

# Evaluation of Road Weather Messages on DMS Based on Roadside Pavement Sensors

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Western States Forum (June 2022)



**Introduction**

**System Overview**

**Methodology**

**Data Analysis**

**Conclusion**

**Benefits**

# **Inform drivers of Hazardous Conditions**





A map of the Highway 12 Corridor in Minnesota, showing the route from Delano in the northwest to Orono in the southeast. The map highlights Highway 12 in yellow and shows various local roads, lakes, and towns. The text is overlaid on the map.

# **Objective:**

**Measure the impact system has on changing driver behavior**

## **Highway 12 Corridor**

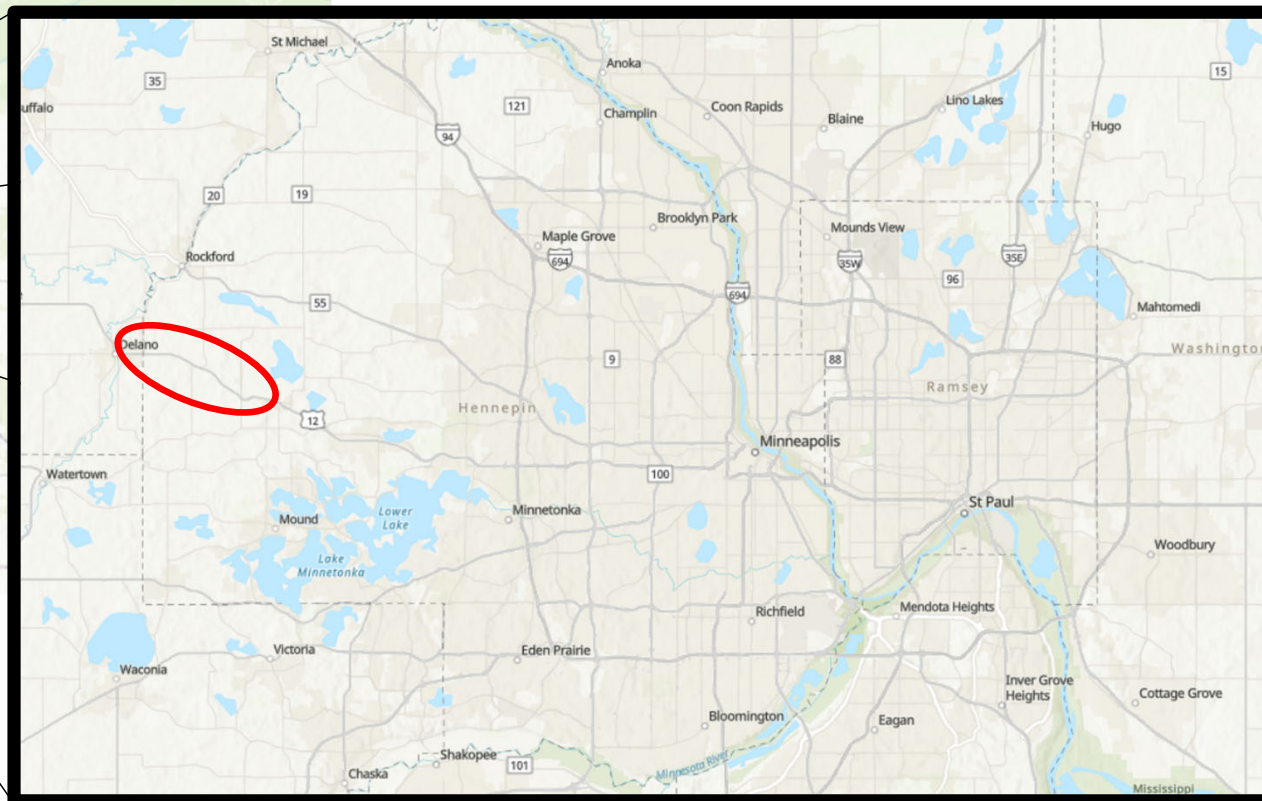
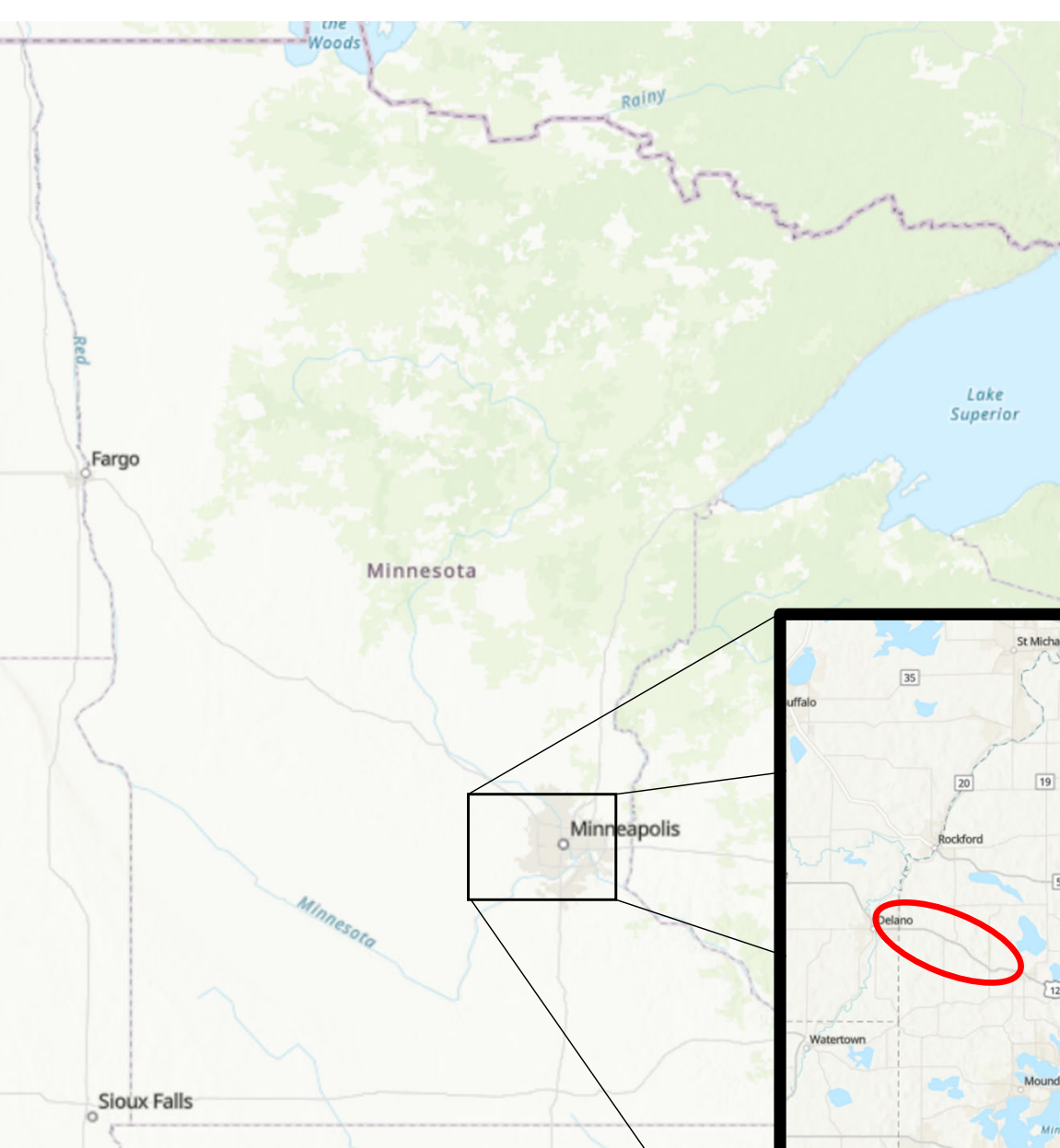
**Specially instrumented with:**  
**Roadside pavement sensors**  
**Dynamic Message Signs (DMS)**  
**Traffic Detectors**

**System displays messages on DMS based on pavement sensors.**



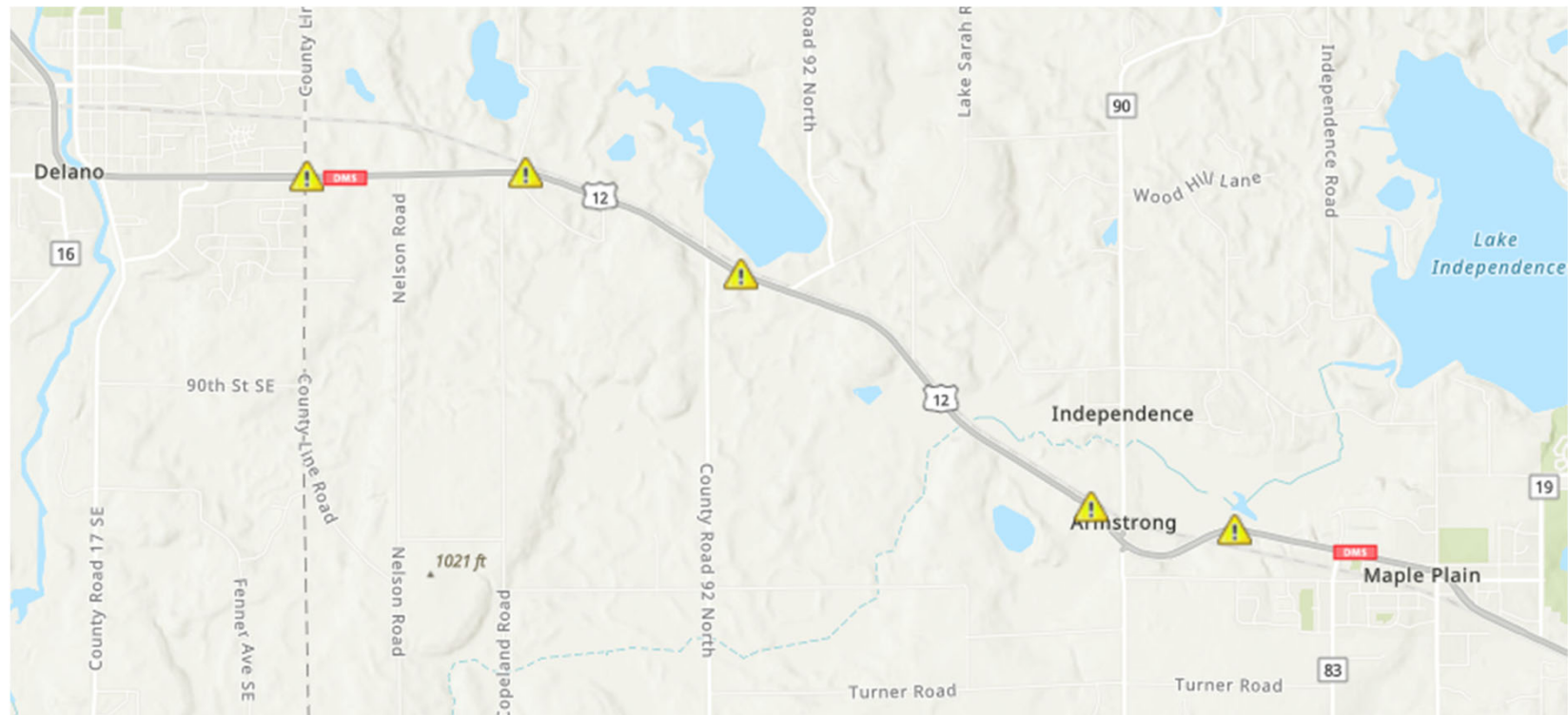
# Rural Corridor

## Some Commuter Traffic



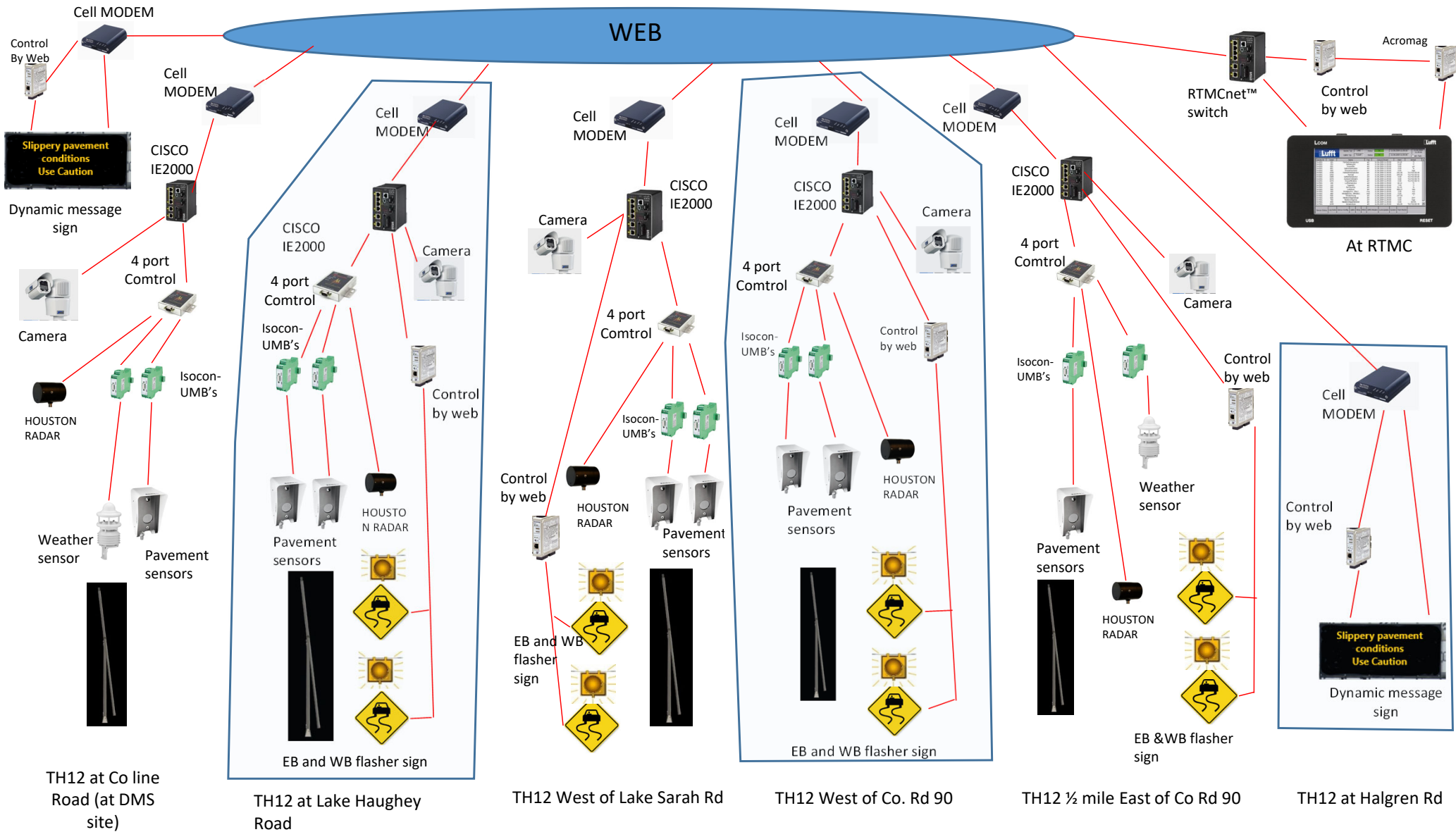
# System Devices:

- 2 DMS on either end of corridor**
- 8 warning flashers – 4 WB, 4 EB**
- 8 friction sensors monitoring for ice, snow or rain**
- 5 Doppler Radar Sensor**



# Trunk Highway (TH) 12 Slippery Pavement Notification System

Rev April 2022



System Overview Provided by MnDOT



# System Operations:

**If any friction sensor goes below defined threshold the DMS message will display along with flashers**



Images provided by Minnesota DOT



# Delano (EB) DMS



Image provided by  
Minnesota DOT

# Maple Plain (WB) DMS

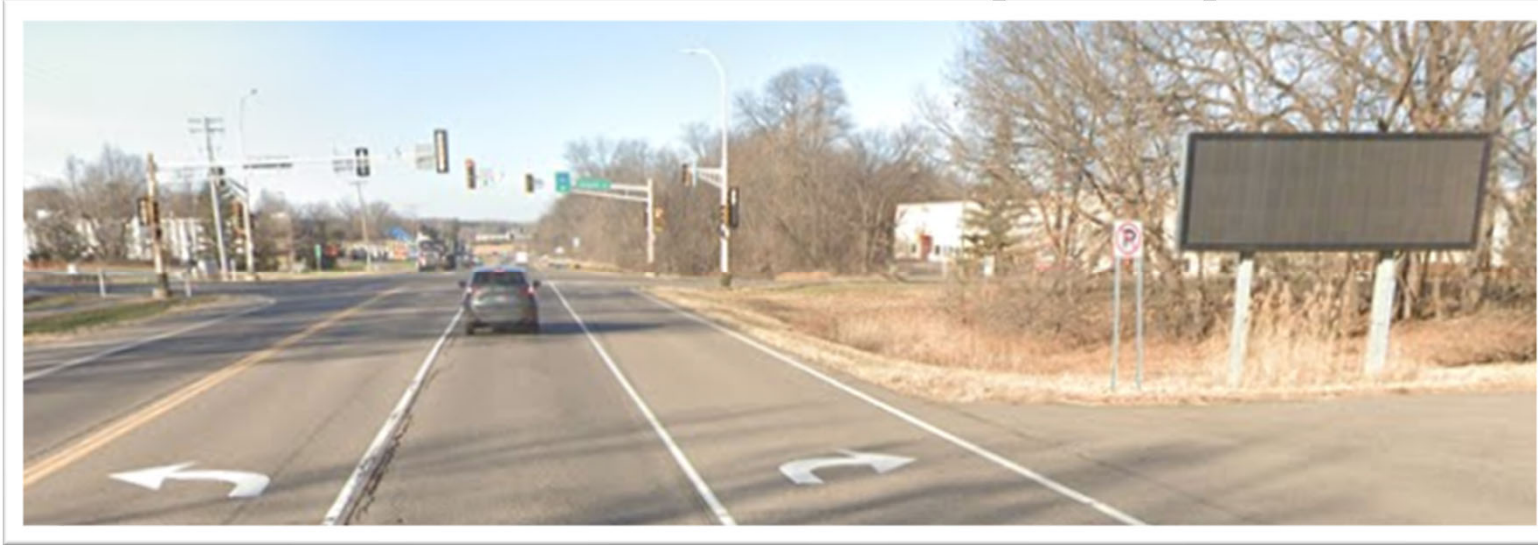


Image provided by Google Streetview



# How to measure driver behavior?





# Data Metrics

- Speed Data
  - Mean speed
  - 85<sup>th</sup> Percentile
  - Speed variation
- Car following behavior
  - Headway
- Traffic flow
  - Vehicle count (summary)

