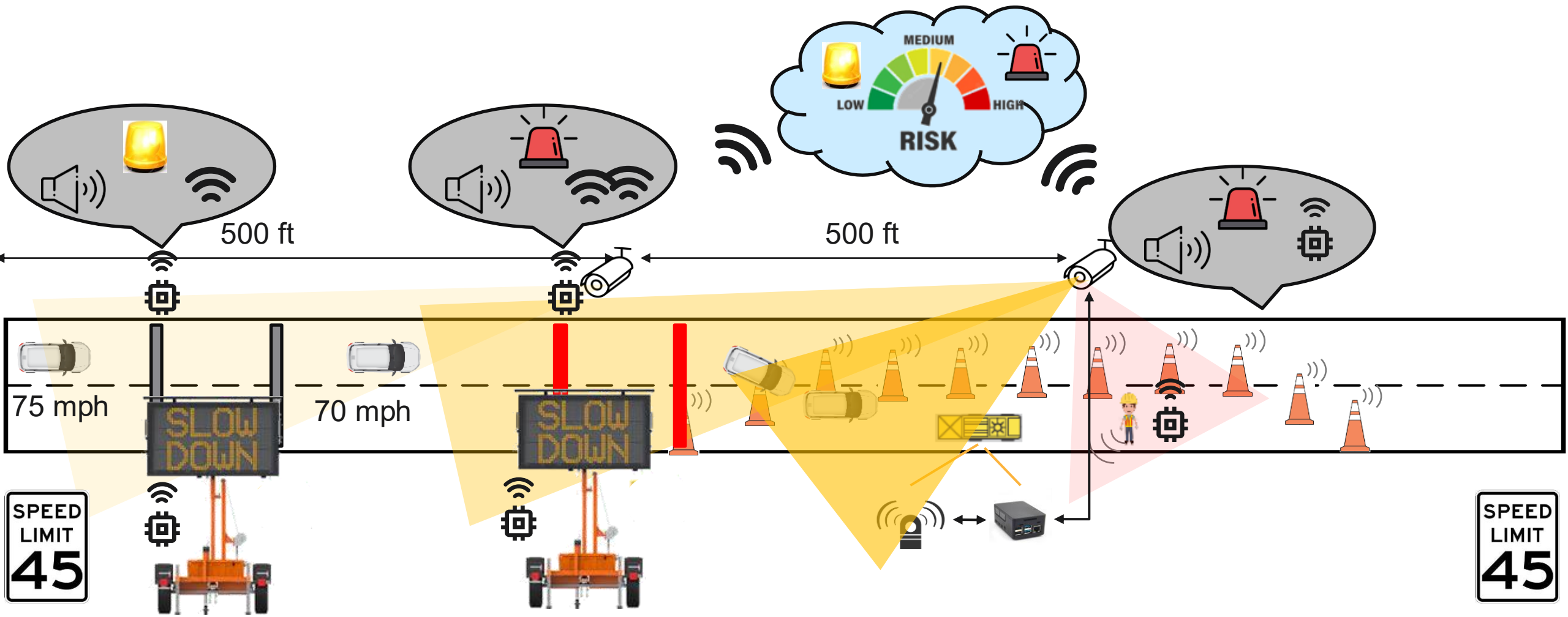
Connected vehicles

Phase III



Autonomous vehicles

Envisioned Smart Work Zone System



Situational Awareness for the Whole Work Zone

WHY THE DIGITAL TWIN MATTERS

The Digital Twin continuously understands where workers are, how vehicles are behaving, and whether risk is rising so the work zone can act on it.

