Data Driven Approach To Characterize And Forecast The Impact Of Work Zones On Freeway Mobility Using Probe Vehicle Data

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Intelligent Transportation Systems

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Presentation Overview

1. Introduction & Motivation

   - Why should we care about work zone impact on mobility?

2. Objectives

   - Can we improve our traffic operation and reduce the impact?

3. Methodology

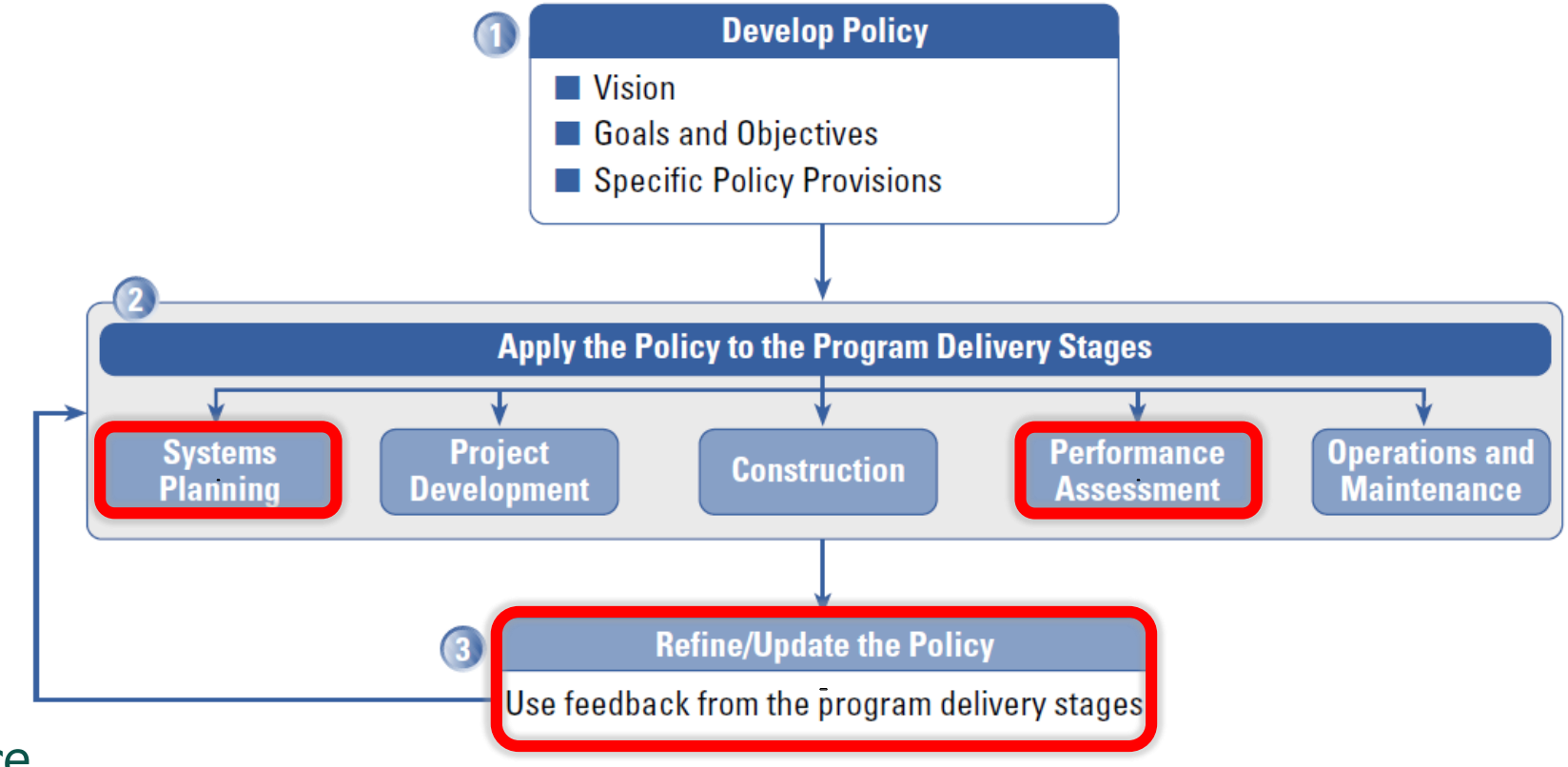
   - Introducing a data drive approach to characterize and forecast the impact.

4. Results & Conclusion

Motivation: Federal Highway Administration (FHWA) Calls For Improvement In Work Zone Mobility Management

FHWA calls for transportation agencies to:

- Develop policies to manage work zone mobility
- Develop systematic approaches for mobility performance measurement
- Update and refine policies to optimize mobility performance



FHWA Policy development and implementation process

Source: Implementing the Rule on Work Zone Safety and Mobility, FHWA, 2005.

Work Zone Traffic Management Key Concerns

Mobility:

- 24% of nonrecurring freeway delays are due to work zone projects
- 888 million hours were lost in 2014
- User dissatisfaction

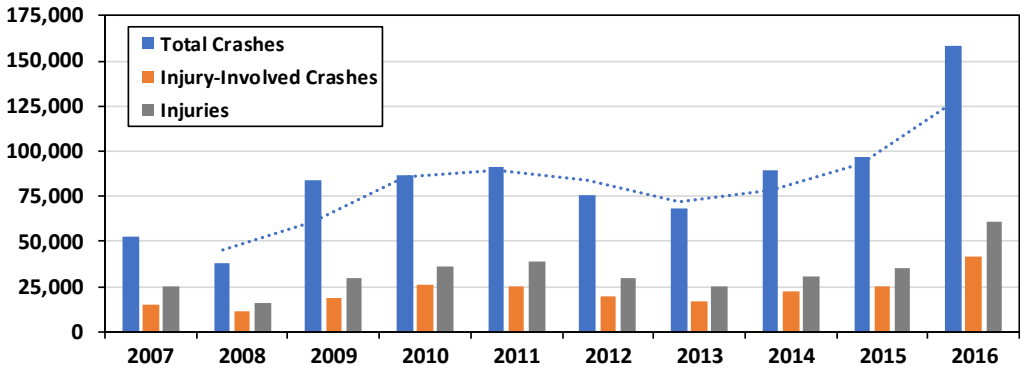
Environment:

- Millions of gallons of fuel used annually
- Emission detrimental to public health
- On average, 300 million gallons of fuel are lost every year as a result of work zones presence.

Work Zone Traffic Management Key Concerns: Safety

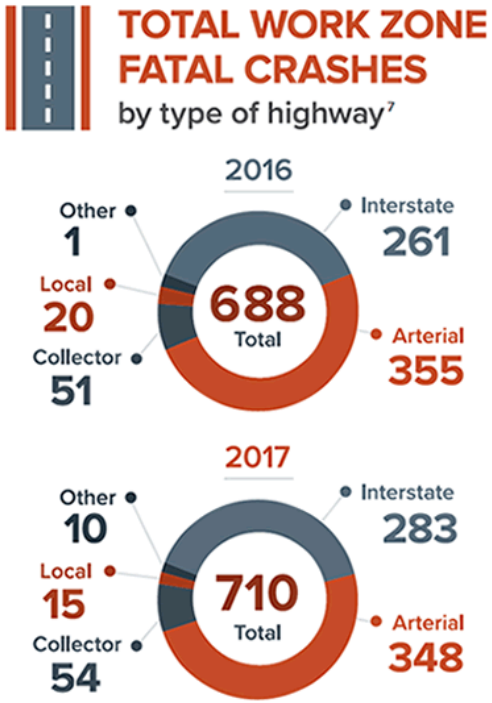
Safety:

- As more work is required to maintain the roadways, more risk is introduced:
  - Commuter's safety
  - Worker's Safety



Source: workzonesafety.org

National Level



Source: FHWA

2018 Michigan

Total

15 Fatal Crashes — Previous 3-year average: 18.3

16 Fatalities — Previous 3-year average: 19.7

Truck-Involved*

3 Fatal Crashes — Previous 3-year average: 5.3

4 Fatalities — Previous 3-year average: 6.3

Bus-Involved****

0 Fatal Crashes — Previous 3-year average: 0

0 Fatalities — Previous 3-year average: 0

Pedestrian-Involved**

5 Fatal Crashes — Previous 3-year average: 3.7

5 Fatalities — Previous 3-year average: 3.7

Worker***

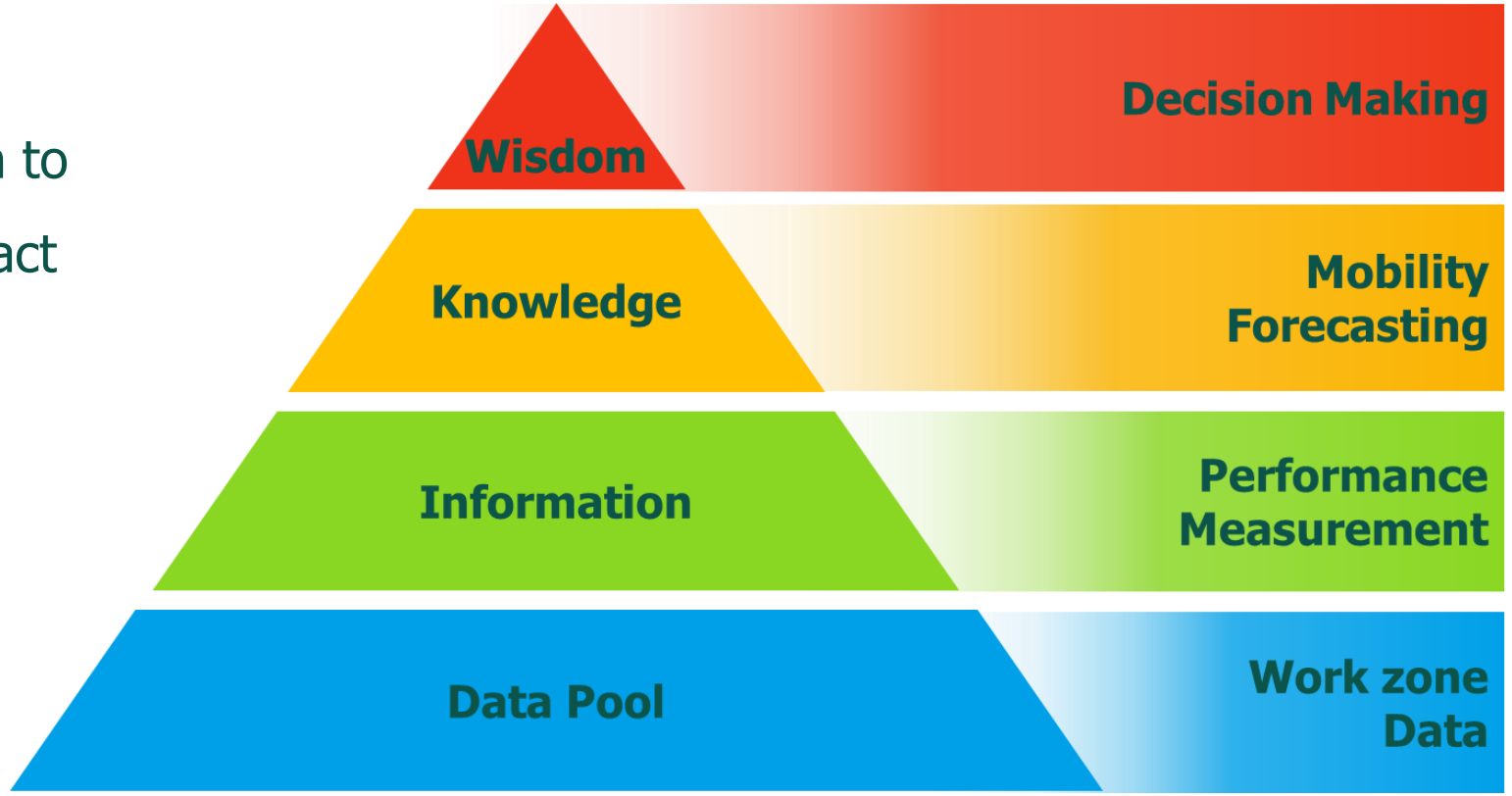
5 Fatalities — Previous 3-year average: 2.7

Source: workzonesafety.org

Specific Research Objectives

The specific objectives of this study were to:

1. Develop a systematic approach to measure and visualize the impact of work zones
2. Predict the impact future work zones will have on interstate's mobility
3. Develop a high-level decision-making process to better plan future work zones



Research Overview

Available Data

- Work zone activities
- Traffic Speed
- Roadway Geometry
- Traffic Incidents

WORK ZONE BIG DATA IS AVAILABLE NOW

Data Fusion

Database

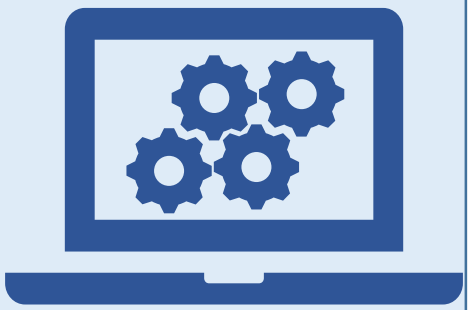
Fuse work zone data

BIG DATA ANALYTICS IS THE EMERGING SOLUTION

Performance Measurement

IF YOU CANNOT MEASURE IT, YOU CANNOT IMPROVE IT

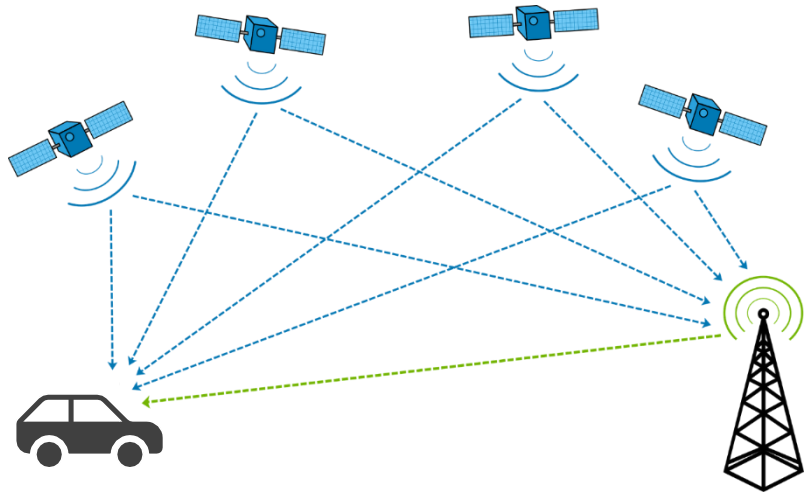
Impact Prediction



MAKING SMARTER DECISIONS

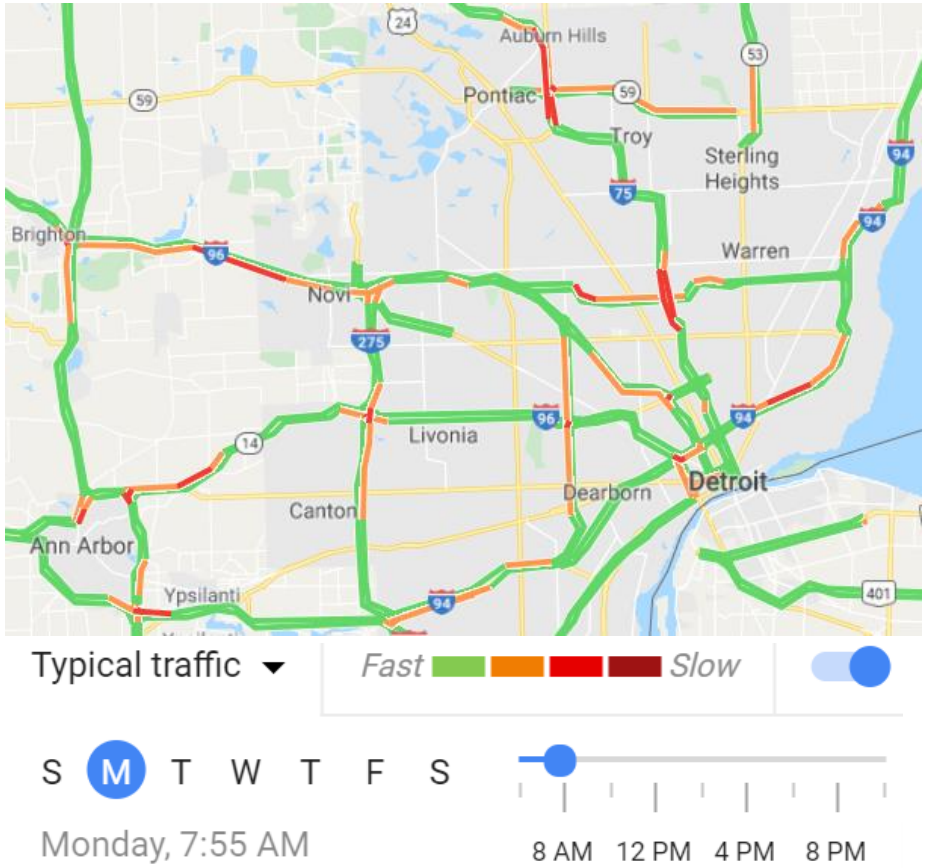
Probe Vehicle Data Introduction

- GPS devices broadcast microwave signals
- GPS receivers collect this data to determine location and time
- Using location and time, probe's speed is derived

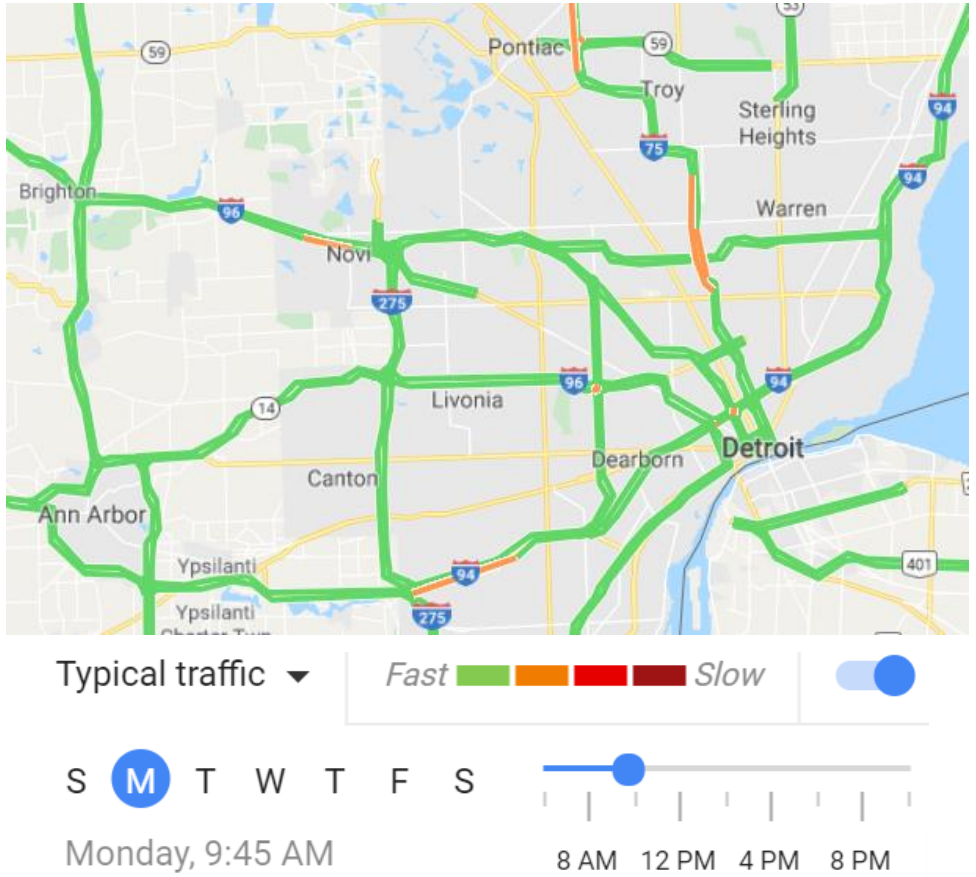


Probe Vehicle Data Usage In Navigation Systems

Morning Rush Hour



Off-peak Hour



Source: https://www.google.com/maps

Probe Vehicle Data Overview

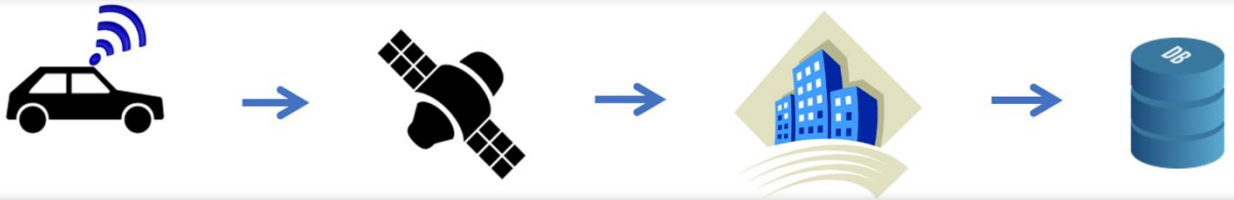
Probe Vehicle Data Providers

INRIX

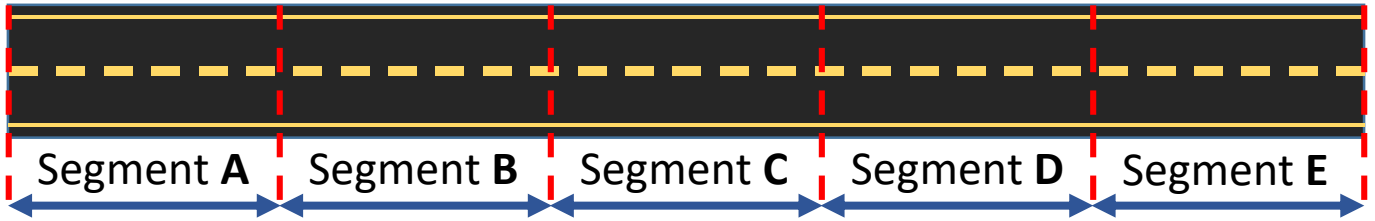
here

TOMTOM

Probe Vehicle Data Collection Process



Probe Vehicle Data Segmentation Scheme



Segment	Timestamp	Speed (mph)
A	2/1/2015 14:00	56
B	2/1/2015 14:00	50
C	2/1/2015 14:00	45
D	2/1/2015 14:00	53
E	2/1/2015 14:00	65
A	2/1/2015 14:01	59
B	2/1/2015 14:01	53
C	2/1/2015 14:01	48
D	2/1/2015 14:01	56
E	2/1/2015 14:01	68