## Temporary Houston Radar

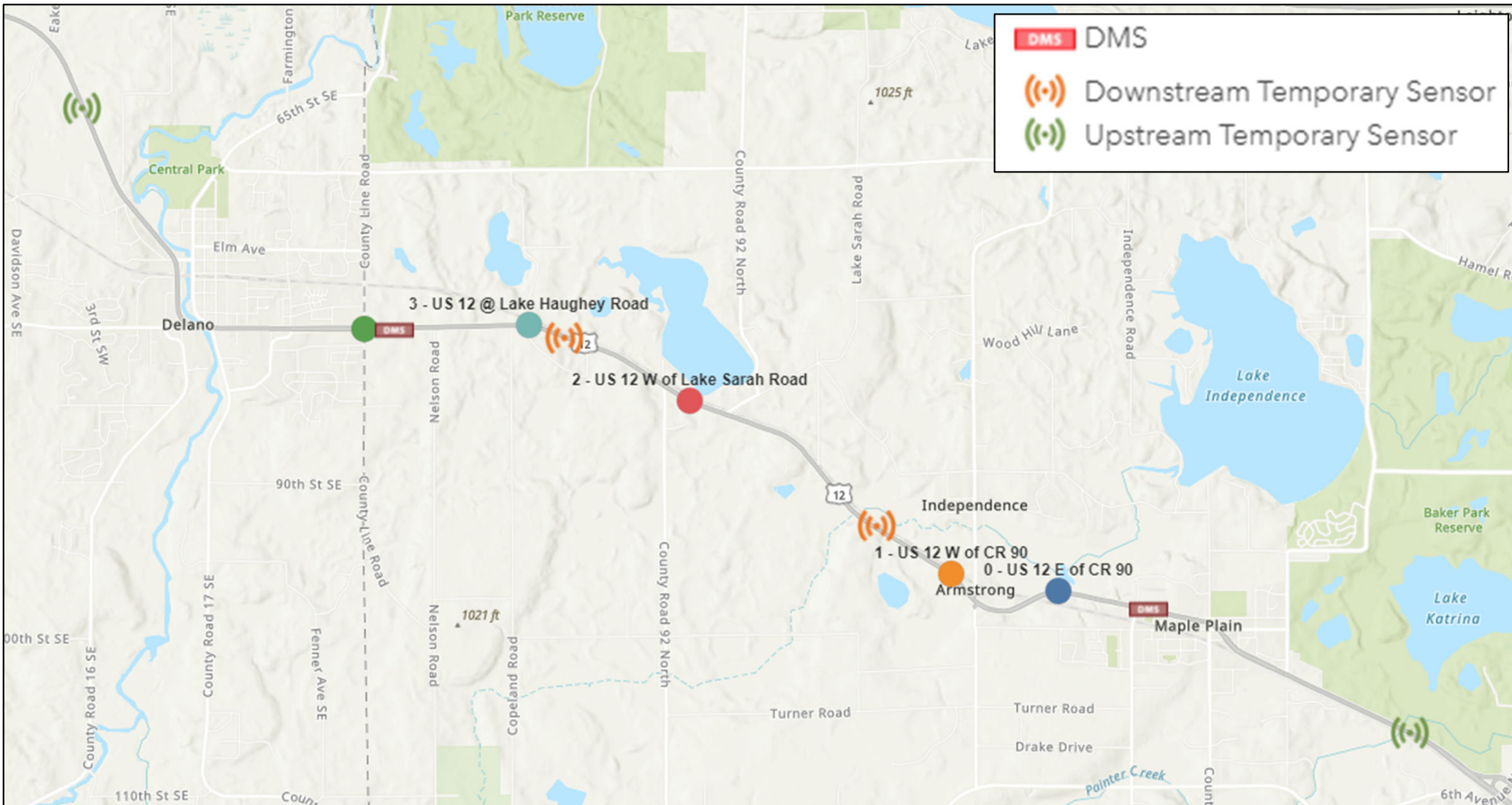


Did not use Probe Data for  
Final Analysis

iteris ClearMobility™

Speed	Length	Lane	Direction	Start	Gap	UID	Range	DirectionStr
64	22	2	1	12/8/2020 21:57	0		1	0 Going Left
62	16	2	1	12/8/2020 21:57	0		2	0 Going Left
62	16	1	2	12/8/2020 21:57	0		3	0 Going Right
60	16	1	2	12/8/2020 21:57	883		4	0 Going Right
60	20	2	1	12/8/2020 21:58	4157		5	0 Going Left
65	15	1	2	12/8/2020 21:58	4478		6	0 Going Right

# Data Sources: Device Map

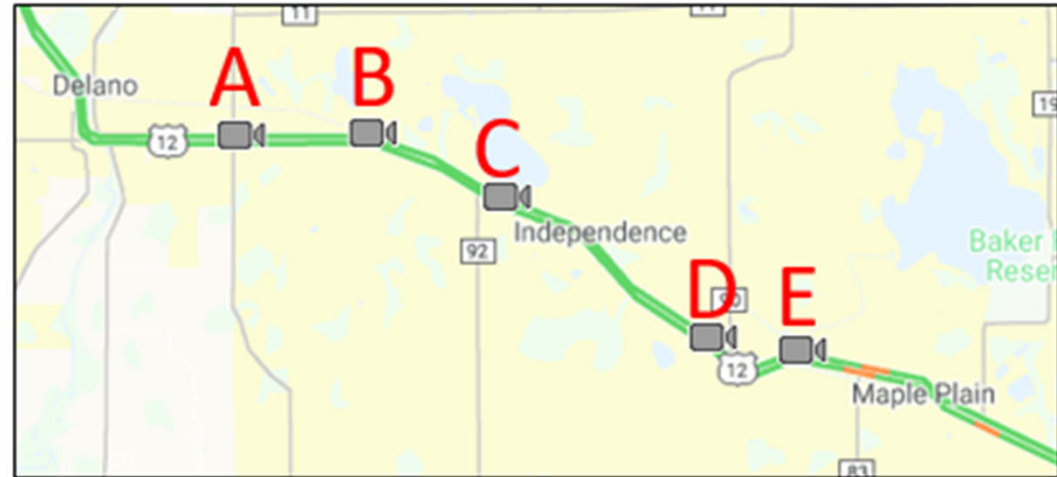


# Camera Composite

Camera images were downloaded every 5 minutes

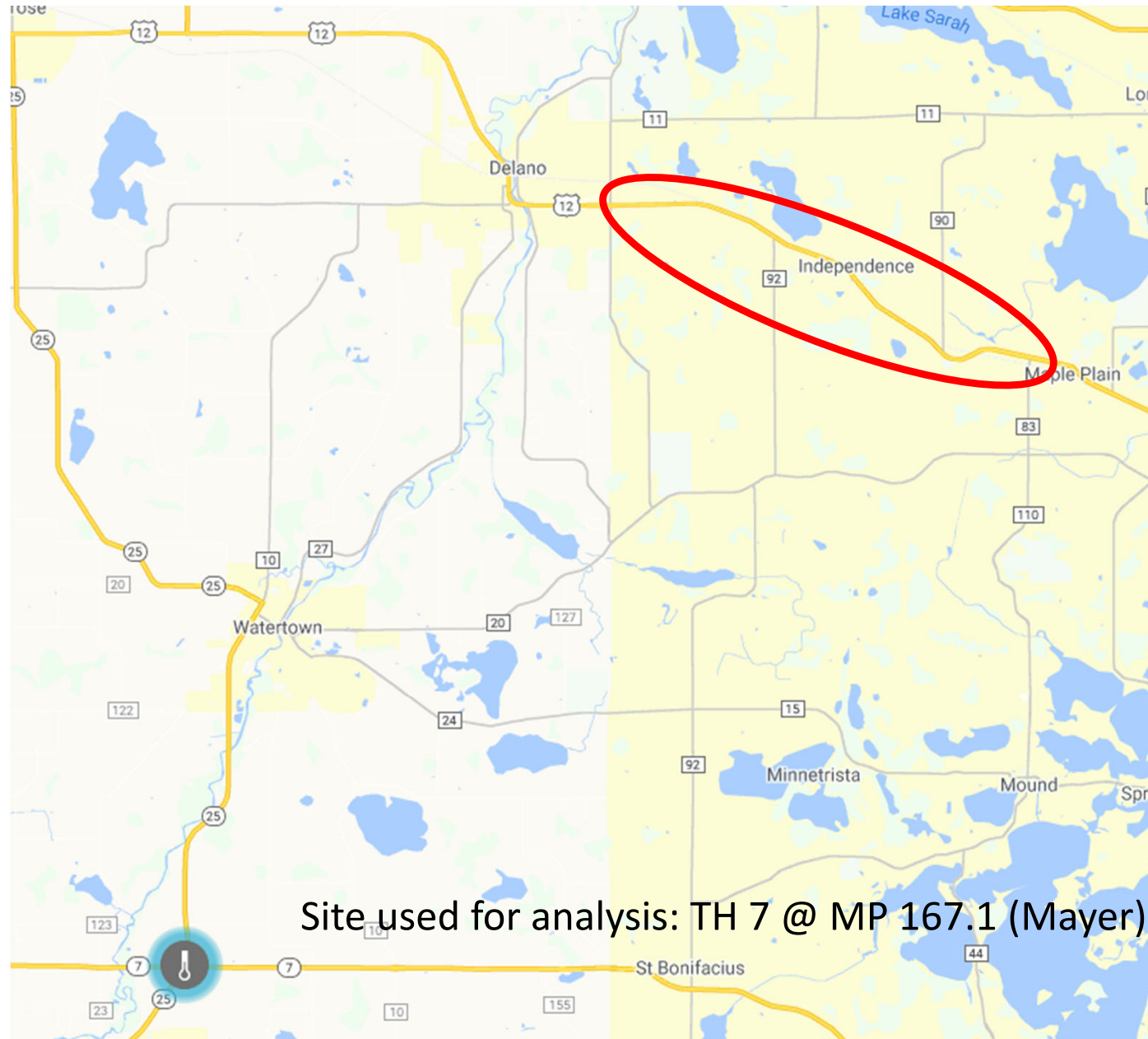
Tableau dashboard developed allowing researchers to scan all cameras for duration of storm

Would verify impact of weather event and flag events which would impact metrics (i.e crashes)





# Road Weather Information System (RWIS)



Site used for analysis: TH 7 @ MP 167.1 (Mayer) (330022)

# Winter Weather Events

## Winter Weather Events Evaluated

Event	Event Start	Event End	Duration (minutes)	Duration (hours)
1	12/13/2020 12:51	12/13/2020 17:12	270	4.5
2	12/23/2020 11:57	12/28/2020 9:03	7026	117.1
3	12/28/2020 18:23	12/29/2020 0:43	380	6.3
4	12/29/2020 14:48	12/30/2020 5:24	876	14.6
5	12/30/2020 21:58	12/31/2020 2:32	274	4.6
6	12/31/2020 22:24	12/31/2020 23:37	73	1.2
7	1/5/2021 0:54	1/5/2021 9:15	501	8.4
8	1/14/2021 21:13	1/15/2021 5:39	506	8.4
9	1/19/2021 9:02	1/19/2021 13:38	276	4.6
10	1/23/2021 15:07	1/24/2021 9:26	1099	18.3
11	2/4/2021 4:54	2/4/2021 10:22	328	5.5
12	2/8/2021 0:13	2/8/2021 8:28	495	8.25
13	2/9/2021 4:18	2/9/2021 8:54	276	4.6
14	2/11/2021 19:52	2/12/2021 11:25	933	15.6
15	2/17/2021 8:24	2/18/2021 8:14	1430	23.8
16	2/28/2021 6:03	2/28/2021 9:37	214	3.6

# Winter Weather from DMS

## Identifying Winter Weather Events

Timestamp	Description	Deviceid	Message	Owner	Duration (min)
1/19/2021 9:02	Sign DEPLOYED	V12E00		OTHER SYSTEM	13
1/19/2021 9:15	Sign CLEARED	V12E00	None	FIELD BLANK	2
1/19/2021 9:17	Sign DEPLOYED	V12E00		OTHER SYSTEM	261

**Confirmed by weather data and camera imagery**

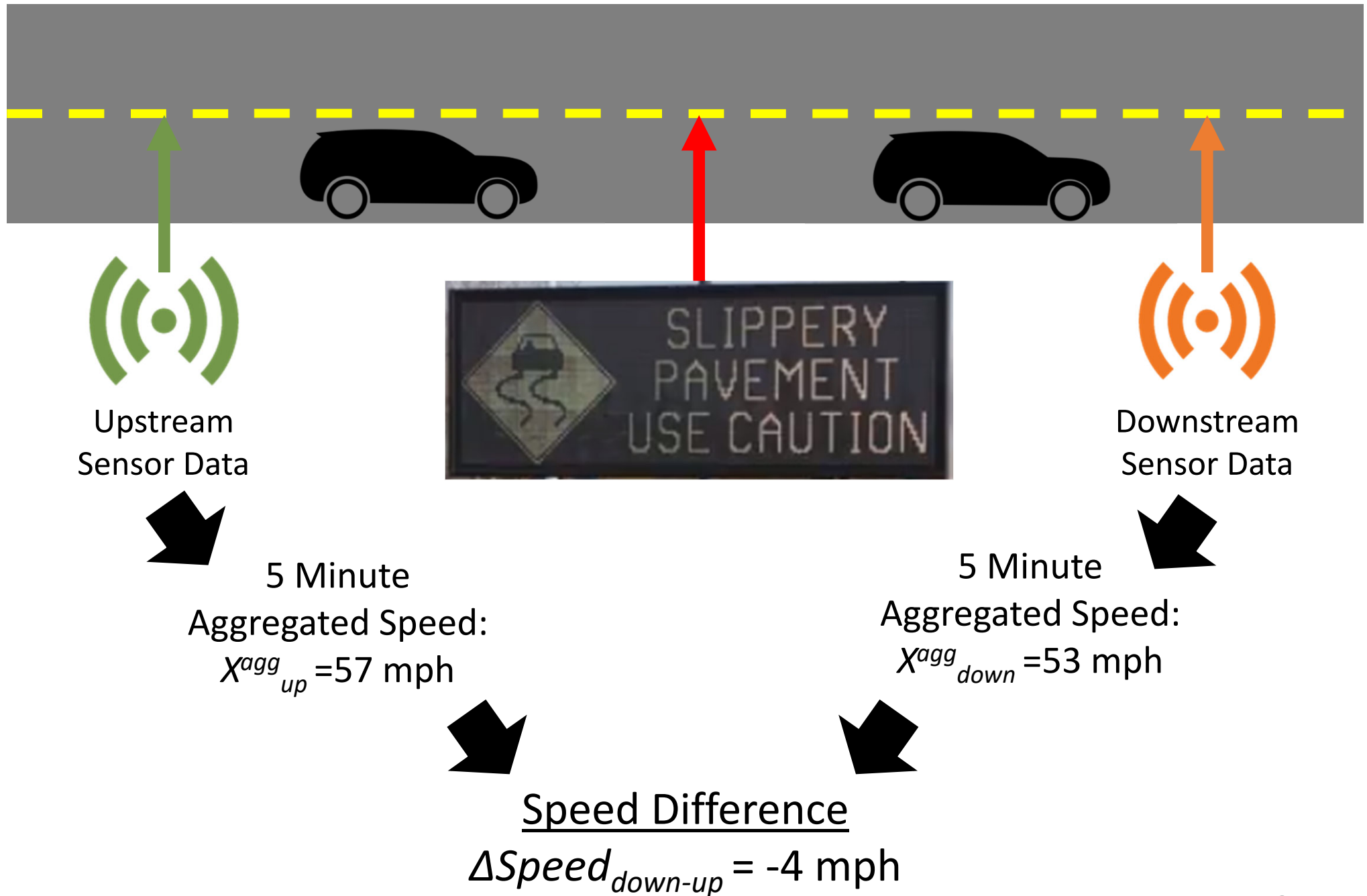


# Winter Weather Control Events

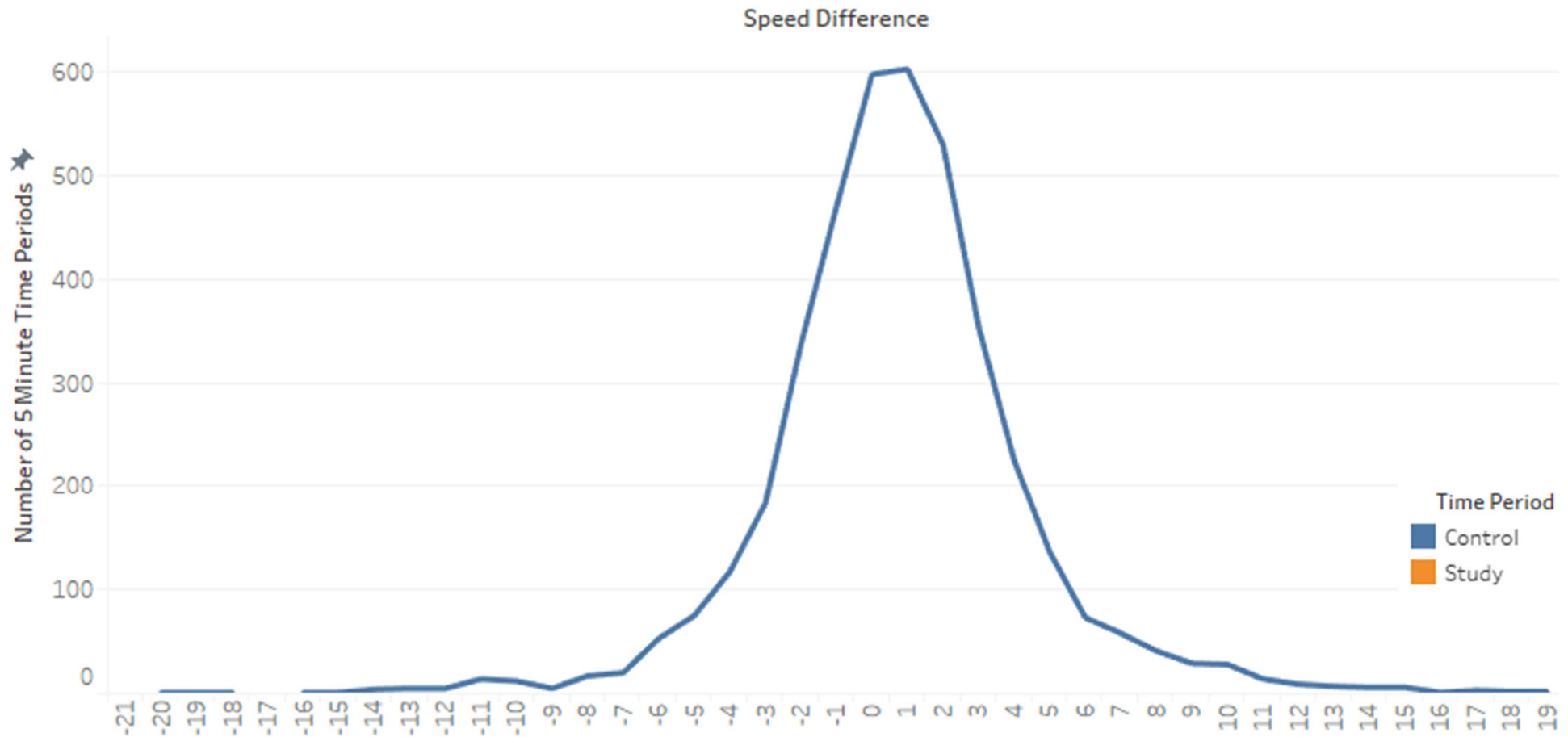
- The same time period as winter event one week before/after
- Removed control if impacted by weather (based on DMS or camera imagery)
- Select additional controls two weeks before/after as needed
- 13 of 14 events had at least two control periods

Event	Control Start	Control End	Duration (minutes)	Type
1	12/20/2020 12:51	12/20/2020 17:12	270	Control
2	12/9/2020 11:57	12/9/2020 23:57	720	Control
2	12/16/2020 11:57	12/21/2020 9:03	7026	Control
3	12/14/2020 18:23	12/15/2020 0:43	380	Control
3	12/21/2020 18:23	12/22/2020 0:43	380	Control
4	12/15/2020 14:48	12/16/2020 5:24	876	Control
4	12/22/2020 14:48	12/23/2020 5:24	876	Control
5	12/16/2020 21:58	12/17/2020 2:32	274	Control