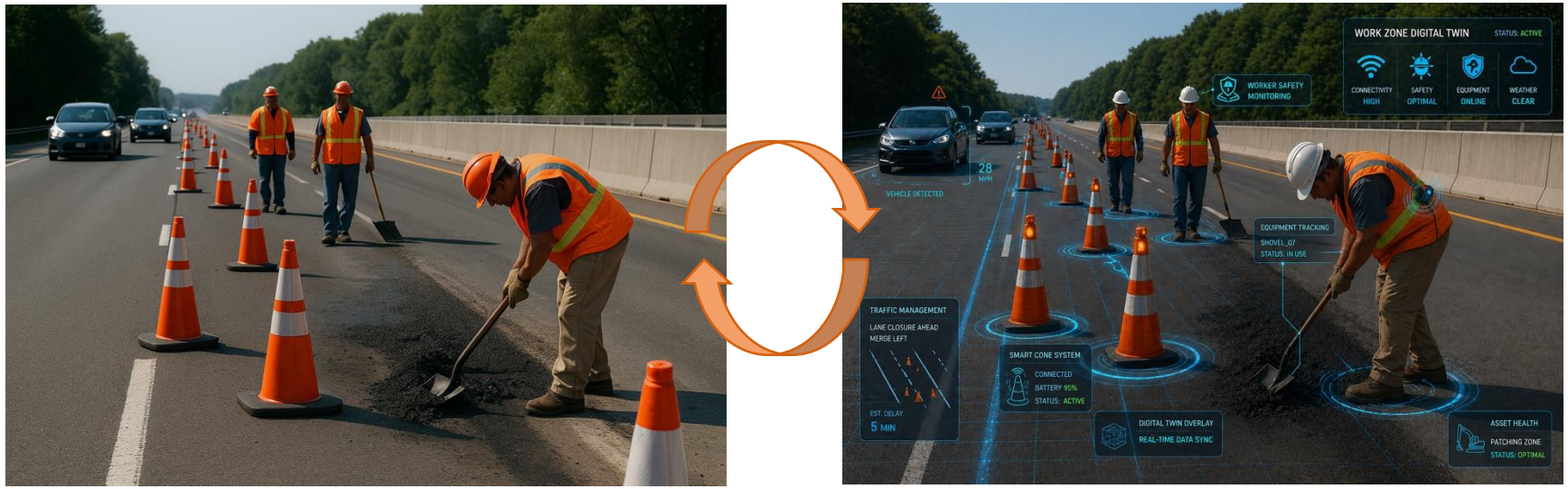
SEE
traffic, workers, work-zone layout

→ **PREDICT**
vehicle-level intrusion and crash risk

→ **WARN**
drivers and workers

→ **SUPPORT**
Targeted warning

→ **MEASURE**
behavior, response and outcomes



Workzone Digital Twin Framework

Smart Sensing

Traffic:


Radar


Camera

Workers:


Beacon


LiDAR

Workzones:





Channelizing devices (w/ GPS)

Work Zone Digital Twin

Synchronization

Continuously update from physical workzone

Prediction

Predict risk levels and potential intrusions

Input





Output



Data Fusion

Integrate multimodal sensing data into decision making

Visualization

Help users understand current situations

Alerting

Road users:





HAAS + Map

At-risk drivers:



PCMS


PSA

Workers:


PSA

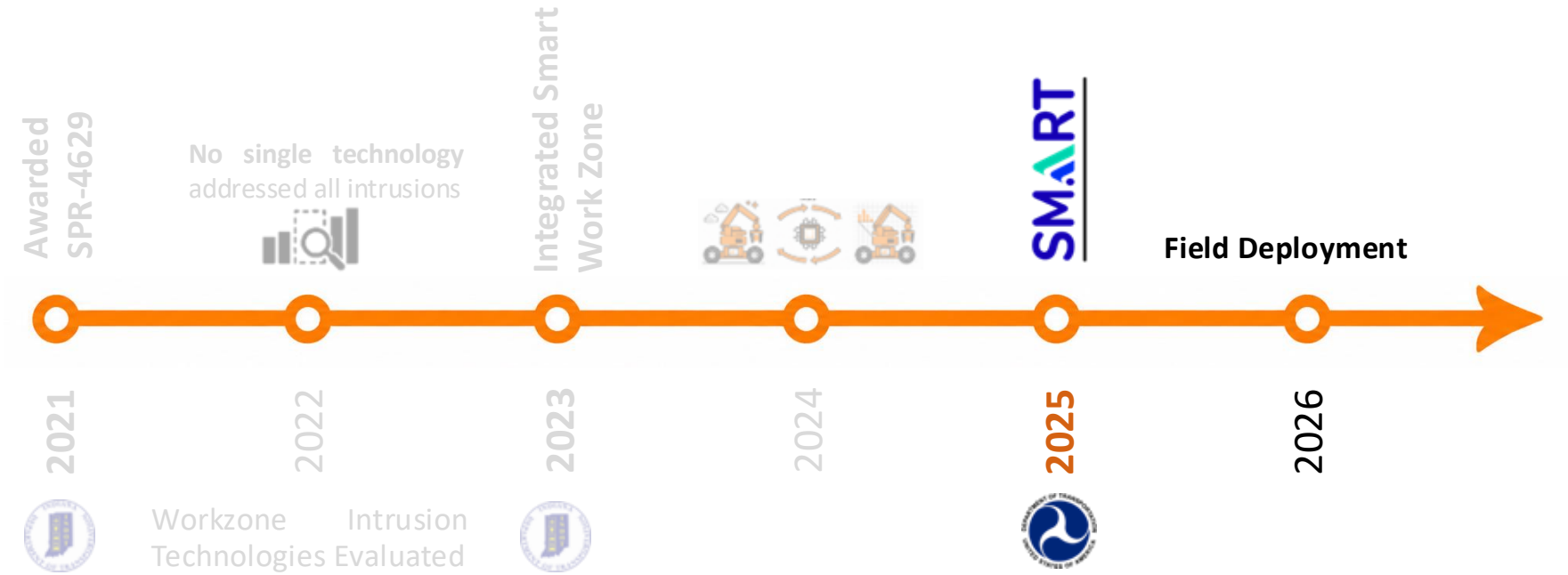
Year – 2025 USDOT SMART GRANT

Smarter and Safer Work Zone Through Multimodal Intrusion Detection

US Department of Transportation (USDOT) SMART

Integrated Smart Work Zone

Indiana Department of Transportation (INDOT)