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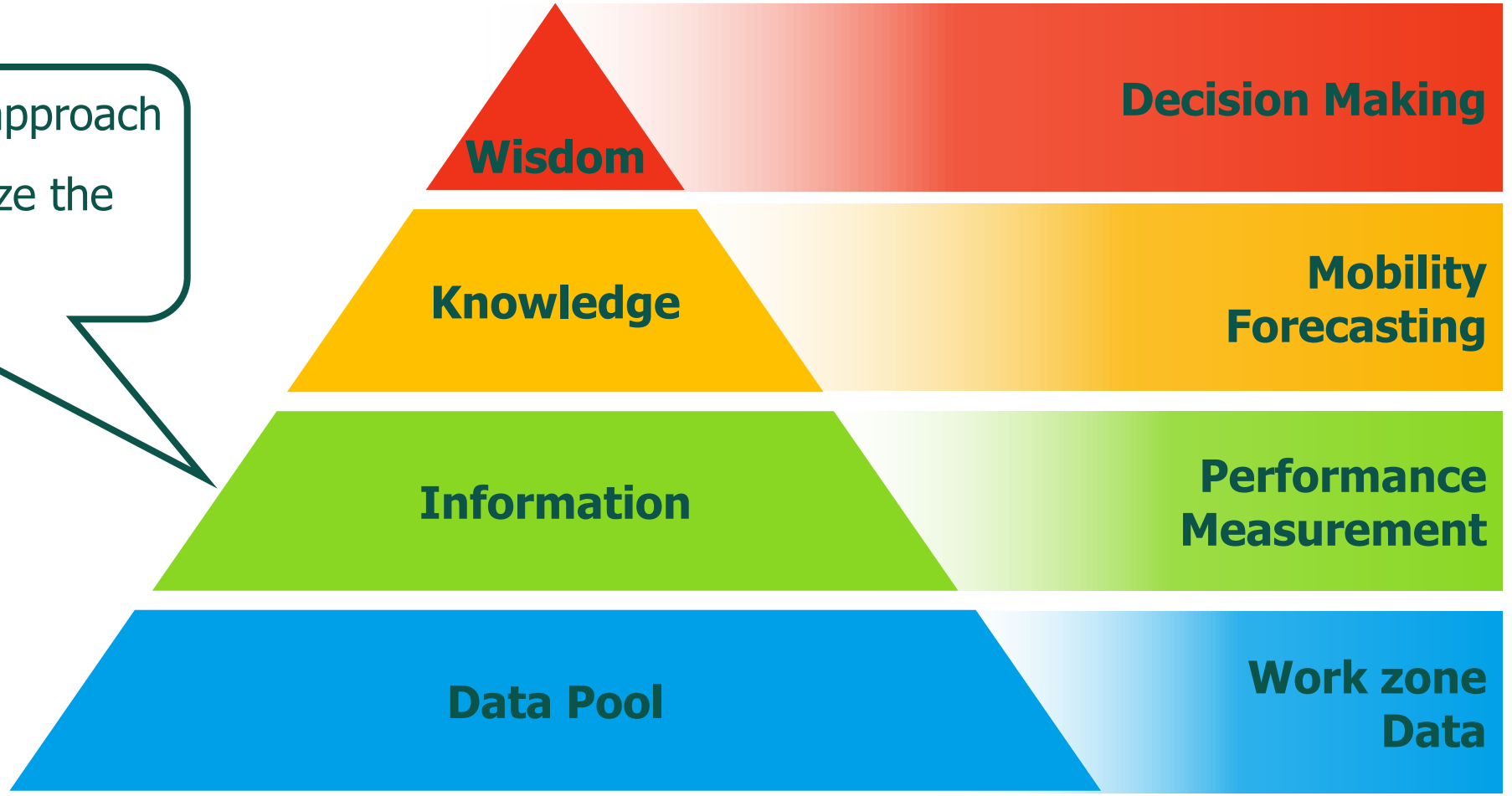
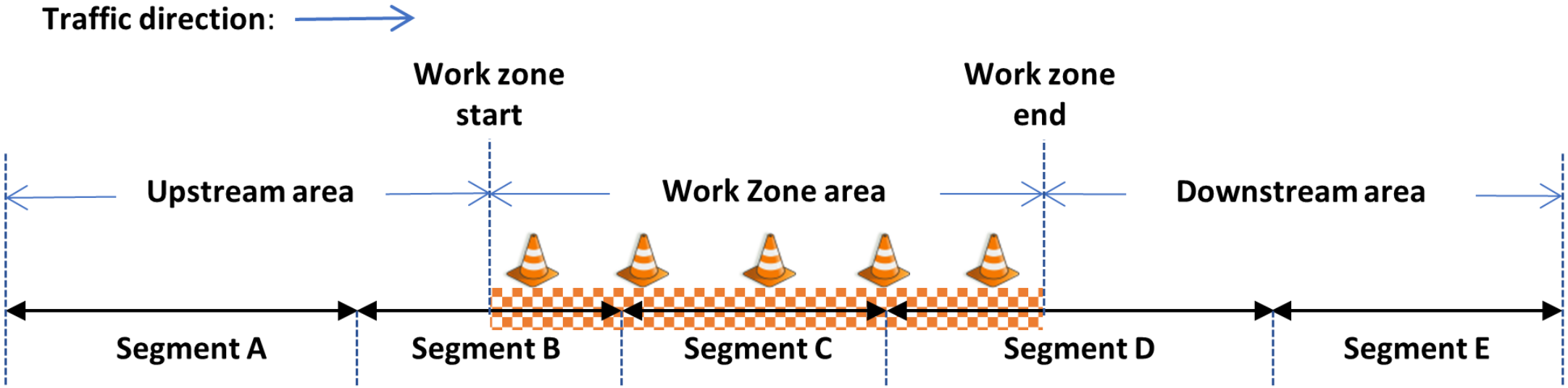
Mobility Performance Measurement Framework

Develop a systematic approach to measure and visualize the impact of work zones



Highway Segments Selection



Upstream Area:
5 miles prior to work zone start mile marker

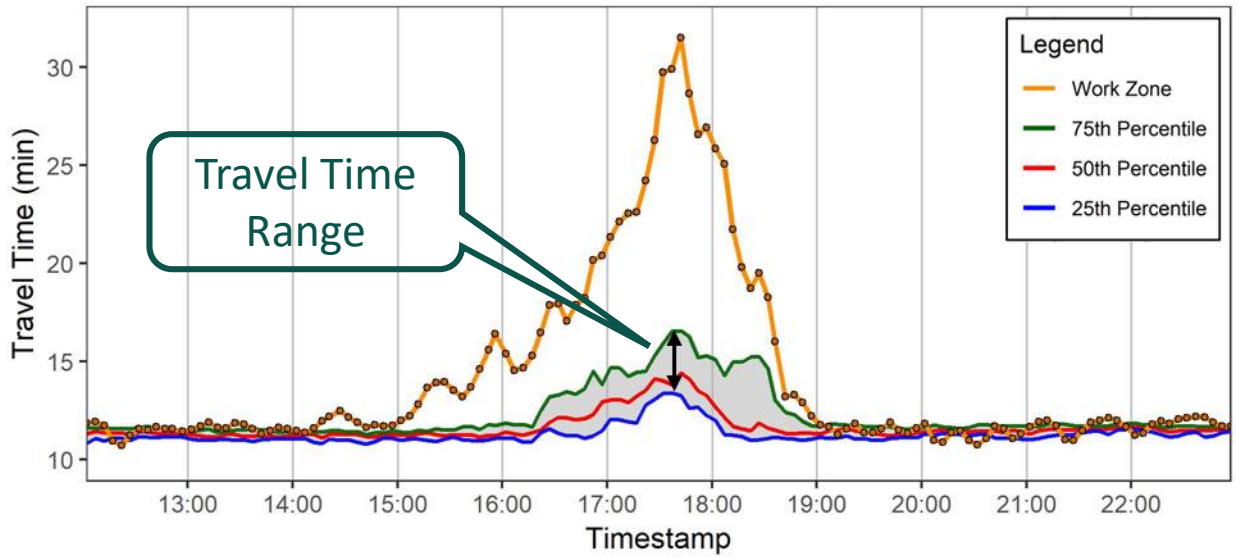
Work Zone Area:
Segments falling between work zone start and end mile markers

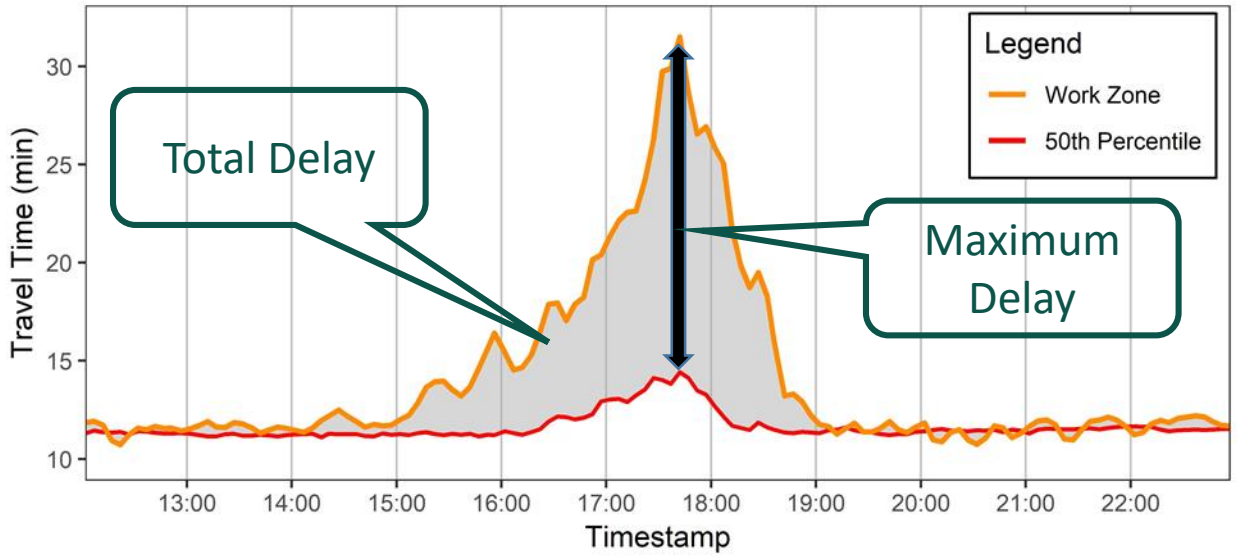
Downstream Area:
3 miles after work zone end mile marker

Delay Measurement

Work zone VS typical traffic condition:

- Provides realistic delay measurement
- Account for corridors that are congested even when work zone is not present

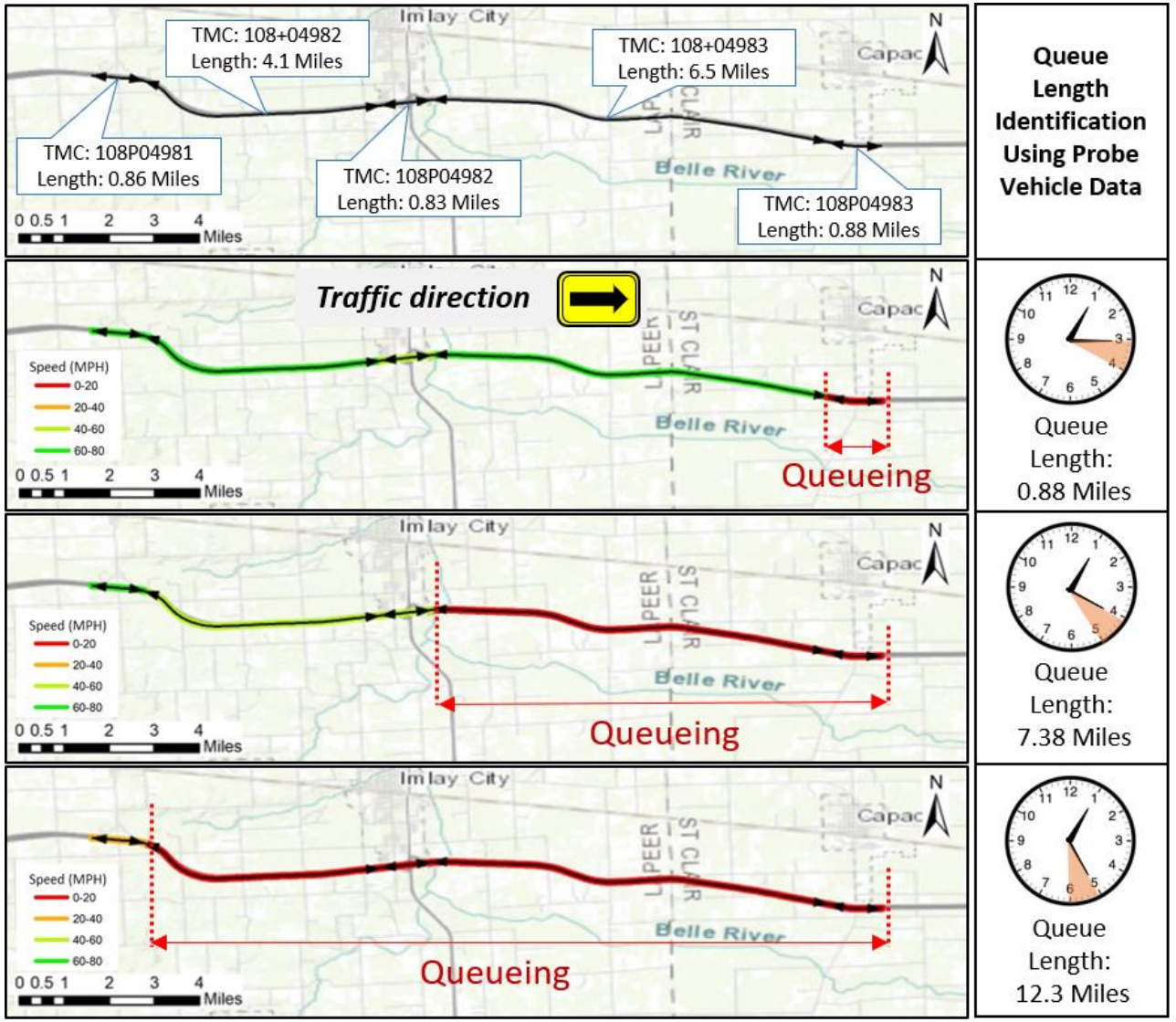




Queue Measurement

Using probe vehicle data:

- Segments with queueing condition (speed less than 15 mph) can be identified.
- Queue propagation to the upstream segments can be tracked.



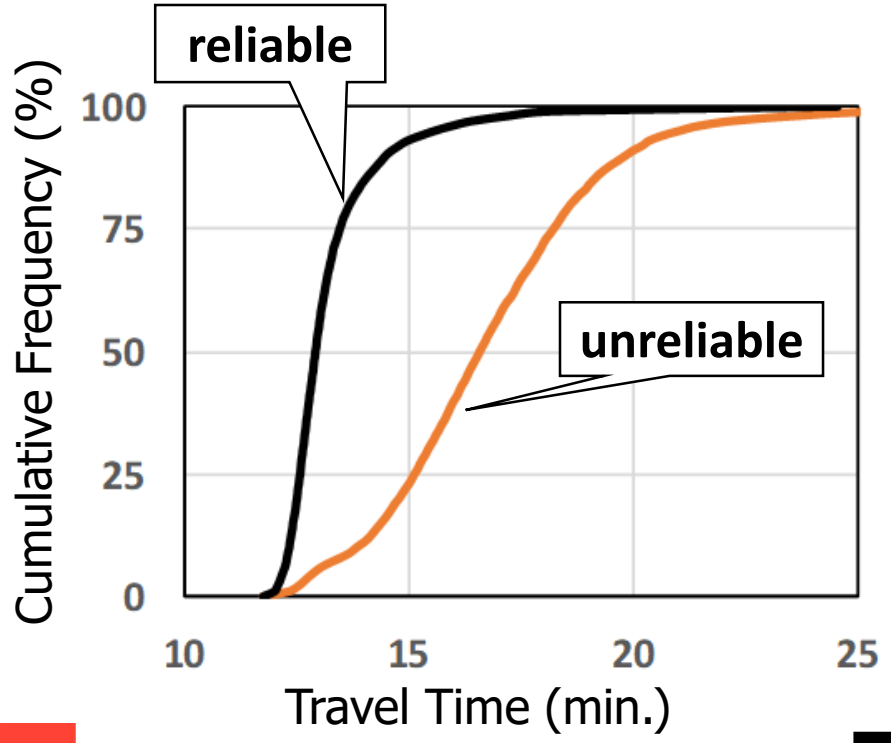
Proposed Performance Measures

	Metric	What does it Measure?
User Delay	Total Delay	Cumulative travel time delay experienced by users throughout the lane-closure duration
	Longest User Delay	Longest travel time delay experienced by users
Presence of Queueing Condition	Longest Queue Length (mile)	Longest length of queue caused by lane-closure
	Longest Queue Duration (min)	Longest time that at least one segment of highway was performing in queueing condition.
	Total Queue Duration(hours)	Cumulative times that at least one segment of highway was performing in queueing condition.
	Number of Queues	Number of times that queueing condition formed on the highway.

Corridor-level Mobility Assessment

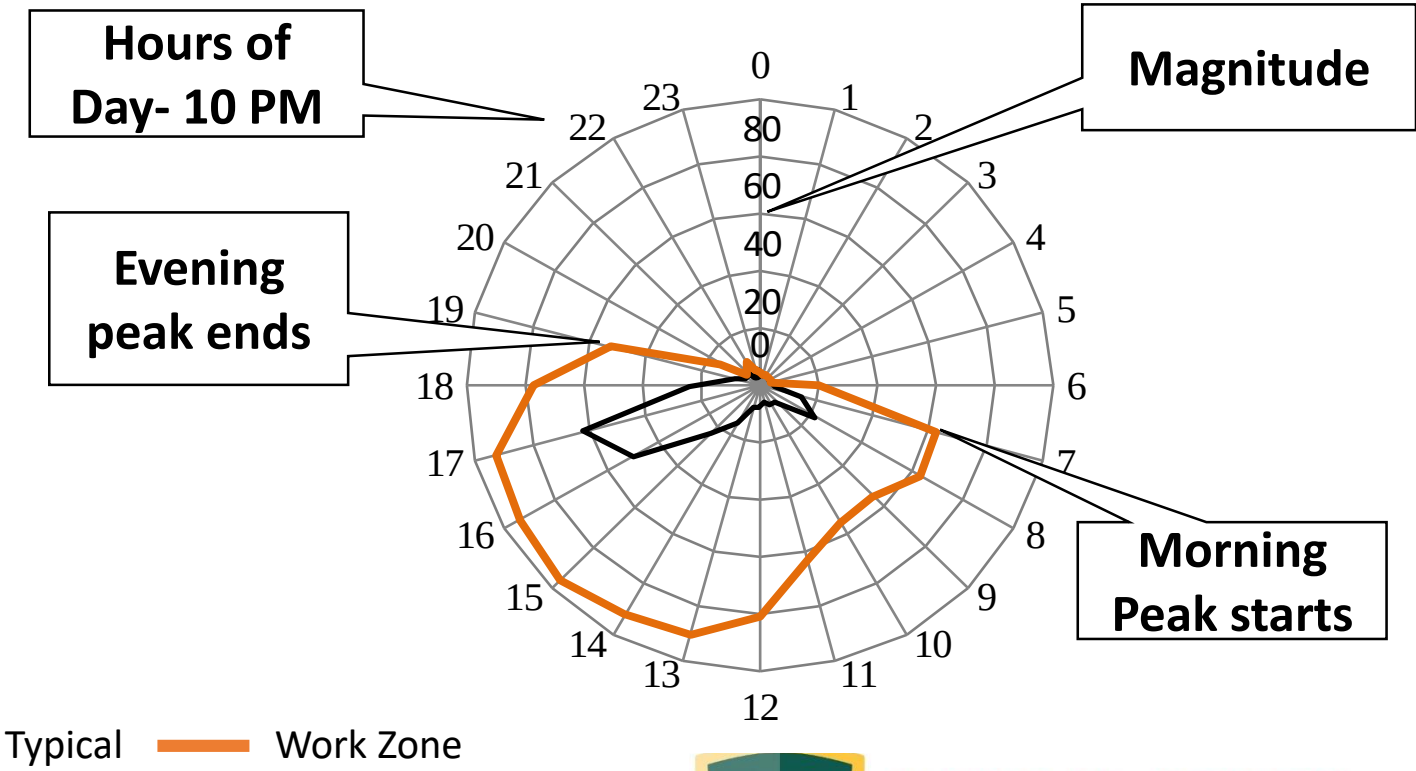
CDF plots

- Represents travel time variation
- Monitors travel time reliability
- Useful for high-level monitoring