# Analysis Approach

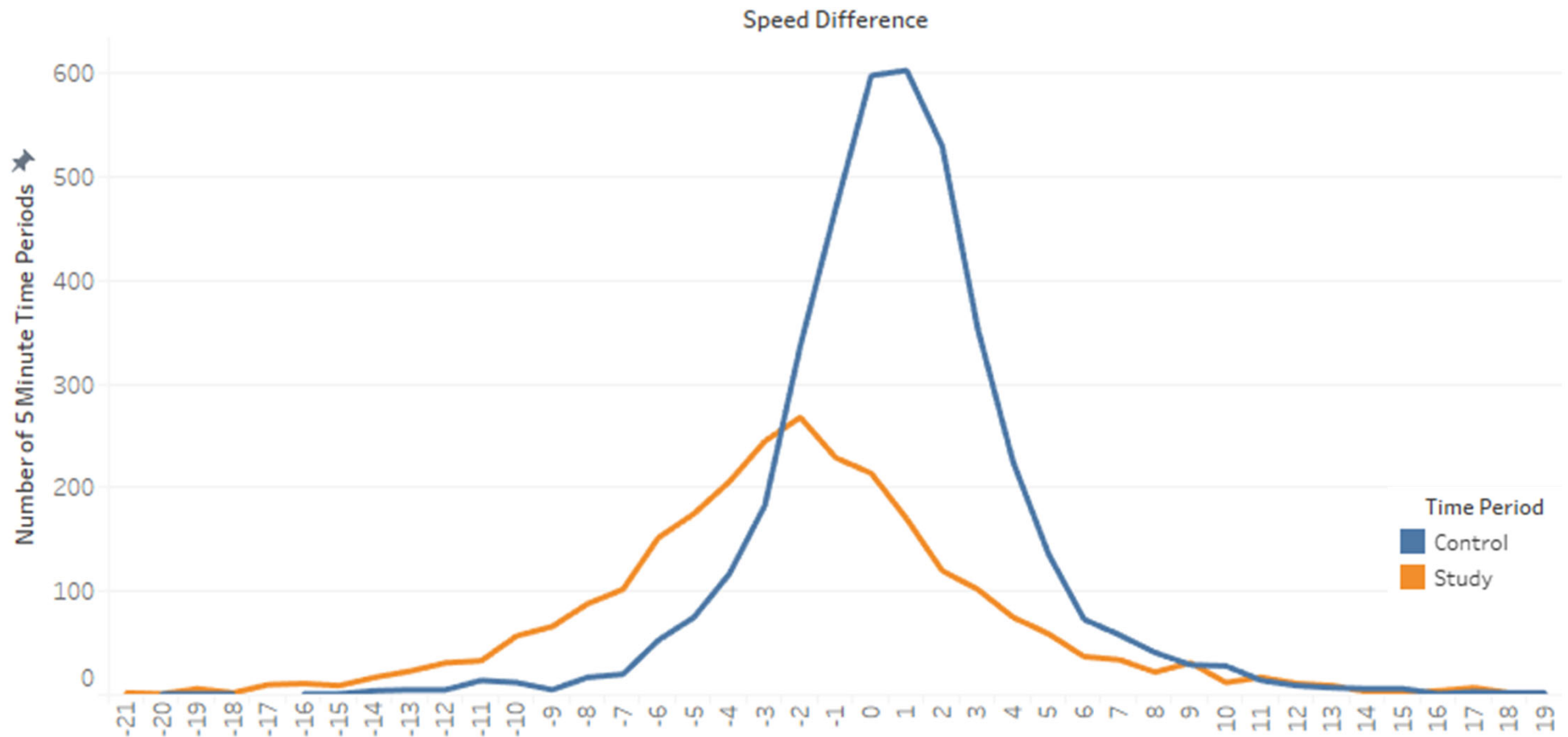


# Average Speed Distribution

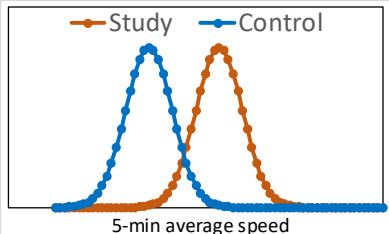
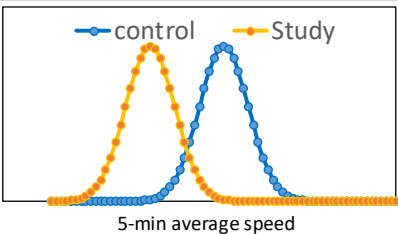
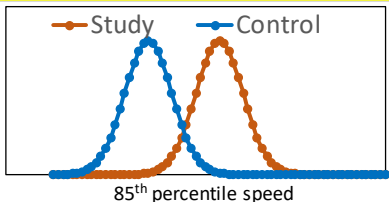
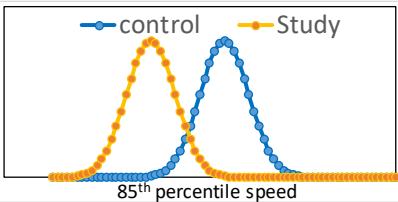
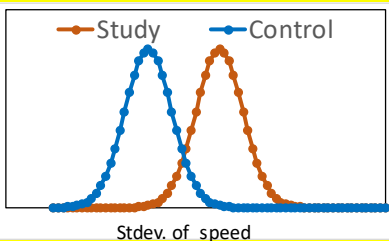
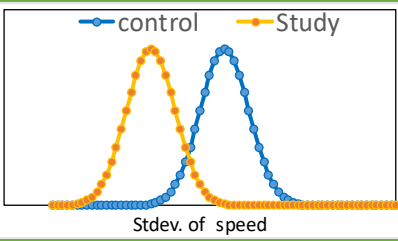
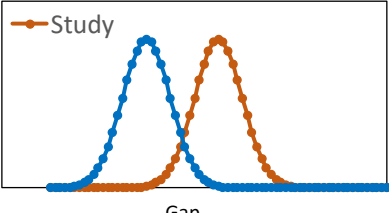
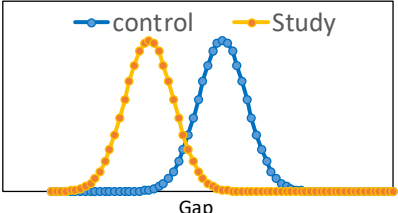




# Average Speed Distribution

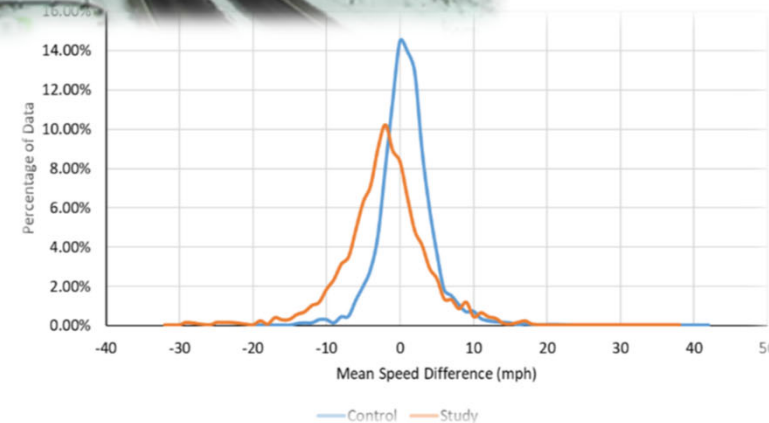
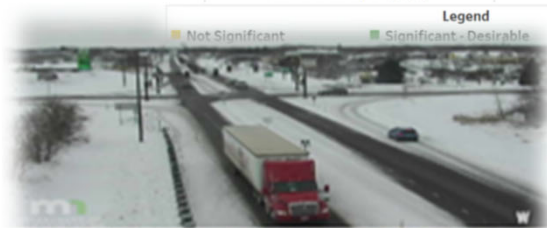


# Statistical Analysis Changes

$X^{agg}$	Change of Driving Behavior from Upstream to Downstream		Significance tests and charts	
	V1 and V2		V3	
	$\geq 0$	$< 0$	$\geq 0$	$< 0$
Speed	Speed increased or unchanged from upstream to downstream	Speed Reduced from upstream to downstream	Undesirable change in speed regime 	Desirable change in speed regime 
85th Percentile Speed	Speed increased or unchanged from upstream to downstream	Speed Reduced from upstream to downstream	Undesirable change in speed regime 	Desirable change in speed regime 
Standard Deviation	Speed variation (Stdev) increased or unchanged from upstream to downstream	Speed variation (Stdev) Reduced from upstream to downstream	Undesirable change in Speed variation (Stdev) 	Desirable change in Speed variation (Stdev) 
Gap	Gap increased or unchanged from upstream to downstream	Gap reduced from upstream to downstream	Desirable change in Gap acceptance 	Undesirable change in Gap acceptance 

# Data Analysis

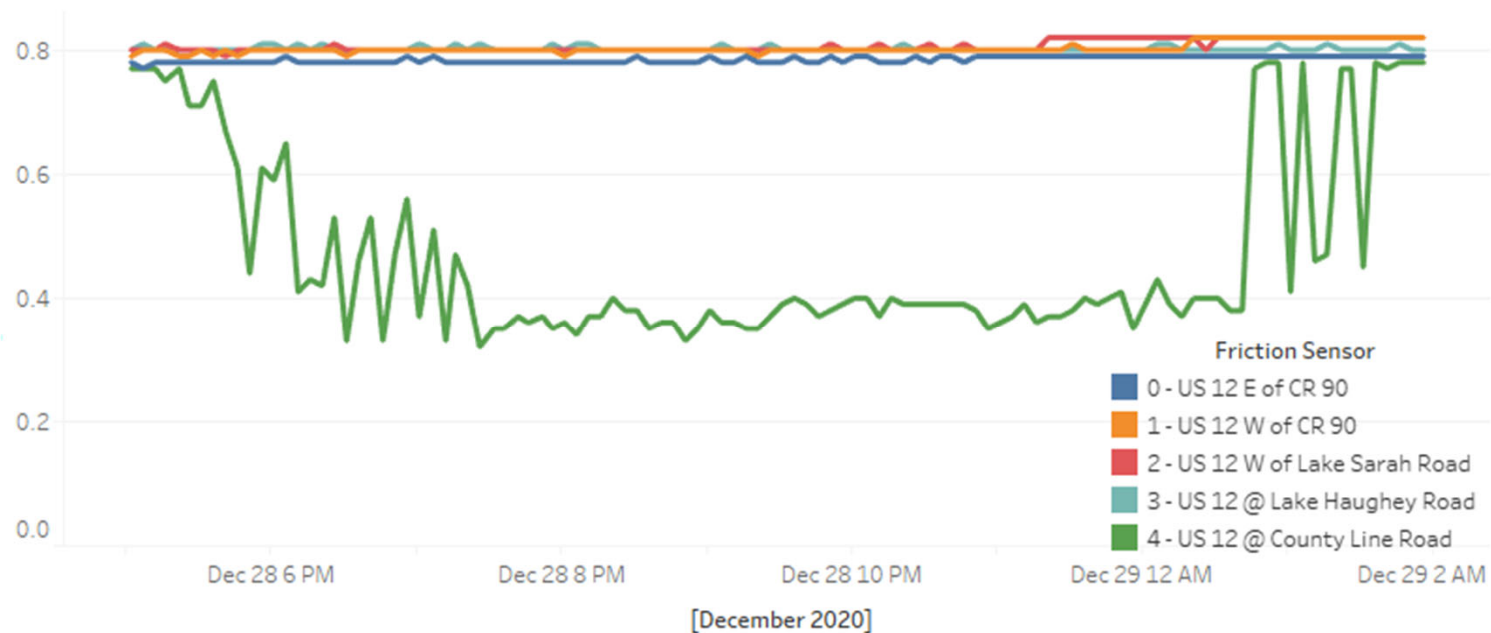
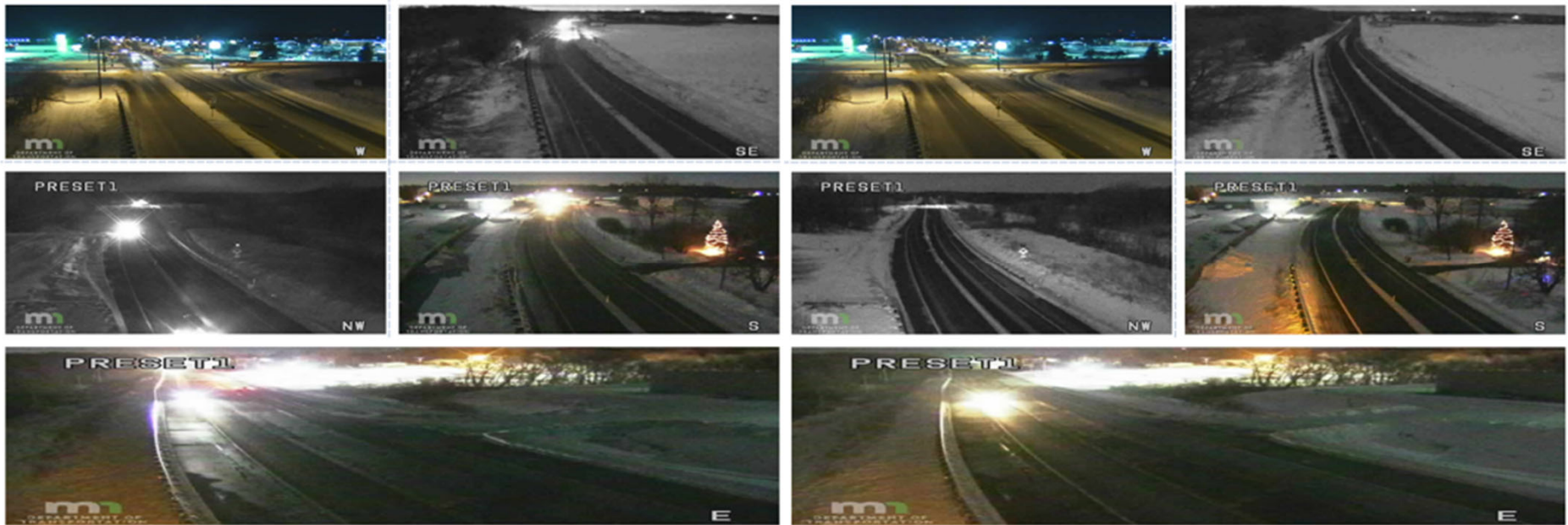
- Individual Winter Weather Events (based on duration and amount of snow accumulation)
  - Minimal Winter Impact (Event 3)
  - Typical Winter Impact (Event 9)
  - Significant Winter Impact (Event 11)
- Summary of All Individual Winter Weather Events
- Analysis of All Winter Weather Events Combined
- Discussion of Results





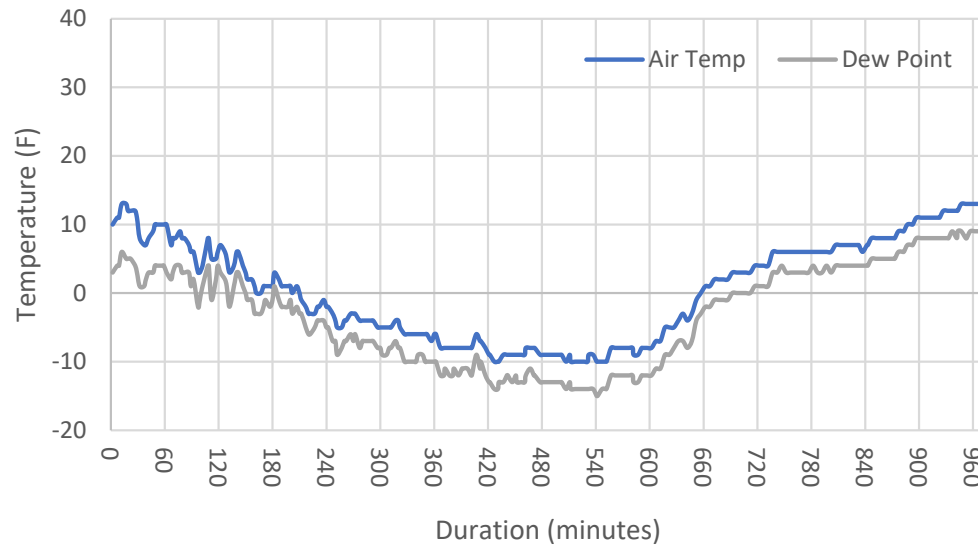
# Event 3 (minor event)

380 Minute Duration

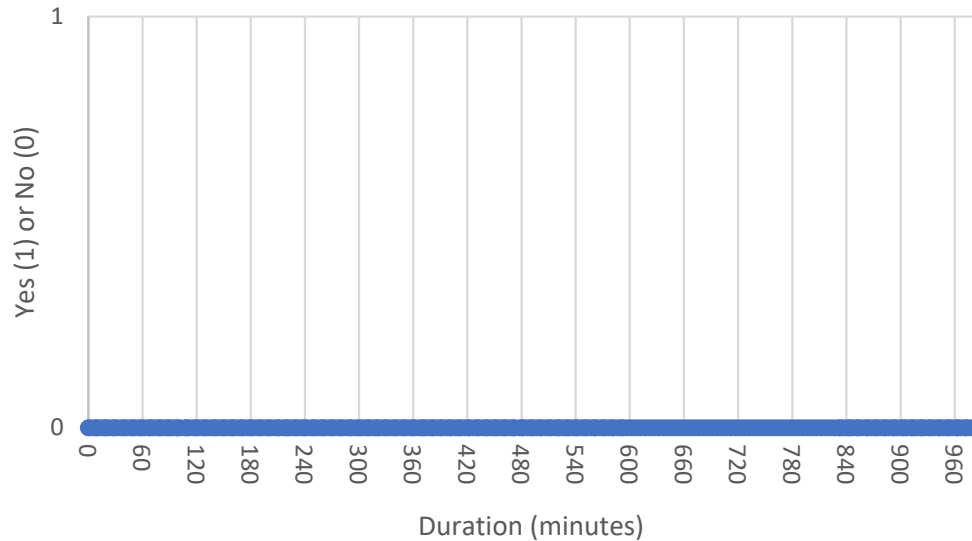


# Event 3 (minor event)

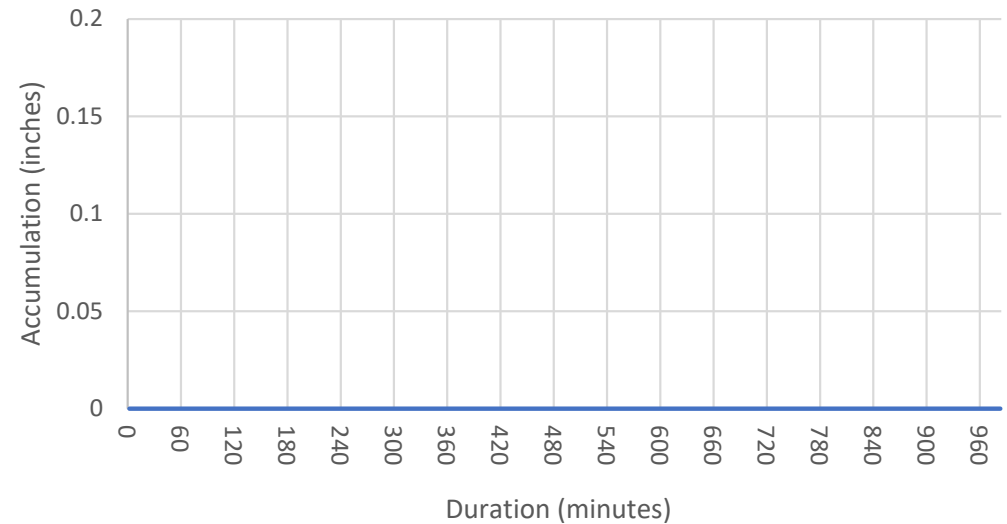
Atmospheric Conditions



Precipitation Presence



One Hour Precipitation Accumulation



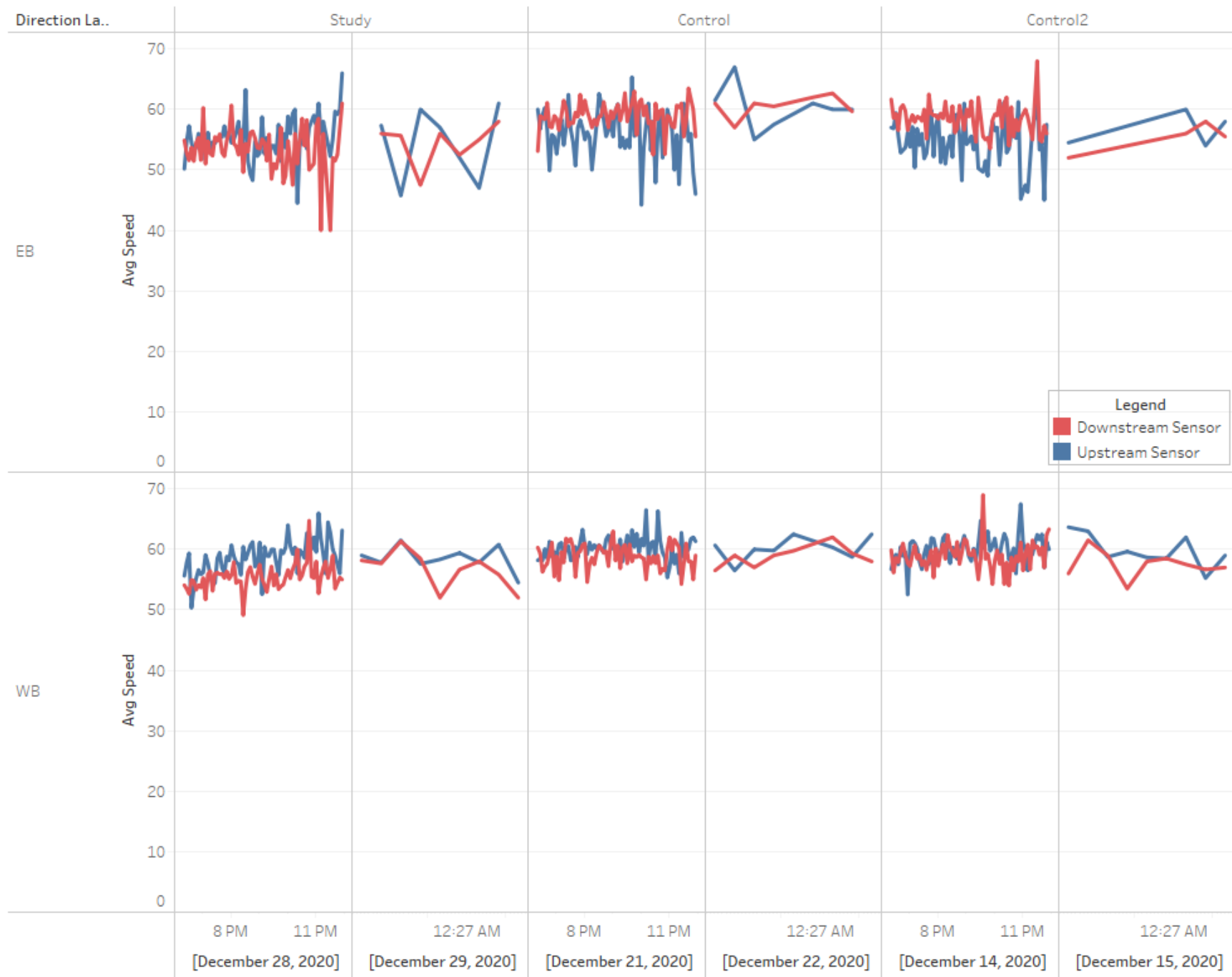
# Event 3 (minor event)

