Chain-Up Delay Tracking and Estimation for Interstate 5 in Northern California

Western States Forum
Grass Valley, CA
June 16 – 18, 2026

Ozair Purmul
ITS Engineer
Caltrans, District 2

Jeremiah Pearce, PE
Chief, Office of ITS Engineering and Support
Caltrans, District 2

Doug Galarus, PhD
Associate Professor, Computer Science Department,
Montana Tech

Montana Tech Students: Emily Martin, Jason Decker, Jacob Sriraman, Reese Lester, River Sheppard, Hunter Valdez

Disclaimer

The opinions, findings and conclusions expressed in this presentation are those of the authors and not necessarily those of the California Department of Transportation, the Western States Rural Transportation Consortium, or Montana Tech.

Outline

Background, Technology, Deployment, Methodology

Part 1: Early Proof of Concept
Part 2: Validation, Expansion, Bad Data
Part 3: Bad Weather, Good Data
Part 4: ITE 2025 Presentation
Part 5: In Search of Ground Truth
Part 6: Confirming Ground Truth
Part 7: Representing Ground Truth with a Single Aggregate Measure
Part 8: Here.com Data
Part 9: Preliminary Algorithm(s)
Part 10: Testing
Part 11: Related Side Project(s)
Part 12: Conclusions and Next Steps

In the spirit of the Forum, we are presenting the nuts-and-bolts details of what worked and the challenges faced to date.

Abbreviations

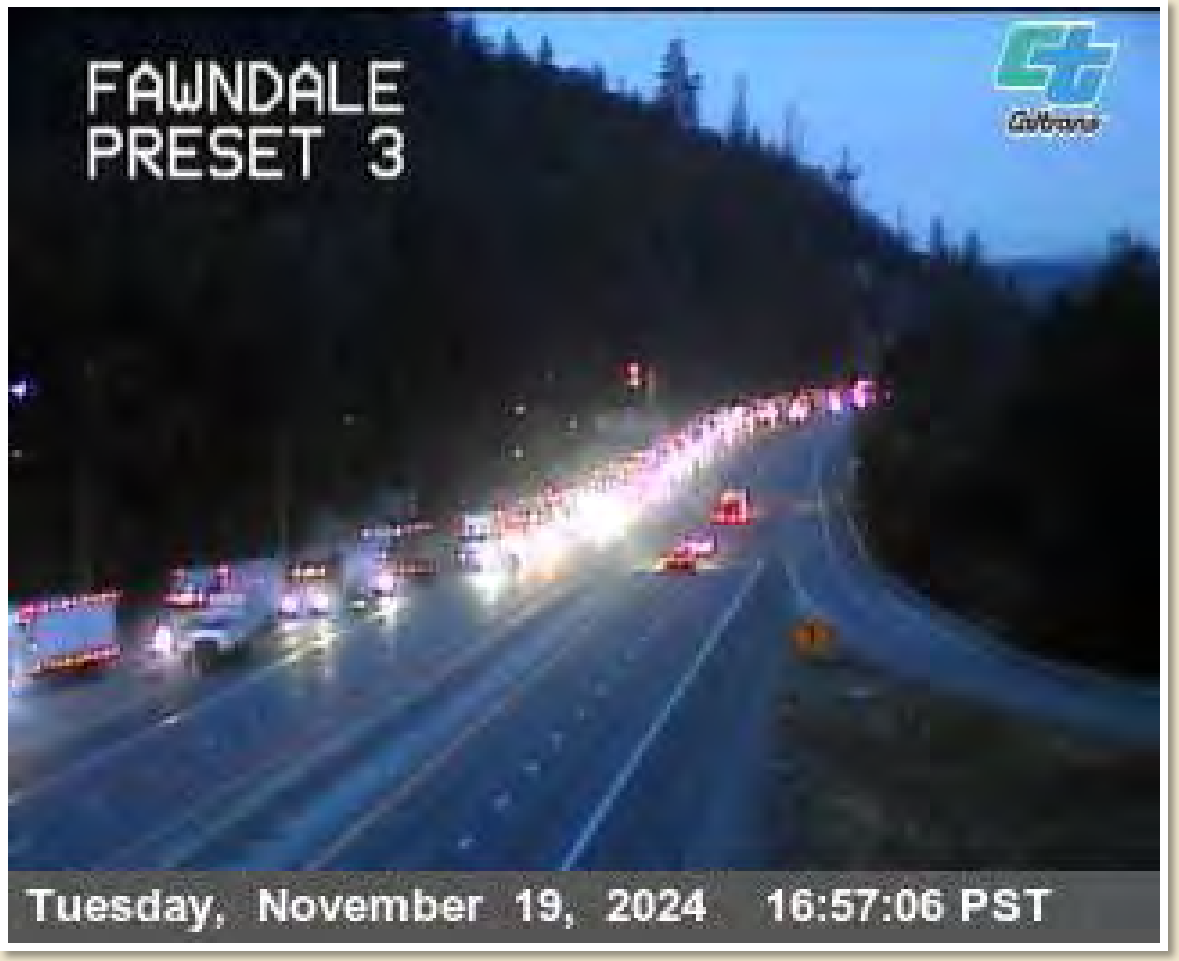
AM	Ante Meridiem (Before Midday)
API	Application Programming Interface
BT	Bluetooth
BTE	Traditional Bluetooth
BTLE	Bluetooth Low-Energy
CA	California
CA273	California State Route 273
CALTRANS	California Department of Transportation
CCTV	Closed-Circuit Television
CMS	Changeable Message Sign
CSV	Comma Separated Values (File Format)
DOT	Department of Transportation
EMA	Exponential Moving Average
GPS	Global Positioning System
I5	Interstate 5
ITE	Institute of Transportation Engineers
JSON	JavaScript Object Notation
MAC	Media Access Control
MD5	Message Digest Algorithm 5 Hashing Algorithm
min	Minutes
MT	Montana

Abbreviations

NTP	Network Time Protocol
O(n)	Big O n (Linear Computation Time)
O(n^2)	Big O n-squared (Quadratic Computation Time)
OUI	Organizationally Unique Identifier (Bluetooth)
PDT	Pacific Daylight Time
PM	Post Meridiem (After Midday)
PST	Pacific Standard Time
Q1	First Quartile (25th Percentile)
Q3	Third Quartile (75th Percentile)
RSSI	Received Signal Strength Indicator
sec	Seconds
SR273	California State Route 273
SR299	California State Route 299
SR44	California State Route 44
Techxpo	Montana Tech Student Research Exposition
TMC	Traffic Message Channel
UTC	Coordinated Universal Time
VPN	Virtual Private Network
WiFi	Wireless Fidelity
WSRTC	Western States Rural Transportation Consortium
WSRTTIF	Western States Rural Transportation Technology Implementer's Forum

Background

When chain controls are in effect on Interstate 5 north of Redding, CA, vehicles are required to chain up near Fawndale and there can be a backup of trucks extending 5 miles or more.



Background



Determining accurate delay times and displaying them on changeable message signs (CMS) before the backup starts could reduce the wait times and backup length and improve safety within this corridor.

Background

The purpose of this project is to use data from 12 Caltrans-deployed Bluetooth and Wi-Fi sensors that log time and MAC address, and to use the data collected by these devices in conjunction with chain control status and other data to develop an algorithm to estimate travel time/delay through the affected area. This data and approach will be compared to third-party data from Here.com.

Background

This project will directly benefit travelers on Interstate 5 north of Redding, California, and along all of Interstate 5 from Southern California to Washington State.

The results are also expected to benefit other states that operate chain-up sites.

Background

Original Vision – approx. 2008

Vision: Provide accurate corridor winter travel times

Problem: Lack of detection infrastructure in Rural use case



Background

Prior Forum Presentations – Bluetooth was Hot (2010 thru 2012)

2010 "Field Experiments with Bluetooth Devices" Y. Wang, Y. Malinovskiy, Y. Wu, U. Lee. University of Washington

2011 "Antenna Characterization for Bluetooth" D. Kim, A. Saeedi. Oregon State University

2011 "MAC Address-based Delay Measurements" T. Bailey, Y. Wang, Y. Malinovskiy. WashDOT and University of Washington

2012 "Travel Time Using Bluetooth" L. Randolph. Southwest Research Institute

2016 "JBLM Bluetooth Traveler Information" T. Liangang, T. Stidham. WashDOT

2019 "Organic vs. Purchased Data for Travel Times" A. Chavez. Caltrans District 3

Background

Winter Travel Time evaluation project initiated through California Oregon Advanced Transportation System (COATS) Phase V – Final Report 2016

Background

Winter Travel Time evaluation project initiated through California Oregon Advanced Transportation System (COATS) Phase V – Final Report 2016

Project scoped to evaluate Bluetooth detection sensors and potential site locations

Background

Winter Travel Time evaluation project initiated through California Oregon Advanced Transportation System (COATS) Phase V – Final Report 2016

Project scoped to evaluate Bluetooth detection sensors and potential site locations

Staffing changes and shifting priorities during COVID led to significant delay

Background

Winter Travel Time evaluation project initiated through California Oregon Advanced Transportation System (COATS) Phase V – Final Report 2016

Project scoped to evaluate Bluetooth detection sensors and potential site locations

Staffing changes and shifting priorities during COVID led to significant delay

In 2022 Caltrans initiated a research project to determine whether Bluetooth detection data could be used to quantify travel delay induced by chain-on conditions

Background

Is it too late? Is Bluetooth detection now out of vogue? Useful?