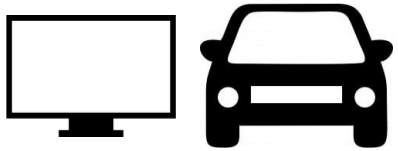
USDOT SMART GRANT

Phase I



Regular vehicles

Phase II



Connected vehicles

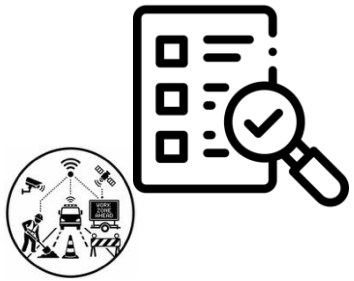
Phase III



Autonomous vehicles



Development



Evaluation



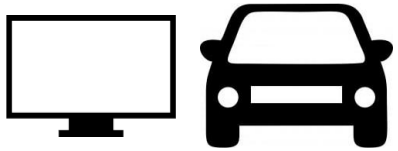
Deployment

USDOT SMART GRANT

Phase I | **Phase II** | **Phase III**



Regular vehicles



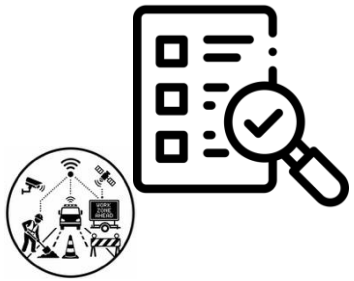
Connected vehicles



Autonomous vehicles



Development