	Eastbound		Westbound	
	Study	Control	Study	Control
Downstream Total Volume	449	523/368*	868	1017/829*
Mean Speed Difference (mph)	-1.57	3.44	-3.08	-1.35
Speed Difference Standard Deviation (mph)	5.39	4.64	3.22	3.19
Mean Speed Difference Shift (mph)	-5.01		-1.73	
Mean Speed Difference Significance	Significant		Significant	
Mean 85th Percentile Difference (mph)	-2.99	0.95	-2.85	-1.78
Mean 85th Percentile Difference Shift (mph)	-3.94		-1.07	
Mean 85th Percentile Difference Significance	Significant		Significant	
Mean Standard Deviation Difference (mph)	-2.56	-2.77	0.24	-0.08
Mean Standard Deviation Difference Shift (mph)	0.21		0.32	
Mean Standard Deviation Difference Significance)	Not significant		Not significant	
Mean Gap Difference (seconds)	-0.01	-0.57	0.26	0.03
Mean Gap Difference Shift (seconds)	0.56		0.23	
Mean Gap Difference Significance	Not significant		Not significant	

\*Total Volume for both control time periods

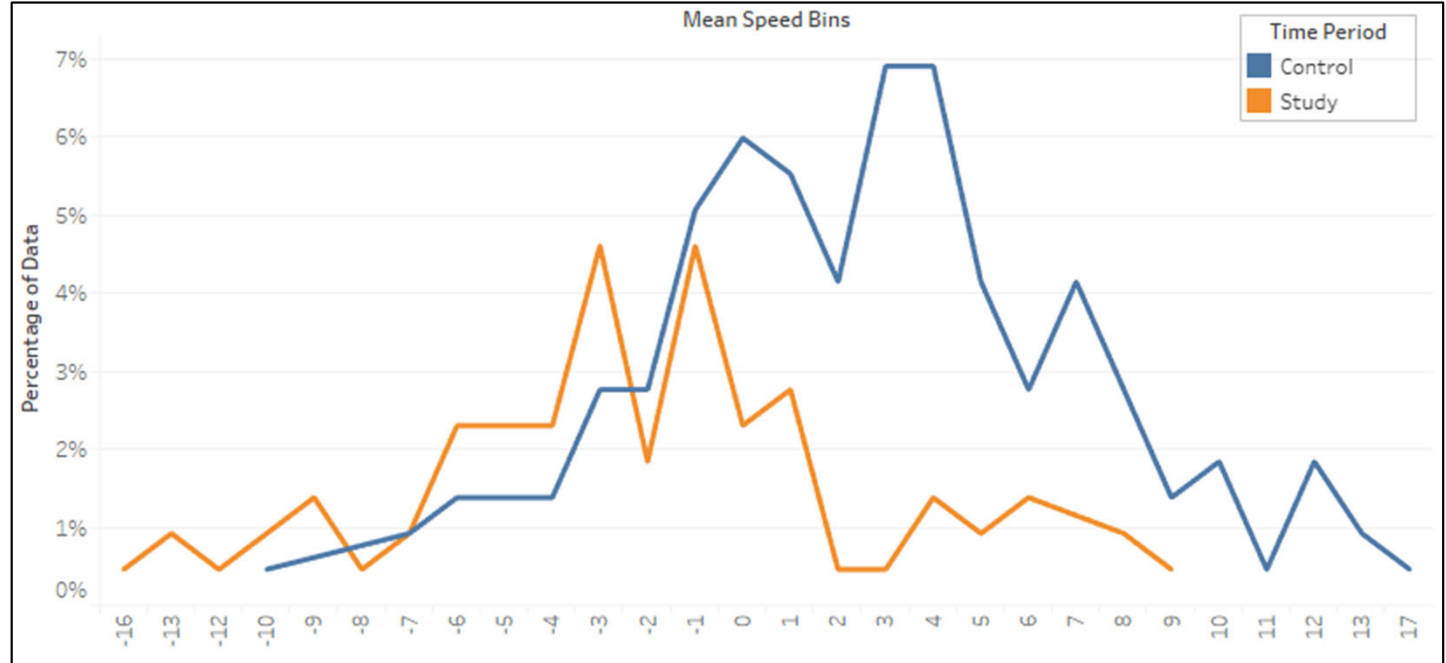


# Event 3 (minor event)

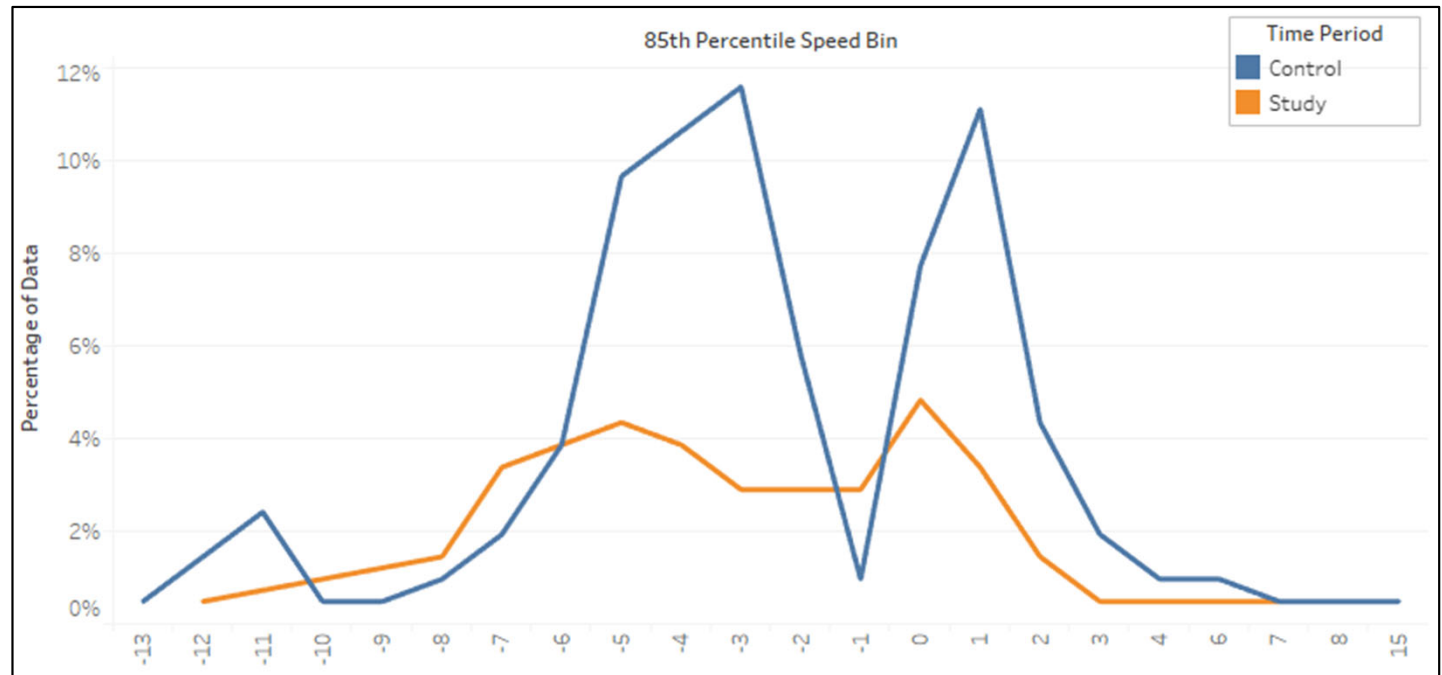


# Event 3 (minor event)

## Eastbound Average Speed

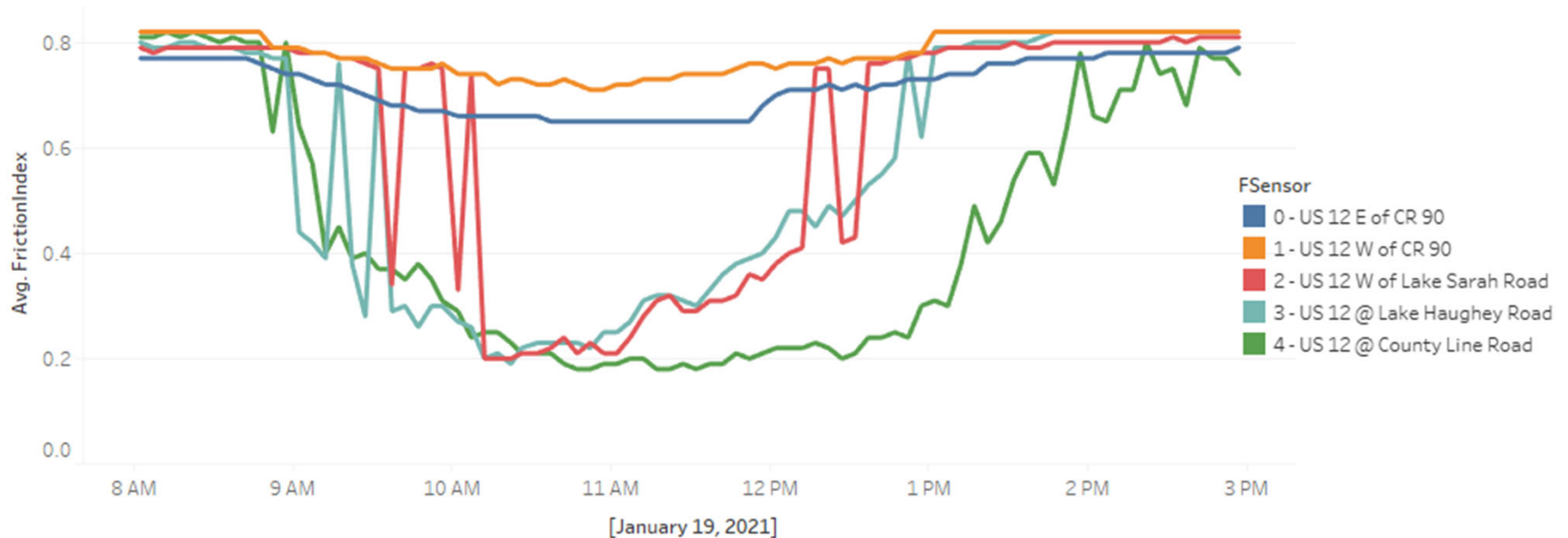
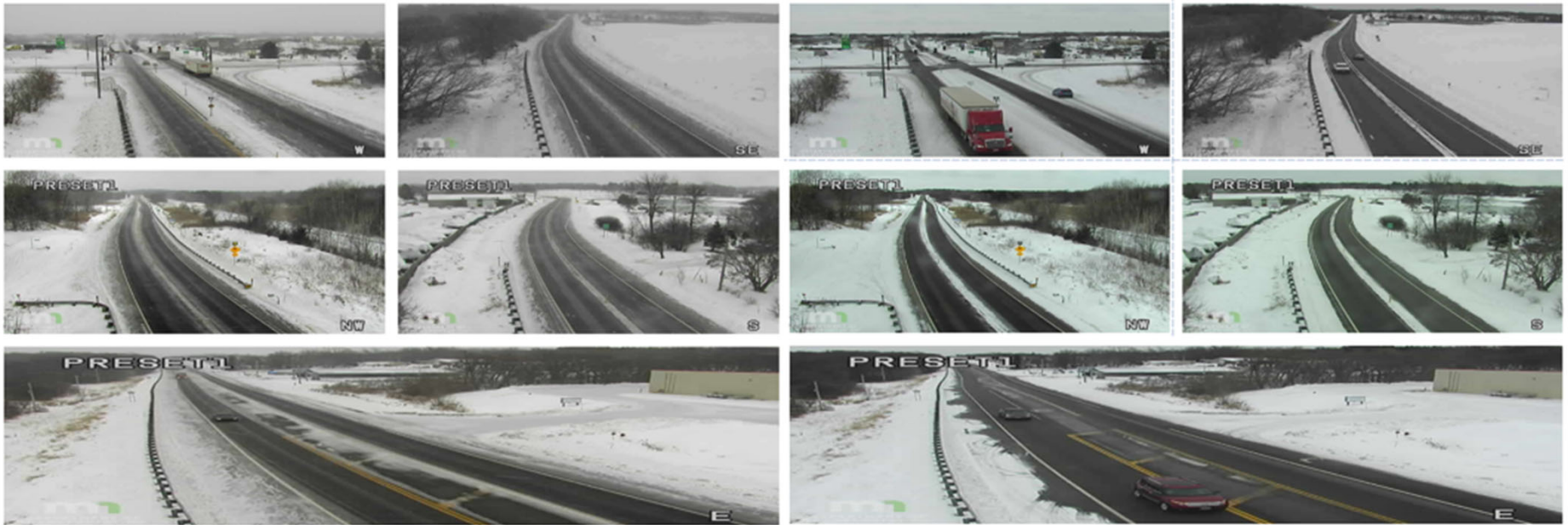


## Westbound 85<sup>th</sup> Percentile Speed



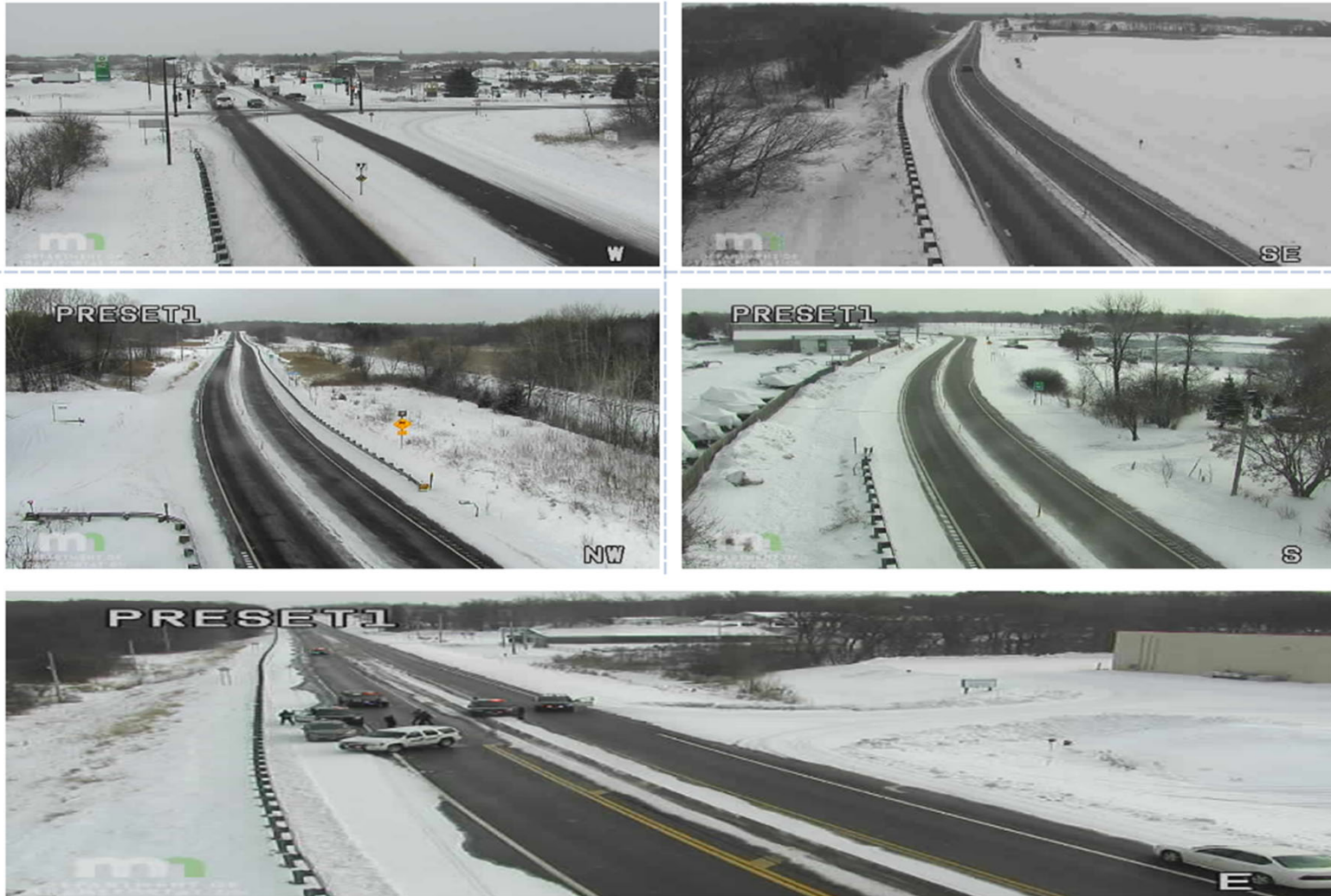
# Event 9 (typical event)

276 Minute Duration





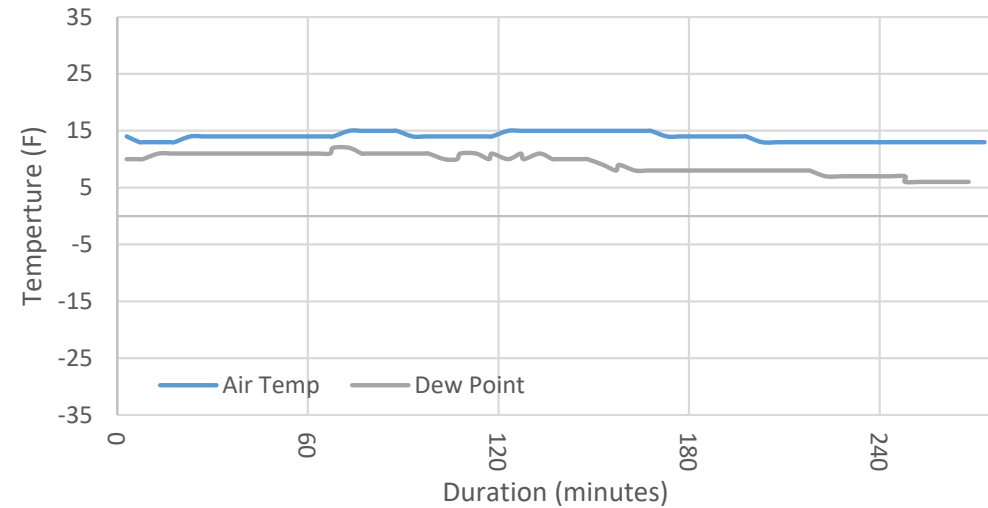
# Event 9 (typical event)