Radar plot

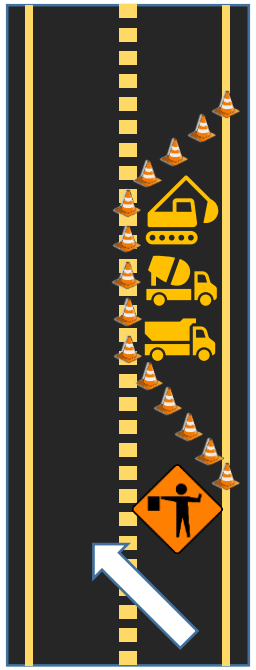
- Summarizes traffic condition over hours of a day
- Represents aggregated traffic metrics
- Identifies problematic hours

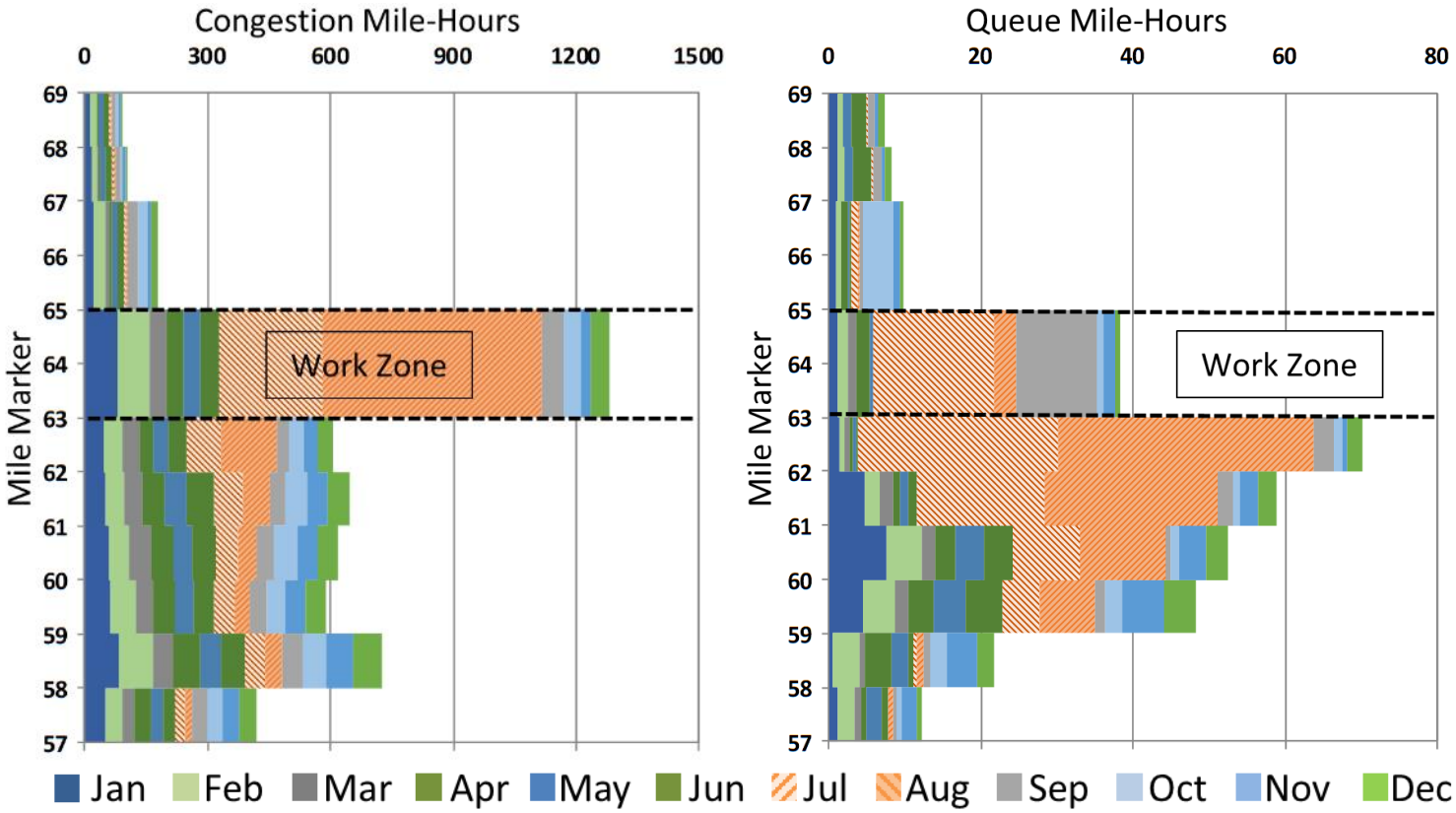


Segment-level Mobility Assessment: Spatial Assessment

Volcano plot

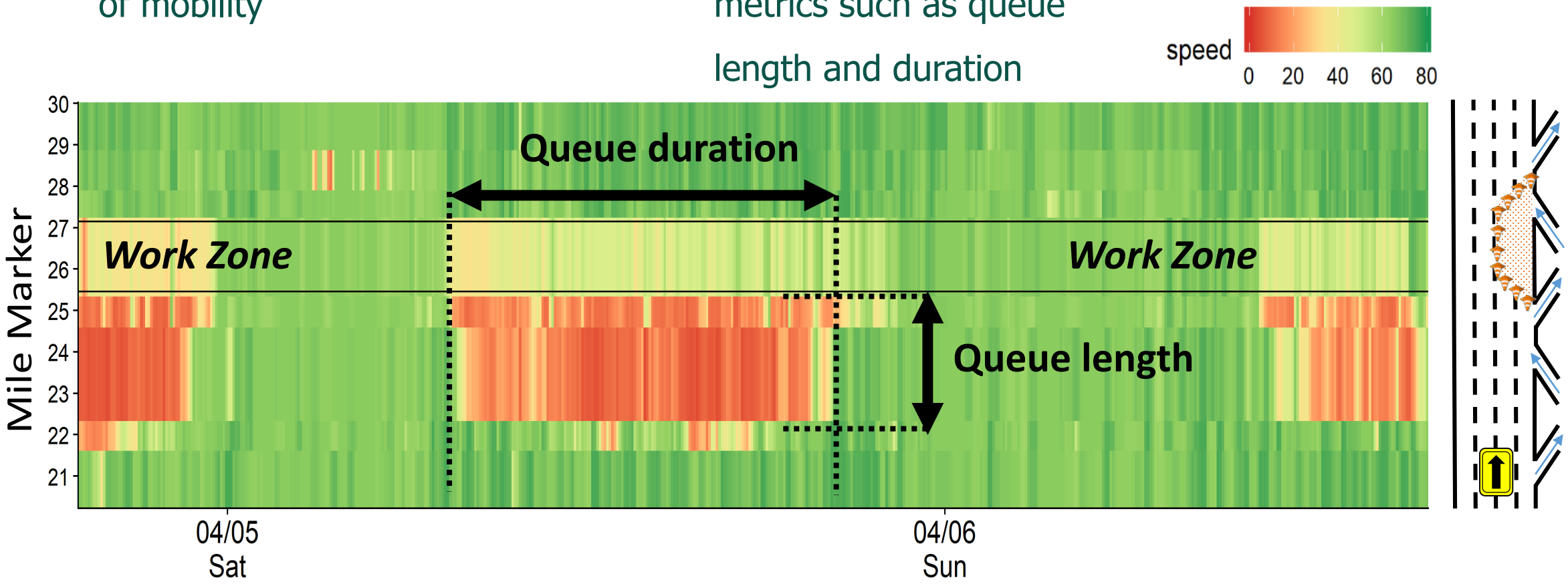
- Summarizes traffic condition for each segment
- Represents cumulative traffic measures
- Identifies problematic segments
- Useful for high-level monitoring





Spatiotemporal Mobility Assessment Using Speed Heat-map

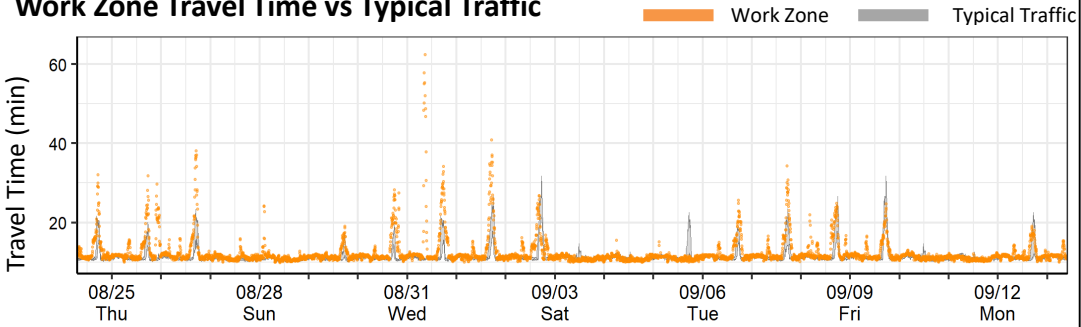
- Provides an instant overview of mobility
- Useful to extract queue metrics such as queue length and duration



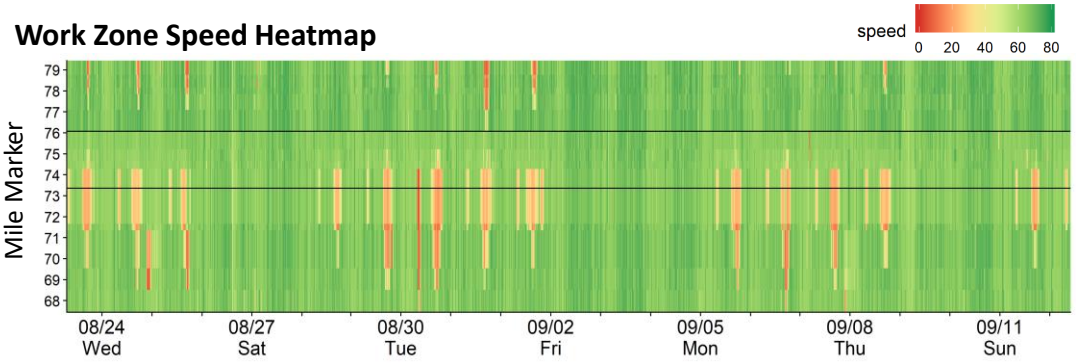
Work Zone Mobility Audit

Overview	Information
Work Zone ID	104811
County	Oakland County
Roadway	I-75
Closure type	Single Lane Closure
Direction	Northbound
Start Milemarker	73.4
End Milemarker	76.1
Workzone Start	2016-08-24 07:00
Workzone End	2016-09-13 10:00

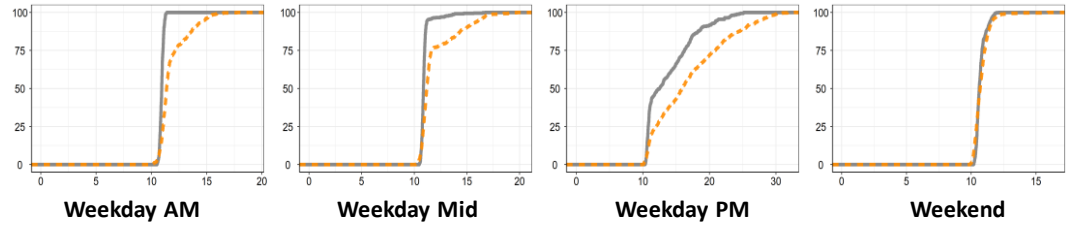
Work Zone Travel Time vs Typical Traffic



Work Zone Speed Heatmap



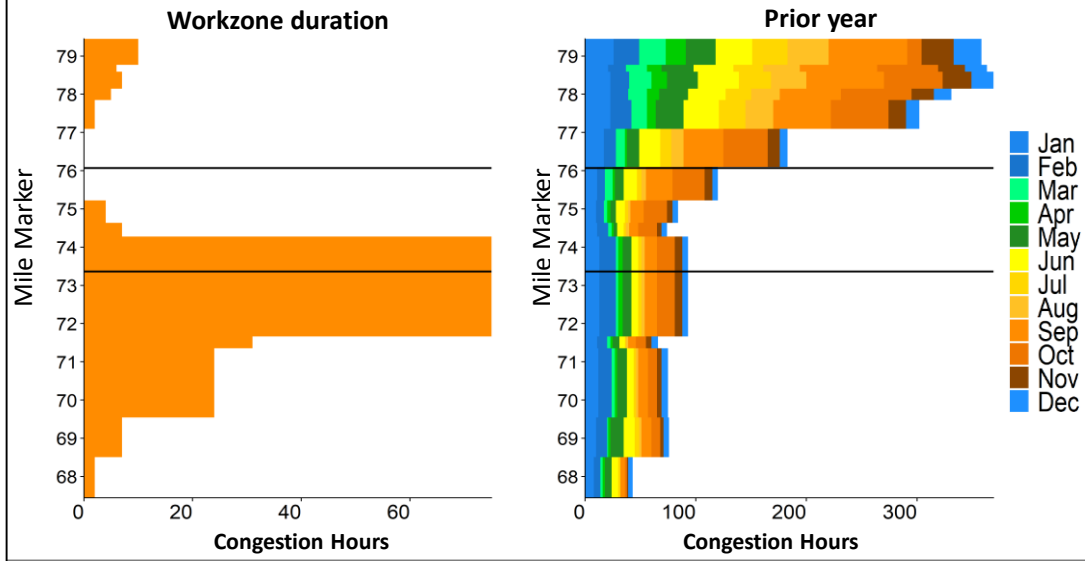
Work Zone Travel Time Reliability



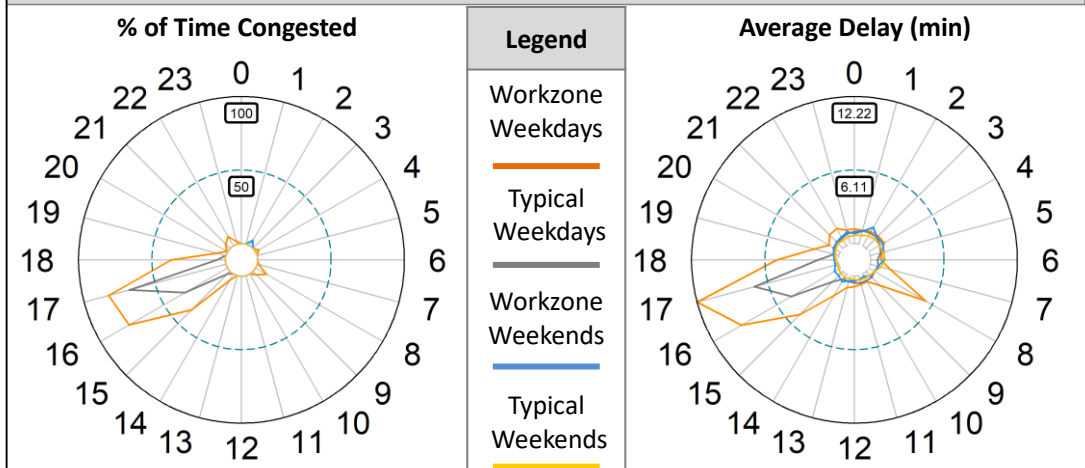
Comments:

Work Zone Mobility Audit Example

Spatial Characterization



Temporal Characterization



Delay & LOTTR Metrics

Stats	AM	Mid	PM	Weekend	Total
Avg Delay(min)	0.5	0.3	2.6	0.0	0.3
Max Delay(min)	72.5	11.0	19.9	5.2	72.5
Total Delay(min)	1338.8	1139.8	2841.9	243.1	6675.8
LOTTR	1.2	1.3	1.5	1.1	1.2

Queueing Metrics

Stats	Queue
Max Duration(min)	185.0
Total Duration(min)	2300.0
Max Length(miles)	6.8
# of Queues	39.0

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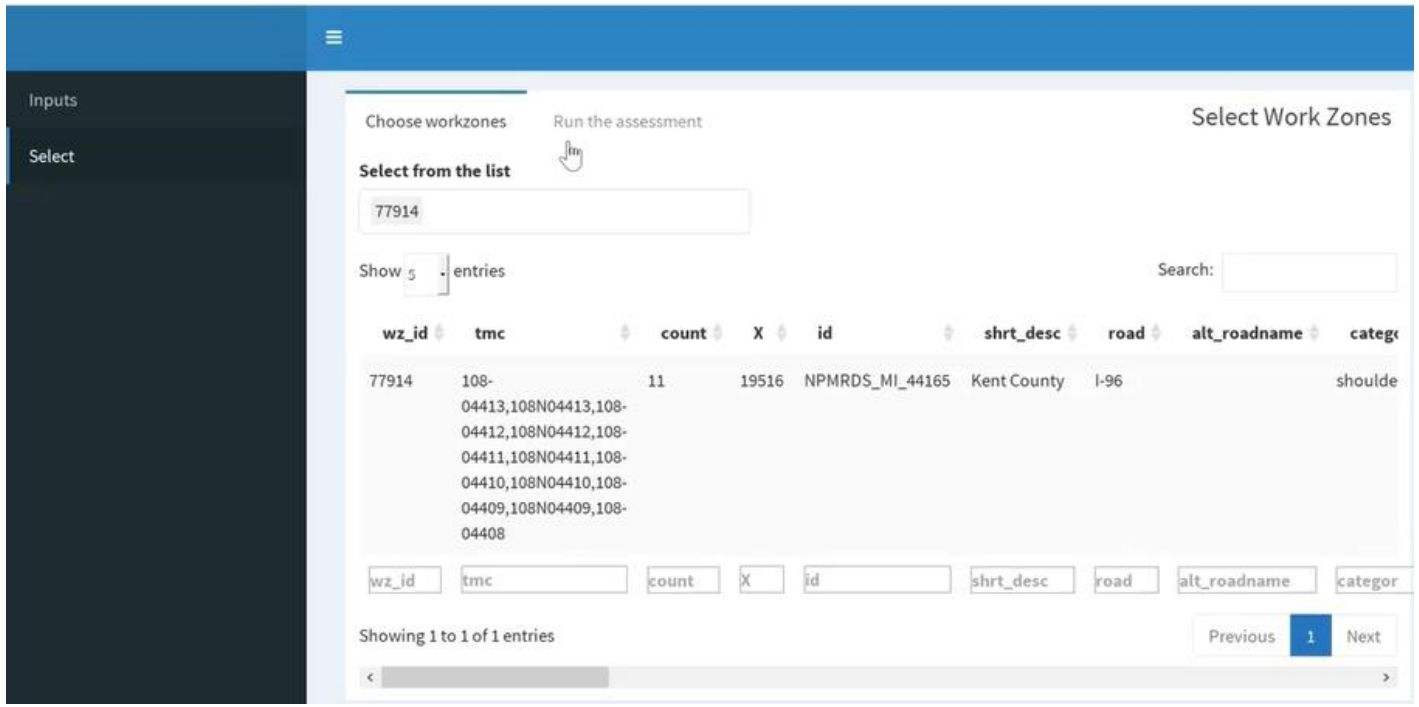
Work Zone Mobility Audit Tool

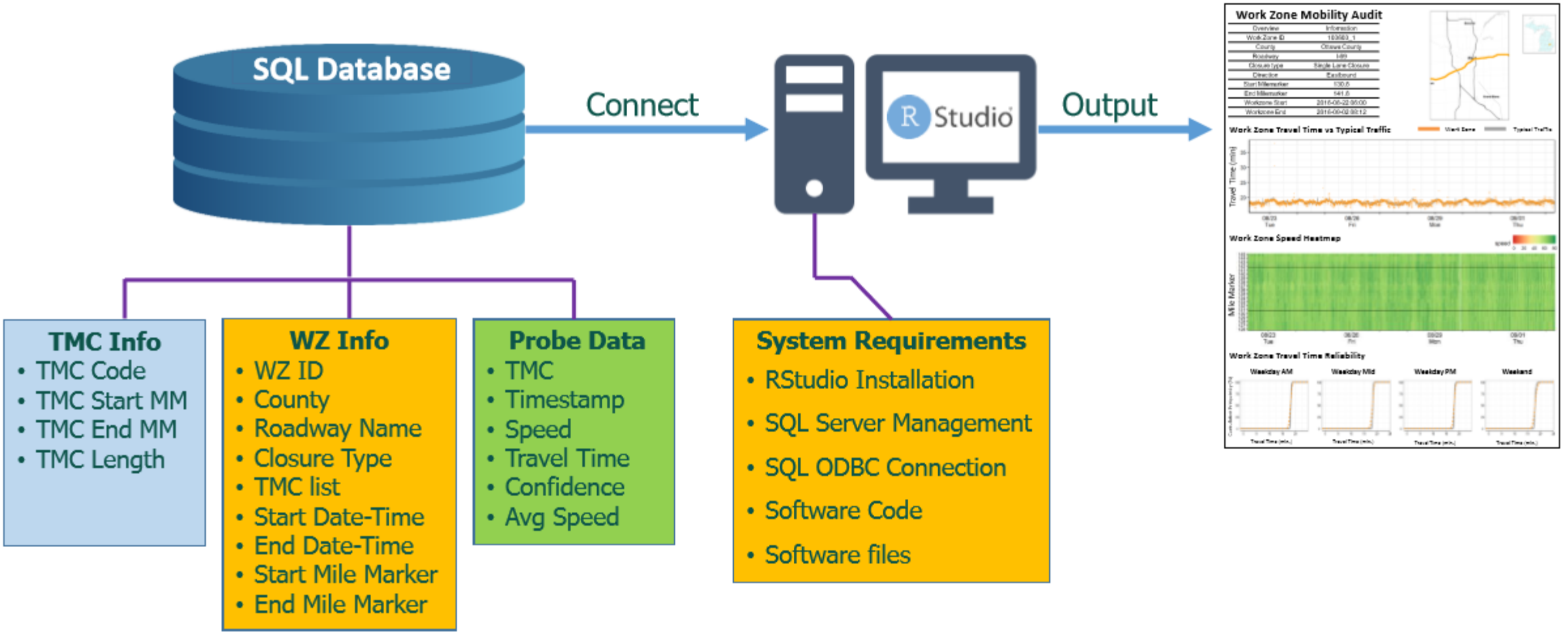
WZMA Software is built to:

1. Utilizes probe vehicle data and work zone configuration information as an input
2. Automatically creates WZMA for individual or multiple work zones
3. Archives the mobility statistical summary for further mobility assessment

Shiny by RStudio

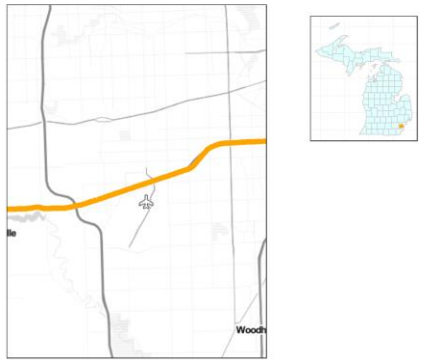


Work Zone Mobility Audit Tool Overview

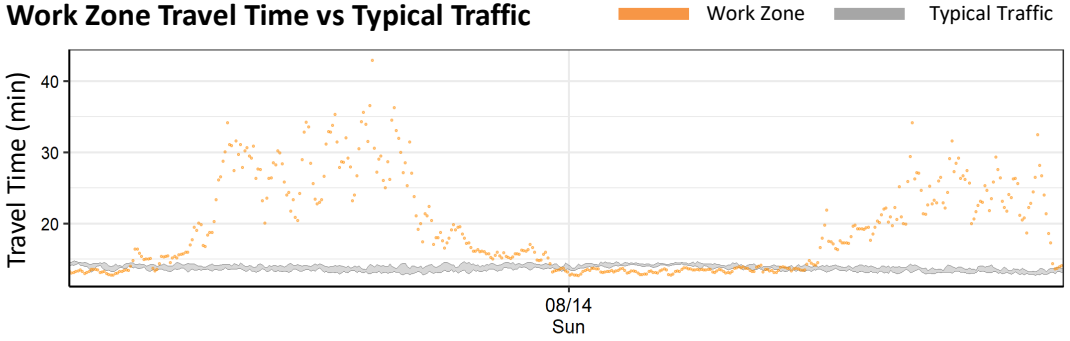


Work Zone Mobility Audit

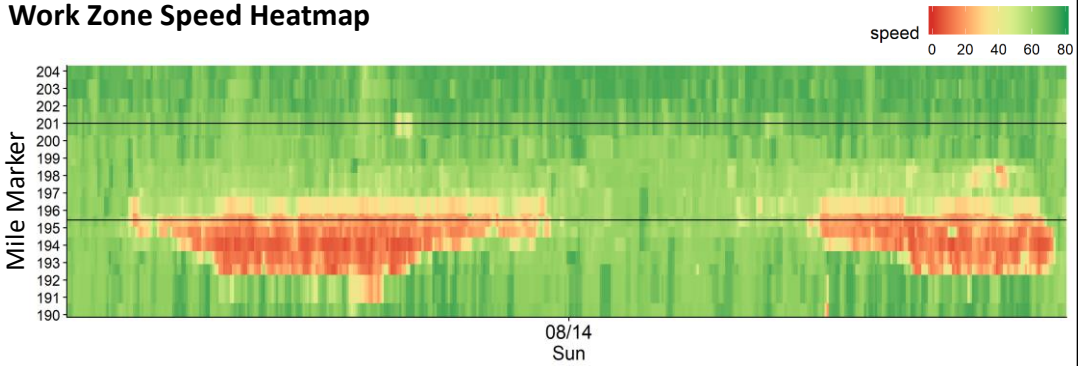
Overview	Information
Work Zone ID	104704
County	Wayne County
Roadway	I-94
Closure type	Double Lane Closure
Direction	Eastbound
Start Milemarker	195.4
End Milemarker	201
Workzone Start	2016-08-13 05:00
Workzone End	2016-08-14 18:49



Work Zone Travel Time vs Typical Traffic



Work Zone Speed Heatmap



Work Zone Travel Time Reliability

WZMA For A Weekend Work Zone With Severe Impact

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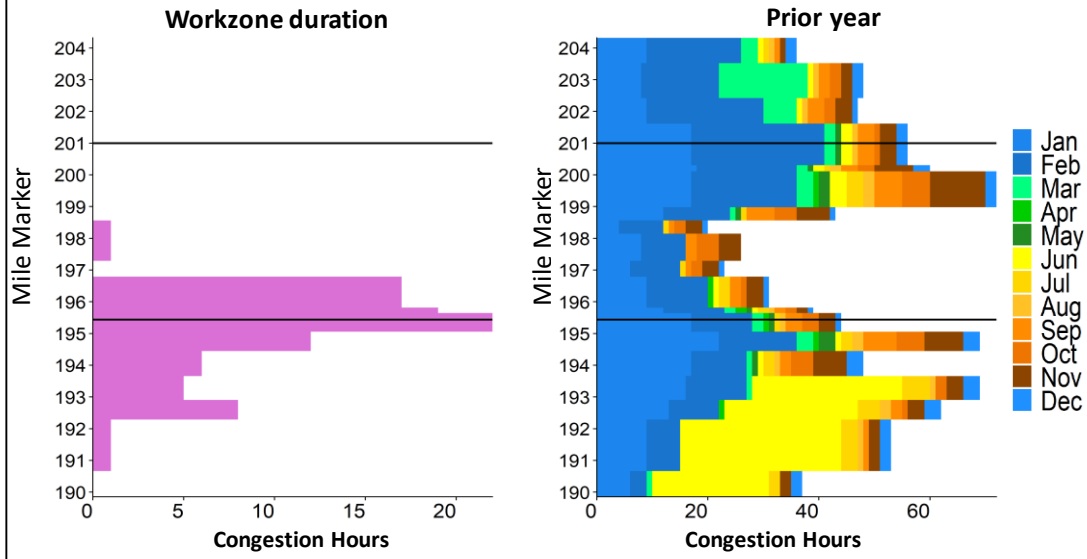
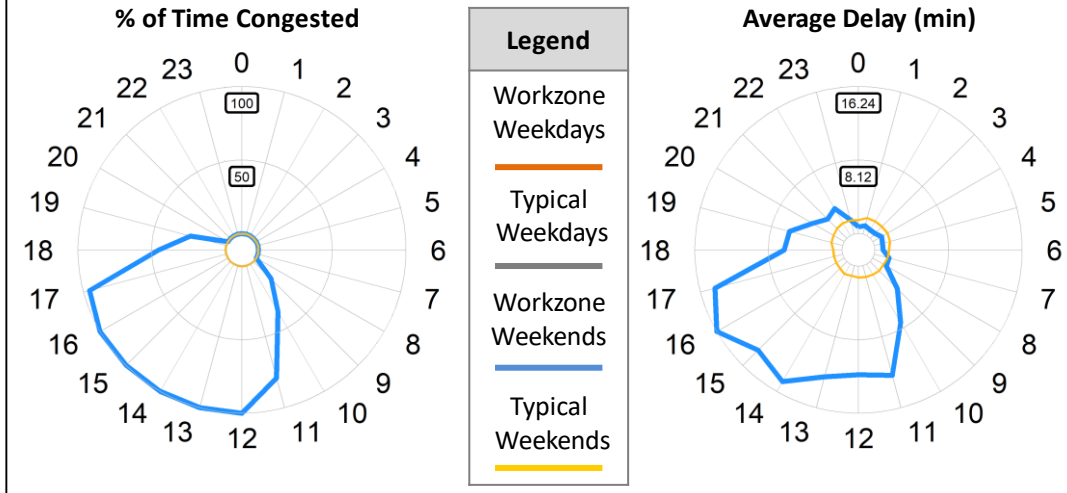
Work Zone Congestion: Spatial Characterization



Work Zone Congestion: Temporal Characterization



Delay & LOTTR Metrics

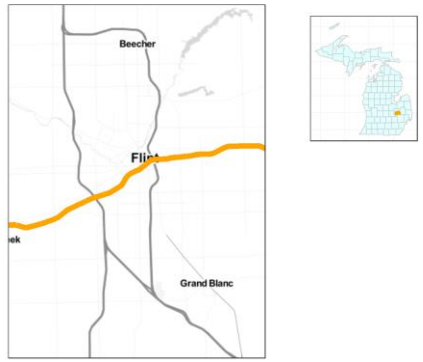
Stats	AM	Mid	PM	Weekend	Total
Avg Delay(min)				7.2	3.3
Max Delay(min)				29.5	29.5
Total Delay(min)				2547.3	2624.6
LOTTR				1.4	1.6

Queueing Metrics

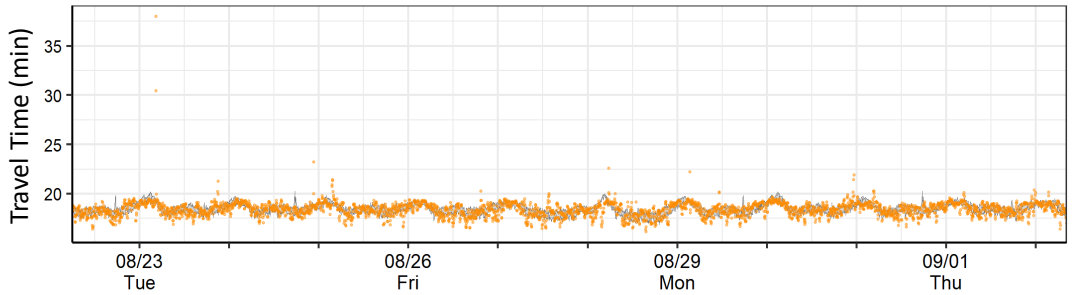
Stats	Queue
Max Duration(min)	575.0
Total Duration(min)	1200.0
Max Length(miles)	5.0
# of Queues	8.0

Work Zone Mobility Audit

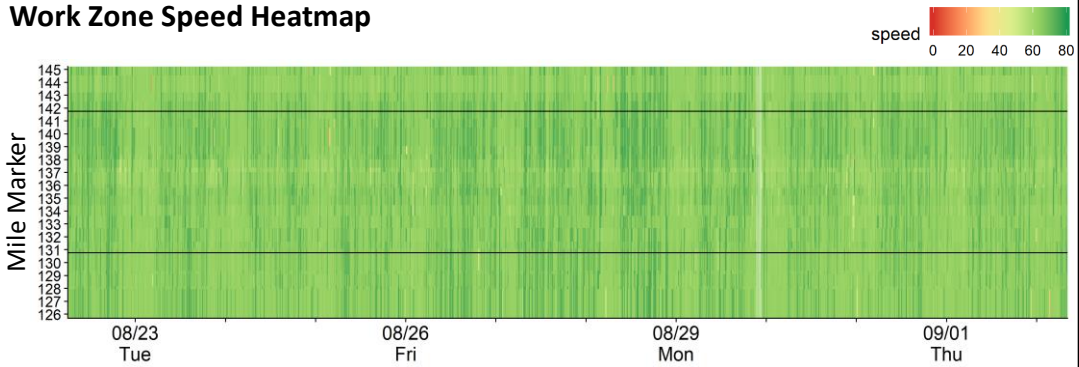
Overview	Information
Work Zone ID	103603_1
County	Ottawa County
Roadway	I-69
Closure type	Single Lane Closure
Direction	Eastbound
Start Milemarker	130.8
End Milemarker	141.8
Workzone Start	2016-08-22 06:00
Workzone End	2016-09-02 08:12



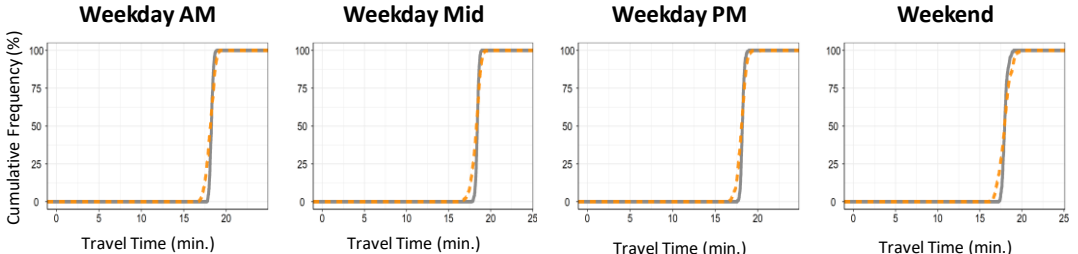
Work Zone Travel Time vs Typical Traffic



Work Zone Speed Heatmap



Work Zone Travel Time Reliability



WZMA For A Weekend Work Zone With No Impact

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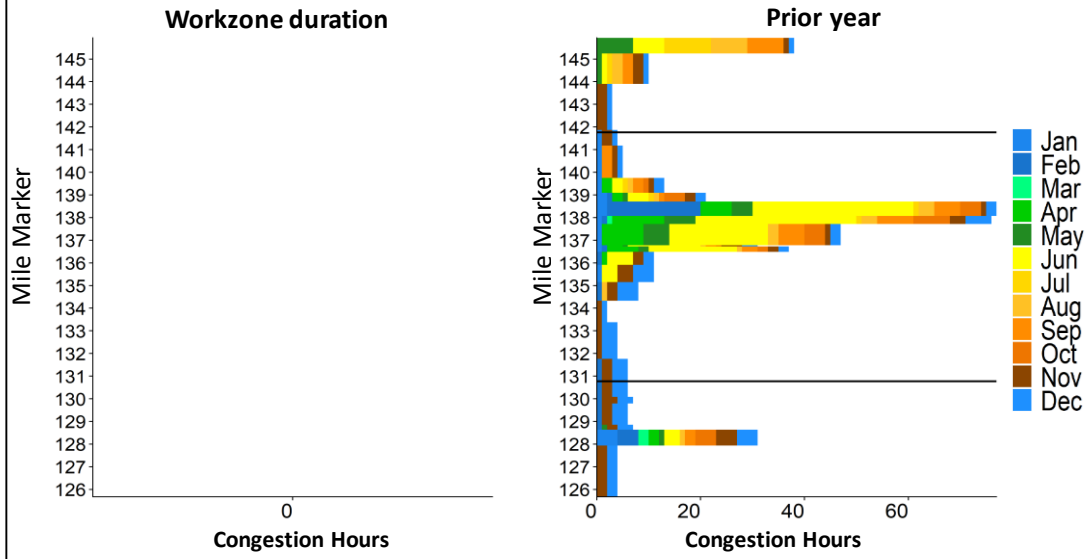
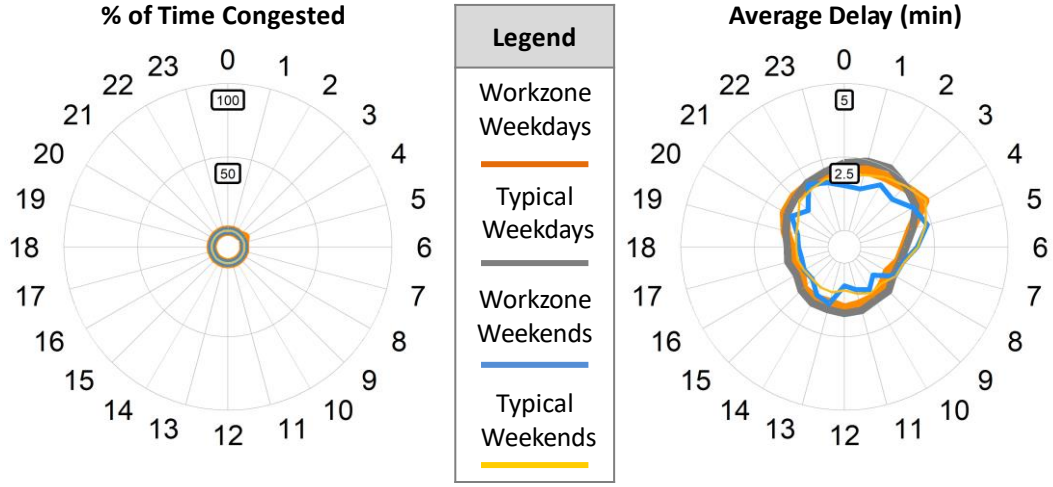
Work Zone Congestion: Spatial Characterization



Work Zone Congestion: Temporal Characterization



Delay & LOTTR Metrics

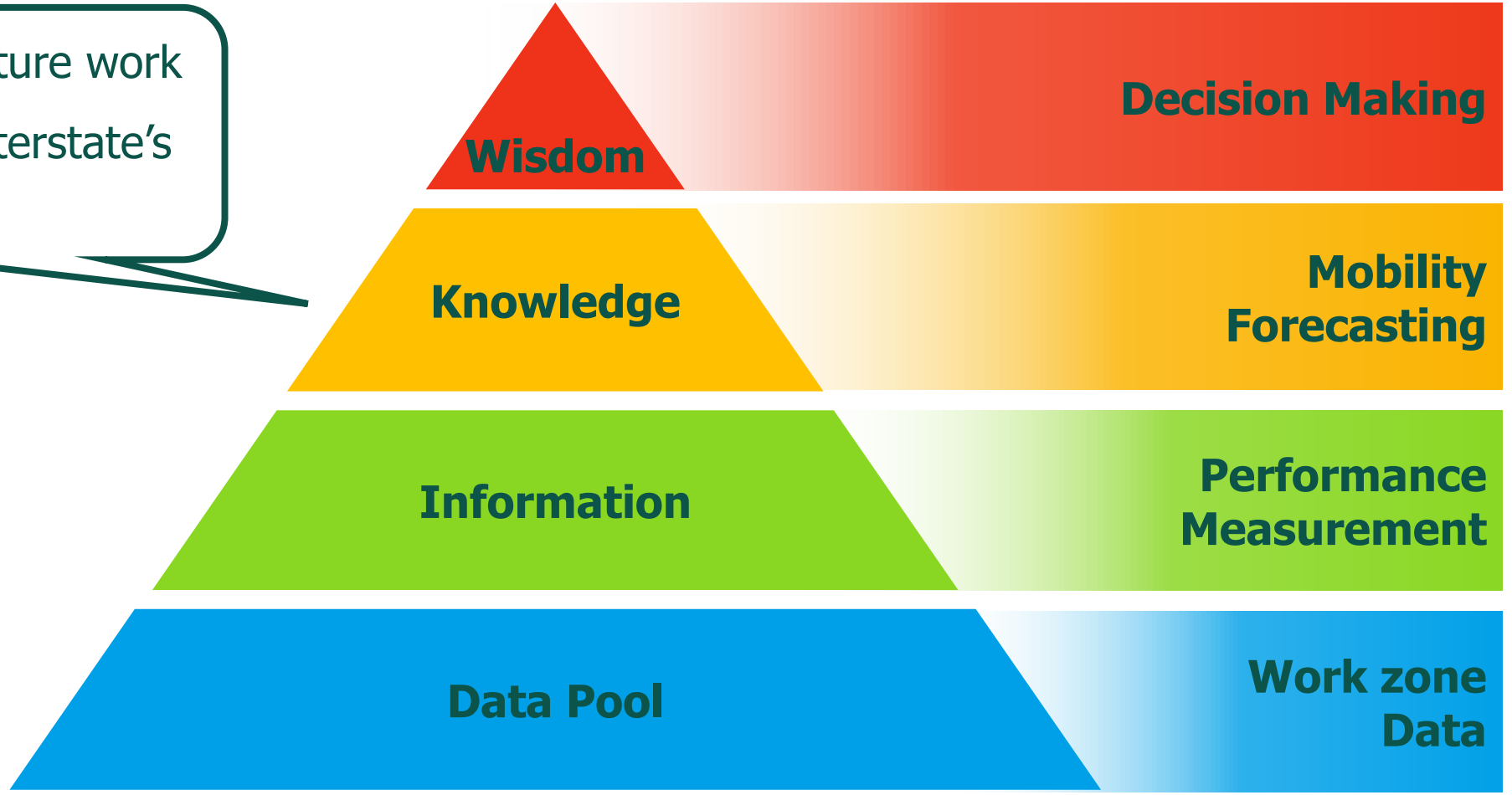
Stats	AM	Mid	PM	Weekend	Total
Avg Delay(min)	0.0	0.0	0.0	0.0	0.0
Max Delay(min)	1.0	2.2	2.1	2.0	18.6
Total Delay(min)	64.1	92.1	65.5	80.4	535.9
LOTTR	1.0	1.0	1.0	1.0	1.0

Queueing Metrics

Stats	Queue
Max Duration(min)	10.0
Total Duration(min)	30.0
Max Length(miles)	1.3
# of Queues	5.0