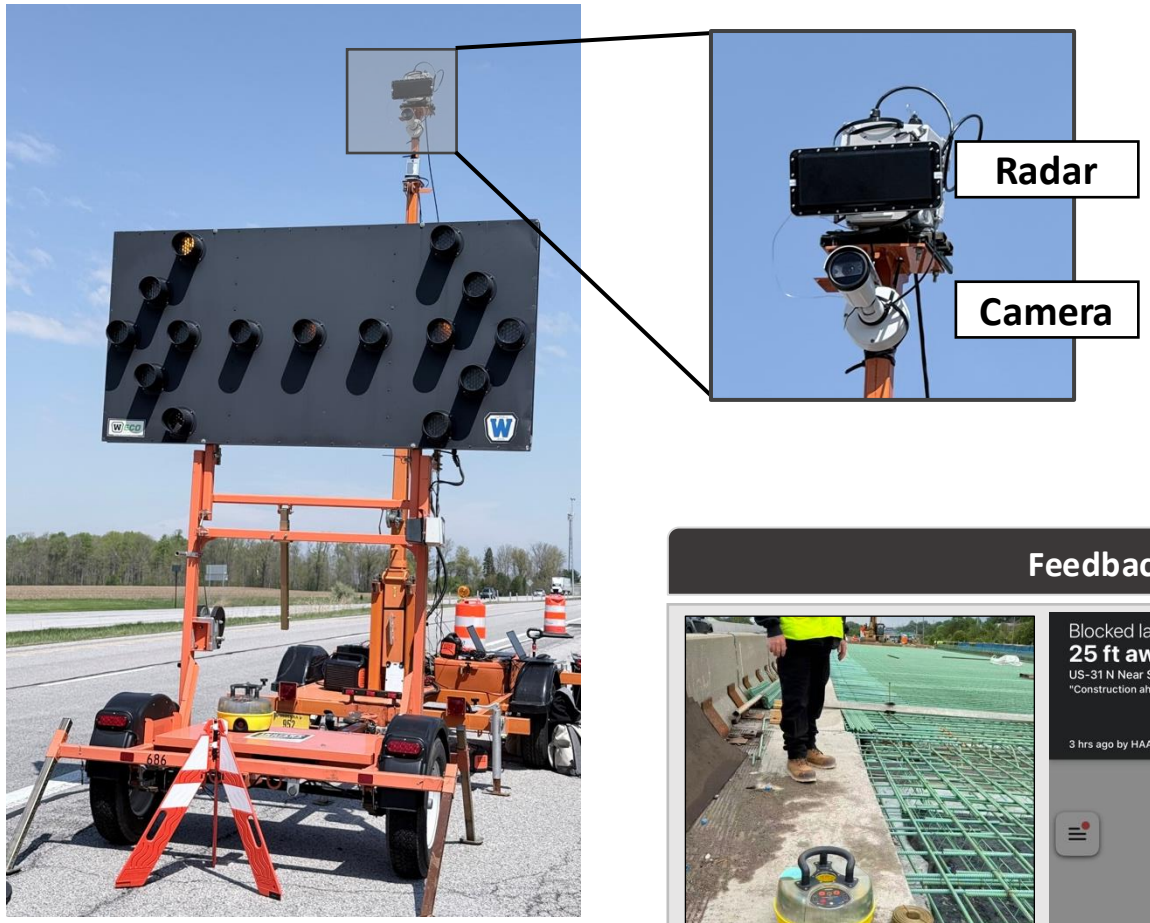
Evaluation



Deployment

Set Up

Traffic Sensors on Trailer



FirstGards setup



Purpose: Establish the geofence boundary

Beacons setup

Beacons attached to Worker's Hardhat

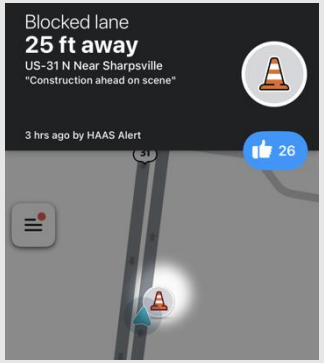


Worker's Presence at the worksite



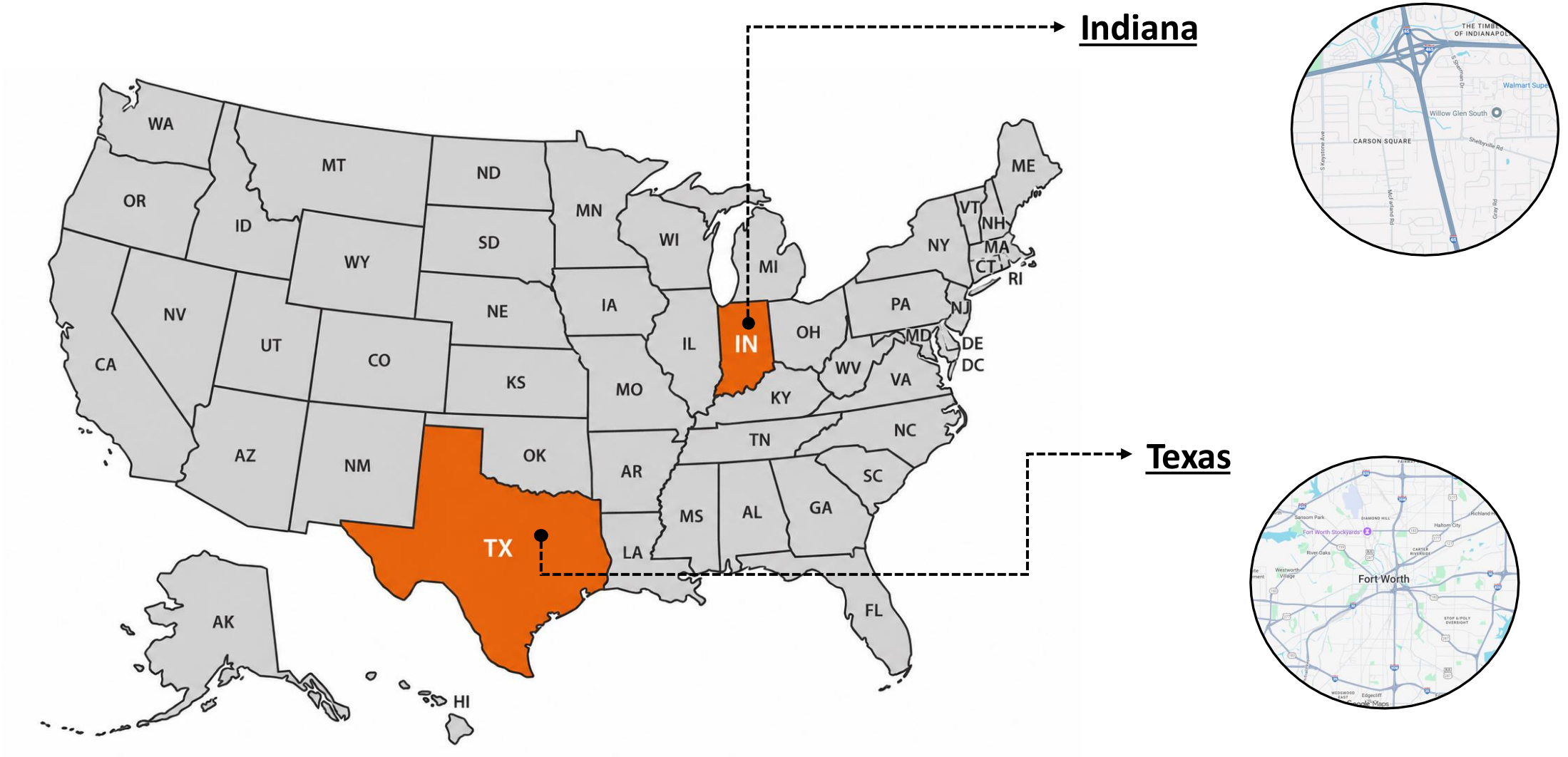
Purpose: Beacons enables the system to count workers and verify their real-time presence within the work zone