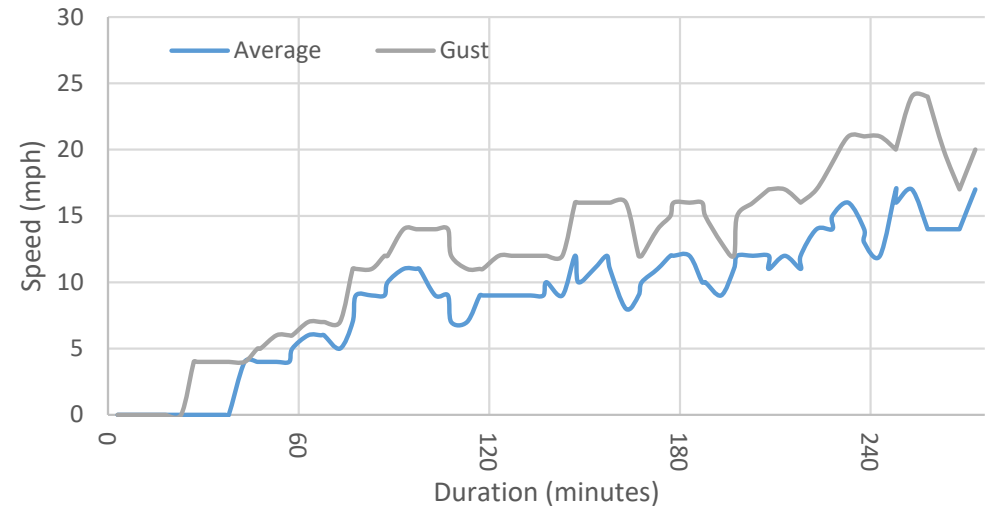
Present for ~30 minutes

# Event 9 (typical event)

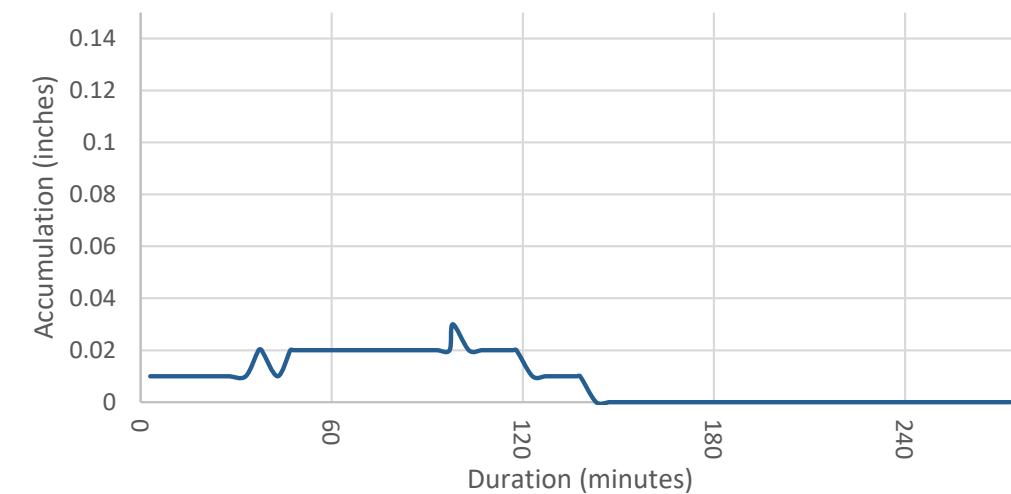
## Atmospheric Conditions



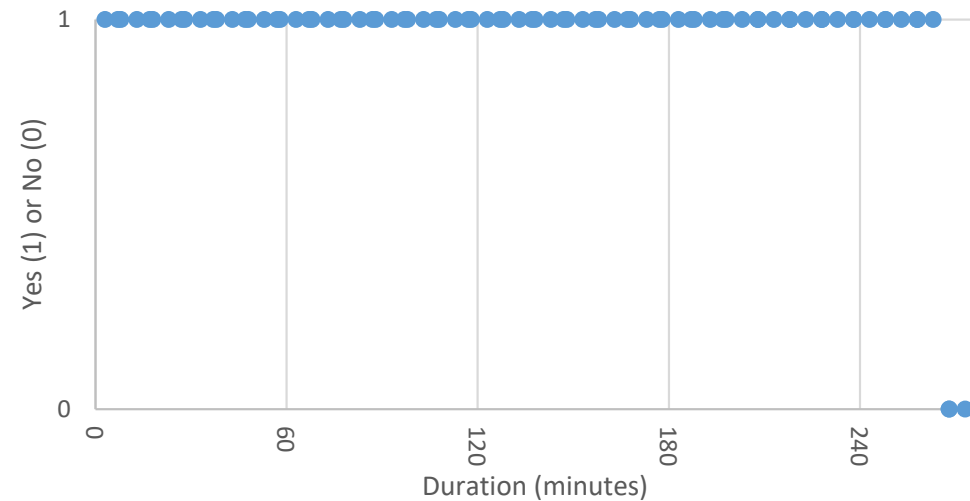
## Wind Speed



## One Hour Precipitation Accumulation



## Precipitation Presence



# Event 9 (typical event)

	Eastbound		Westbound	
	Study	Control	Study	Control
Downstream Total Volume	180	271/258*	174	302/289*
Mean Speed Difference (mph)	-2.38	0.30	-0.69	-2.62
Speed Difference Standard Deviation (mph)	3.51	1.98	3.26	2.06
Mean Speed Difference Shift (mph)	-2.68		1.94	
Mean Speed Difference Significance	Significant		Significant	
Mean 85th Percentile Difference (mph)	-2.62	0.06	-1.24	-3.48
Mean 85th Percentile Difference Shift (mph)	-2.68		2.24	
Mean 85th Percentile Difference Significance	Significant		Significant	
Mean Standard Deviation Difference (mph)	-1.10	-0.77	-0.65	-0.21
Mean Standard Deviation Difference Shift (mph)	-0.33		-0.44	
Mean Standard Deviation Difference Significance	Not significant		Not significant	
Mean Gap Difference (seconds)	-0.10	-0.21	0.23	0.35
Mean Gap Difference Shift (seconds)	0.11		-0.12	
Mean Gap Difference Significance	Not significant		Not significant	

\*Total Volume for both control time periods

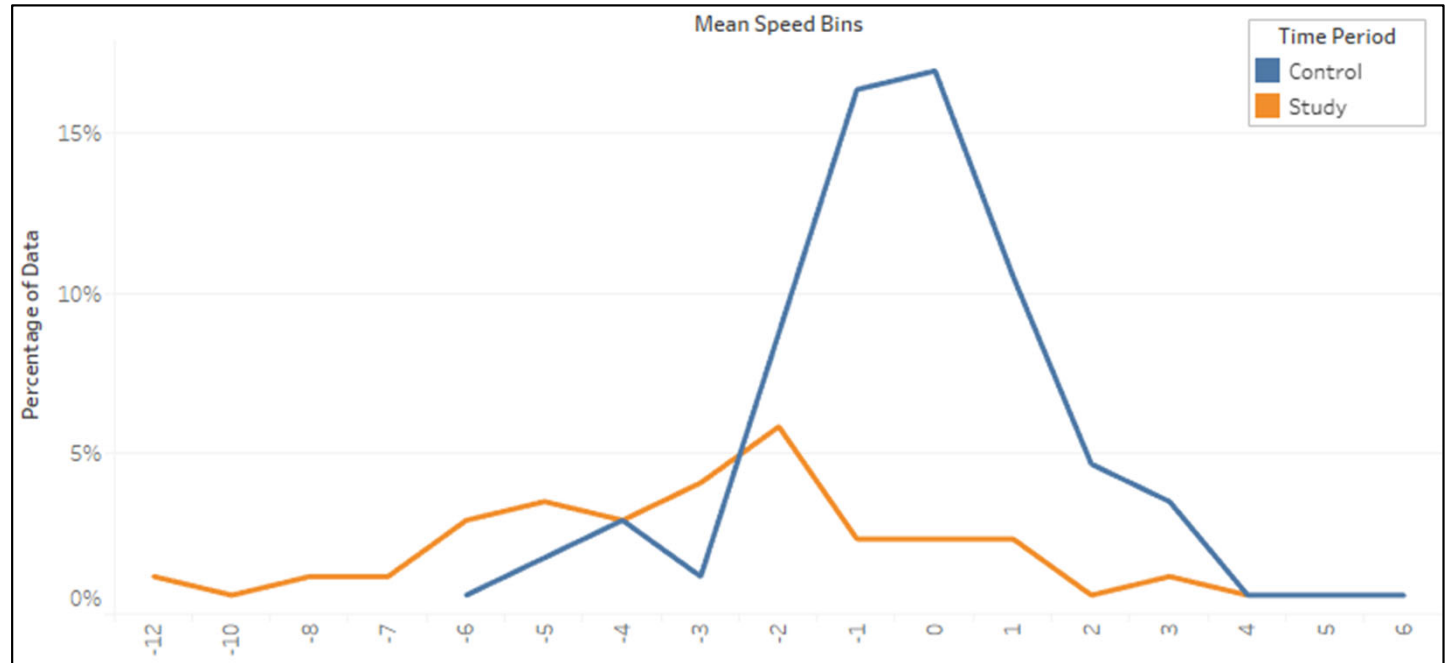
# Event 9 (typical event)



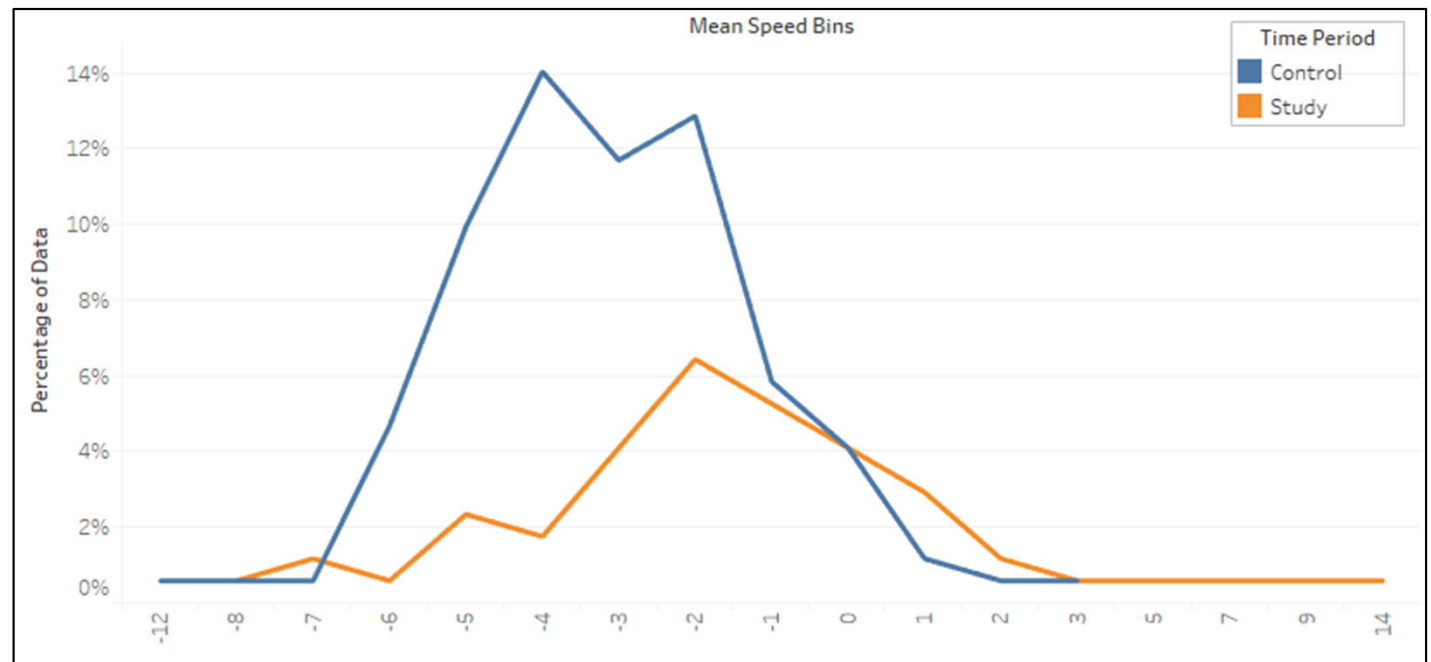


# Event 9 (typical event)

## Eastbound Average Speed

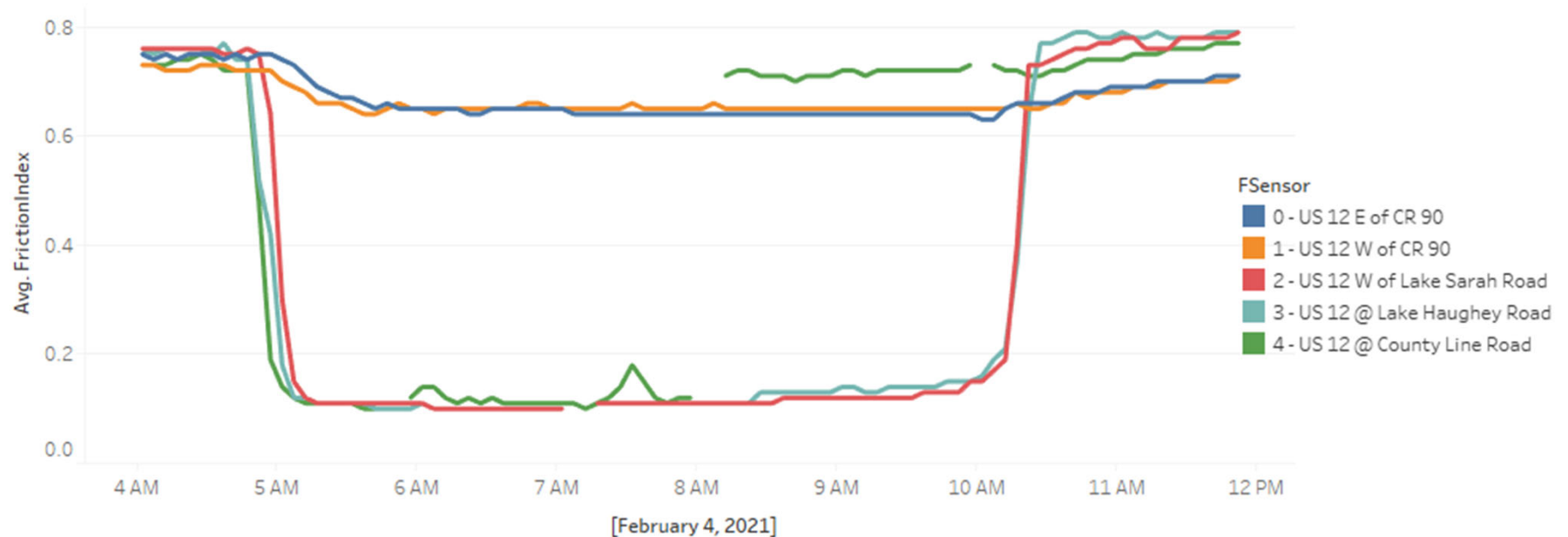


## Westbound Average Speed



# Event 11 (major event)

328 Minute Duration



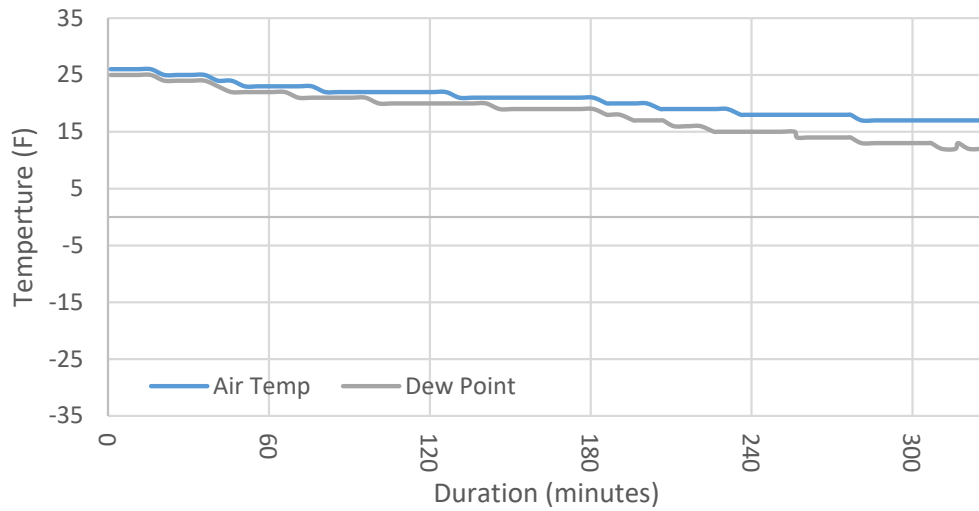
# Event 11 (major event)

	Eastbound		Westbound	
	Study	Control	Study	Control
Downstream Total Volume	320	743/692*	77	162/187*
Mean Speed Difference (mph)	0.76	0.95	1.33	-2.01
Speed Difference Standard Deviation (mph)	4.12	2.02	5.75	2.74
Mean Speed Difference Shift (mph)	-0.19		3.35	
Mean Speed Difference Significance	Not significant		Significant	
Mean 85th Percentile Difference (mph)	0.93	0.39	0.87	-2.56
Mean 85th Percentile Difference Shift (mph)	0.55		3.43	
Mean 85th Percentile Difference Significance	Not significant		Significant	
Mean Standard Deviation Difference (mph)	-0.02	-0.87	0.38	-0.44
Mean Standard Deviation Difference Shift (mph)	0.85		0.82	
Mean Standard Deviation Difference Significance)	Significant		Significant	
Mean Gap Difference (seconds)	0.28	-0.23	-0.05	0.38
Mean Gap Difference Shift (seconds)	0.51		-0.43	
Mean Gap Difference Significance	Significant		Significant	

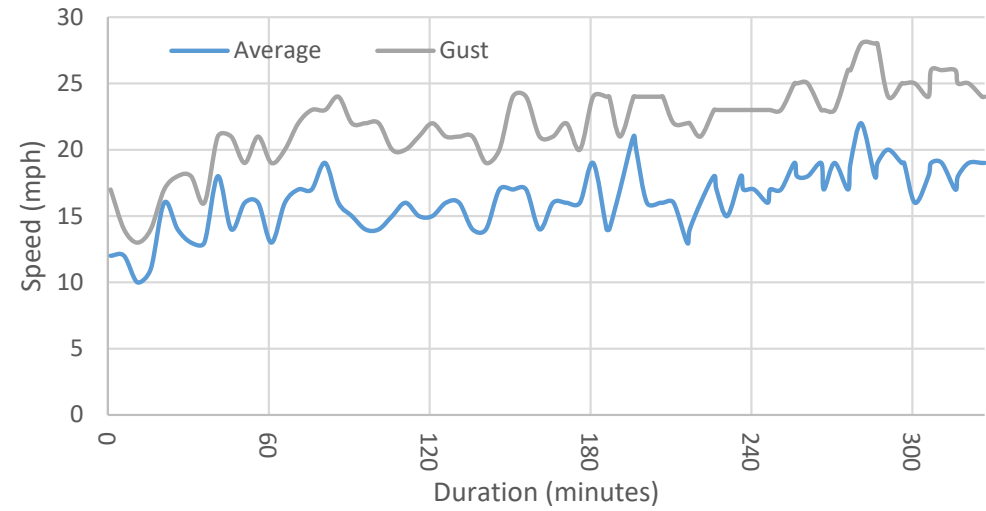
\*Total Volume for both control time periods