Mobility Forecasting Using Machine Learning

Predict the impact future work zones will have on interstate's mobility



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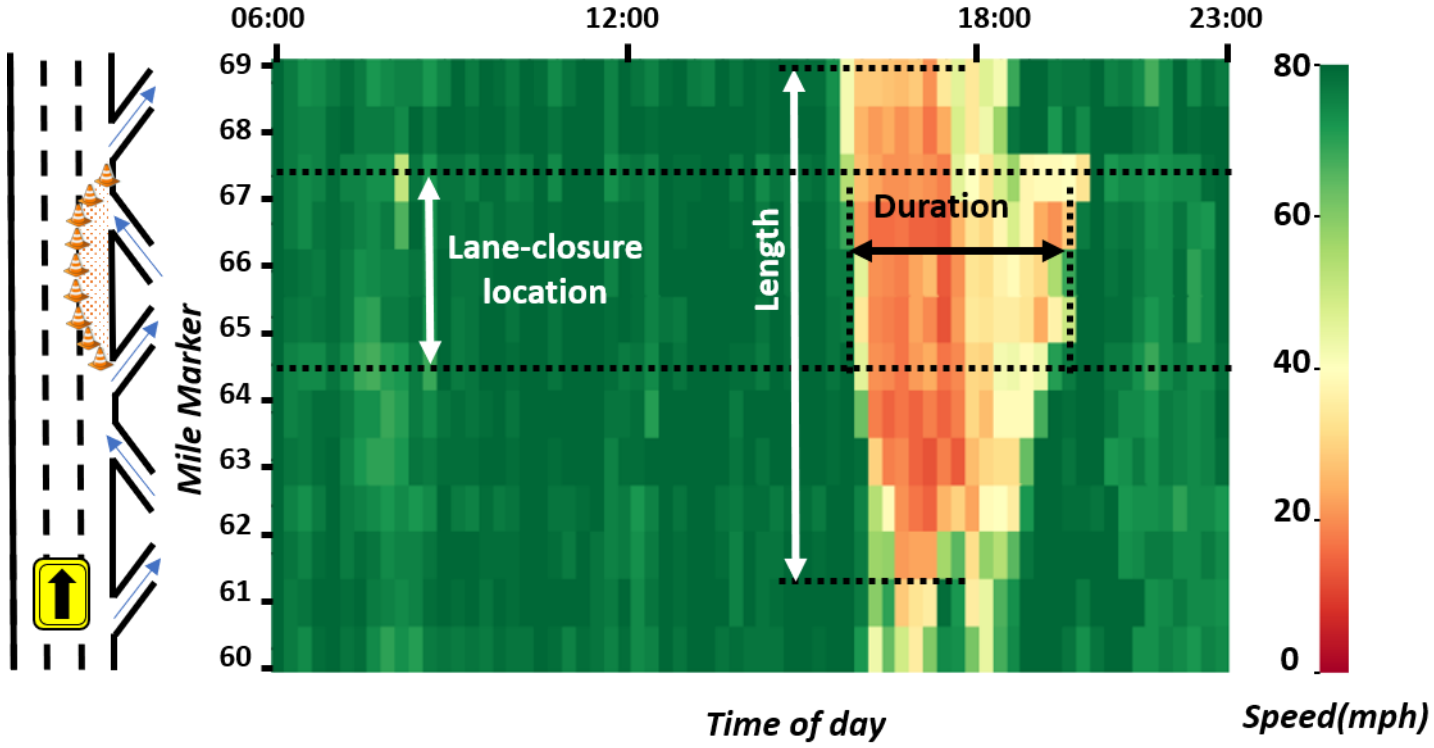
Work Zone Mobility Forecasting Objectives

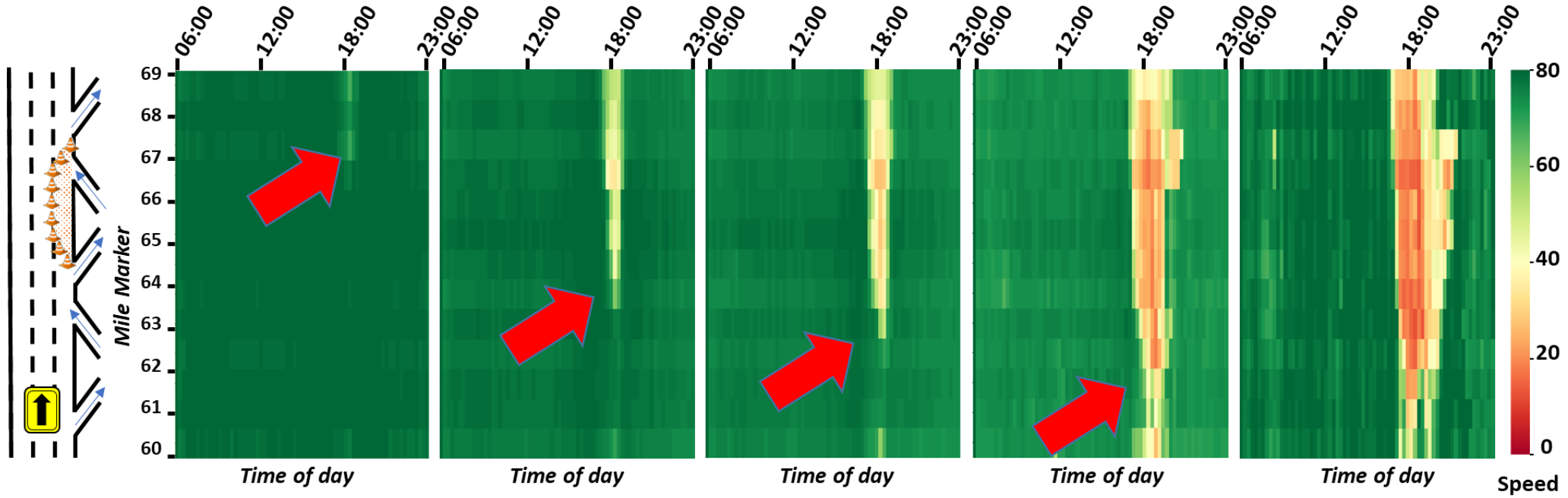
- Objective was to learn from historical work zones and predict mobility for future work zones.
- Can we predict speed for each segment throughout work zone presence?



Speed heatmap for a single-lane closure

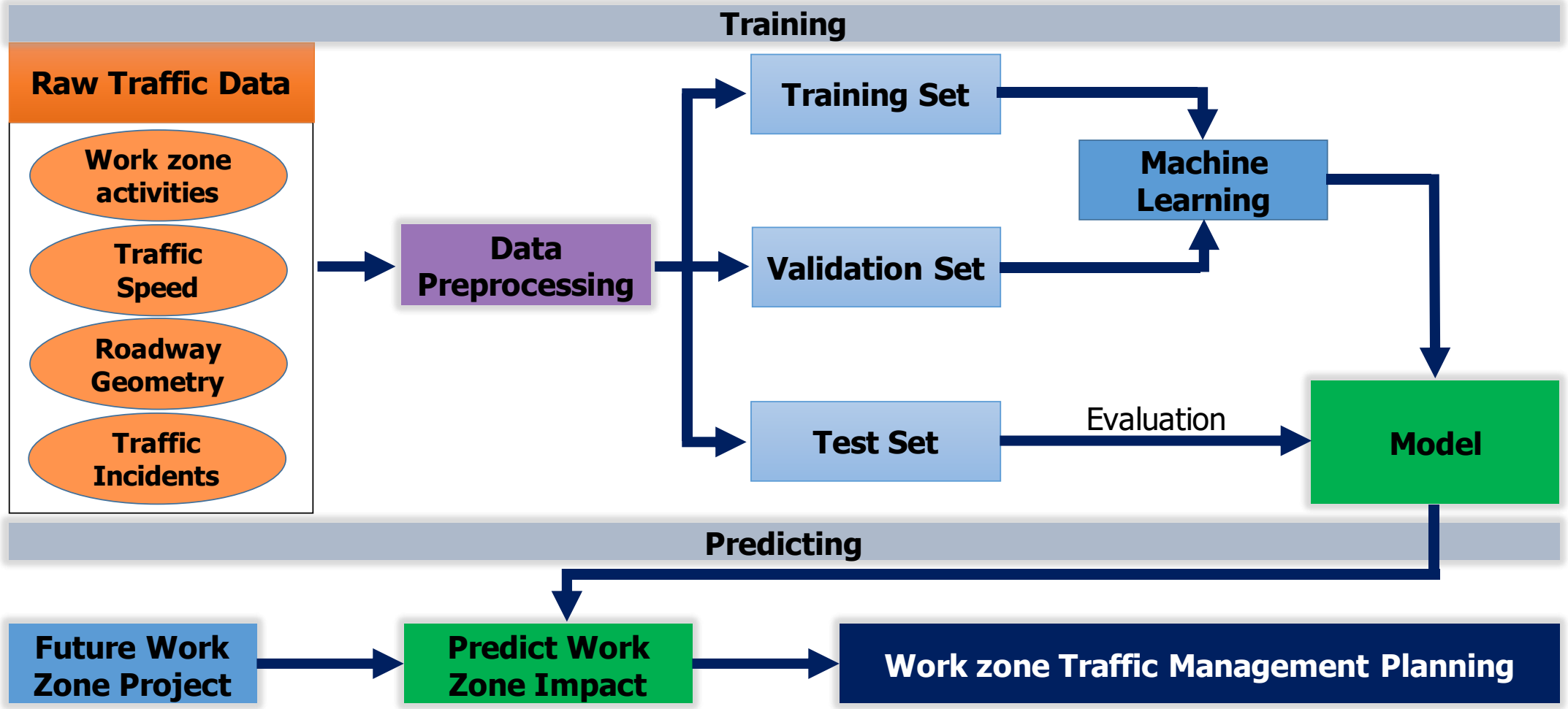
Using Historical Speed Distribution To Predict Work Zone Mobility

- Historical speed distribution represents variation of mobility behavior
- Using this variation, corridor's vulnerability is characterized
- This helps algorithms to better predict work zone impact



85th percentile | 50th percentile | 25th percentile | 5th percentile | Work Zone

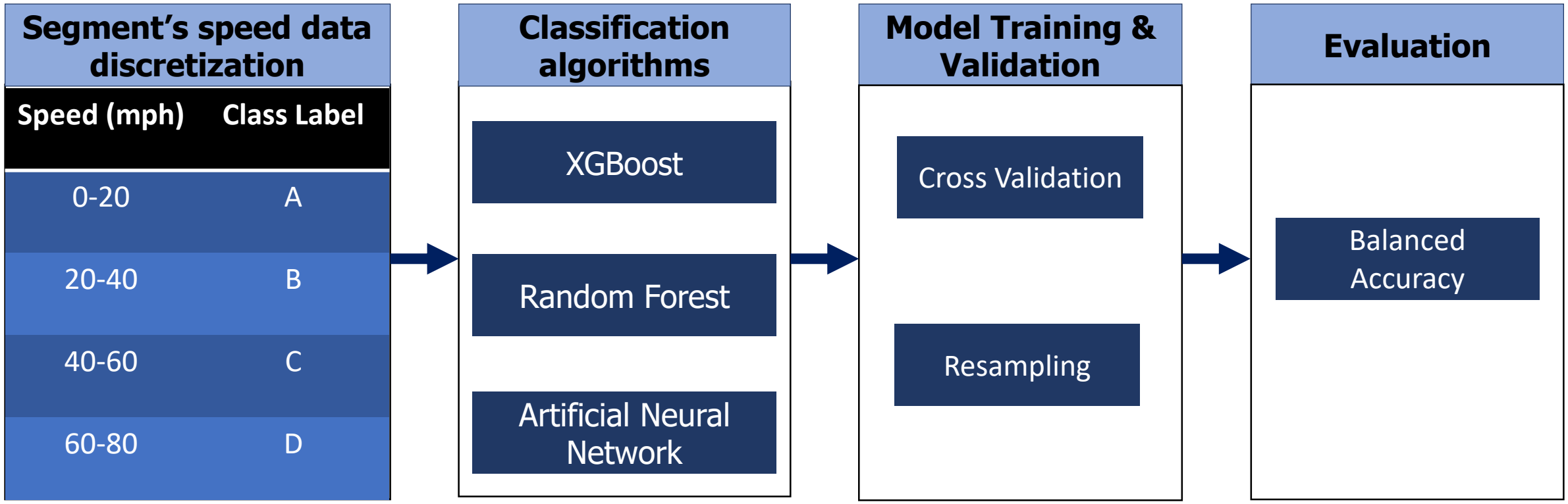
How To Train Machine Learning Algorithms?



Case Studies For Prediction Purposes

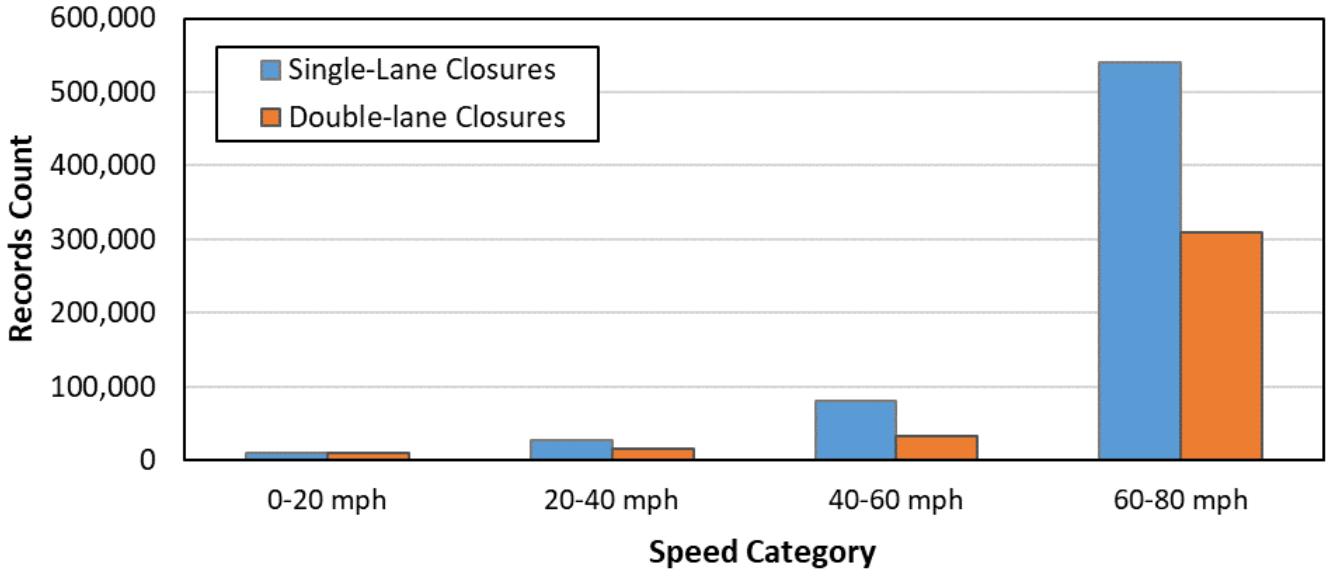
- 1,160 work zone projects occurring on Michigan Interstates from 2014 to 2017
- Including single-lane and double-lane closures
- Lane-closures were in place at least for one day to maximum 15 days

Mobility Prediction Using Classification Algorithms



How To Preprocess The Data To Improve Prediction Performance?

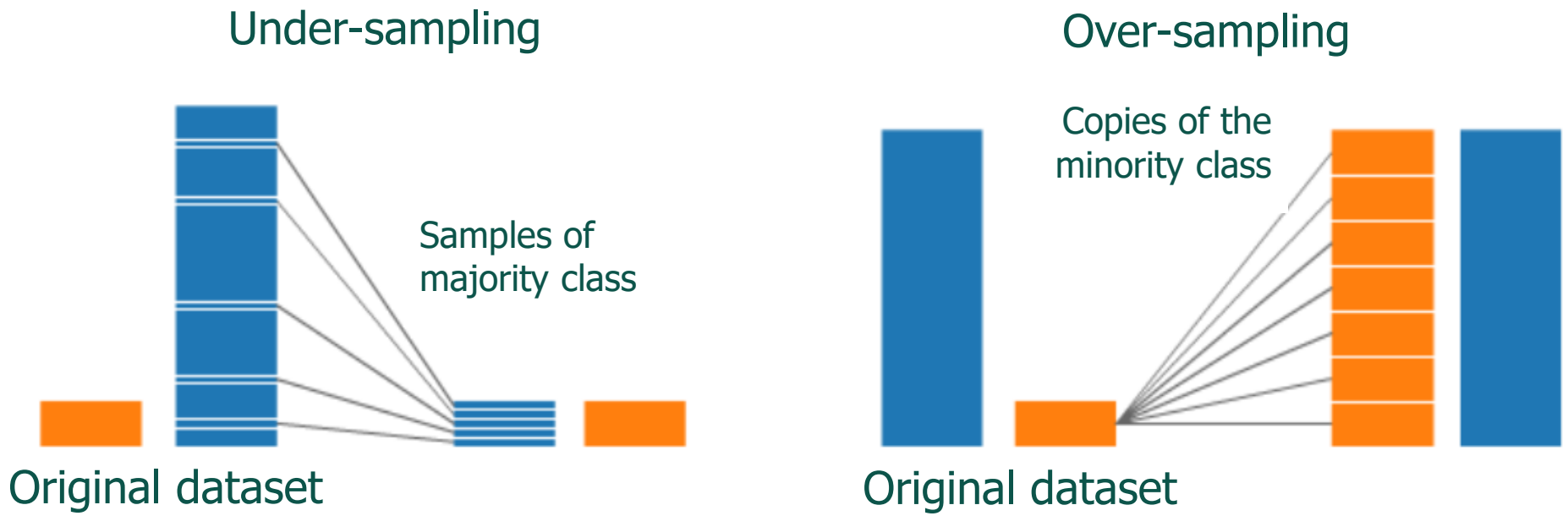
- Interstate speed data set is highly imbalanced.
- Far more high-speed records were present compared to low-speed records
- This can confuse training algorithms to predict records from minority classes



Resampling Techniques To Balance The Dataset

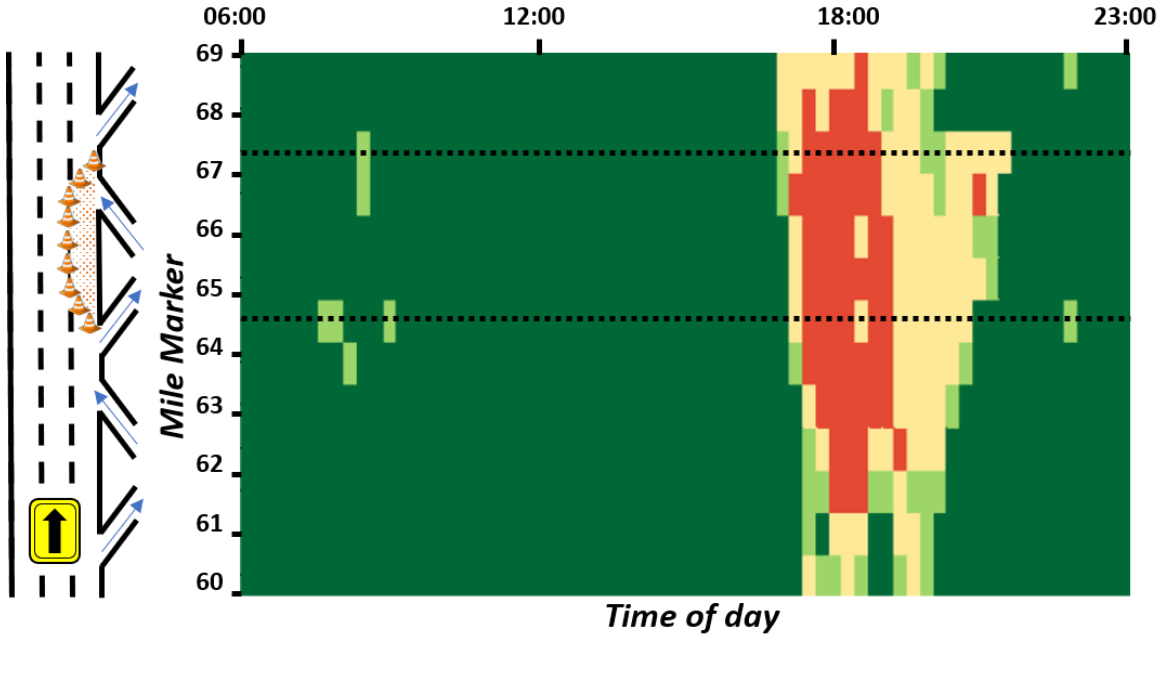
Algorithms used to resample data:

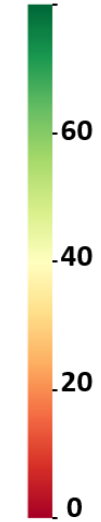
- Random Under Sampling
- Over-Sampling
- SMOTE: Synthetic Minority Over-sampling



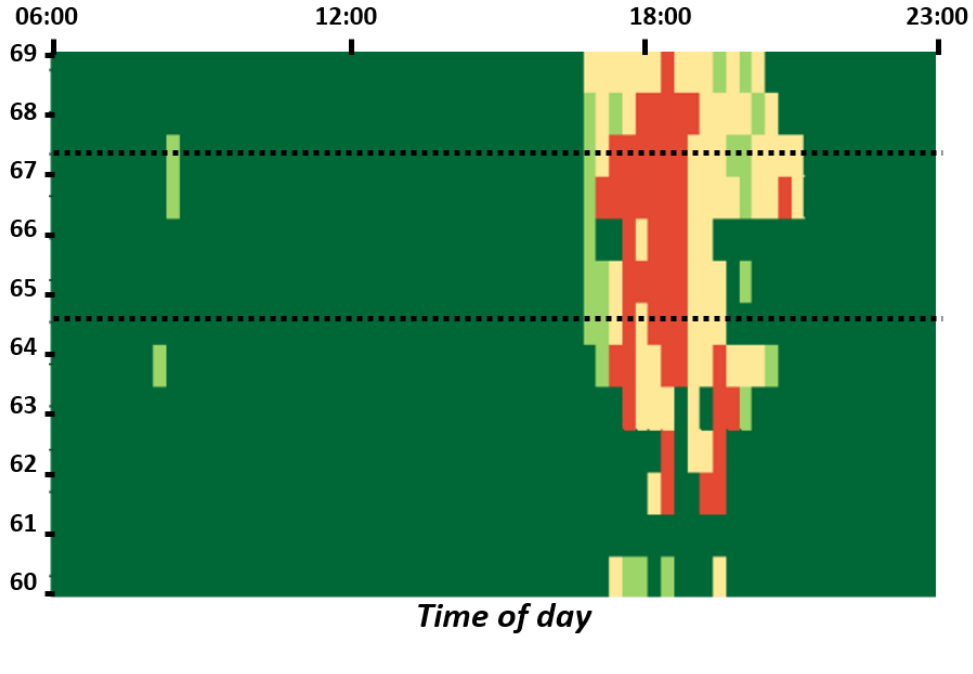
Speed Heat-maps From Predicted And Actual Observation