Background

Is it too late? Is Bluetooth detection now out of vogue? Useful?

Cons from A. Chavez's 2019 WSF Presentation 2019

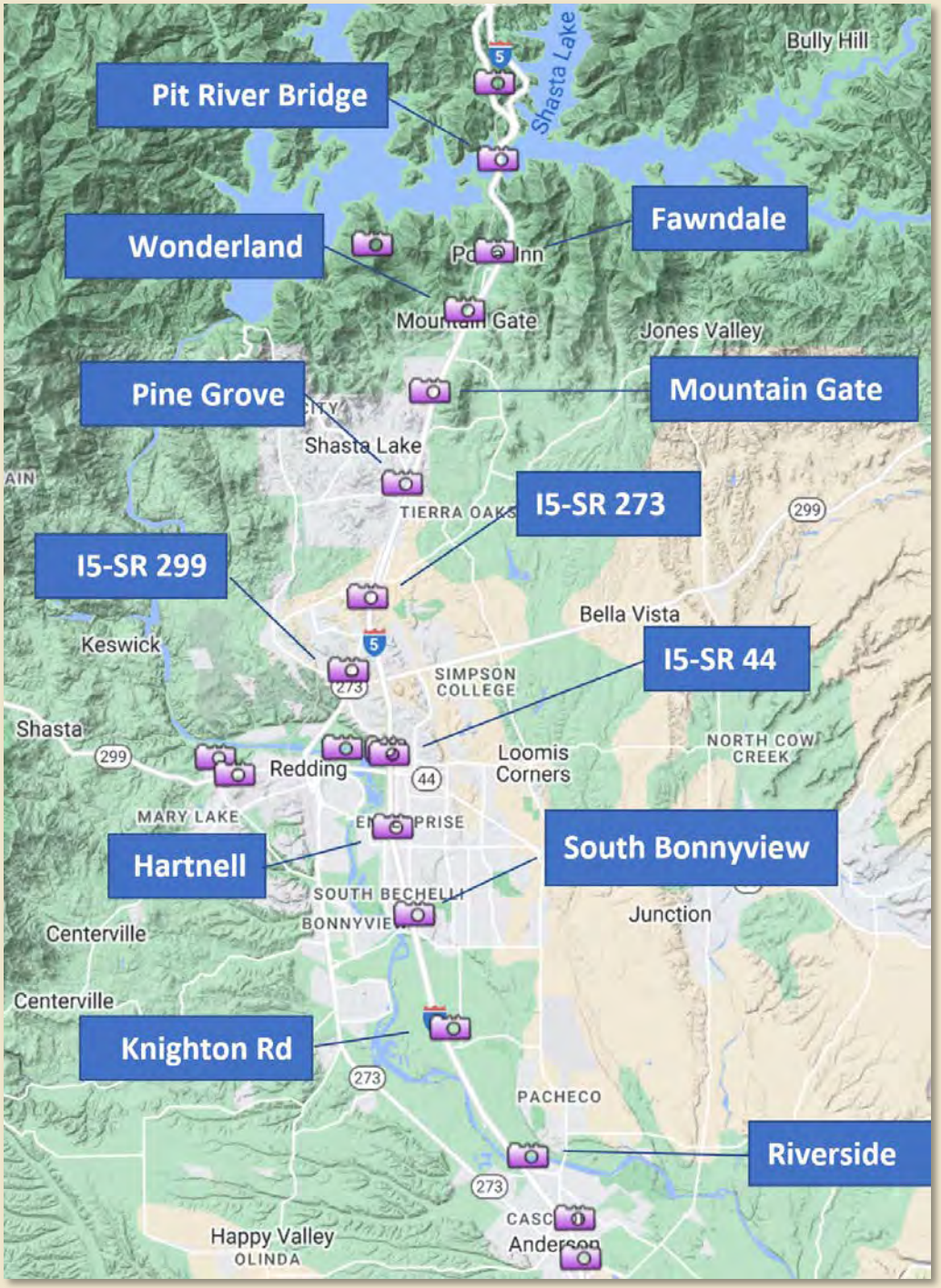
1. Low Rural penetration –
2. HW Failure –
3. Snowpack –
4. Rural power –
5. Few cabinets –
6. Duplicate MAC Addresses –
7. 2.4 GHz Interference –
8. Erratic Travel Times –

Background

Is it too late? Is Bluetooth detection now out of vogue? Useful?

See end of presentation …

In preparation for this research project, Caltrans deployed 12 Bluetooth and Wi-Fi Sensors along Interstate 5



Bluetooth Technology

Bluetooth: Low power (less than +20 dBm or 100 mW) RF technology that operates on the 2.4-GHz ISM band leveraging frequency hoping spread spectrum for good noise immunity and interference resilience

Bluetooth Technology

Bluetooth: Low power (less than +20 dBm or 100 mW) RF technology that operates on the 2.4-GHz ISM band leveraging frequency hoping spread spectrum for good noise immunity and interference resilience

Bluetooth Detection: Sensors that listen for Bluetooth enabled devices “transmitting” near the highway

Bluetooth Technology

Bluetooth: Low power (less than +20 dBm or 100 mW) RF technology that operates on the 2.4-GHz ISM band leveraging frequency hoping spread spectrum for good noise immunity and interference resilience

Bluetooth Detection: Sensors that listen for Bluetooth enabled devices “transmitting” near the highway

Many/most vehicles have Bluetooth devices

Examples include: Vehicle diagnostics, vehicle sound systems, personal cell phones, ear-buds, etc.

Bluetooth Technology

Bluetooth: Low power (less than +20 dBm or 100 mW) RF technology that operates on the 2.4-GHz ISM band leveraging frequency hoping spread spectrum for good noise immunity and interference resilience

Bluetooth Detection: Sensors that listen for Bluetooth enabled devices "transmitting" near the highway

Many/most vehicles have Bluetooth devices

Examples include: Vehicle diagnostics, vehicle sound systems, personal cell phones, ear-buds, etc.

Range of up to 1000'

Bluetooth

Bluetooth Technology

Why Bluetooth Detection?

Bluetooth Technology

Why Bluetooth Detection?

Cheap – Sensors low cost of deployment and low cost of maintenance

Bluetooth Technology

Why Bluetooth Detection?

Cheap – Sensors low cost of deployment and low cost of maintenance

Easy to integrate NTCIP format ingestible into most ATMS systems

Bluetooth Technology

Why Bluetooth Detection?