# Event 11 (major event)

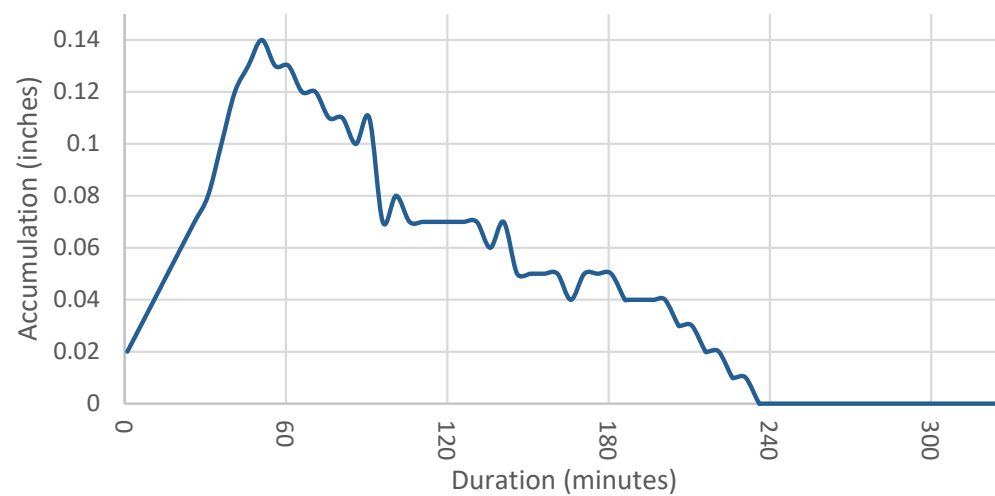
Atmospheric Conditions



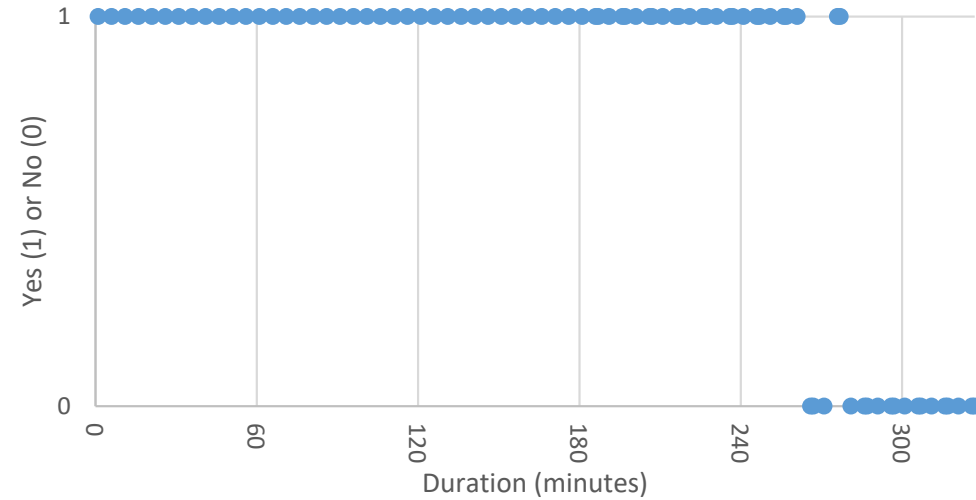
Wind Speed



One Hour Precipitation Accumulation

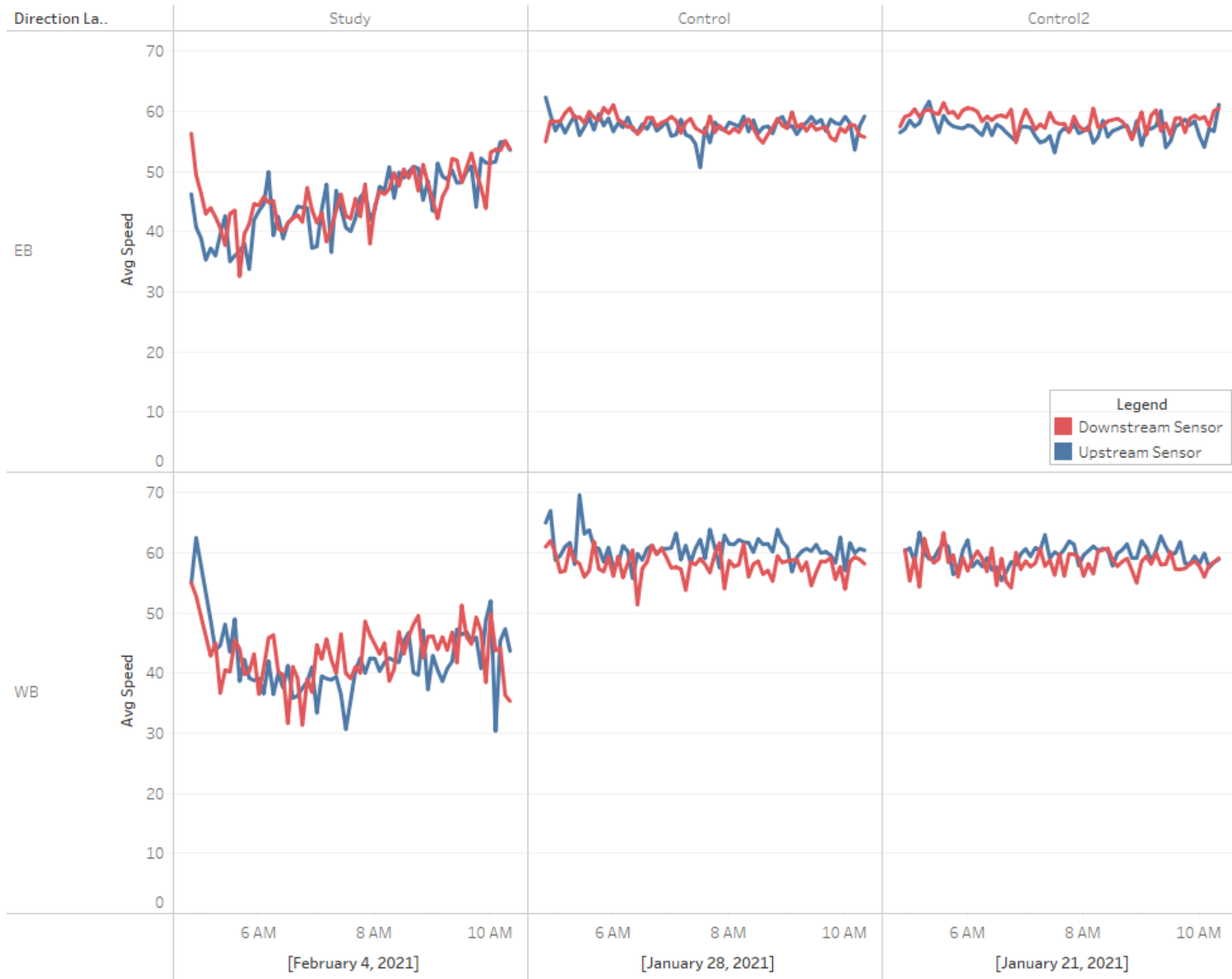


Precipitation Presence





# Event 11 (major event)



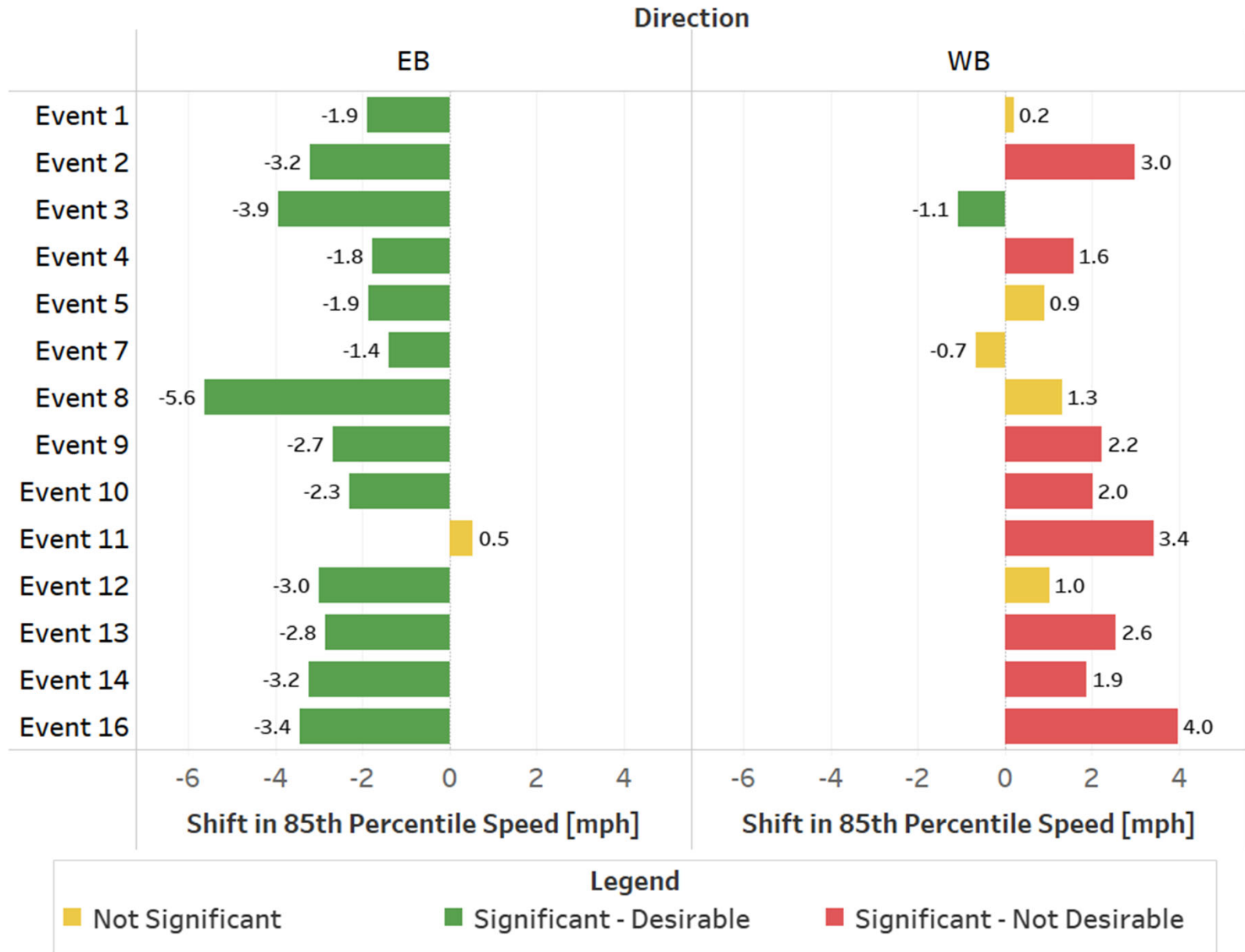
# Summary of Individual Events

## Mean Speed



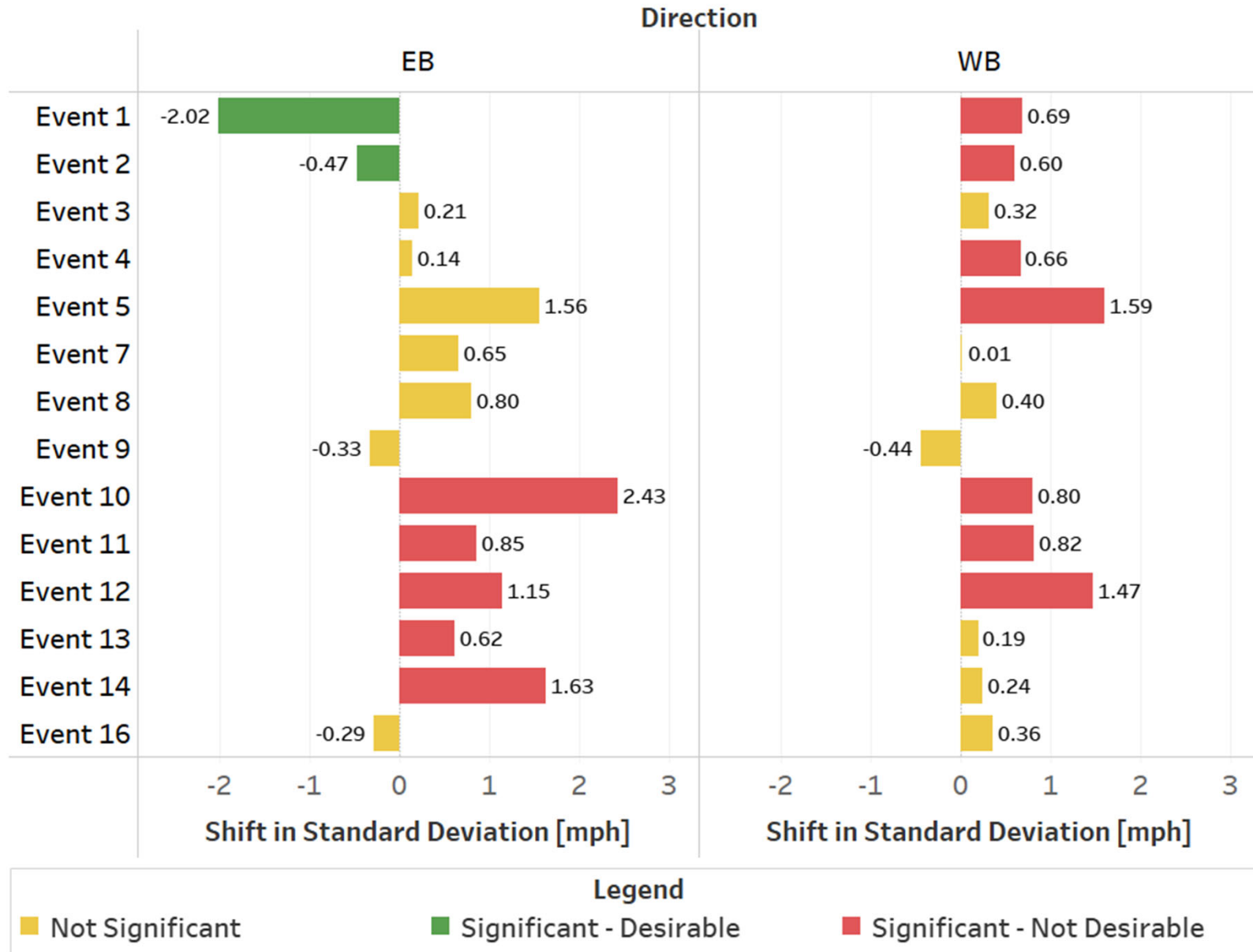
# Summary of Individual Events

## 85<sup>th</sup> Percentile Speed



# Summary of Individual Events

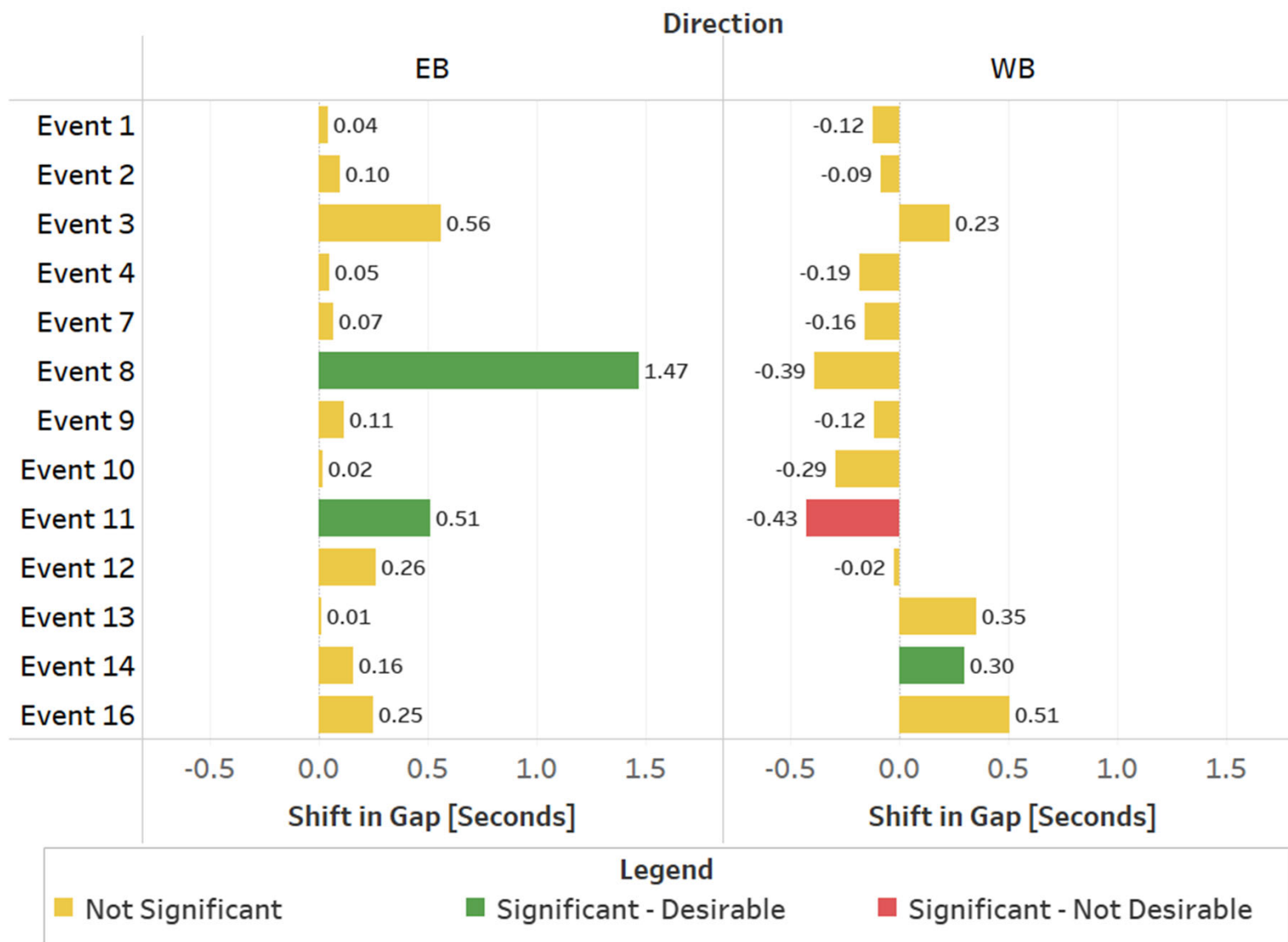
## Standard Deviation





# Summary of Individual Events

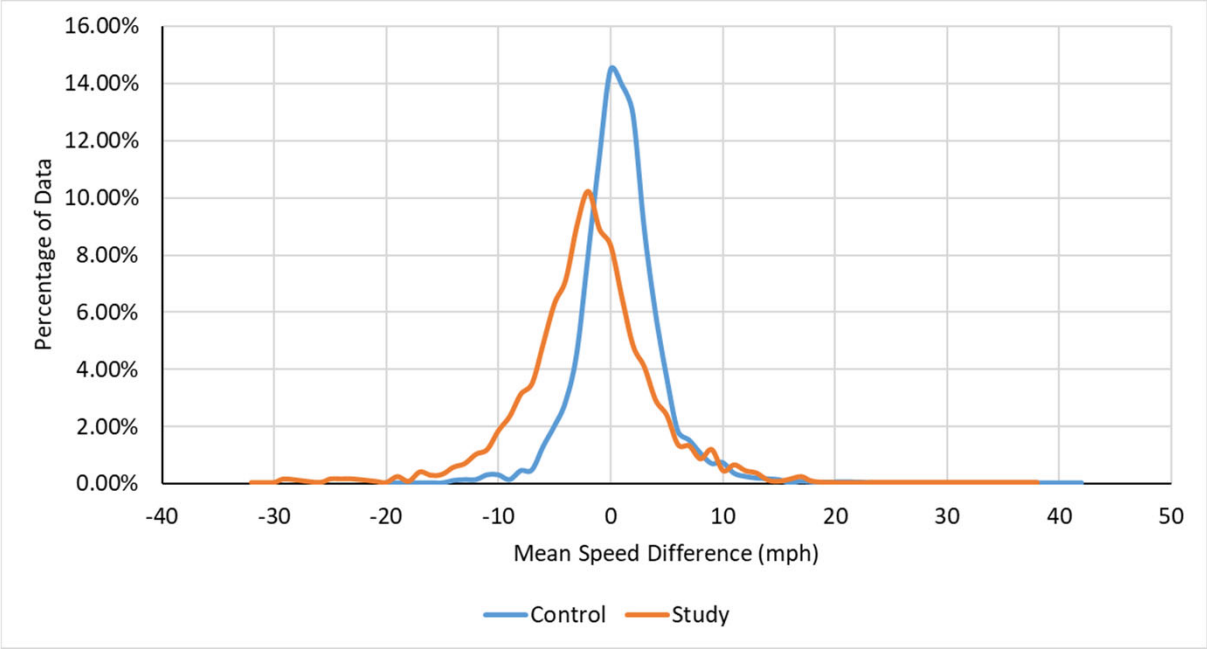
## Vehicle Gap



# Summary of All Events Combined

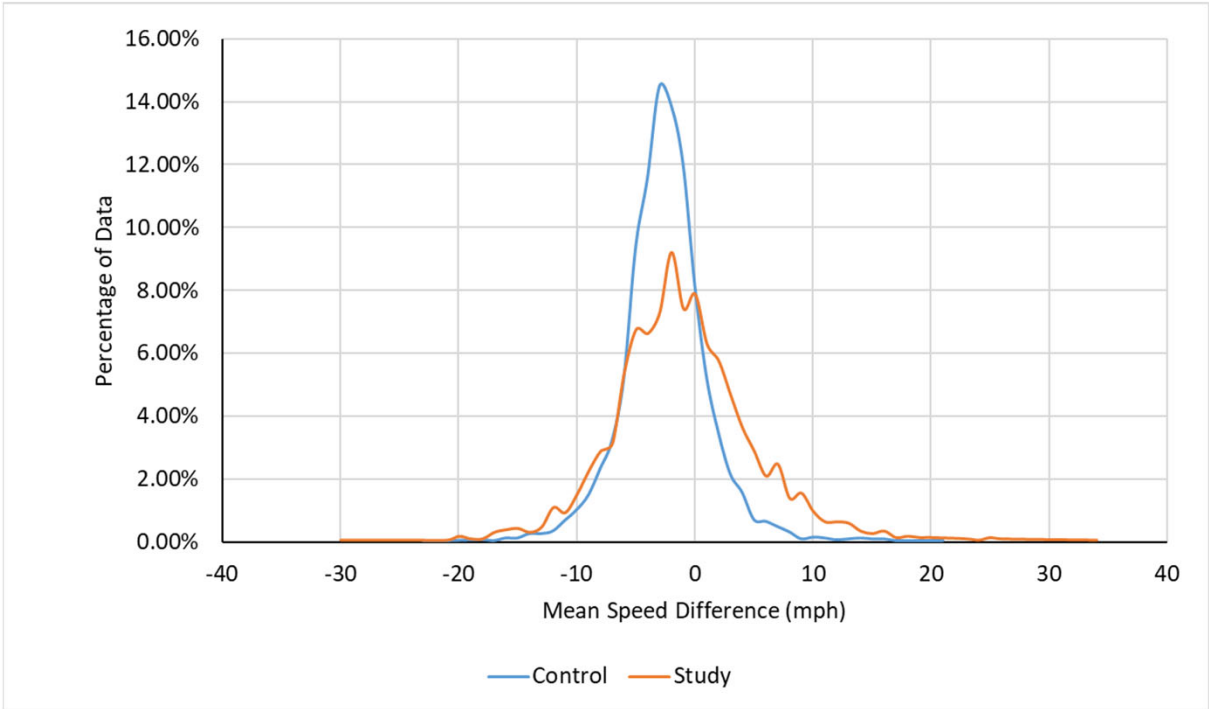
	Eastbound		Westbound	
	Study	Control	Study	Control
Mean Speed Difference (mph)	-1.50	1.28	-0.57	-2.02
Speed Difference Standard Deviation (mph)	5.97	3.79	6.04	3.65
Mean Speed Difference Shift (mph)	-2.78		1.45	
Mean Speed Difference Significance	Significant		Significant	
Mean 85th Percentile Difference (mph)	-2.01	0.62	-0.52	2.71
Mean 85th Percentile Difference Shift (mph)	-2.63		2.19	
Mean 85th Percentile Difference Significance	Significant		Significant	
Mean Standard Deviation Difference (mph)	-1.02	-1.15	0.17	-0.43
Mean Standard Deviation Difference Shift (mph)	0.13		0.60	
Mean Standard Deviation Difference Significance)	Not significant		Significant	
Mean Gap Difference (seconds)	-0.12	-0.26	0.14	0.20
Mean Gap Difference Shift (seconds)	0.14		-0.07	
Mean Gap Difference Significance	Significant		Not significant	