Actual observation

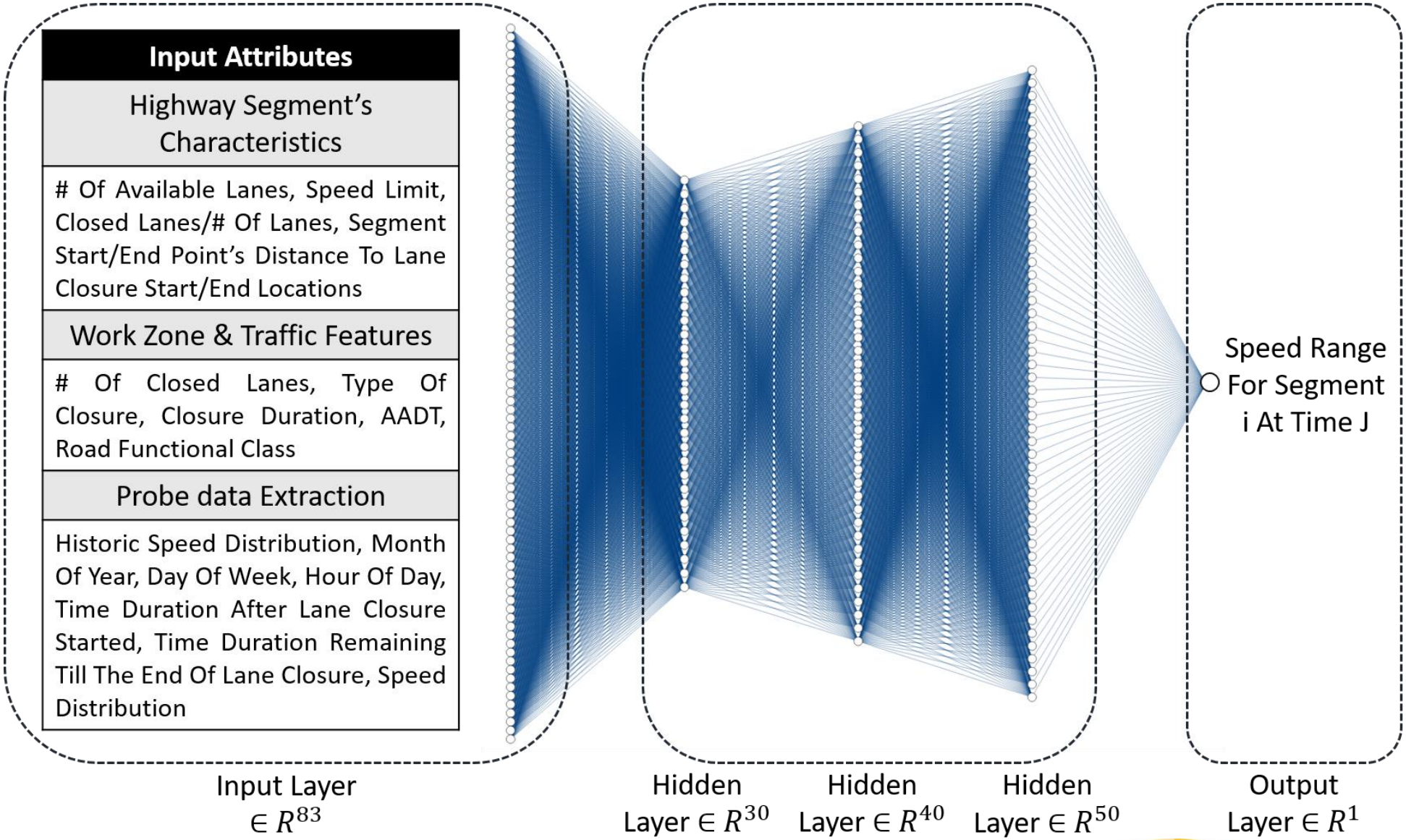


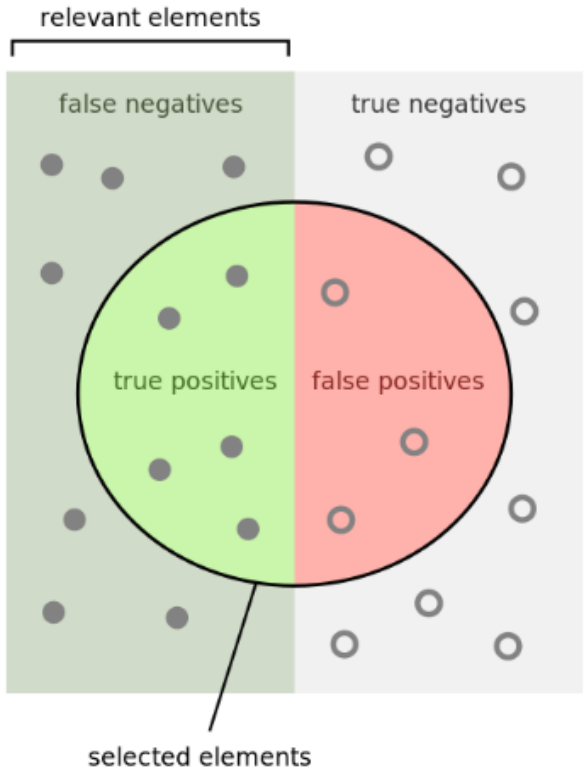


Prediction



Artificial Neural Network Architecture





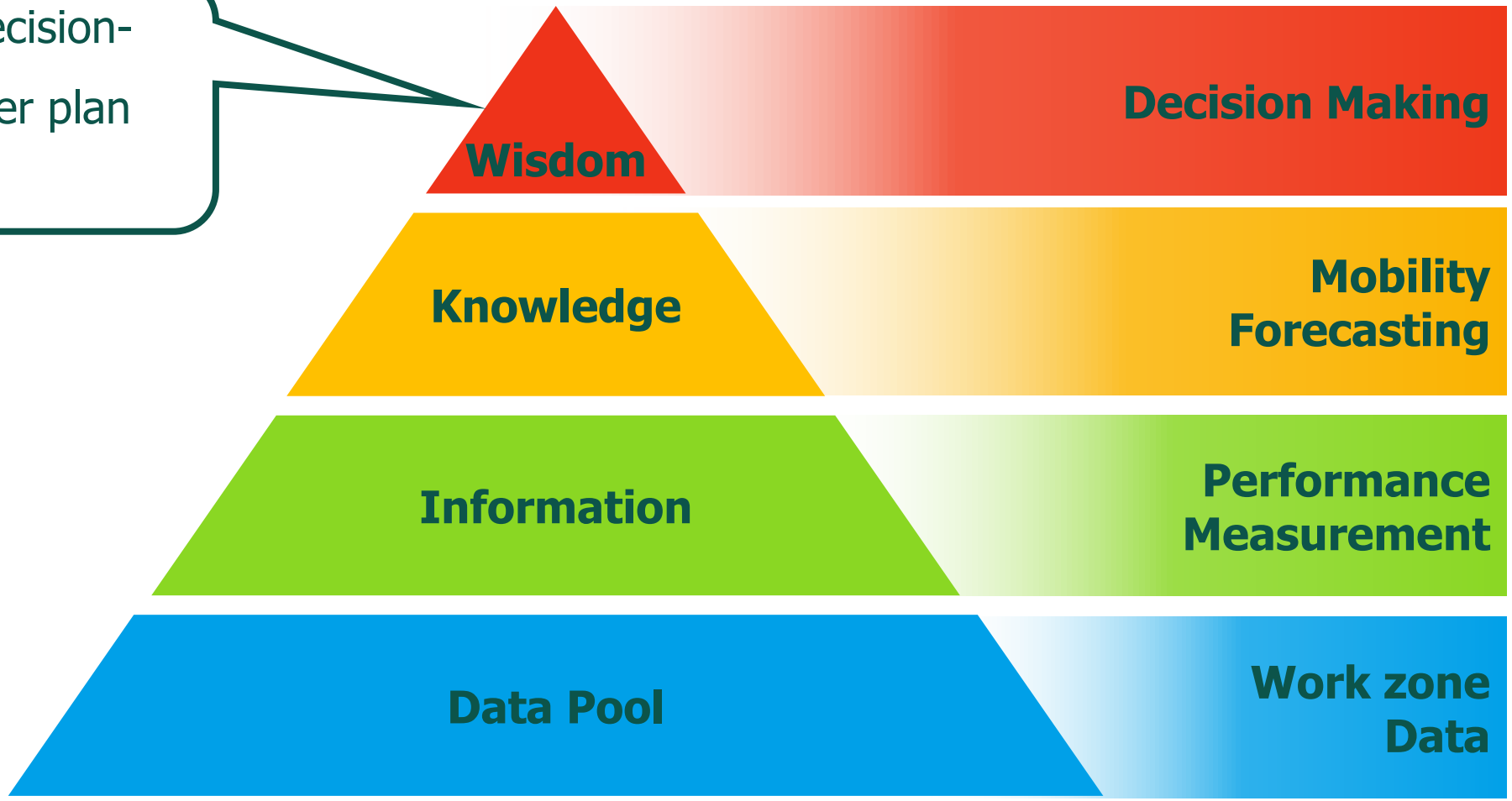
Model Performance Results

Model	Speed range (mph)	Evaluation Metrics			
		Precision	Recall	F1-score	Balanced Accuracy
Random Forest	0-20	0.8	0.76	0.78	0.74
	20-40	0.67	0.67	0.67	
	40-60	0.66	0.61	0.63	
	60-80	0.94	0.95	0.94	
	Macro average	0.76	0.74	0.75	
	Micro average	0.87	0.87	0.87	
XGBoost	0-20	0.78	0.84	0.81	0.79
	20-40	0.69	0.74	0.71	
	40-60	0.67	0.65	0.66	
	60-80	0.94	0.94	0.94	
	Macro average	0.77	0.79	0.78	
	Micro average	0.88	0.88	0.88	
ANN	0-20	0.85	0.88	0.87	0.85
	20-40	0.79	0.80	0.80	
	40-60	0.77	0.73	0.75	
	60-80	0.95	0.96	0.96	
	Macro average	0.85	0.85	0.85	
	Micro average	0.92	0.92	0.92	

Source: https://en.wikipedia.org/wiki/Precision_and_recall

State-wide Mobility Assessment & Management

Develop a high-level decision-making process to better plan future work zones



WMZA For Individual Work Zones

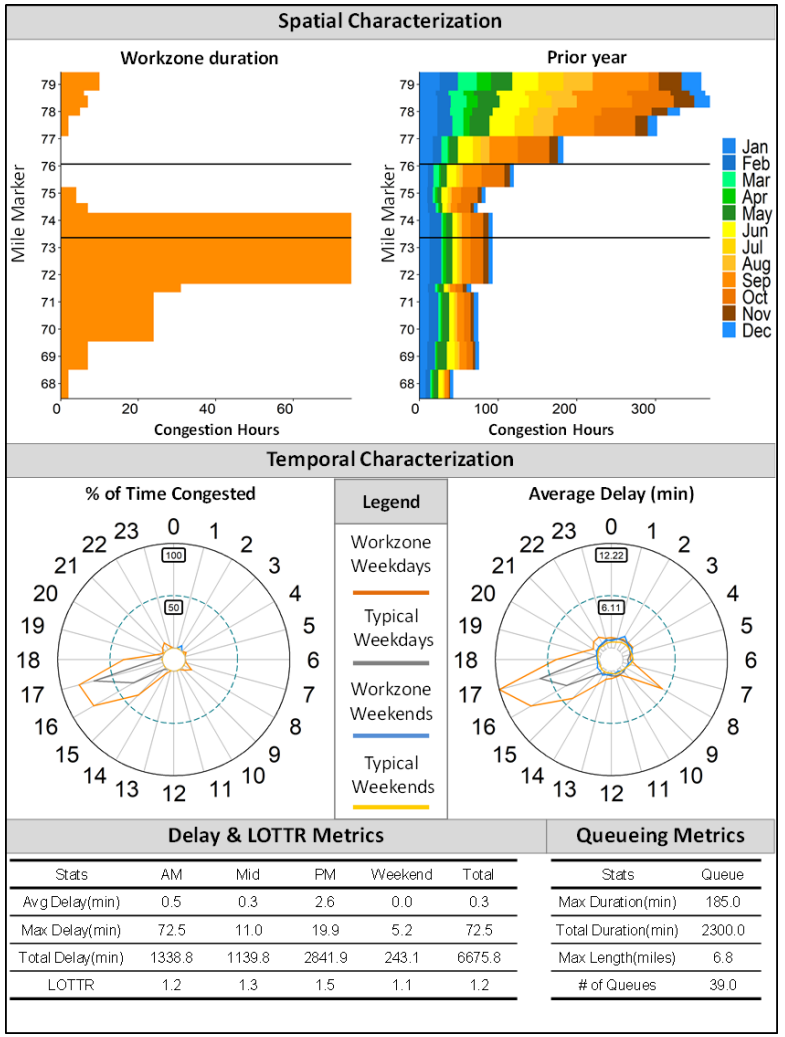
Single Work Zone Mobility Measurement

Delay & LOTTR Metrics

Stats	AM	Mid	PM	Weekend	Total
Avg Delay(min)	0.0	5.9	4.0	0.2	0.1
Max Delay(min)	5.2	22.8	26.7	3.3	26.7
Total Delay(min)	183.7	3585.4	2111.4	107.3	6151.7
LOTTR	1.3	1.6	1.9	1.0	1.7

Queueing Metrics

Stats	Queue
Max Duration(min)	580.0
Total Duration(min)	2895.0
Max Length(miles)	3.3
# of Queues	20.0



State-wide Mobility Impact Measurement

Selected Work Zone Projects:

- 2014 – 638 Work Zones
- 2015 – 601 Work Zones
- 2016 – 535 Work Zones
- 2017 - 344 Work Zones

More than 1,700 case studies

Performance Measures

A	B	C	D	E	F
wz_id	avg_wz_d	max_wz_c	total_wz_	avg_am_d	max_am_
88617	0.174799	108.3724	3854.192		
81678	0	91.44173	1049.92	0.18786	91.4417
86816	0.139736	86.87521	2006.634	0.002265	0.68807
86358	0.230484	86.81255	4210.739	0	0.77911
86216_2	0.139727	81.02689	2582.273	0	1.05434
89472_2	0.379282	74.29893	1374.003	0.321379	1.07812
91151	0.49243	72.56915	1438.097	0.51033	5.04644
93621	0.749222	72.33886	5423.167	0.745331	5.29612
86625	0.075759	71.53694	1700.485	0.039499	2.29214
91973	1.588364	67.28621	5098.544		
93622	0.875525	64.26964	9496.47	0.68335	7.41939

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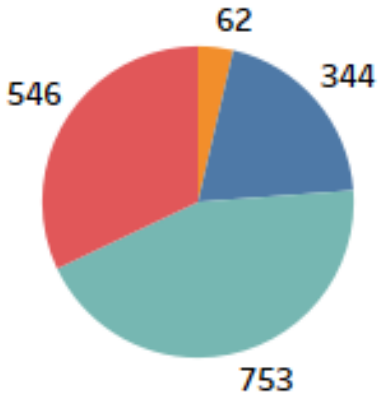
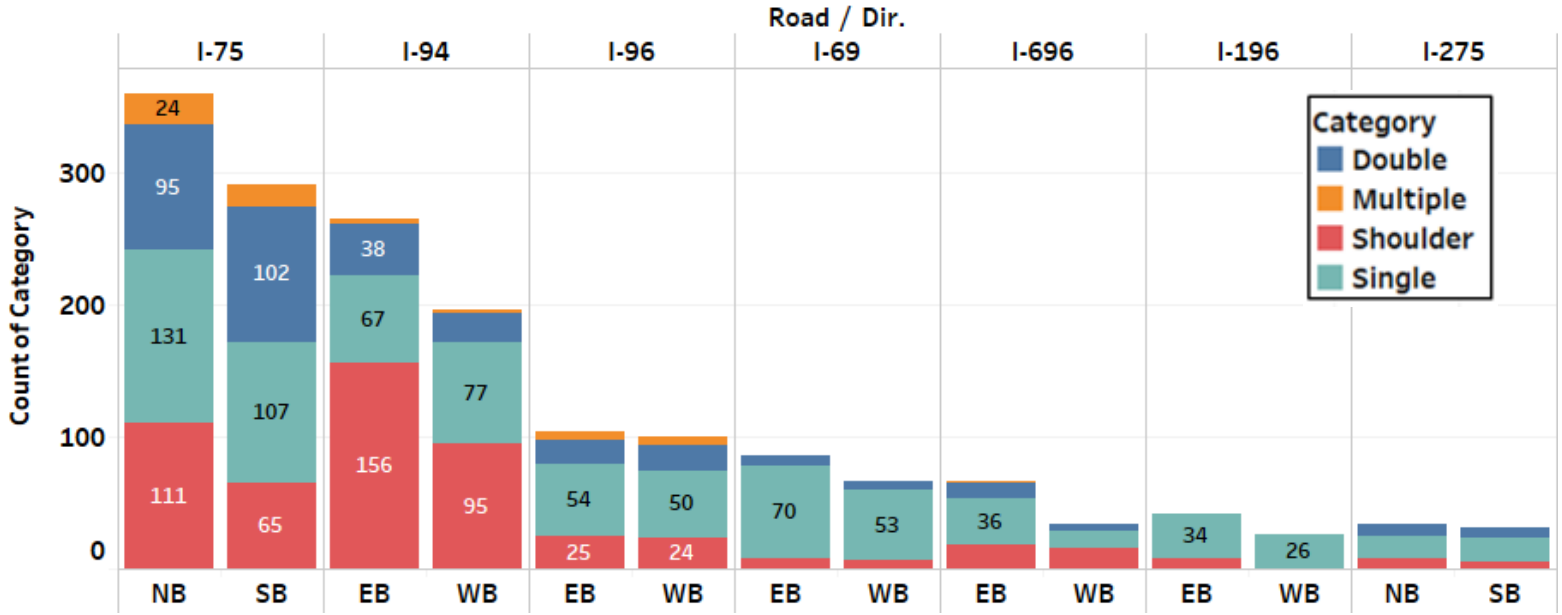
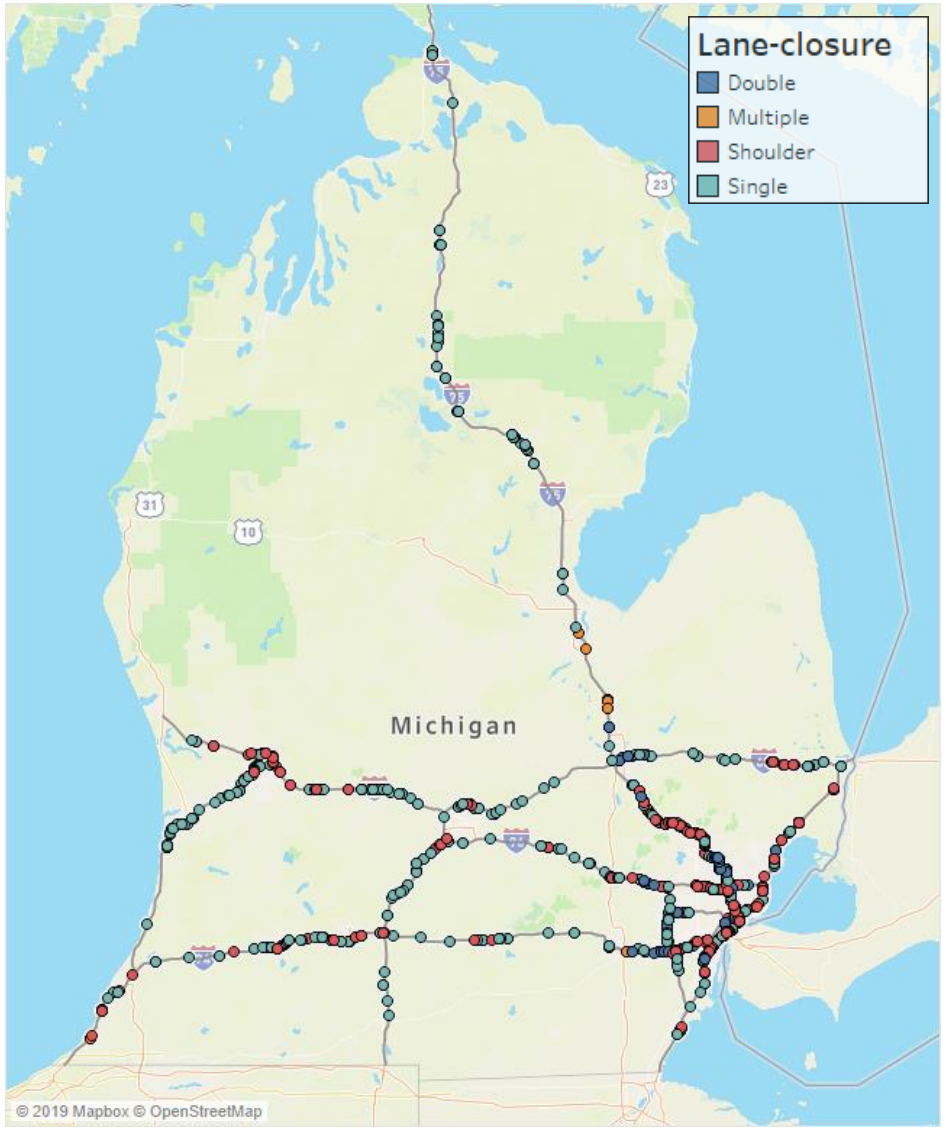
Work Zone Case Studies