Cheap – Sensors low cost of deployment and low cost of maintenance

Easy to integrate NTCIP format ingestible into most ATMS systems

Most vehicles are going to have a Bluetooth enabled device

Bluetooth Technology

Product Evaluation



Bluetooth Technology

Product Evaluation

System requirements

1. Access to raw data
2. Detection range
3. Form factor
4. Power requirements
5. Data format
6. Environmental specs



Bluetooth Technology

Product Evaluation

Evaluated 6 Products

1. Iteris BlueTOAD Spectra
2. DeepBlue Model V
3. TPA BTM
4. Q-Free HI-TRAC BLUE2
5. SMATS TrafficXHub
6. Sensys APCC-BT



Bluetooth Technology

Product Evaluation

Evaluated 6 Products

1. Iteris BlueTOAD Spectra
2. DeepBlue Model V
3. TPA BTM
4. Q-Free HI-TRAC BLUE2
5. SMATS TrafficXHub
6. Sensys APCC-BT

Product	Access to Raw Data	Detection Range	Form Factor	Power Requirements	Data Format	Environmental Specs
Iteris Blue TOAD Spectra	No	Undefined	NEMA 4X	AC/DC/PoE	NTCIP	-40°C to +85°C
Deep Blue Model V	Yes	1000'	NEMA 4X	PoE	NTCIP	-40°C to +80°C
TPA BTM	No	400'	Undefined	DC	NTCIP	-40°C to +65°C
Q-Free HI-TRAC BLUE 2	No	Undefined	IP68	DC	Undefined	Undefined
SMATS TrafficXHub	Yes	Undefined	IP68	AC/DC/PoE	Undefined	-40°C to +75°C
Sensys APCC-BT	No	325'	IP66	PoE	Undefined	-40°C to +80°C

Bluetooth Technology

Product Evaluation

Evaluated 6 Products

1. Iteris BlueTOAD Spectra
2. DeepBlue Model V
3. TPA BTM
4. Q-Free HI-TRAC BLUE2
5. SMATS TrafficXHub
6. Sensys APCC-BT

Product	Access to Raw Data	Detection Range	Form Factor	Power Requirements	Data Format	Environmental Specs
Iteris Blue TOAD Spectra	No	Undefined	NEMA 4X	AC/DC/PoE	NTCIP	-40°C to +85°C
Deep Blue Model V	Yes	1000'	NEMA 4X	PoE	NTCIP	-40°C to +80°C
TPA BTM	No	400'	Undefined	DC	NTCIP	-40°C to +65°C
Q-Free HI-TRAC BLUE 2	No	Undefined	IP68	DC	Undefined	Undefined
SMATS TrafficXHub	Yes	Undefined	IP68	AC/DC/PoE	Undefined	-40°C to +75°C
Sensys APCC-BT	No	325'	IP66	PoE	Undefined	-40°C to +80°C

Bluetooth Technology

SMATS

Technical Specifications

TrafficXHub™

Item	Value
Operating temperature	-40°C~75°C
Dimension	270x220x100 mm
Weight	1.8 Kg
Data Encryption	MD5 MAC Address Hashing
Power Supply Input Options	110-220VAC/9-48VDC External Power Supply
	Solar Panel
	Power over Ethernet (802.3at/af)
Power Consumption	Typical <4 W with GSM without Wi-Fi
	Typical <6 W with GSM with WI-FI
Bluetooth Module Classic	Class 1
	+18dBm TX power, -90dBm RX Sensitivity
Bluetooth Module Low Energy	+4dBm TX power (Max), -96dBm RX Sensitivity
Bluetooth Module Paired Mode	-98 RX Sensitivity
Wi-Fi Module	802.11 b/g/n
	-92dBm RX Sensitivity
Processor	Quad Core 1.2 GHz
RAM	1 GB SD
Antennas	Omnidirectional
	Bluetooth and Wi-Fi: 2400-5000 MHz, 1.5, 2, 5 dBi gain op-tions, IP65
	GPS: 1574~1610MHz, 28dB gain, IP67
Operating System	Linux 3.1
Enclosure	IP68
GPS	SiRF Start 4, -163dBm tracking sensitivity, 48 Track channels
Cellular Modem	LTE: North America (B2, B4, B5, B17) Europe (B1, B3, B7, B8, B20)
Solar Panel Power (Optional)	50 W, 10 Amp Charge Controller
Available Ports	Ethernet (PoE)
	USB (2 ports)
RF Compliance	FCC,IC Compliant



Bluetooth Technology

DeepBlue Sensor

POWER SUPPLY
12-48VDC
Typical 3.5W with modem
Typical 1.8 W without modem
PoE (Power over Ethernet)

CPU & MEMORY
ARM 9 Processor
128 MB RAM / Flash
Micro SD storage

COMMUNICATIONS
Ethernet
Internal modem
Dual SIM-Card slot
MQTT Remote Sensor Access

OPERATIONS
Linux based OS
LED for operations diagnostics

ENVIRONMENTAL
–40°C to +80°C 0-90% humidity
NEMA 4X / IP67 housing
Shock/vibration: NEMA TS2-2003

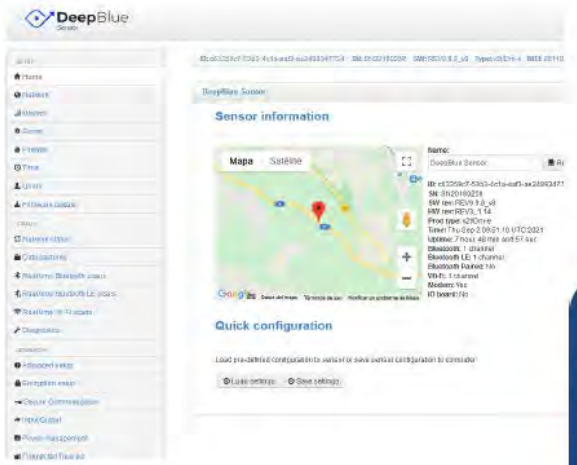
DIMENSIONS & WEIGHT
H x W x L 276 mm x 272 mm x 96.5 mm
2.00 kg

DETECTION
Bluetooth detection internal 12dBi antenna
Wi-Fi detection
BLE detection

REGULATORY
RoHS Compliant, CE, FCC, IC certified

WARRANTY
2 years standard, extension available

With our dedication to continuous development the specifications are subject to change. To verify the current information please visit www.deepbluesensor.com



V-model





Bluetooth Technology

Not mentioned in any of the spec or data sheets – the availability of raw data from the sensor



Bluetooth Technology

Not mentioned in any of the spec or data sheets – the availability of raw data from the sensor

Only two vendors met the raw data requirement



Bluetooth Technology

Not mentioned in any of the spec or data sheets – the availability of raw data from the sensor

Only two vendors met the raw data requirement

Deep Blue Model V sensor was selected for the pilot deployment



Bluetooth Deployment

Getting started – Retrofitting to an existing ITS Node



Bluetooth Deployment

Getting started – Retrofitting to an existing ITS Node

- Mounting Height: 12’ AGL
  Perpendicular to traffic



Bluetooth Deployment

Getting started – Retrofitting to an existing ITS Node

- Mounting Height: 12’ AGL
  Perpendicular to traffic
- ¾” conduit penetration



Bluetooth Deployment

Getting started – Retrofitting to an existing ITS Node

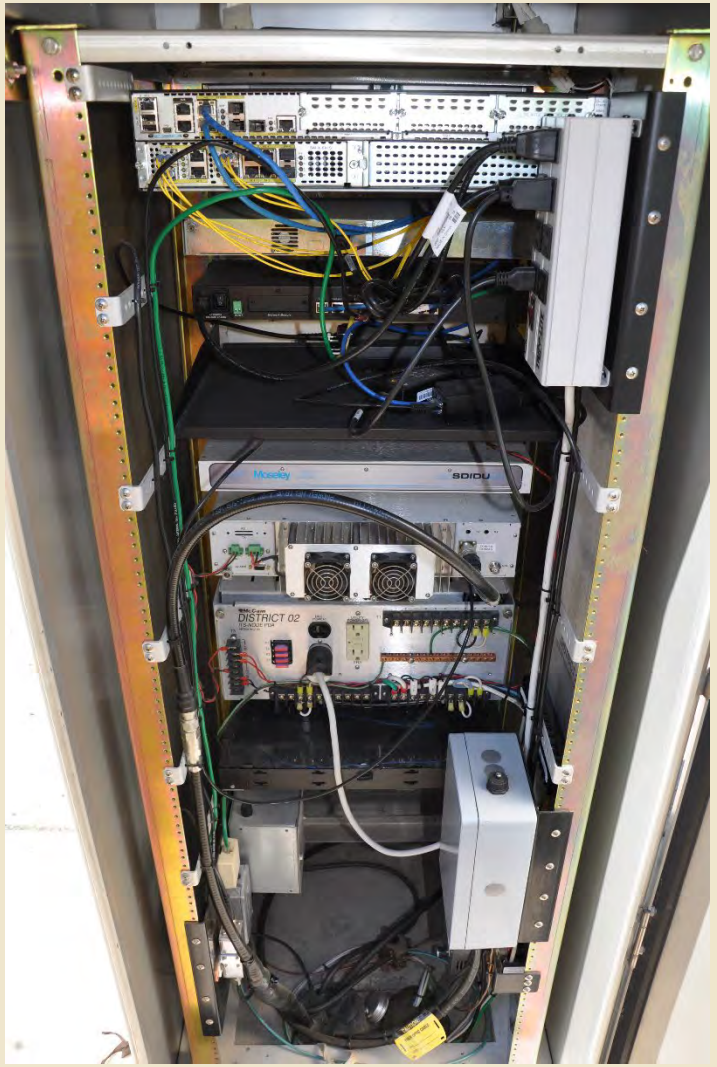
- Mounting Height: 12’ AGL Perpendicular to traffic
- ¾” conduit penetration
  - Drill & Tap, cold galv, ¾” nipple, drip loop in cable