# Summary of All Events Combined



Eastbound  
Mean Speed

Westbound  
Mean Speed



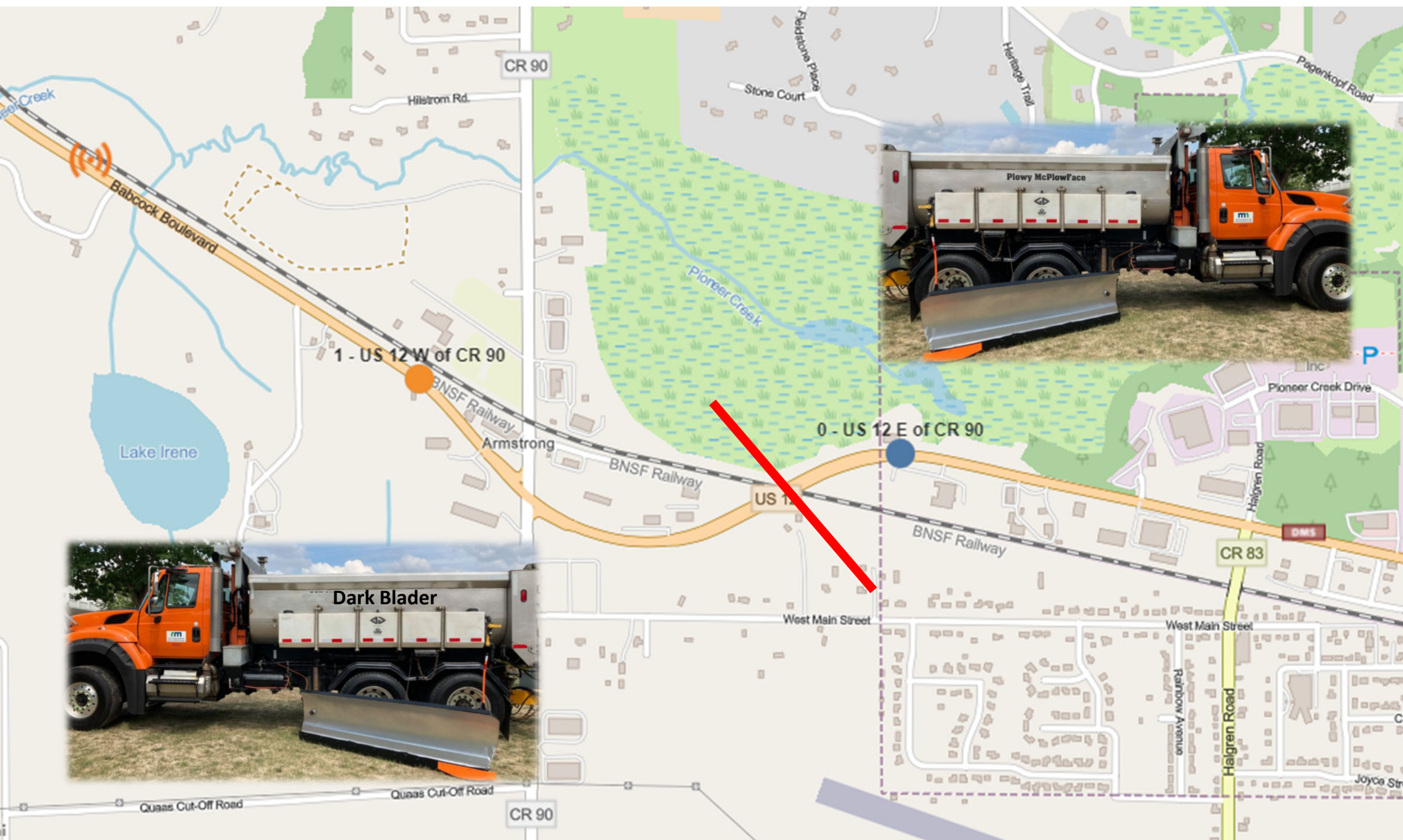
# Results Discussion

- Eastbound Direction show potential positive influence
  - Results aligned with expectations on impacting driver behavior
  - Represented best study layout (DMS and Sensor)
- Westbound Direction less uniform and negative influence
  - Possible explanation for irregular results
    - Placement of DMS
    - External influences (intersection, maintenance districts)





# Maintenance Boundaries



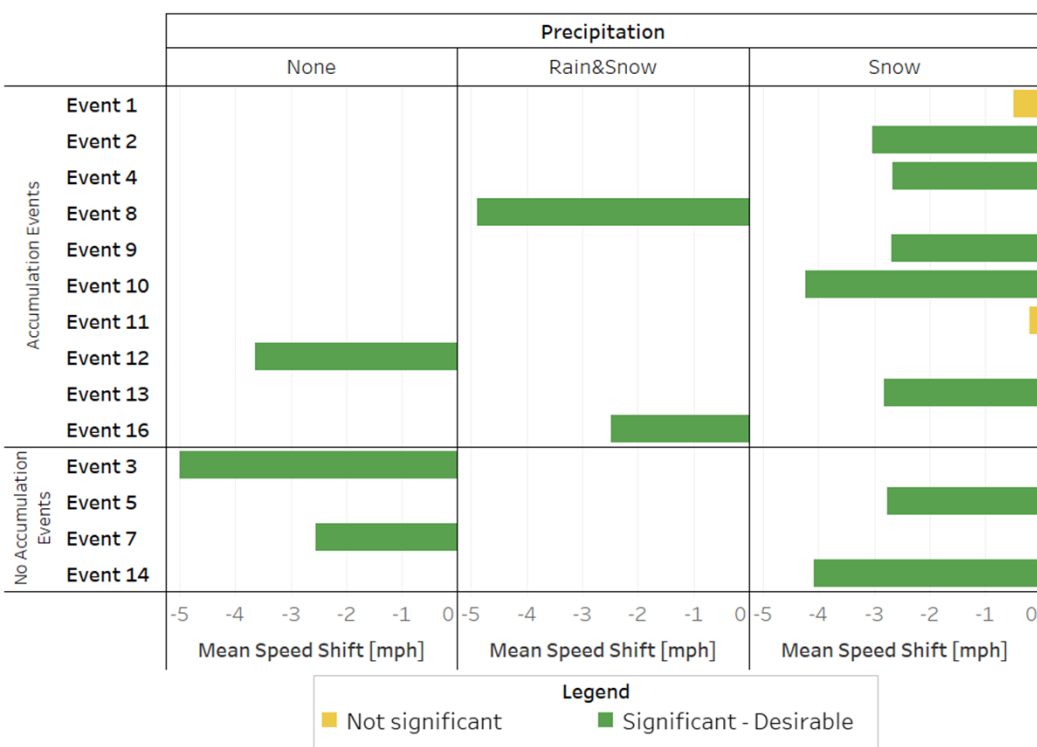
# Traffic Volumes

Event	Eastbound			Westbound		
	Upstream	Downstream	Volume Change	Upstream	Downstream	Volume Change
1	1,370	1,283	-87	1,693	1,383	-310
2	18,638	18,745	107	22,758	20,246	-2512
3	514	449	-65	1,075	868	-207
4	1,598	1,401	-197	3,190	2,871	-319
5	110	138	28	262	221	-41
7	2,502	2,751	249	1,164	892	-272
8	713	327	-386	302	342	40
9	1,147	1,197	50	1,384	1,103	-281
10	1,665	1,739	74	2,500	2,045	-455
11	2,336	2,586	250	1,233	947	-286
12	2,235	2,336	101	780	651	-129
13	2,346	2,478	132	890	685	-205
14	3,337	3,445	108	2,486	1,956	-530
16	333	339	6	412	363	-49

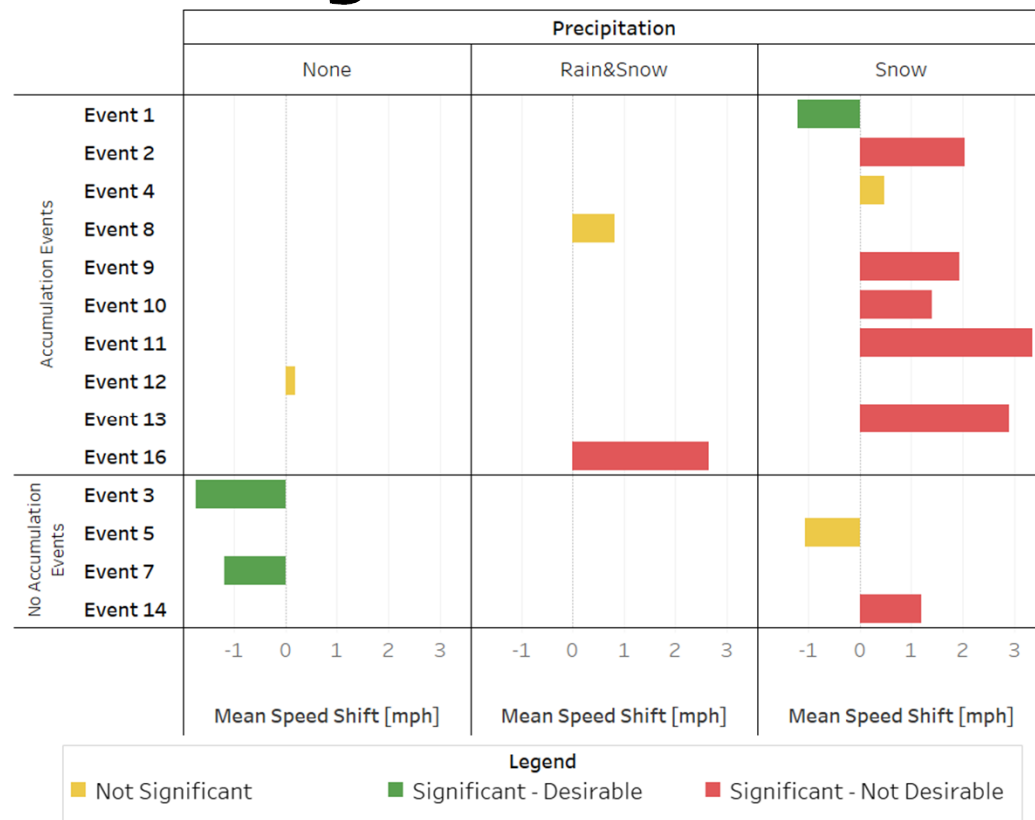
**Eastbound – Majority less than 10% change; two event >15%**

**Westbound – Majority 10-20% change**

# Winter Weather Severity



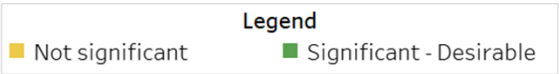
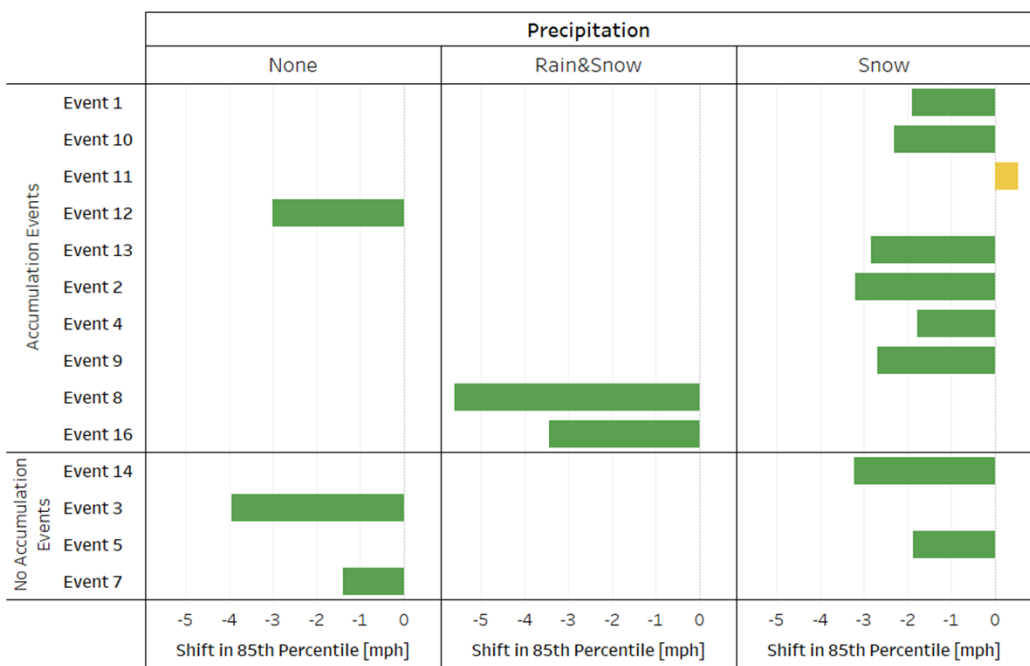
## Eastbound Mean Speed



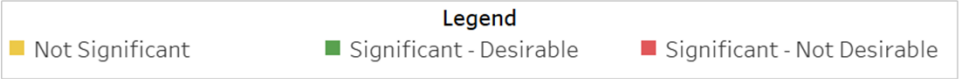
## Westbound Mean Speed

Drivers may be more likely to comply with DMS when they cannot perceive poor surface conditions