Feedback Devices





Field Deployment



Field Deployment and Scalability

Road Geometry



A **flat** road

+



An **uphill** road

+



A **downhill** road



Intercity Highway

+



Interstate Highway

+



Intersection of two Highway

Workzone Type



Stationary work zone



Mobile work zone

Work Type

Long term Construction work



Short term Maintenance work



What Field Deployment Shows so Far



~92%

Risk-prediction accuracy

<10%

Vehicles identified as elevated risk

>65%

At-risk vehicles showing meaningful speed reduction after warning

~3 s

Advanced warning window before work-zone entry

Site1: US31 (Kokomo)

Risk	93.89 %	6.76 %	0.35 %	ΔSpeed	-15 mph	-22 mph	-36 mph

Site2: I-65 (Indianapolis)

Risk	99.81 %	0.19 %	0.00 %	ΔSpeed	-24 mph	-28 mph	-

Site3: I-70 (Indianapolis)

Risk	98.36 %	0.89 %	0.75 %	ΔSpeed	-1.7 mph	-5.2 mph	-4.8 mph



∞ ft

Work zone coverage



1500 ft

Max. vehicle detection



100 %

Worker presence acc.



6.04 ft

Avg. displacement error

Safety Impact of Predictive & Proactive Warning

Comparison of baseline condition and warning enabled condition

Critical-Risk Speed
Average speed during High-risk conditions

Baseline	With Warning
71.49 mph	55.92 mph

↓ 15.57 mph
21.8% lower

Hazard Resolution
Medium/High risk later returned to SAFE

Baseline	With Warning
3.36%	18.78%

+15.42 %
5.6× higher

Lane-Change Response
Vehicles merging early

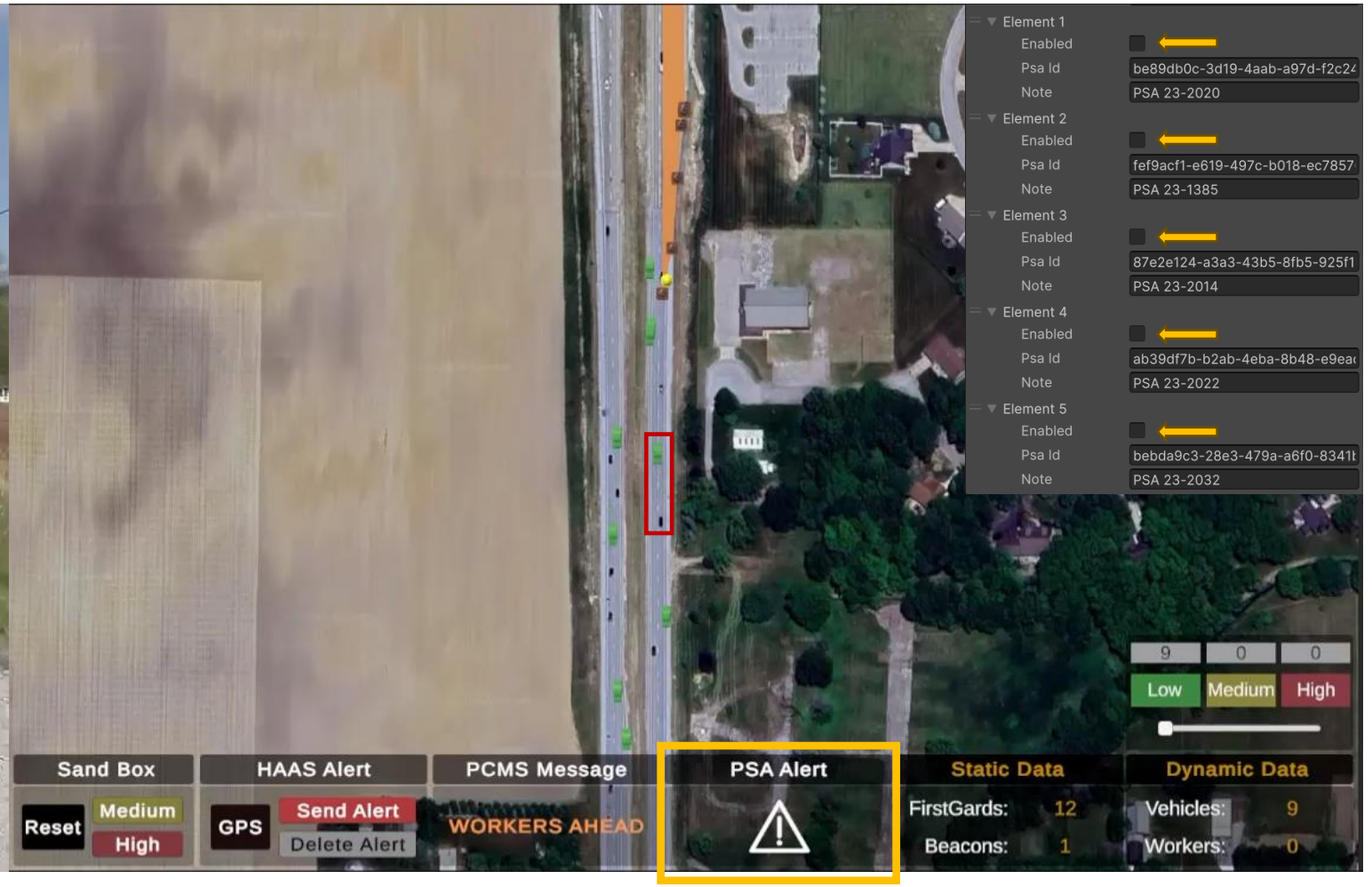
Baseline	With Warning
30.15%	60.33%

+30.18 %