- 1,705 work zone case studies from 2014 to 2017
- Shoulder to multiple lane closures
- One to 15 days







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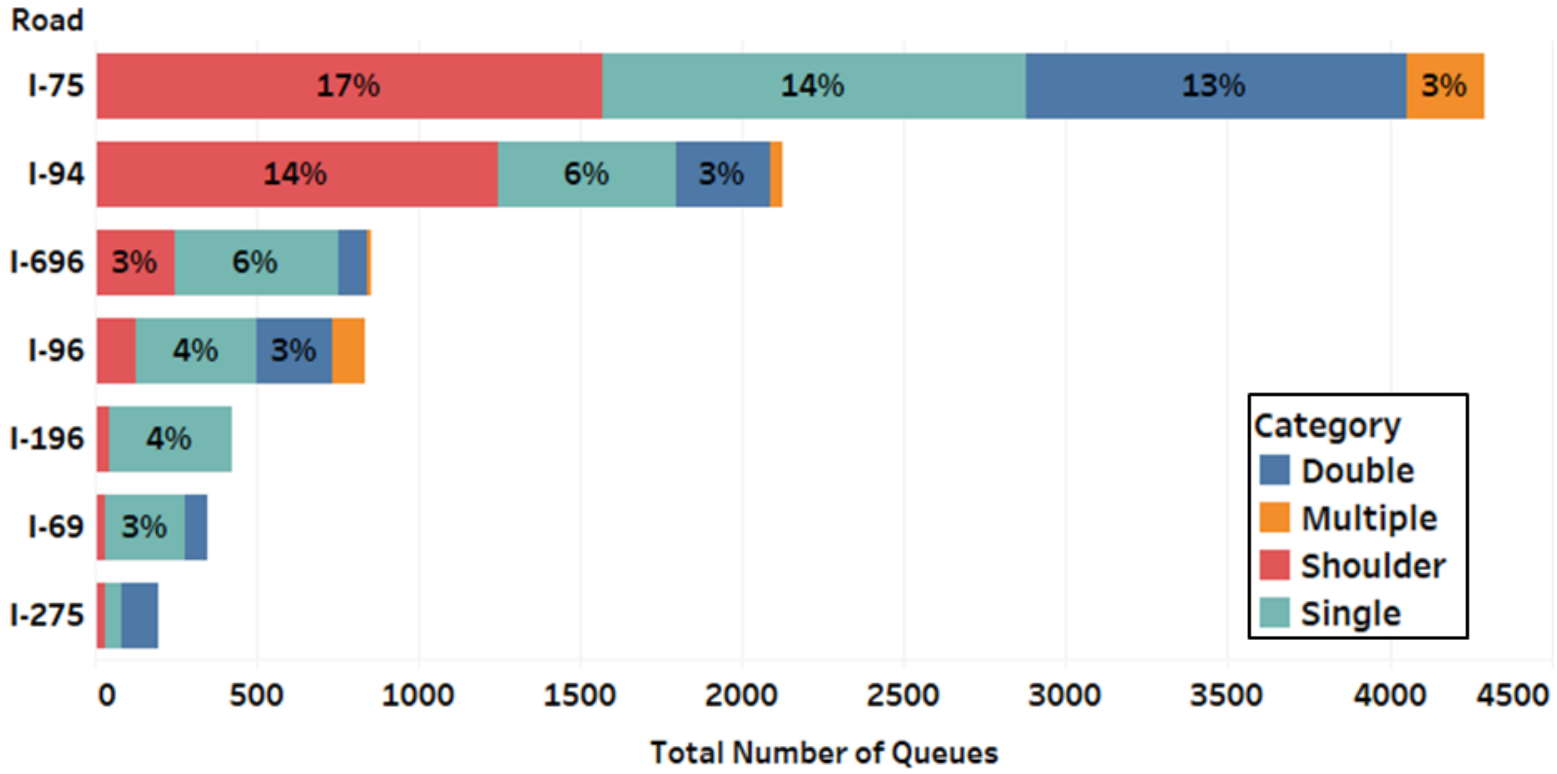
Ranking Interstates Based On Mobility Impact

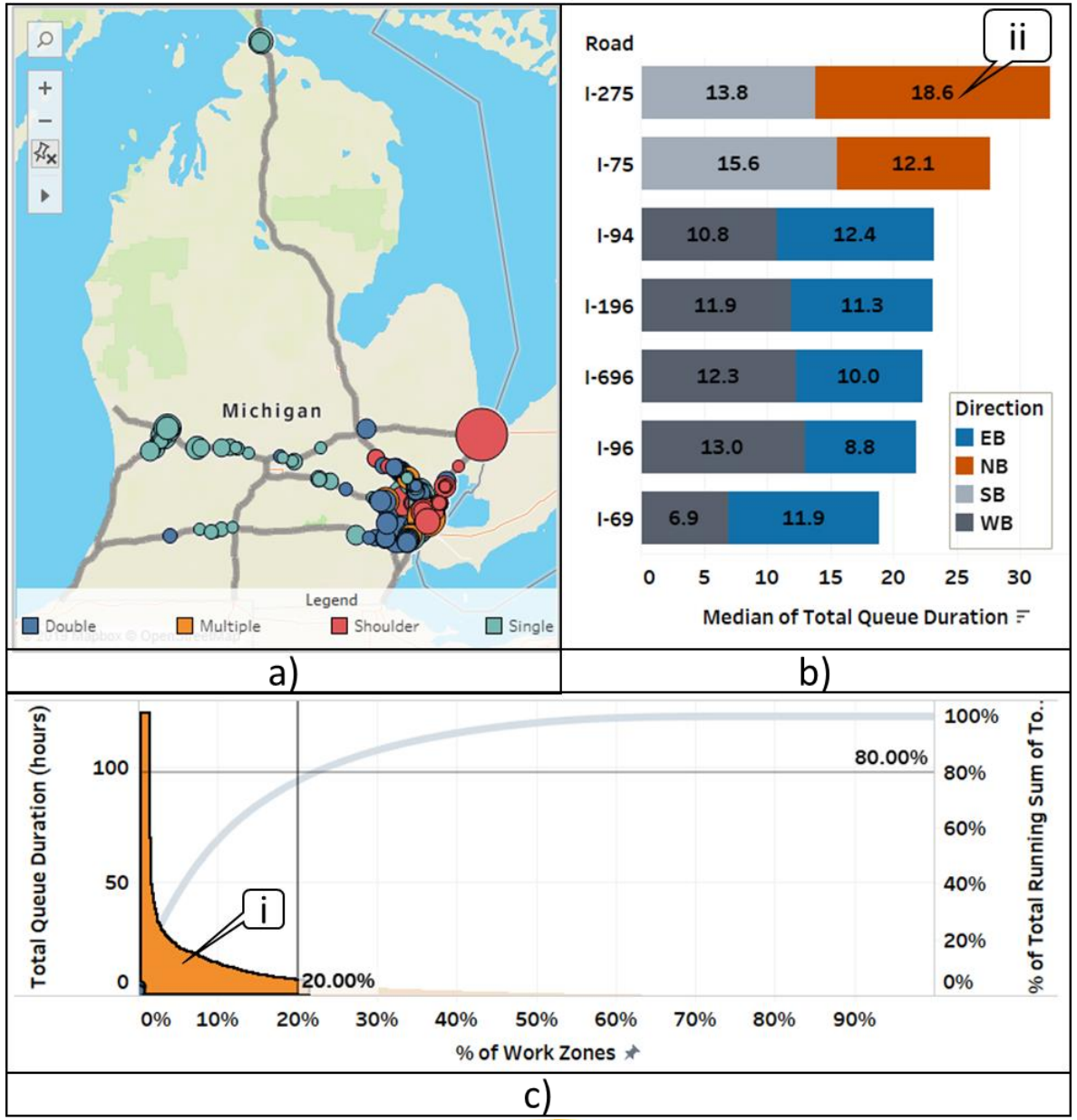
- Identifying interstates with the highest impact on mobility.
- More information on how different work zone categories impacted mobility.
- Useful for budget allocation and high-level planning



Significant Projects?

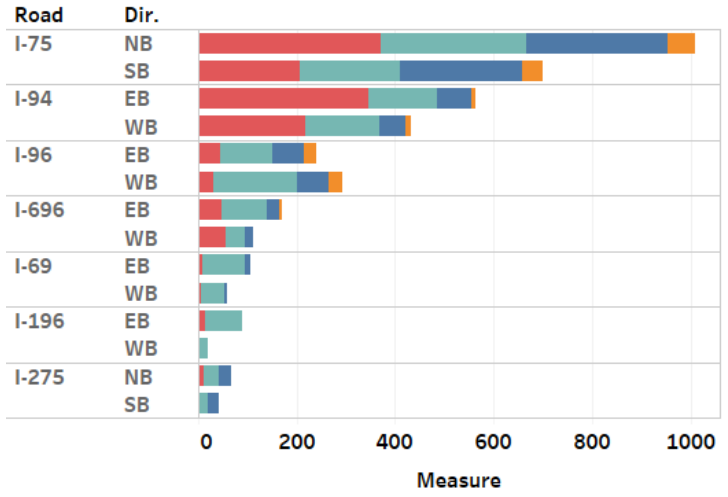
Ranking Work Zones Using Pareto Principle

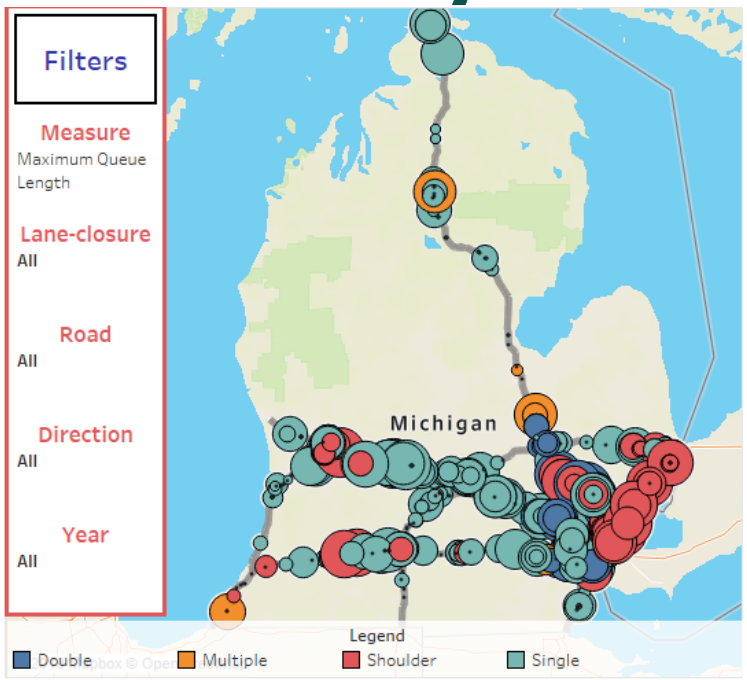
- Determines 20% of work zones which accounted for 80% of the overall impact.
- These projects can be considered "significant" projects.
- Agencies could prioritize these work zones to improve their mobility management.



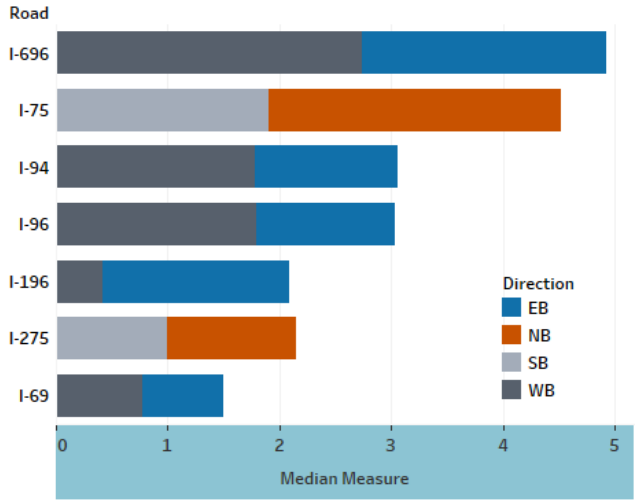
Work Zone Mobility Dashboard

Overal Impact

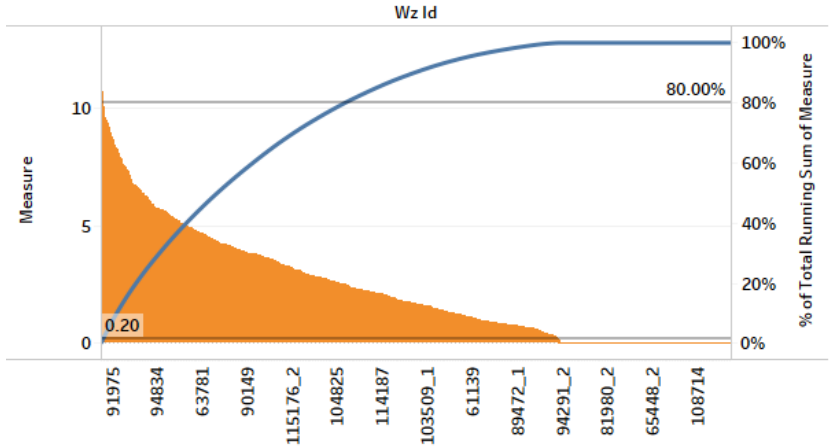




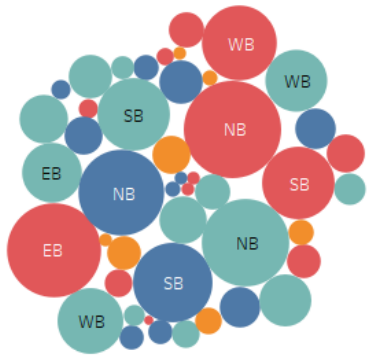
Median Impact



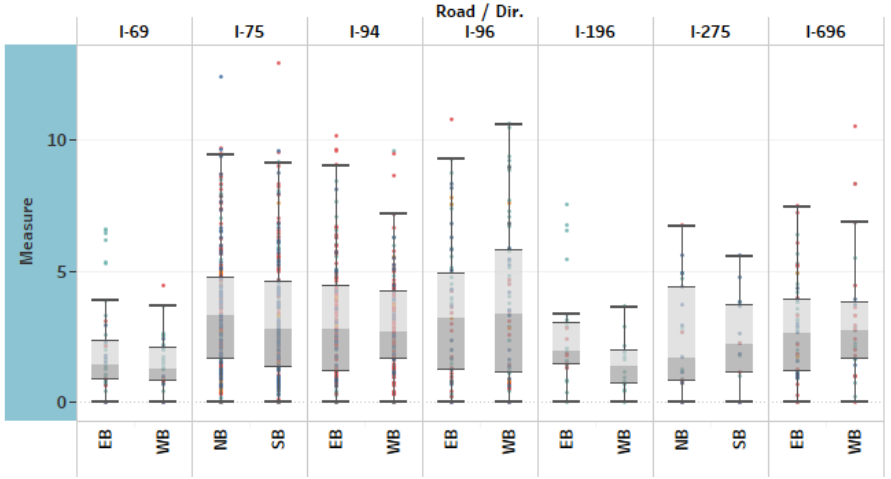
Pareto sort: significant projects



Relative Impact

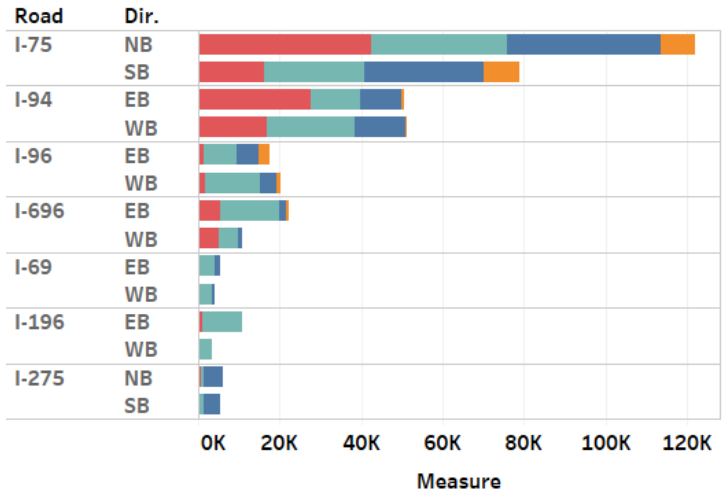


Impact Distribution

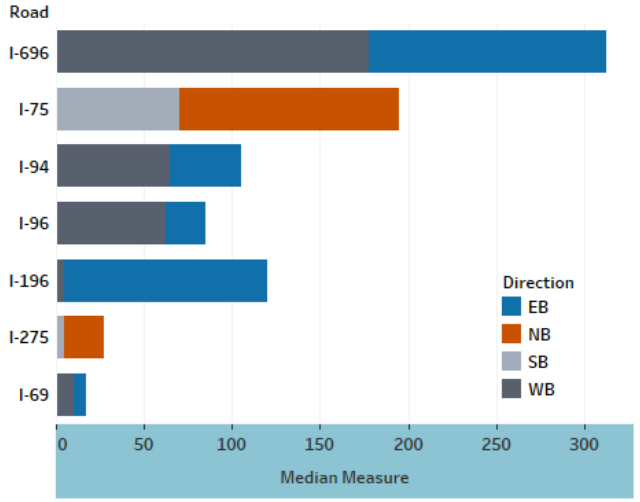


Work Zone Mobility Dashboard

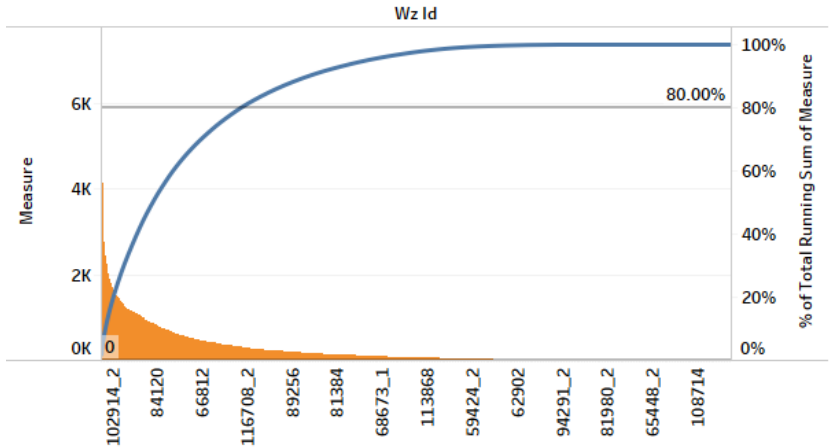
Overal Impact



Median Impact

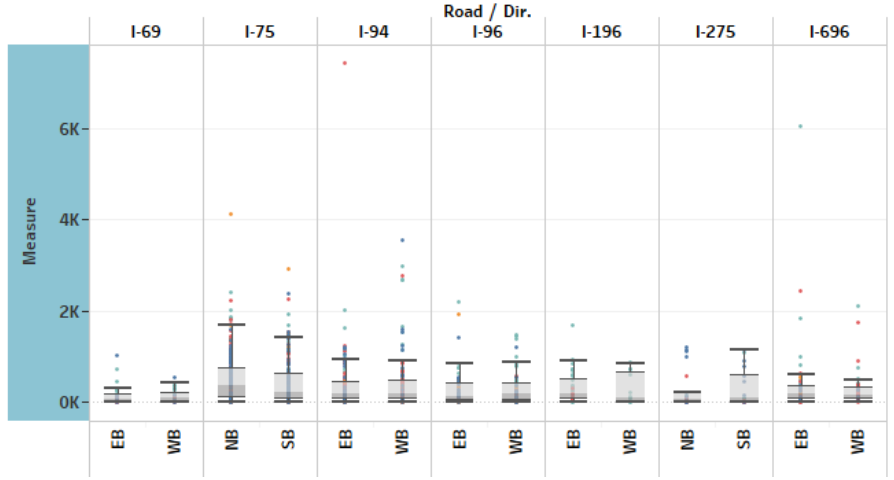


Pareto sort: significant projects



Relative Impact

Impact Distribution



Making Decisions Based On Data!

Research questions:

- What is the relationship between work zone characteristics and its impact on mobility?
- Which work zone strategies work more efficiently?
- What are significant factors effecting mobility performance?
- Can we develop decision rules based on data?