# Winter Weather Severity



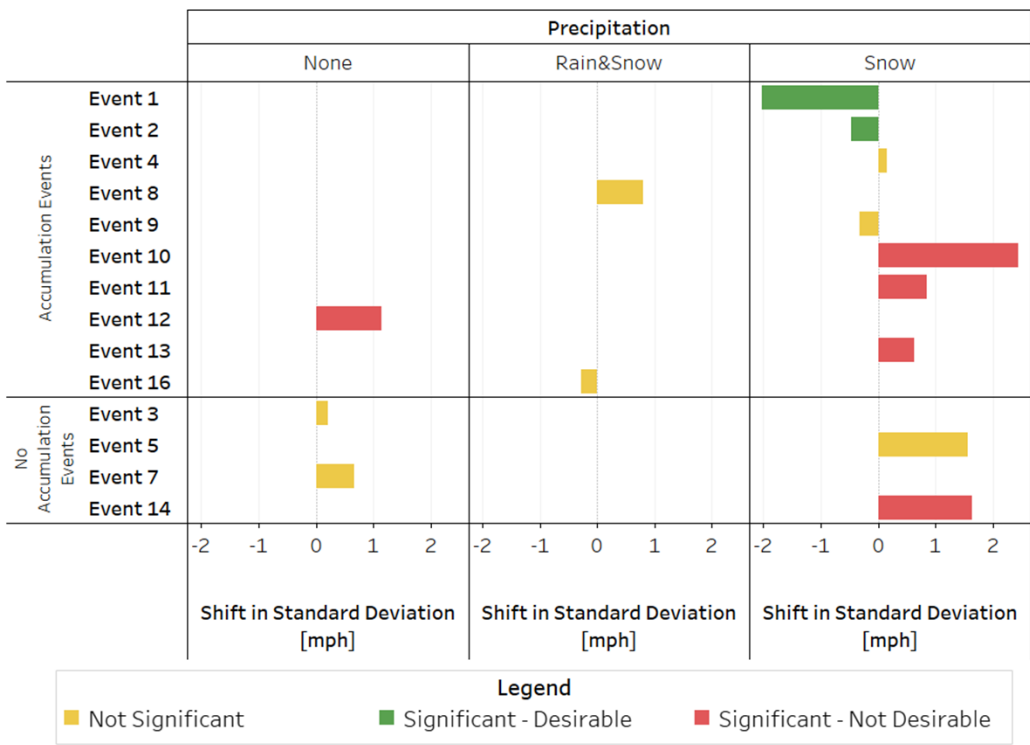
Eastbound  
85th Speed



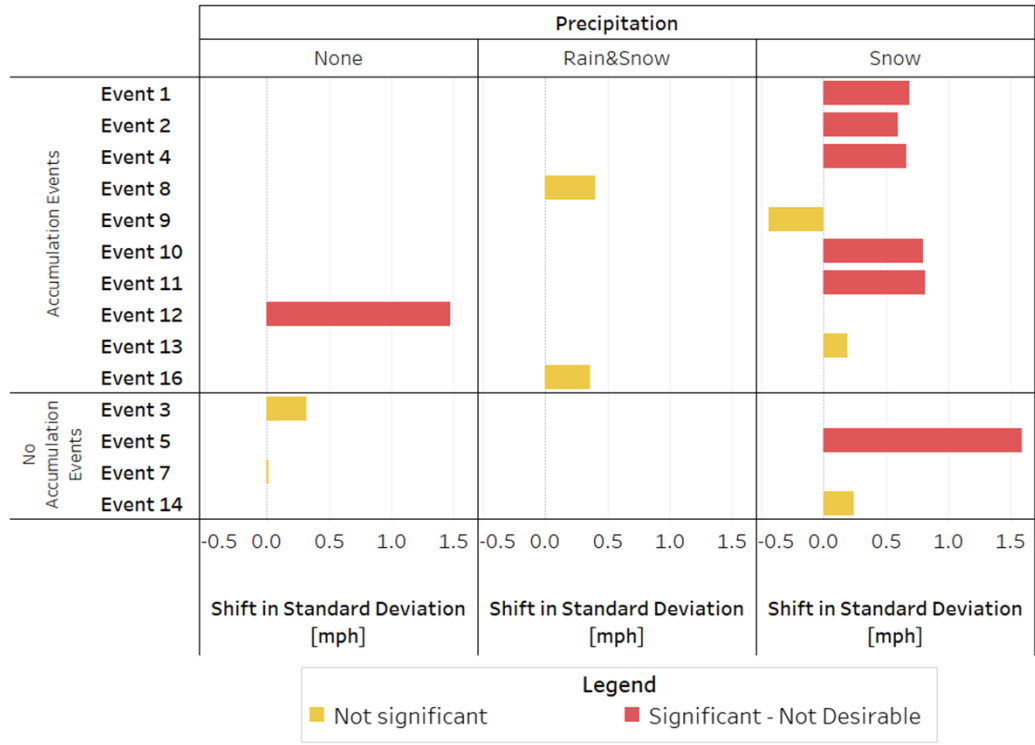
Westbound  
85th Speed



# Winter Weather Severity

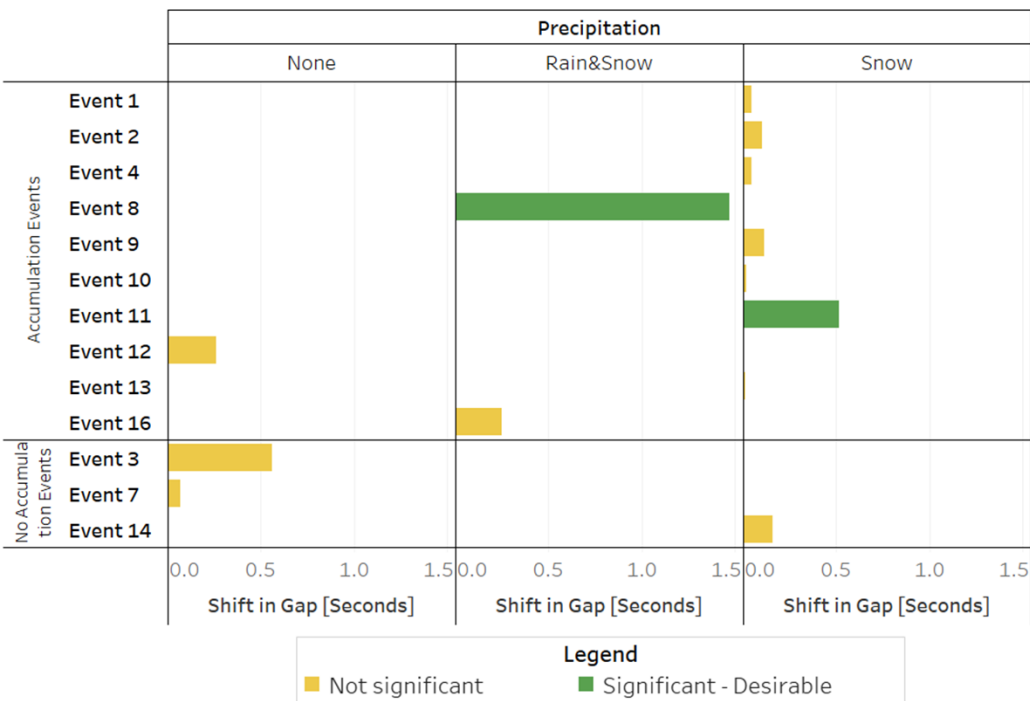


Eastbound  
Standard Deviation

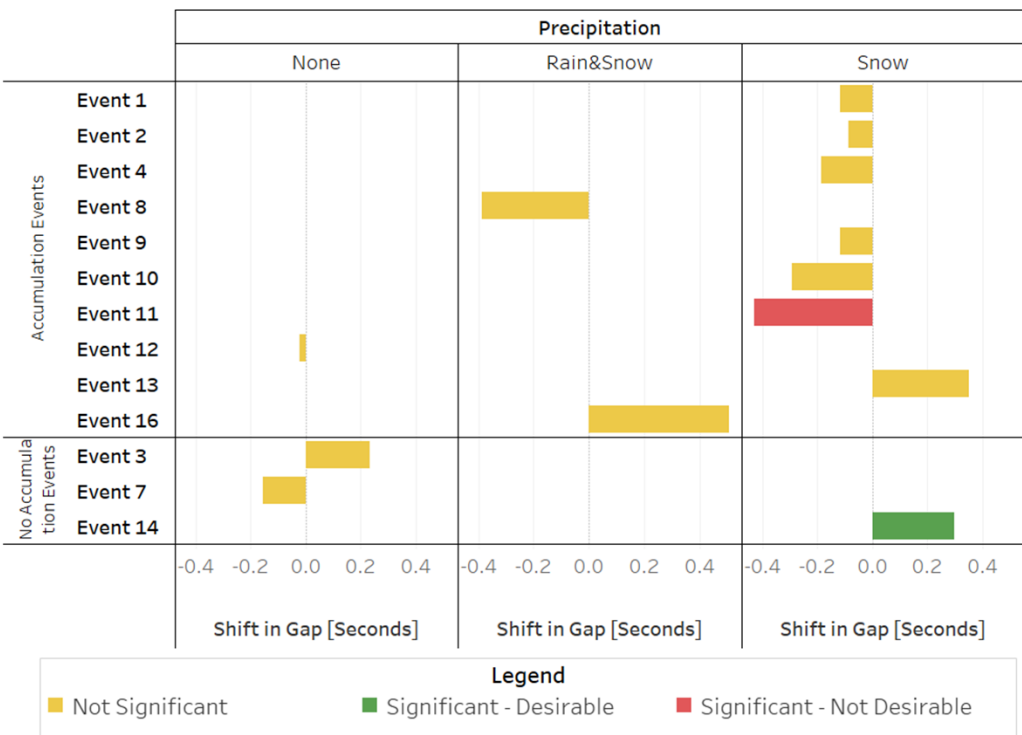


Westbound  
Standard Deviation

# Winter Weather Severity



Eastbound Gap



Westbound Gap

# Conclusions

## Eastbound Direction

- Speed Data – 12 of 14 events had a **significant decrease**
  - Average decrease of **3.5 mph**
  - Combined results = **2.8 mph decrease**
- 85<sup>th</sup> Percentile Speed – 13 of 14 events had **significant decrease**
  - Average decrease of **2.9 mph**
  - Combined results = **2.6 mph decrease**
- Standard Deviation – 2 event with decrease, 6 events with increase
- Vehicle Gap – 2 events with significant increase



# Conclusions

## Westbound Direction

- Speed Data – 3 events with decrease, **7 events with increase**
  - Average increase of **2.5 mph**
  - Combined results = **1.5 mph increase**
- 85<sup>th</sup> Percentile Speed – 1 event with decrease, **8 events with increase**
  - Average increase of **2.5 mph**
  - Combined results = **2.2 mph increase**
- Standard Deviation – **7 events with increase**
- Vehicle Gap – 1 event with increase, 1 event with decrease

# Conclusions

## Potential External Factors

- Placement of DMS in Urban Environment
- Multiple Intersections between DMS and Sensor
- Maintenance Boundaries
- Other factors not accounted for





# Conclusions

## Potential External Factors

- Winter weather severity
  - Severe events showed *no statistically significant* changes
- No accumulation/precipitation showed *statistically significant decreases* in both directions
- No accumulation with precipitation had six events with *statistically significant decrease*, one event not significant and one event significant increase WB

## Limited results



# Conclusions

## Overall

- EB results **indicate** DMS winter weather messaging has **positive effect** by decreasing mean and 85<sup>th</sup> percentile speed
- Indications of **positive** effect on **gap** in combined results in EB
- WB direction showed **mixed results** for mean and 85<sup>th</sup> percentile
- External factors in WB direction may contribute to **inconclusive findings**

# Benefits

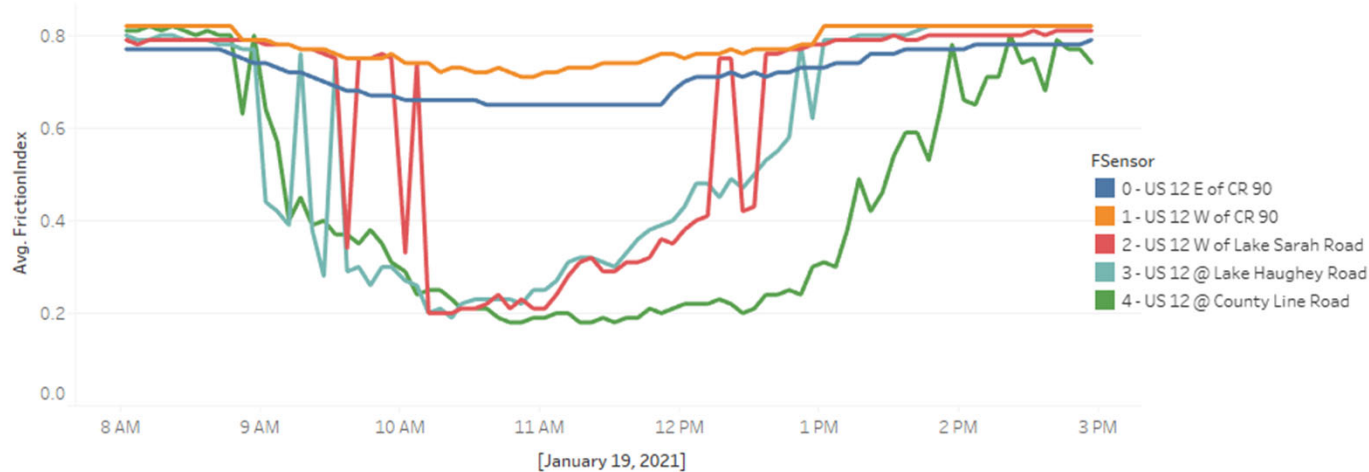
- Reduction in speeds should improve safety and mobility
- Lower speeds allow for time to make safe driving decisions
- Reduced conflicts leads to lower damage costs and economic impact
- Safety benefits of DMS depend on driver compliance



# Potential Implementation Steps

## Sensor Health Monitoring

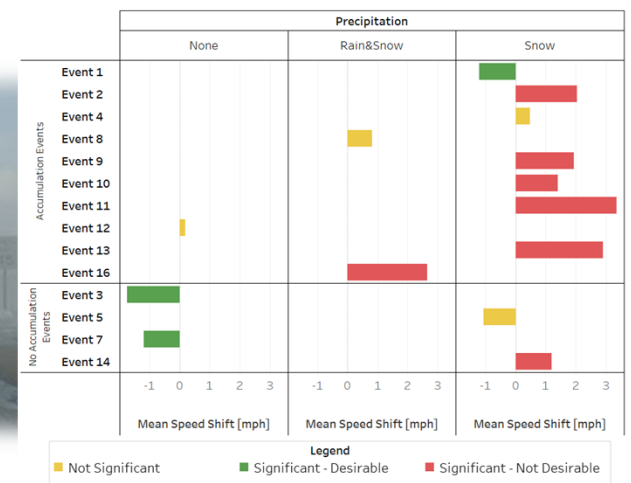
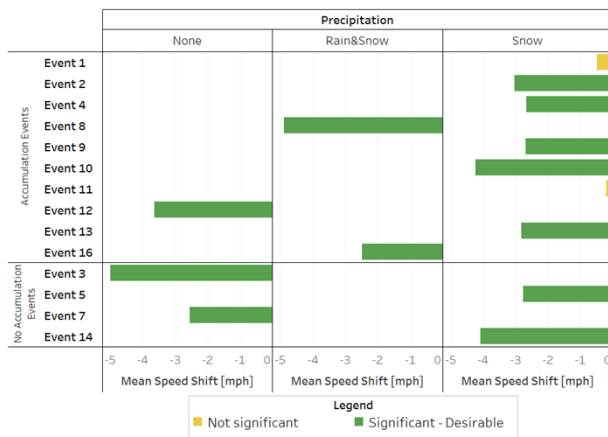
- Provide regular health checks of sensors
- Install redundant sensors similar to Highway 12



# Potential Implementation Steps

## Driver Compliance Correlation with Event Severity

- Future study to develop models understanding various elements impacting results
- Could validate anecdotal findings from report
- Potentially show greater impacts of system for minor events

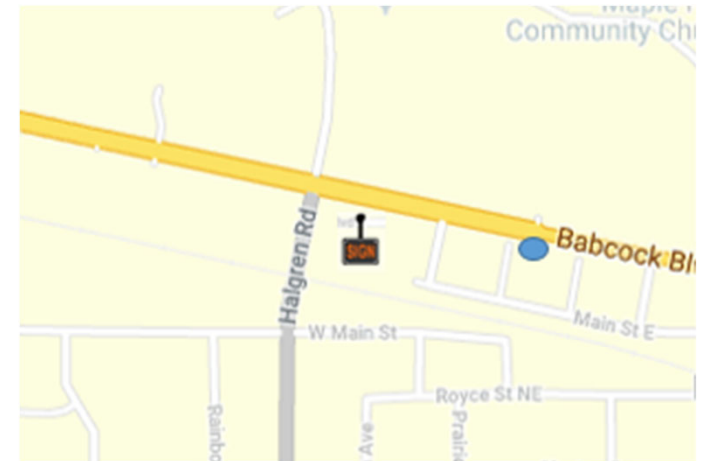




# Potential Implementation Steps

## External Impact and Placement of DMS

- Future study on placement of DMS in relation to desired influence area
- Potential to understand influence area of DMS and effects of external factors



# Evaluation of Road Weather Messages on DMS Based on Roadside Pavement Sensors

Skylar Knickerbocker



Western States Forum (June 2022)

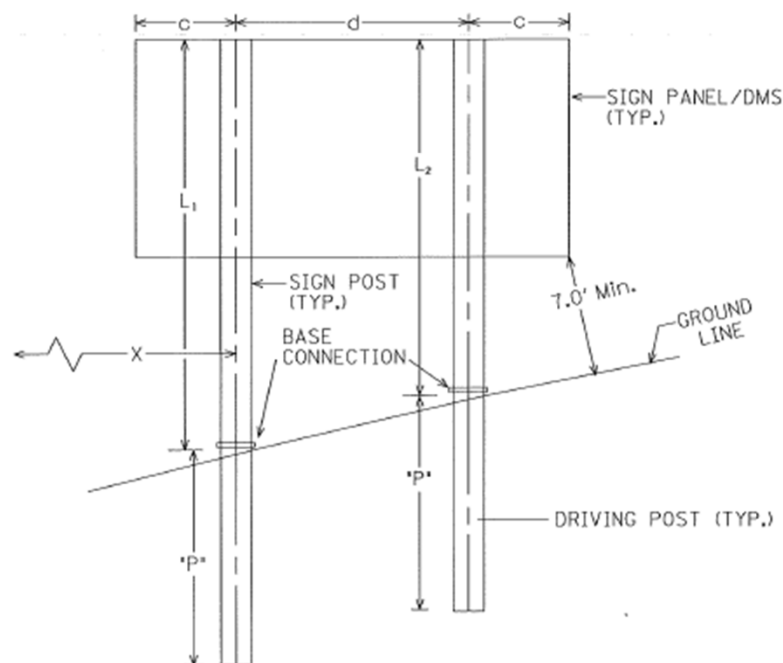


# STRUCTURAL STEEL POSTS FOR TYPE A SIGN

S-A

① DWS NO	LOCATION	PANEL		POST				BASE & STIFFENER PLATE	FOOTING PILE DATA				TOTAL WEIGHT STRUCTURAL STEEL	
		SIZE	AREA	SIZE	QTY	LENGTH			WEIGHT	c	d	"P"		WEIGHT
						L1	L2							
DMS-1	RP 140+00.560 TH12 EB	220.8 x 82		W 8 x 31	2	13.9	13.9	862.00	283.00	57.5	105.8	14	868.00	2013
DMS-2	RP 146+00.10 TH12 WB	220.8 x 82		W 8 x 31	2	14.1	13.7	862.00	283.00	57.5	105.8	14	868.00	2013

TOTAL 4026 POUNDS



## POSTS/PILE FOOTING

(L<sub>1</sub> IS POST NEAREST ROADWAY)

### SPECIFIC NOTE:

- ① DMS TO BE PROVIDED BY MNDOT.

### GENERAL NOTES:

1. DRIVING POST SHALL BE THE SAME SIZE AS THE SIGN POST AND IS TO BE DRIVEN TO A 12 TO 14 TON BEARING CAPACITY.
2. POST LENGTHS ARE APPROXIMATE.
3. X IS THE DISTANCE FROM THE EDGE OF THE THRU LANE TO THE FIRST POST.
4. H IS THE HEIGHT ABOVE THE PAVEMENT EDGE TO THE BOTTOM EDGE OF THE PANEL.
5. P IS THE LENGTH OF DRIVING POST.
6. SEE INDIVIDUAL DMS SITE LOCATION PLAN SHEETS FOR CROSS SECTIONS.
7. WELDING SHALL ONLY BE ALLOWED ABOVE THE BOTTOM OF THE DMS.

EB TH12

℄

INP R/W

PLACE 3" X 2' AGGREGATE SURFACING  
CLASS 2 FOR THE LENGTH  
OF THE GUARDRAIL INSTALLATION

VIEW LOOKING EASTBOUND

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90

18'-4 $\frac{3}{4}$ "

ROADSIDE DMS

6'-10"

10'-0"

7'-0"

L1

L2

6' MIN. SLOPE  
DRESSING

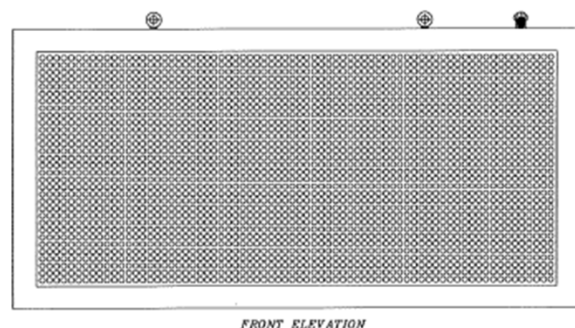
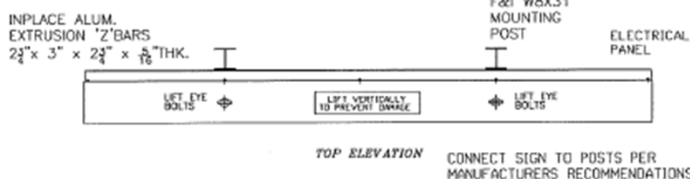
P

14'-0"  
MIN. BURY

P

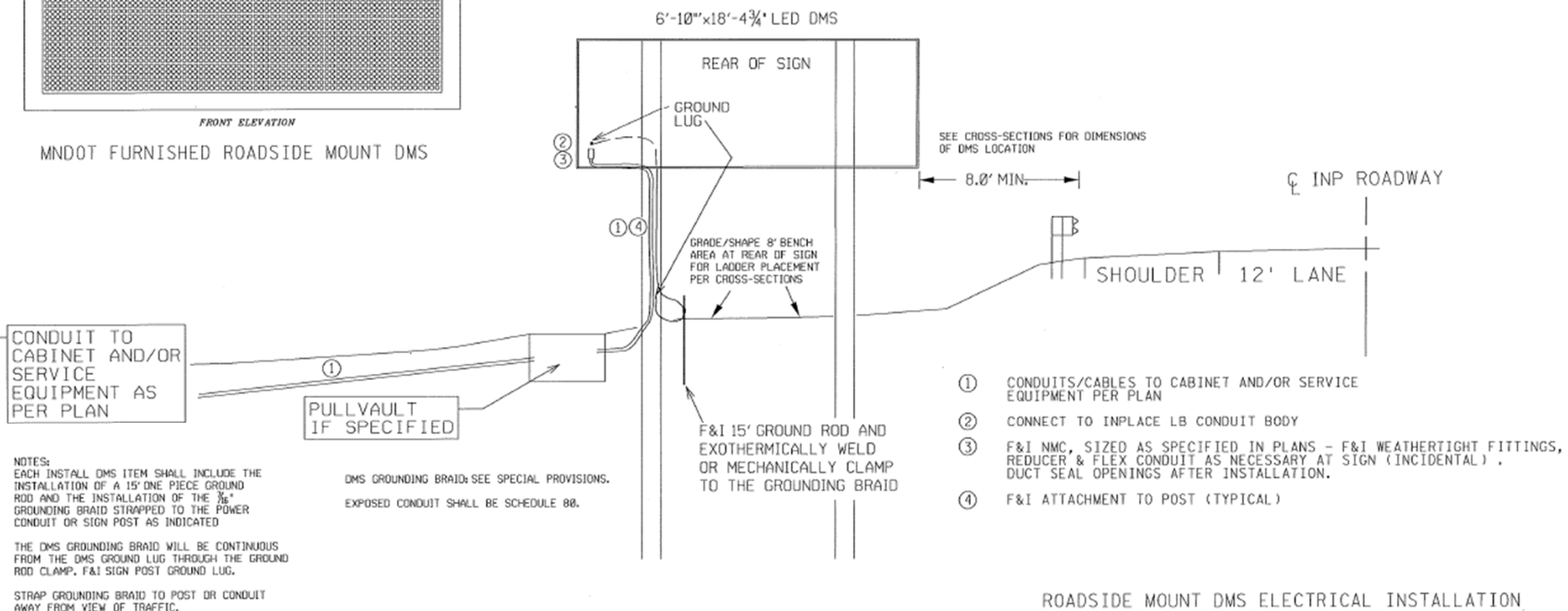
F&I COMMON EMBANKMENT  
TO CREATE BENCH FOR  
DMS PLACEMENT

18" CS PIPE CULVERT  
SEE SHEETS 2 & 3



MNDOT FURNISHED ROADSIDE MOUNT DMS

DETAIL SHOWS STANDARD INSTALLATION OF  
MNDOT FURNISHED ROADSIDE MOUNT DMS  
NOTE: ELECTRICAL COMPONENTS AND CONNECTIONS  
WILL BE DONE UNDER SEPERATE CONTRACT



REV. NO.	DATE: / /
REV. NO.	DATE: / /

CERTIFIED BY Mick P. Manly LIC. NO. 43957 AUG 15, 2019  
LICENSED PROFESSIONAL ENGINEER

STATE PROJ. NO. 2713-131

SHEET NO. 11 OF 16 SHEETS