2.0× higher

Warning particularly influenced vehicle behavior during higher-risk (predictive) conditions

Digital Twin Demonstration





From an Indiana Demonstration to a National Scalability

NATIONAL RELEVANCE

1. **Indiana and Texas field demonstrations**
2. **All work-zone types: stationary, mobile, construction, maintenance**
3. **Interoperable work-zone data exchange (WZDx)**
4. **Integration with DOT & connected-vehicle systems**
5. **Replicable across states**

Portable

Not tied to one contractor or one roadway.

Interoperable

Works with national work-zone data systems (WZDx).

Scalable

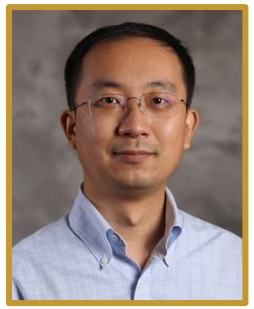
Many work zones supported from one common operational framework.

Parameters
Modular Architecture
Scalability
Predictive Framework
Proactive safety
Multimodal Alerting
Multiuser alerting
Digital Replica
Vehicle Compatibility
Data Management

Interdisciplinary Team

PIs Purdue


Dr. Sogand Hasanzadeh


Dr. Yiheng Feng


Dr. Behzad Esmaeili


Dr. Lu Su

INDOT Team

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Partners

Aramsco A FAMILY OF COMPANIES · INDIANA SIGN & BARRICADE · PSS Innovations for Safety® · Ramudden

Researchers


Dr. Woei-Chyi Chang

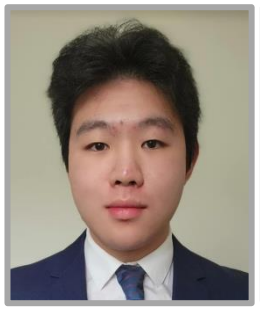

Dr. Bibek Poudel


Almass Riaz


Tianheng Zhu


Yongkang Li


Johnson Adetooto


Minghao Dong


Xingchen Wang


Jie Wie


Nathan Weston


Jionghao Wei

ANY QUESTION?

THANK YOU

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Scan Me!