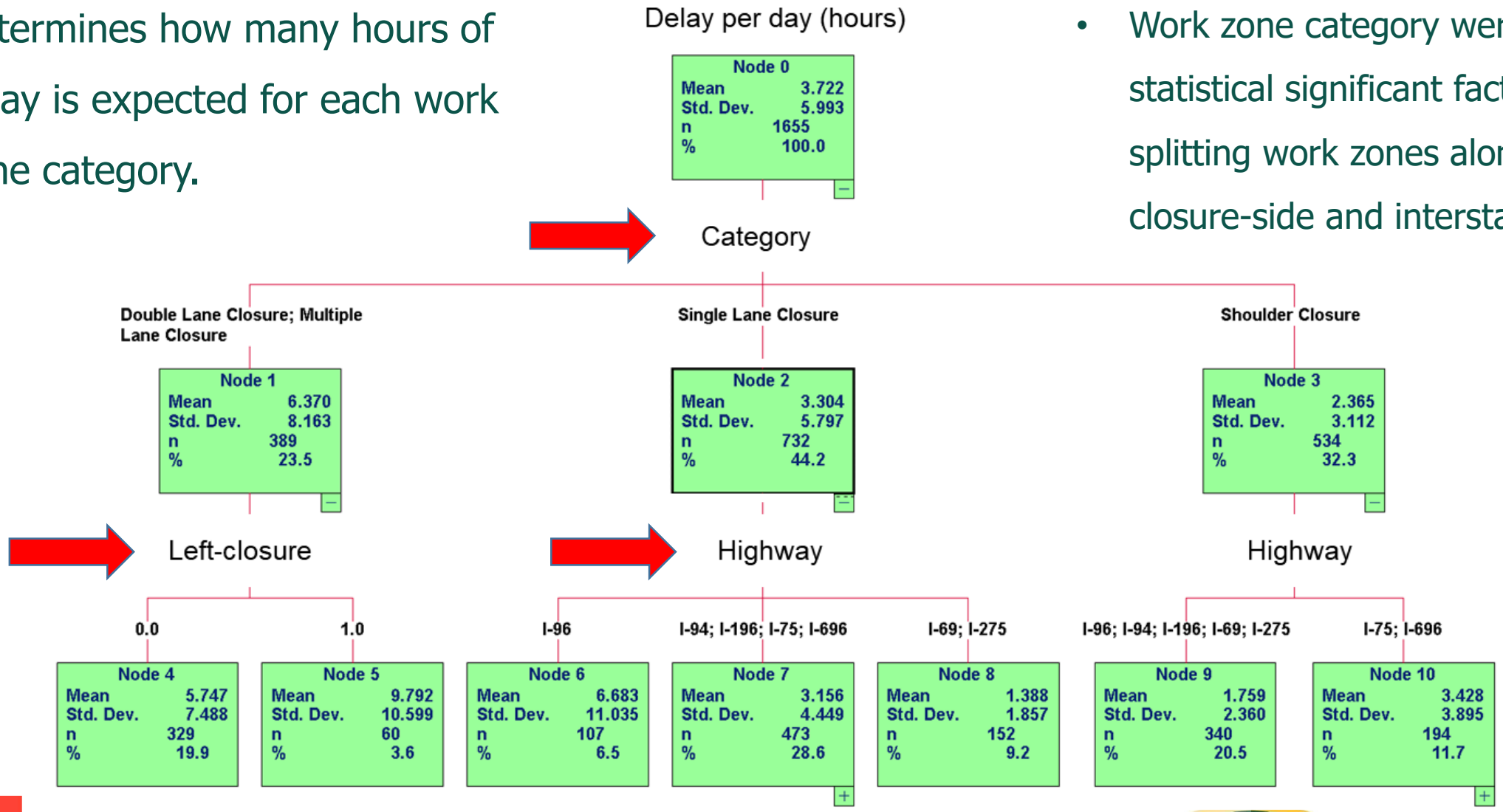
Statistical Analysis: Chi-squared Automatic Interaction Detection

- What is the relationship between dependent and independent variables?
- Used CHAID, Chi-squared Automatic Interaction Detection, algorithm which is based on the chi-square statistics.
- Statistically significant factors were used to split data into decision trees.

Mobility Metrics (dependent variables)	Work Zone Characteristics (independent variables)
• **Total Work zone delay (normalized: hour per day)** • **Total Queue duration (normalized: percent of time performing in queue condition per day)** • **Number of queue (normalized: per day)**	• Work zone category (shoulder to multiple lane closure) • Roadway () • AADT • CAADT • Closure side (Left-closure or right-closure • Duration (intermediate or long-term) • Day of week (work zone starts) • Day of week (work zone ends) • Month of year

Decision-making Based On The Delay Metric

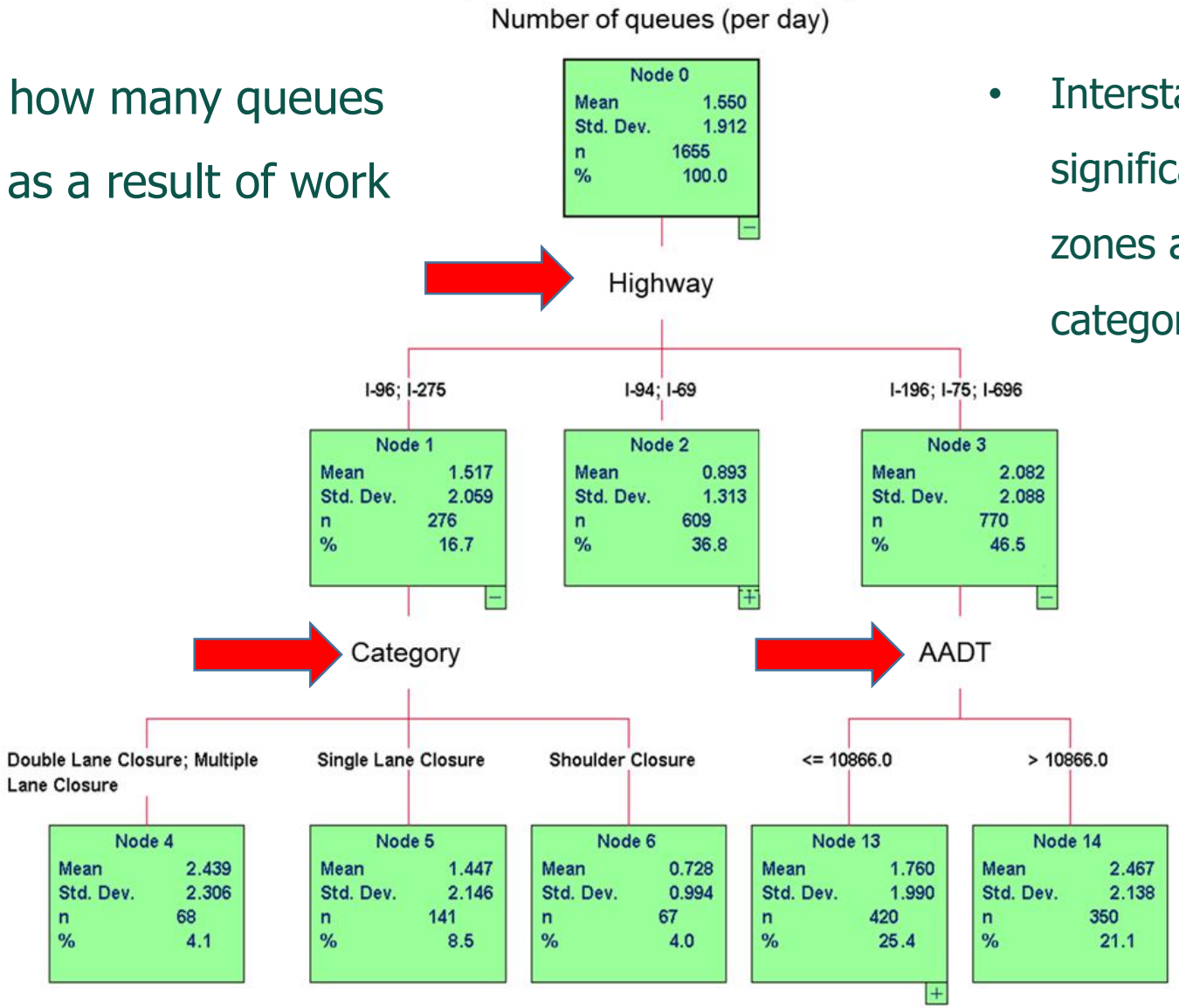
- Determines how many hours of delay is expected for each work zone category.



- Work zone category were the statistical significant factor splitting work zones along with closure-side and interstates.

Decision-making Based On The Queue Frequency Metric

- Determines how many queues would form as a result of work zone.



- Interstates were the statistical significant factor splitting work zones along with work zone category and AADT.

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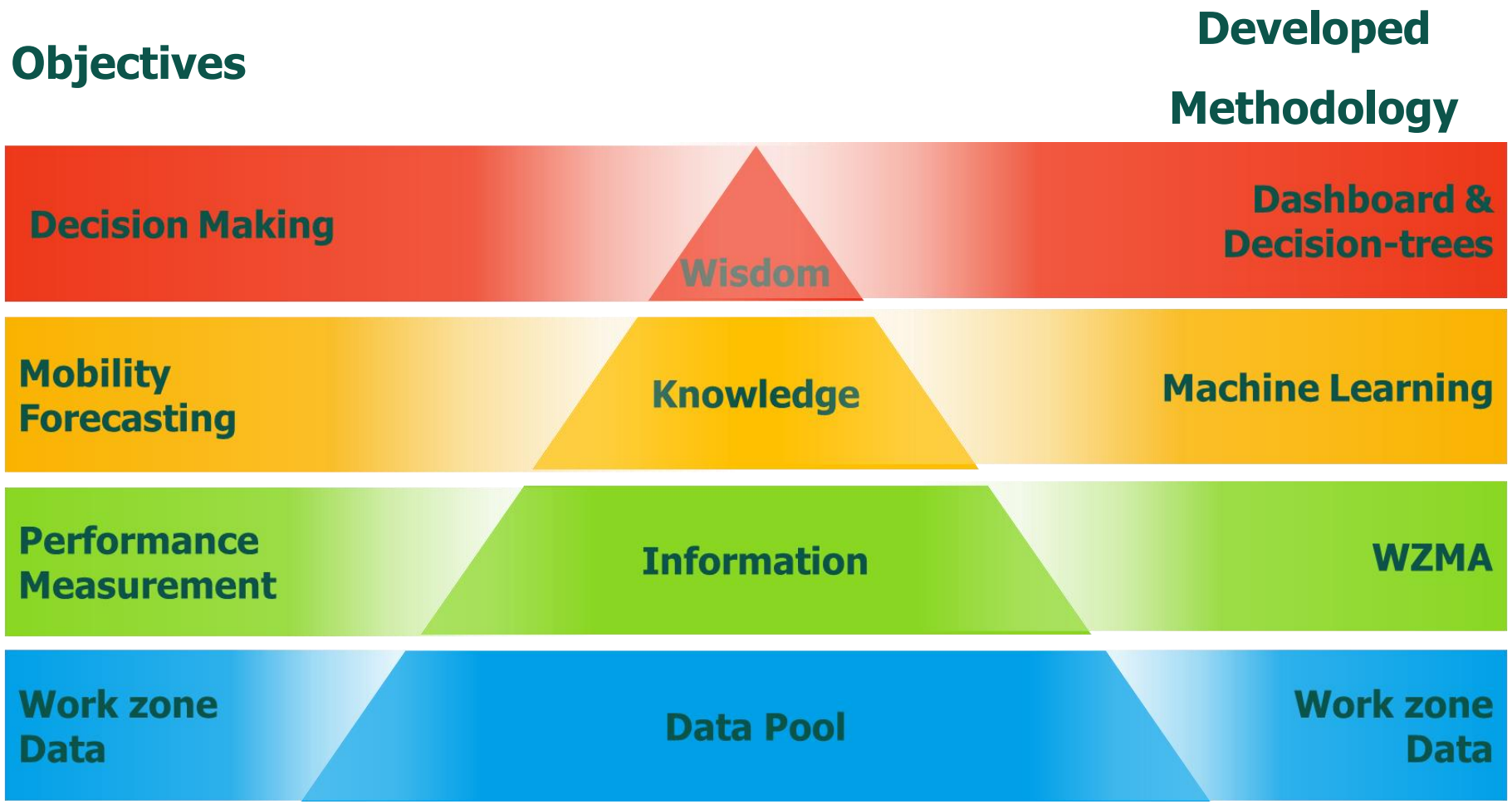
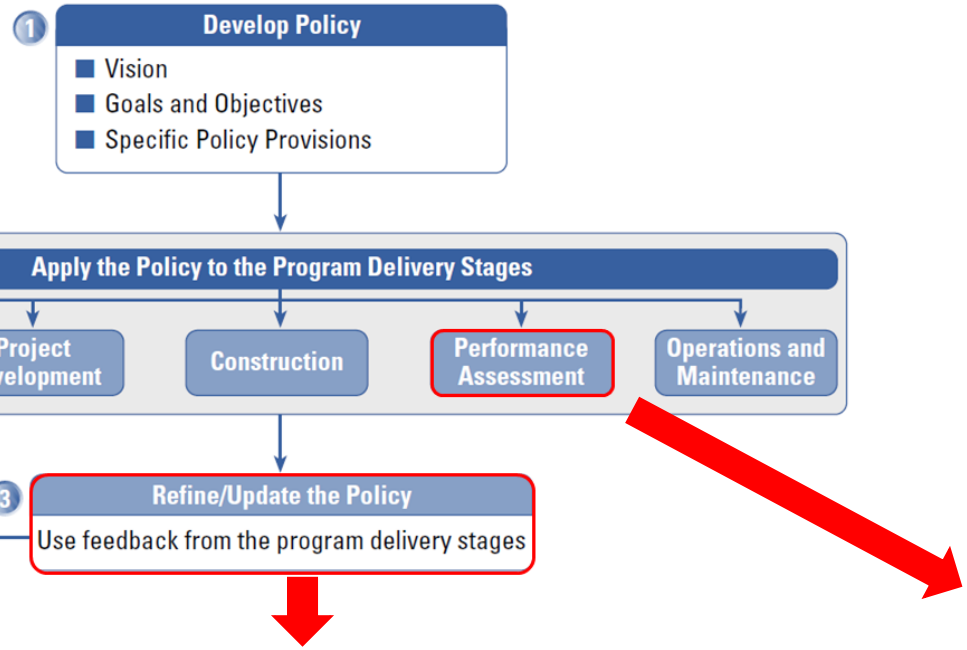
Findings & Conclusion

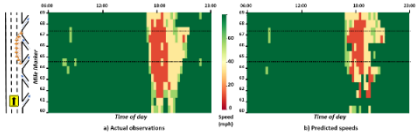


Provided Methodologies To Address The FHWA Call



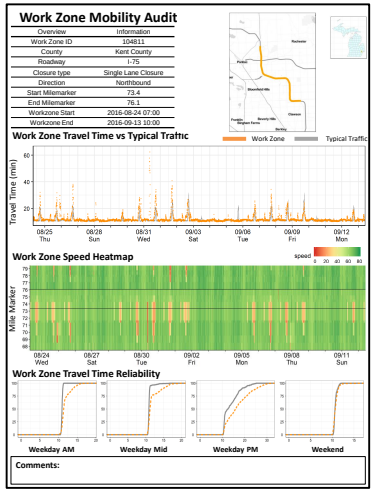
Predictive Analytics

Developed a machine learning method to assist in planning future lane-closures.



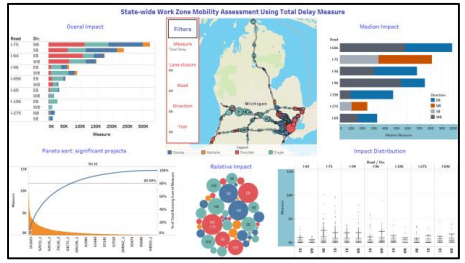
Descriptive Analytics

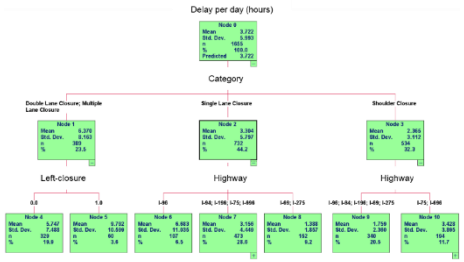
Developed a scalable framework to audit mobility performance measures for individual lane-closures.



Prescriptive Analytic

Developed a Business Intelligence dashboard to assess mobility in a state-wide level.





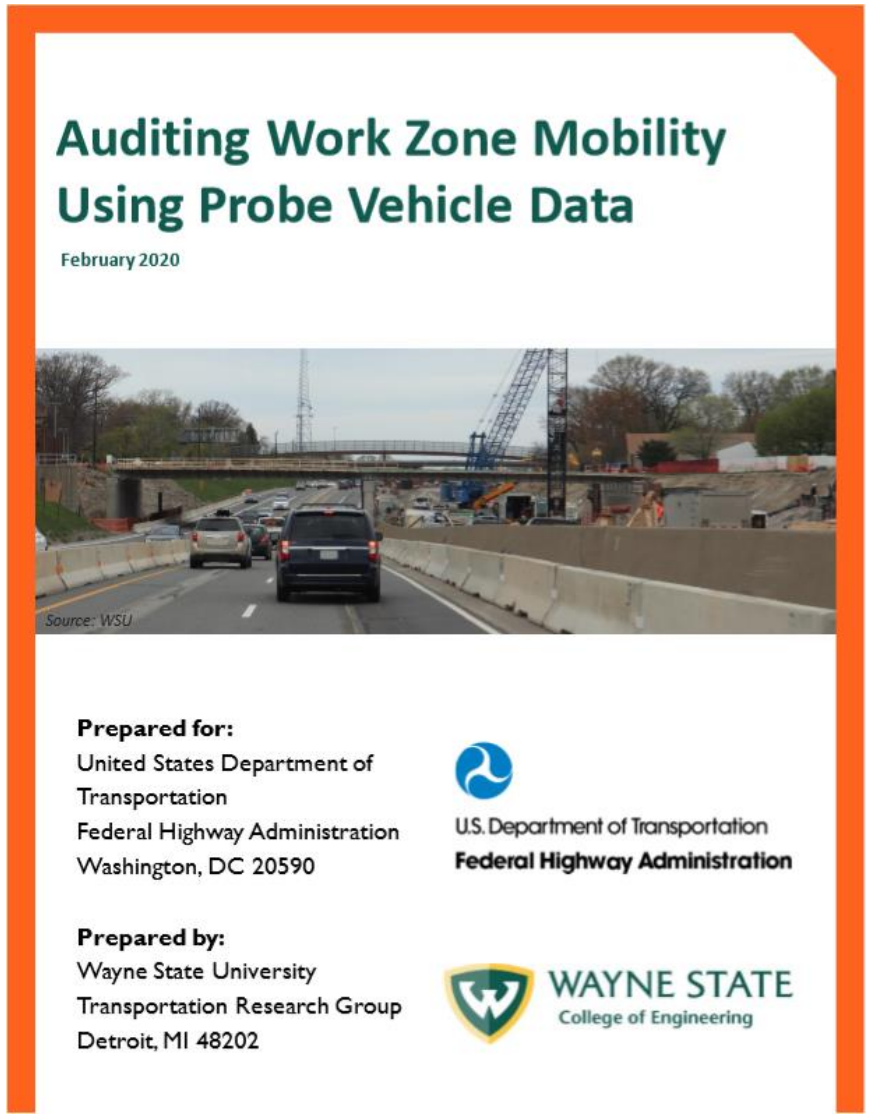
Work Zone Mobility Audit Framework

Link to the "Auditing Work Zone Mobility Using Probe Vehicle Data" document

Link: https://www.workzonesafety.org/publication/auditing-work-zone-mobility-using-probe-vehicle-data/

To access to the source code of the WZMA tool on GitHub:

Link: https://github.com/WSUTRG/WorkZone_Mobility_Audit



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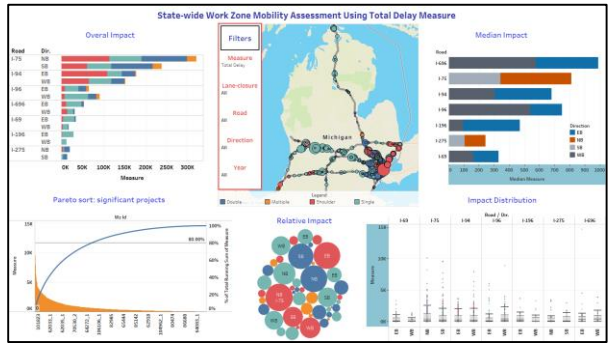
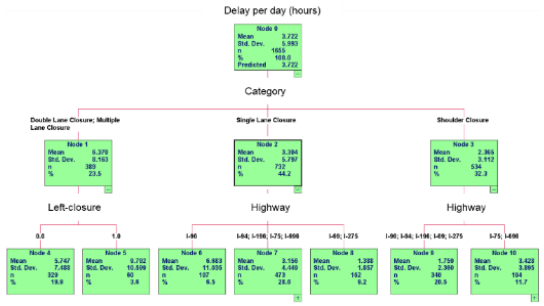
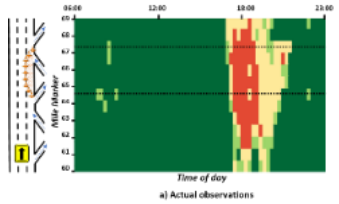
Resources

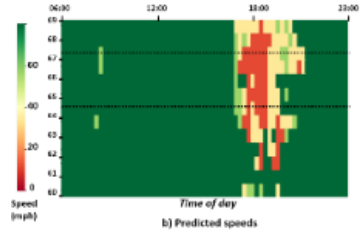
1. FHWA Work Zone Data Initiative: https://ops.fhwa.dot.gov/publications/fhwahop18083/index.htm
2. FHWA Work Zone Data Exchange: https://www.transportation.gov/av/data/wzdx
3. Kamyab, M., Remias, S., Najmi, E., Hood, K., Al-Akshar, M., & Ustun, I. (2019). Evaluation of interstate work zone mobility using probe vehicle data and machine learning techniques. *Transportation research record*, *2673*(2), 811-822. https://journals.sagepub.com/doi/abs/10.1177/0361198119827936
4. Kamyab, M., Remias, S., Najmi, E., Waddell, J., & Rabinia Haratbar, S. (2020). Machine Learning Approach to Forecast Work Zone Mobility using Probe Vehicle Data. *Transportation Research Record.* *https://journals.sagepub.com/doi/abs/10.1177/0361198120927401*

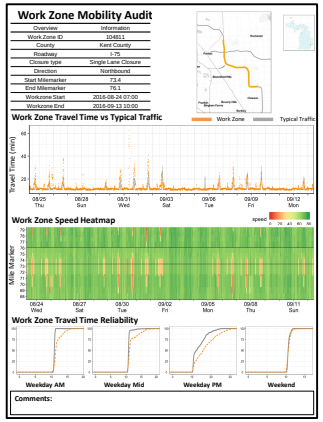
Thank you











Wisdom

Knowledge

Information

Data Pool