Bluetooth Deployment

Getting started – Retrofitting to an existing ITS Node

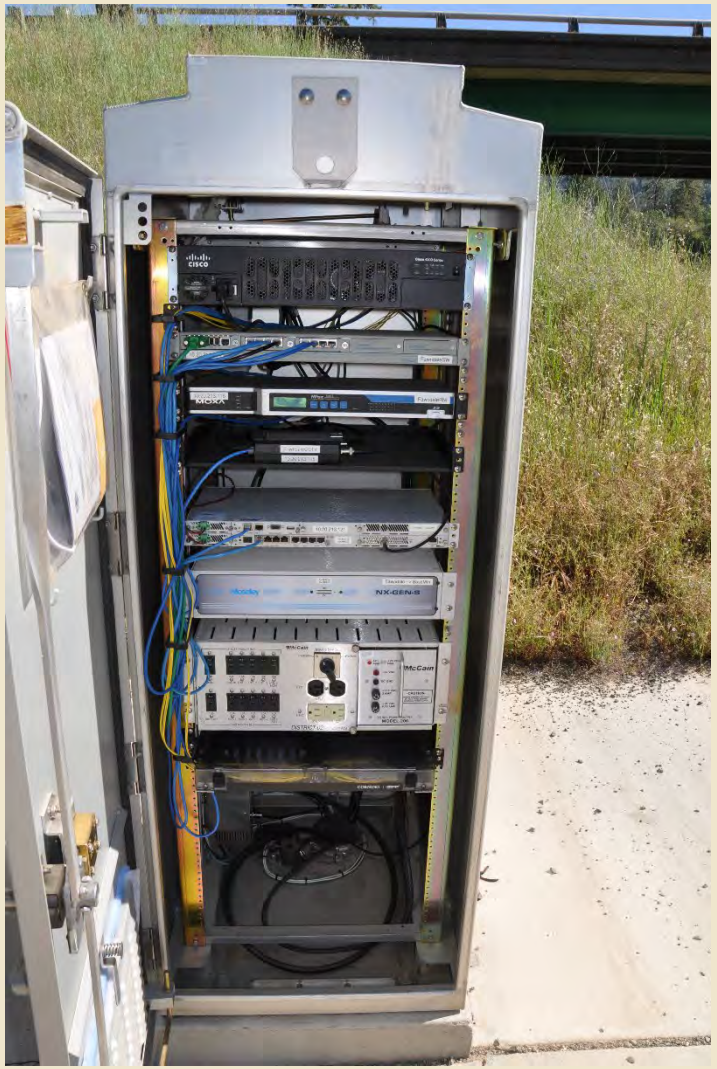
- Mounting Height: 12’ AGL Perpendicular to traffic
- ¾” conduit penetration
  - Drill & Tap, cold galv, ¾” nipple, drip loop in cable
- Power – PoE, external antenna screwed to bottom of sensor, adapter in cabinet



Bluetooth Deployment

Getting started – Retrofitting to an existing ITS Node

- Mounting Height: 12’ AGL Perpendicular to traffic
- ¾” conduit penetration
  - Drill & Tap, cold galv, ¾” nipple, drip loop in cable
- Power – PoE, external antenna screwed to bottom of sensor, adapter in cabinet
- Network Communication – CAT 5e Connection to local roadside LAN ITS Node



Bluetooth Deployment

Sensor setup and configuration

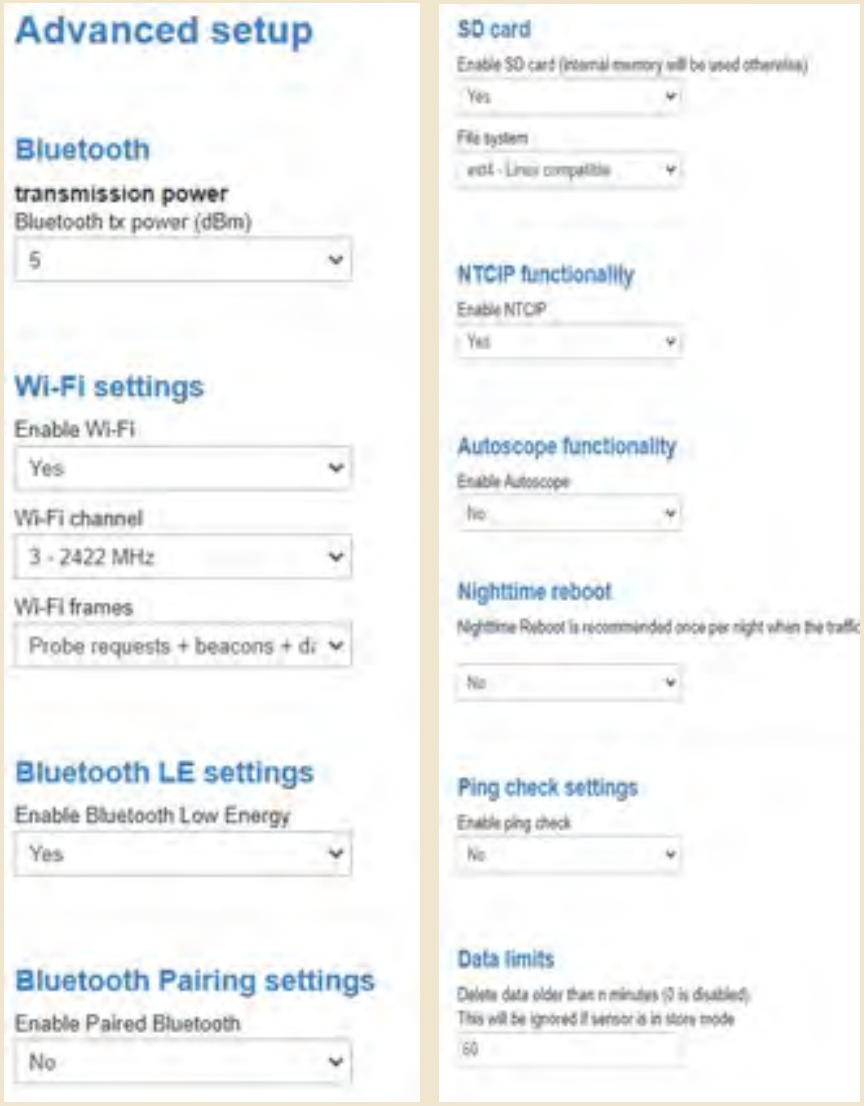
- Network Settings
  - IP (Static)
  - NTP
  - Users



Bluetooth Deployment

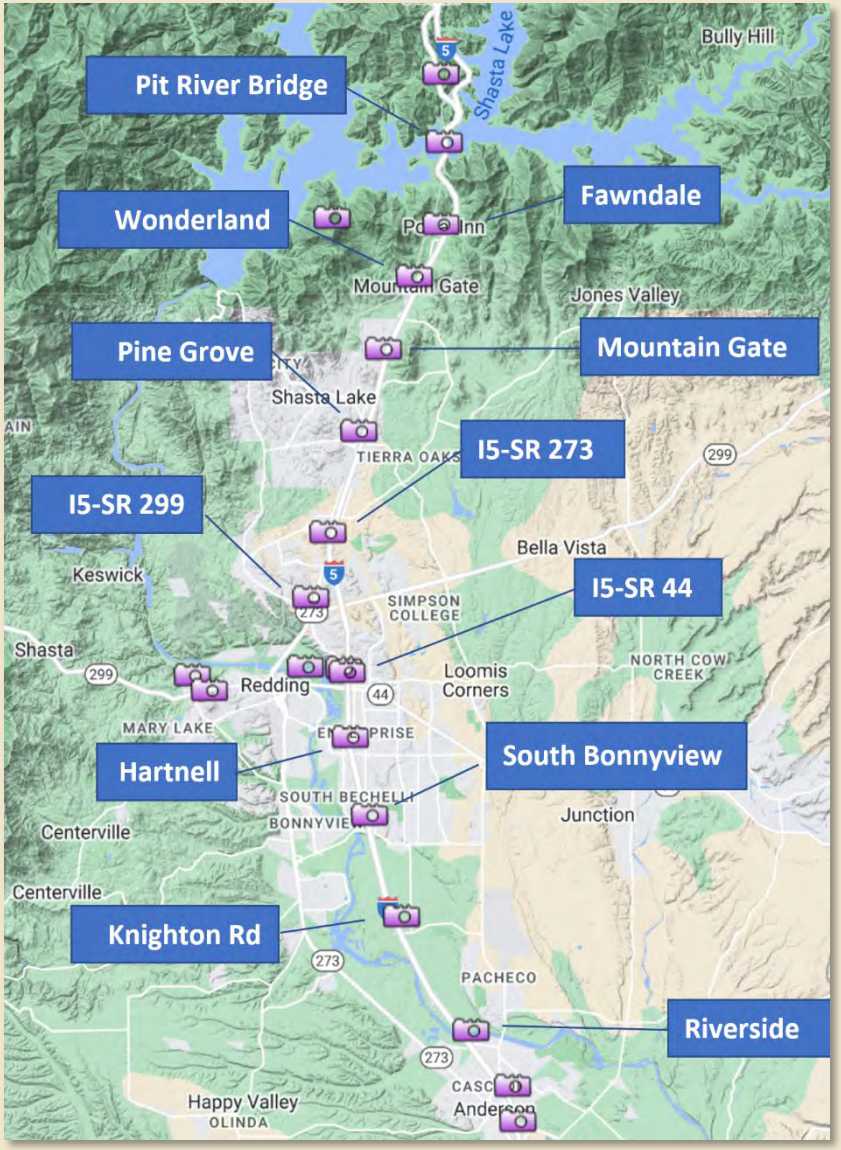
Sensor setup and configuration

- Network Settings
  - IP (Static)
  - NTP
  - Users
- Advanced Setup
  - Enable Bluetooth scanning and set Tx power
  - Enable Wi-Fi scanning
  - Enable Bluetooth LE Scanning
  - Enable NTCIP compatibility
  - Enable local data storage



Bluetooth Deployment

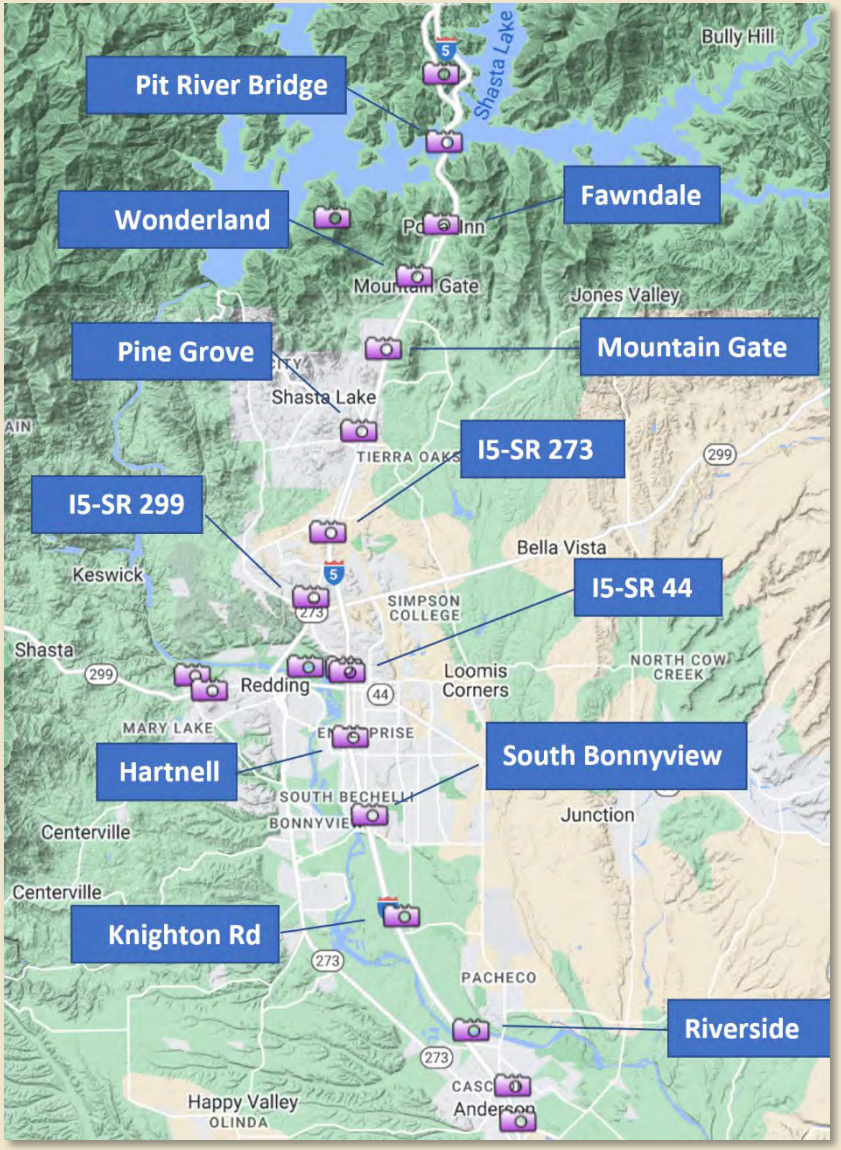
Montana Tech Data Collection



Bluetooth Deployment

Montana Tech Data Collection

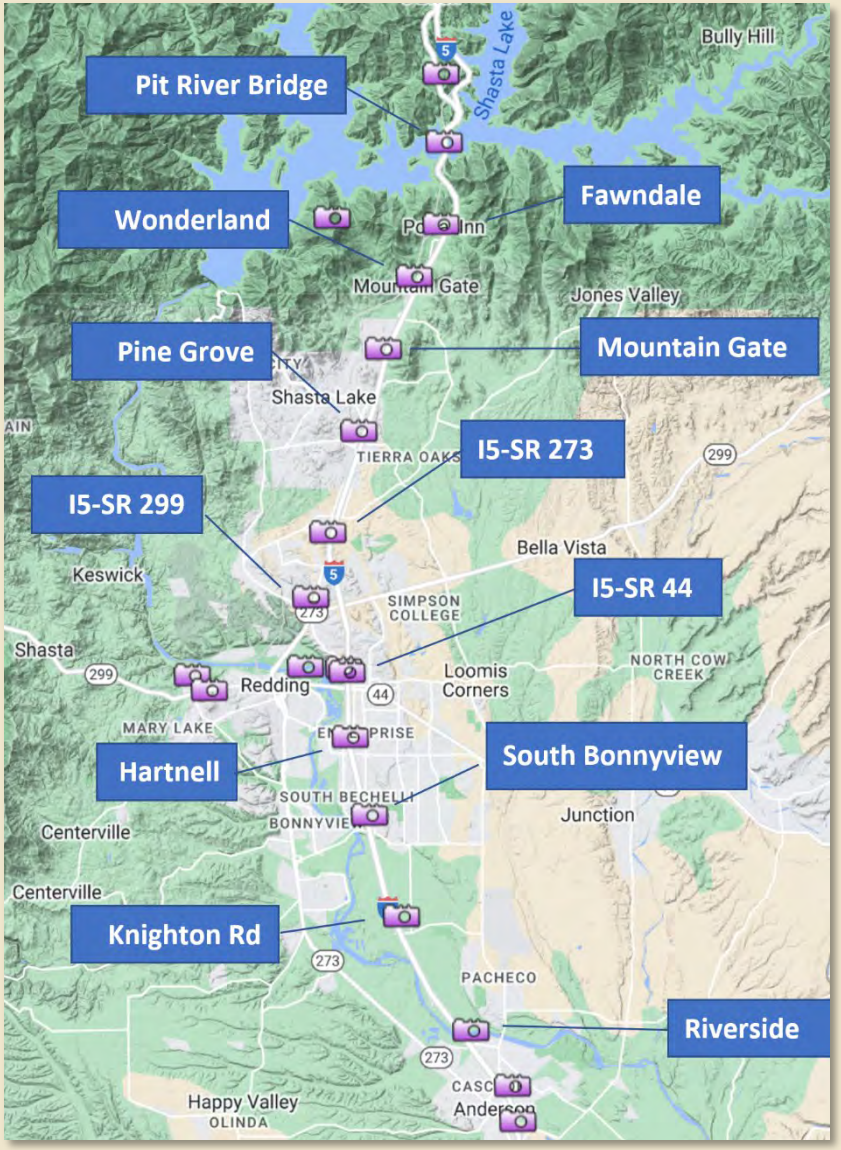
- Using local SD to store data on the sensor



Bluetooth Deployment

Montana Tech Data Collection

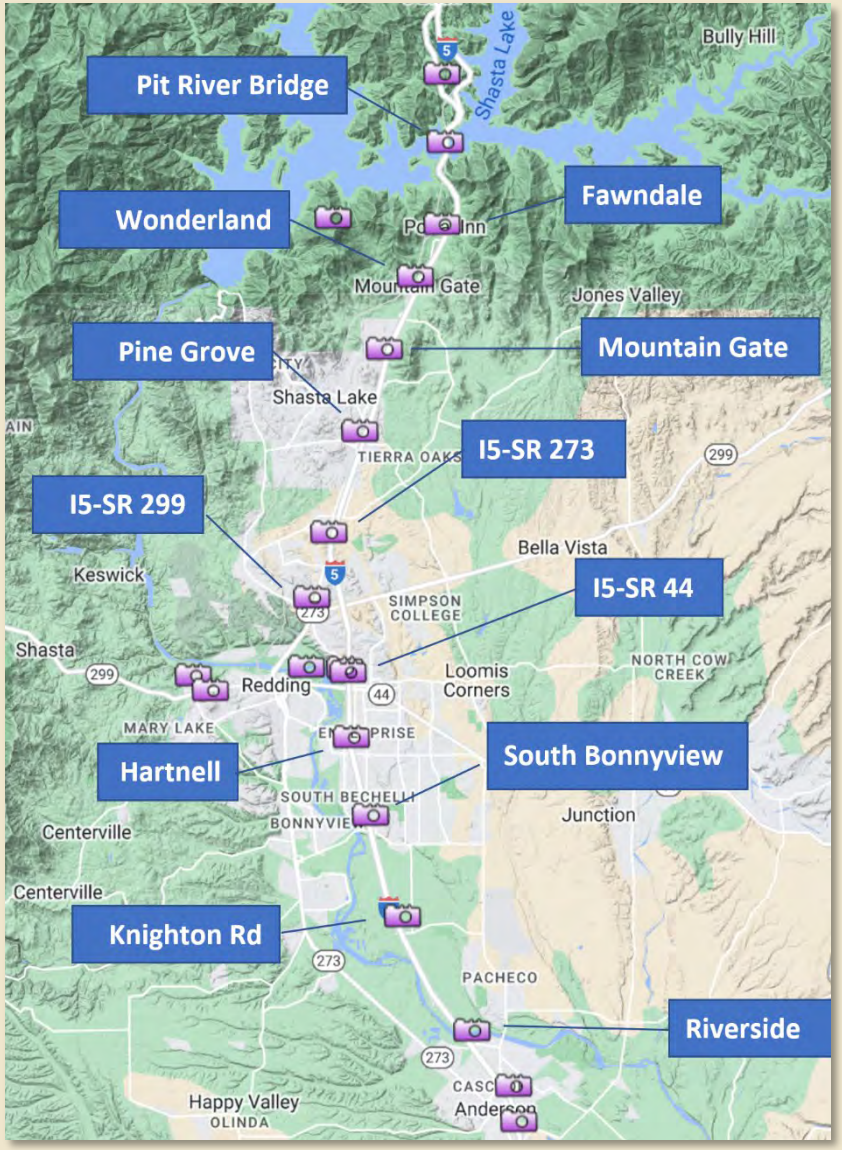
- Using local SD to store data on the sensor
- Montana Tech periodically collects data from each sensor manually



Bluetooth Deployment

Montana Tech Data Collection

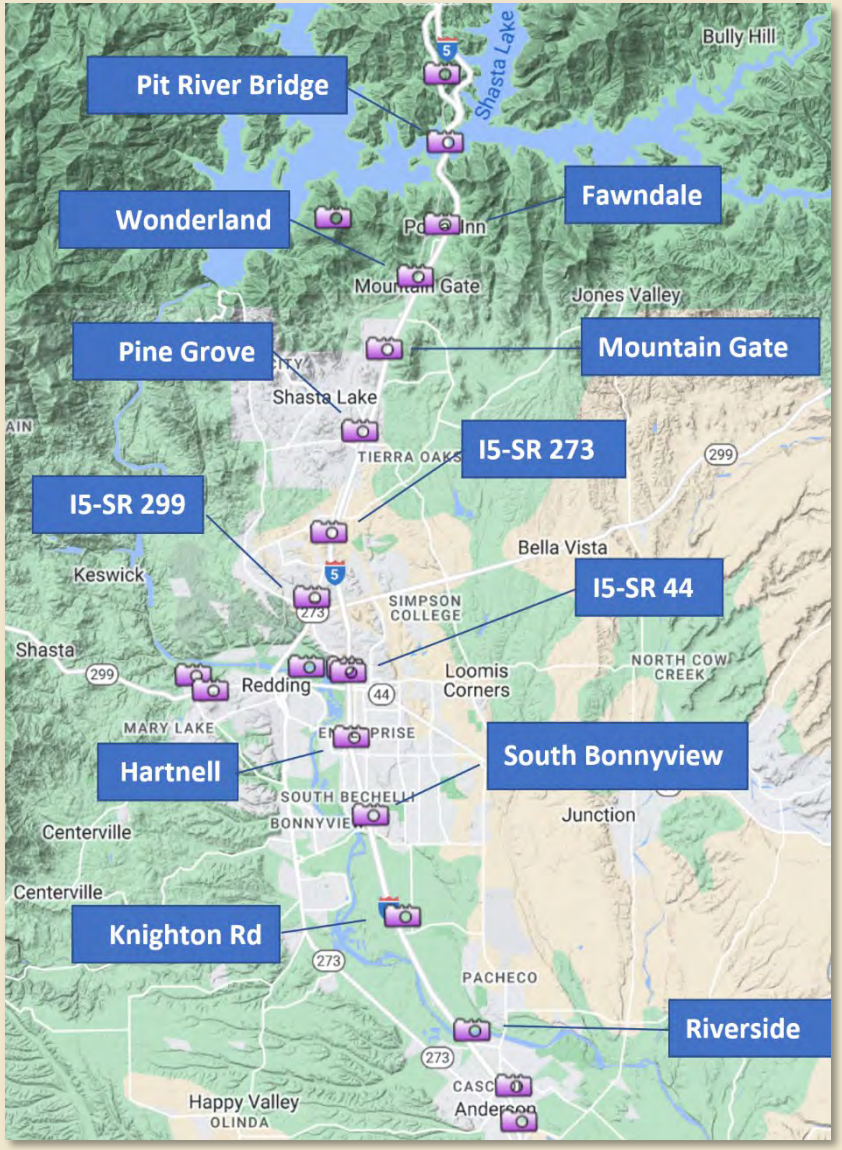
- Using local SD to store data on the sensor
- Montana Tech periodically collects data from each sensor manually
- Data collection coordinated to avoid high traffic periods of the network



Bluetooth Deployment

Montana Tech Data Collection

- Using local SD to store data on the sensor
- Montana Tech periodically collects data from each sensor manually
- Data collection coordinated to avoid high traffic periods of the network
- Other than the periodic MtTech data transfers, no BT data is pushed to a central system (PeMS, ATMS, etc.)



Bluetooth Operations

Bluetooth Detection Deployment Issues



Bluetooth Operations

Bluetooth Detection Deployment Issues

- Sensor Not Collecting Data

Bluetooth Operations

Bluetooth Detection Deployment Issues

- Sensor Not Collecting Data
  - Bluetooth sensor would not collect data for 2-hour periods daily at random times at the Pine Grove location (didn't affect other locations)

Bluetooth Operations

Bluetooth Detection Deployment Issues

- Sensor Not Collecting Data
  - Bluetooth sensor would not collect data for 2-hour periods daily at random times at the Pine Grove location (didn't affect other locations)
  - Reviewed logs, errors indicated a "watchdog failure"

Bluetooth Operations

Bluetooth Detection Deployment Issues

- Sensor Not Collecting Data
  - Bluetooth sensor would not collect data for 2-hour periods daily at random times at the Pine Grove location (didn't affect other locations)
  - Reviewed logs, errors indicated a "watchdog failure"
  - Reached out to Vendor for guidance, recommendation to "reboot" and the issue eventually worked itself out

Bluetooth Operations

Bluetooth Detection Deployment Issues

- Clock Sync Issue

Bluetooth Operations

Bluetooth Detection Deployment Issues

- Clock Sync Issue
  - Clocks not synced between sensors

Bluetooth Operations

Bluetooth Detection Deployment Issues

- Clock Sync Issue
  - Clocks not synced between sensors
  - Issue discovered by MtTech Student

Bluetooth Operations

Bluetooth Detection Deployment Issues

- Clock Sync Issue
  - Clocks not synced between sensors
  - Issue discovered by MtTech Student
  - Firewall exception approved by IT but not implemented

Bluetooth Operations

Bluetooth Detection Deployment Issues

- Clock Sync Issue
  - Clocks not synced between sensors
  - Issue discovered by MtTech Student
  - Firewall exception approved by IT but not implemented
  - Sensor would temporarily sync with local computer and update time but the internal clock was fast and would lose sync when not connected

Bluetooth Operations

Bluetooth Detection Deployment Issues

- Clock Sync Issue
  - Clocks not synced between sensors
  - Issue discovered by MtTech Student
  - Firewall exception approved by IT but not implemented
  - Sensor would temporarily sync with local computer and update time but the internal clock was fast and would lose sync when not connected
  - Upon troubleshooting, unable to connect to NTP server Firewall issue discovered, the exception was never made

Bluetooth Operations

Bluetooth Detection Deployment Issues

- Clock Sync Issue
  - Clocks not synced between sensors
  - Issue discovered by MtTech Student
  - Firewall exception approved by IT but not implemented
  - Sensor would temporarily sync with local computer and update time but the internal clock was fast and would lose sync when not connected
  - Upon troubleshooting, unable to connect to NTP server Firewall issue discovered, the exception was never made
  - Resolved after a second exception request approved by IT

Bluetooth Operations

Bluetooth Detection Deployment Issues

- Clock Sync Issue
  - Clocks not synced between sensors
  - Issue discovered by MtTech Student
  - Firewall exception approved by IT but not implemented
  - Sensor would temporarily sync with local computer and update time but the internal clock was fast and would lose sync when not connected
  - Upon troubleshooting, unable to connect to NTP server Firewall issue discovered, the exception was never made
  - Resolved after a second exception request approved by IT
  - Internal GPS for spatial coordinates, but currently doesn't sync the clock

Bluetooth Operations

Bluetooth Detection Deployment Issues

- I5-SR299 Sensor Not Collecting Data

Bluetooth Operations

Bluetooth Detection Deployment Issues

- I5-SR299 Sensor Not Collecting Data
  - Bluetooth sensor not collecting data

Bluetooth Operations

Bluetooth Detection Deployment Issues

- I5-SR299 Sensor Not Collecting Data
  - Bluetooth sensor not collecting data
  - Failure coincided with a known power surge that effected other devices at the site (CCTV, UPS, etc.)

Bluetooth Operations

Bluetooth Detection Deployment Issues

- I5-SR299 Sensor Not Collecting Data
  - Bluetooth sensor not collecting data
  - Failure coincided with a known power surge that effected other devices at the site (CCTV, UPS, etc.)
  - Suspected power surge and initiated vendor RMA to replace sensor

Bluetooth Operations

Bluetooth Detection Deployment Issues

- I5-SR299 Sensor Not Collecting Data
  - Bluetooth sensor not collecting data
  - Failure coincided with a known power surge that effected other devices at the site (CCTV, UPS, etc.)
  - Suspected power surge and initiated vendor RMA to replace sensor
  - Vendor repaired micro-SD card and returned the unit

Bluetooth Operations

Bluetooth Detection Deployment Issues

- Default Username and Password

Bluetooth Operations

Bluetooth Detection Deployment Issues

- Default Username and Password
  - Unable to change the default username and password

Bluetooth Operations

Bluetooth Detection Deployment Issues

- Default Username and Password
  - Unable to change the default username and password
  - Vendor assured us the next generation of sensor would correct the issue

Bluetooth Operations

Bluetooth Detection Deployment Issues

- Default Username and Password
  - Unable to change the default username and password
  - Vendor assured us the next generation of sensor would correct the issue
  - Vendor later provided a patch for existing sensors to update the system firmware through the GUI

General Methodology

Sensors log time-stamped MAC addresses from Bluetooth and Wi-Fi devices traveling along the highway.

MAC addresses are paired across sensor sites. Travel times and speeds are estimated using these pairs.

General Methodology

Other possible measures include counts of paired MAC addresses and percentage of MAC addresses paired.

These measures characterize delay between sites and will be used in conjunction with chain control status to develop an algorithm to estimate delay.

General Methodology

CCTV camera images are used for visual confirmation and further site analysis.

Chain control messages are used for confirmation of chain control status.

Part 1: Early Proof of Concept

Early Proof of Concept

Work was conducted by the first set of Montana Tech students:

- River Sheppard (Data Science)
- Hunter Valdez (Computer Science)

January – April 2024

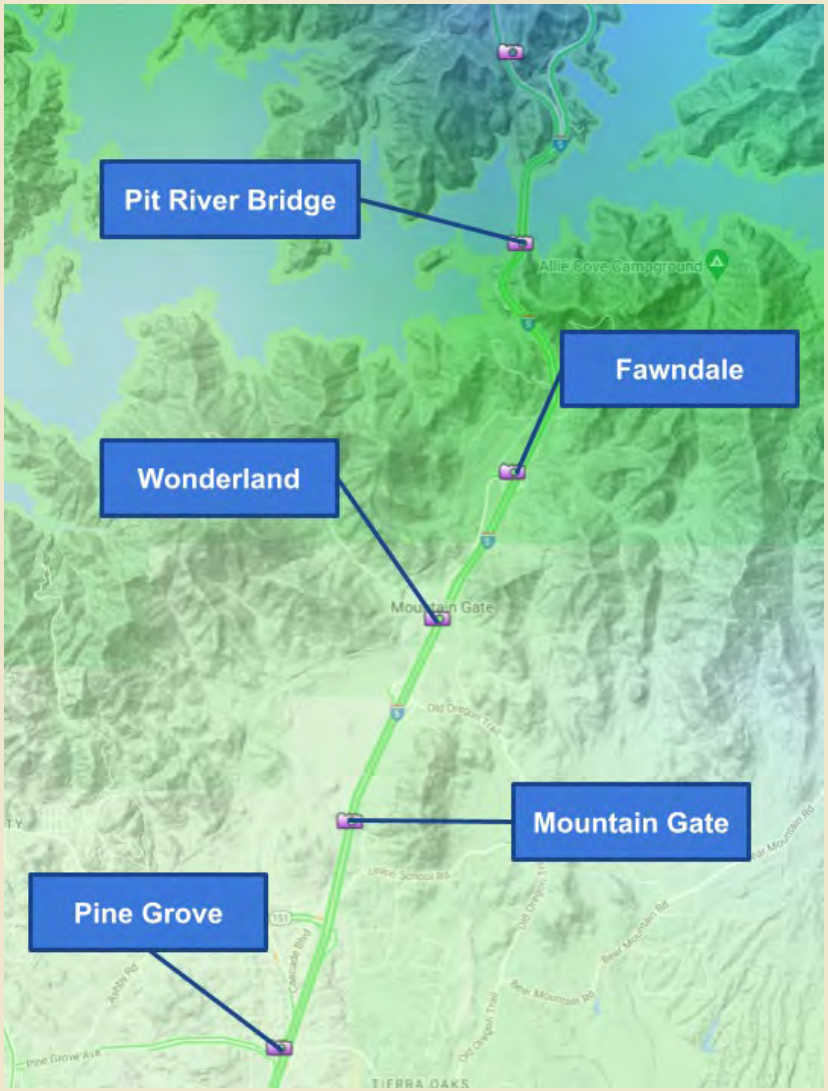
Sites

Pine Grove to Fawndale

These were the first two sites brought online – May 2023.

Data from these sites was used to compute travel times.

CCTV images from nearby sites were used to visually confirm the data.



Data

The sensors recorded the timestamp and device address whenever they detect a Bluetooth device (traditional and BTLE, BlueTooth Low-Energy).

At this time, only Bluetooth data was collected.

Wi-Fi data was not collected.

Data

One Bluetooth device does not necessarily mean one car.

It is possible, although less and less frequent for a car to have no Bluetooth devices.

It is possible and more and more likely for cars to have multiple devices.

Data

Timeframe for Analysis:

- Chain-up Event: January 6, 2024
- Prior data from 2023 was used to characterize normal travel

Privacy

To protect the privacy of drivers, MAC addresses are obscured here. The md5 hash of these addresses can be used in place of the MAC addresses to further protect privacy. This helps but is not perfect.

	TimeStamp	OUI	MAC	h4	RSSI	type	md5
0	1683124164	d2:e7:2b	[illegible]	0xffff	-84	BTLECAPT	032727cf8c6f2b2b89db756189cc7aec
1	1683124164	74:6f:f7	[illegible]	340408	-79	BTCAPT	0350a407c75a0c570c386beaf7173fb3
2	1683124164	74:58:55	[illegible]	0x004c	-85	BTLECAPT	6285722905e7d2e530998614103d65af
3	1683124164	6a:97:5f	[illegible]	0x004c	-71	BTLECAPT	de3563c70ceb9e89ff95178717e996ba
4	1683124164	56:55:20	[illegible]	0x004c	-76	BTLECAPT	ea1c0dd2c2944add79b03af45ac9ffab
5	1683124166	28:a8:6c	[illegible]	0x004c	-85	BTLECAPT	094c9d0eeb782493db83e32725fb5a38
6	1683124166	5c:63:c9	[illegible]	0x004c	-76	BTLECAPT	64bfab4127d16fe56cbe2d540cd9a717
7	1683124167	44:67:55	[illegible]	0x047f	-86	BTLECAPT	a2f52ccf7f455ea8e80fd47c6fd6e136
8	1683124169	3a:7f:6f	[illegible]	0x004c	-75	BTLECAPT	97a6509d50ca70db7a3fcc43b9bf9f09
9	1683124170	41:44:50	[illegible]	0x004c	-71	BTLECAPT	f7da152bde66ab890e5c1e727a232d9d
10	1683124171	76:f6:64	[illegible]	0x004c	-83	BTLECAPT	212387abb67ceb42637b2be1ff6d7dc0

Process - Overview

We tried to mimic what could be the eventual real-time process by sequentially processing data from each site and using the most-recent readings per MAC.

Computation was slow, but it was a first run.

MAC addresses were paired across sensor sites and (arbitrarily) 15th percentile travel times were computed. (Corresponds to 85th percentile speeds that are commonly used.)

Read Data and Compute Statistics

We started with a small set of data from the two Bluetooth sensors (sites) and performed data exploration and initial data processing.

We wrote a processing script that converted the Bluetooth reads into summary data.

We produced summary data in two forms:

- Site summaries that reported the number of unique and overall reads for each site.
- Travel summaries with statistics for travel times between paired sites.

Compute Travel Times

We mimicked what we envisioned for a real-time process:

- For each site we created a dictionary (associative array) with Bluetooth addresses as keys, and the timestamp as the stored value.
- We iterated through the data chronologically and updated the dictionaries.
- We computed travel times by matching the keys (MAC addresses) between two dictionaries and computing the difference between the timestamps for 5-minute intervals.

Summary Statistics

We aggregated data over varying time intervals into summary statistics :

- count, mean, standard deviation, minimum, 15th percentile, first quartile, median, third quartile, maximum, and trimmed means (10 %, 20%, 40%)

Robust statistics were used in anticipation of challenges with outliers.

	originSite	destinationSite	epochUTC	localtimestr	interval	count	mean	stddev	min	pct15	Q1	median	Q3	max	tmeanr10pct	tmeanr20pct	tmeanr40pct
0	Fawndale	PineGrove	1684344214	2023/05/17-10:23 -0700	900	13.0	273.153846	7.861787	262.0	264.00	273.00	274.0	274.00	294.0	273.153846	272.272727	272.777778
1	PineGrove	Fawndale	1684344214	2023/05/17-10:23 -0700	900	10.0	241.900000	6.081849	237.0	238.00	238.00	238.5	247.25	251.0	241.900000	241.375000	240.333333
2	Fawndale	PineGrove	1684344214	2023/05/17-10:23 -0700	1800	13.0	273.153846	7.861787	262.0	264.00	273.00	274.0	274.00	294.0	273.153846	272.272727	272.777778
3	PineGrove	Fawndale	1684344214	2023/05/17-10:23 -0700	1800	10.0	241.900000	6.081849	237.0	238.00	238.00	238.5	247.25	251.0	241.900000	241.375000	240.333333
4	Fawndale	PineGrove	1684344214	2023/05/17-10:23 -0700	3600	13.0	273.153846	7.861787	262.0	264.00	273.00	274.0	274.00	294.0	273.153846	272.272727	272.777778
5	PineGrove	Fawndale	1684344214	2023/05/17-10:23 -0700	3600	10.0	241.900000	6.081849	237.0	238.00	238.00	238.5	247.25	251.0	241.900000	241.375000	240.333333
6	Fawndale	PineGrove	1684344514	2023/05/17-10:28 -0700	900	70.0	276.614286	26.740998	215.0	250.35	260.50	274.0	296.75	330.0	276.750000	276.714286	276.071429
7	PineGrove	Fawndale	1684344514	2023/05/17-10:28 -0700	900	70.0	259.557143	26.057148	208.0	237.35	239.00	251.0	282.50	333.0	259.453125	258.589286	256.619048
8	Fawndale	PineGrove	1684344514	2023/05/17-10:28 -0700	1800	70.0	276.614286	26.740998	215.0	250.35	260.50	274.0	296.75	330.0	276.750000	276.714286	276.071429
9	PineGrove	Fawndale	1684344514	2023/05/17-10:28 -0700	1800	70.0	259.557143	26.057148	208.0	237.35	239.00	251.0	282.50	333.0	259.453125	258.589286	256.619048
10	Fawndale	PineGrove	1684344514	2023/05/17-10:28 -0700	3600	70.0	276.614286	26.740998	215.0	250.35	260.50	274.0	296.75	330.0	276.750000	276.714286	276.071429

Summary Statistics

We computed summary statistics over different interval widths:

- 300 sec (5 min), 600 sec (10 min), 900 sec (15 min), 1200 sec (20 min), 1800 sec (30 min), 3600 sec (60 min)

	originSite	destinationSite	epochUTC	localtimestr	interval	count	mean	stddev	min	pct15	Q1	median	Q3	max	tmeanr10pct	tmeanr20pct	tmeanr40pct
0	Fawndale	PineGrove	1684344214	2023/05/17-10:23 -0700	900	13.0	273.153846	7.861787	262.0	264.00	273.00	274.0	274.00	294.0	273.153846	272.272727	272.777778
1	PineGrove	Fawndale	1684344214	2023/05/17-10:23 -0700	900	10.0	241.900000	6.081849	237.0	238.00	238.00	238.5	247.25	251.0	241.900000	241.375000	240.333333
2	Fawndale	PineGrove	1684344214	2023/05/17-10:23 -0700	1800	13.0	273.153846	7.861787	262.0	264.00	273.00	274.0	274.00	294.0	273.153846	272.272727	272.777778
3	PineGrove	Fawndale	1684344214	2023/05/17-10:23 -0700	1800	10.0	241.900000	6.081849	237.0	238.00	238.00	238.5	247.25	251.0	241.900000	241.375000	240.333333
4	Fawndale	PineGrove	1684344214	2023/05/17-10:23 -0700	3600	13.0	273.153846	7.861787	262.0	264.00	273.00	274.0	274.00	294.0	273.153846	272.272727	272.777778
5	PineGrove	Fawndale	1684344214	2023/05/17-10:23 -0700	3600	10.0	241.900000	6.081849	237.0	238.00	238.00	238.5	247.25	251.0	241.900000	241.375000	240.333333
6	Fawndale	PineGrove	1684344514	2023/05/17-10:28 -0700	900	70.0	276.614286	26.740998	215.0	250.35	260.50	274.0	296.75	330.0	276.750000	276.714286	276.071429
7	PineGrove	Fawndale	1684344514	2023/05/17-10:28 -0700	900	70.0	259.557143	26.057148	208.0	237.35	239.00	251.0	282.50	333.0	259.453125	258.589286	256.619048
8	Fawndale	PineGrove	1684344514	2023/05/17-10:28 -0700	1800	70.0	276.614286	26.740998	215.0	250.35	260.50	274.0	296.75	330.0	276.750000	276.714286	276.071429
9	PineGrove	Fawndale	1684344514	2023/05/17-10:28 -0700	1800	70.0	259.557143	26.057148	208.0	237.35	239.00	251.0	282.50	333.0	259.453125	258.589286	256.619048
10	Fawndale	PineGrove	1684344514	2023/05/17-10:28 -0700	3600	70.0	276.614286	26.740998	215.0	250.35	260.50	274.0	296.75	330.0	276.750000	276.714286	276.071429

Analysis

We focused our analysis on paired MAC counts and 15th percentile travel times:

- The count of paired MACs is a proxy for traffic volume and an indicator of support of computed statistics. (Recall – one device does not equal one car).

- 15th percentile travel corresponds to 85th percentile speed (travel time is inversely related to speed).

Challenges

We encountered challenges that needed to be addressed:

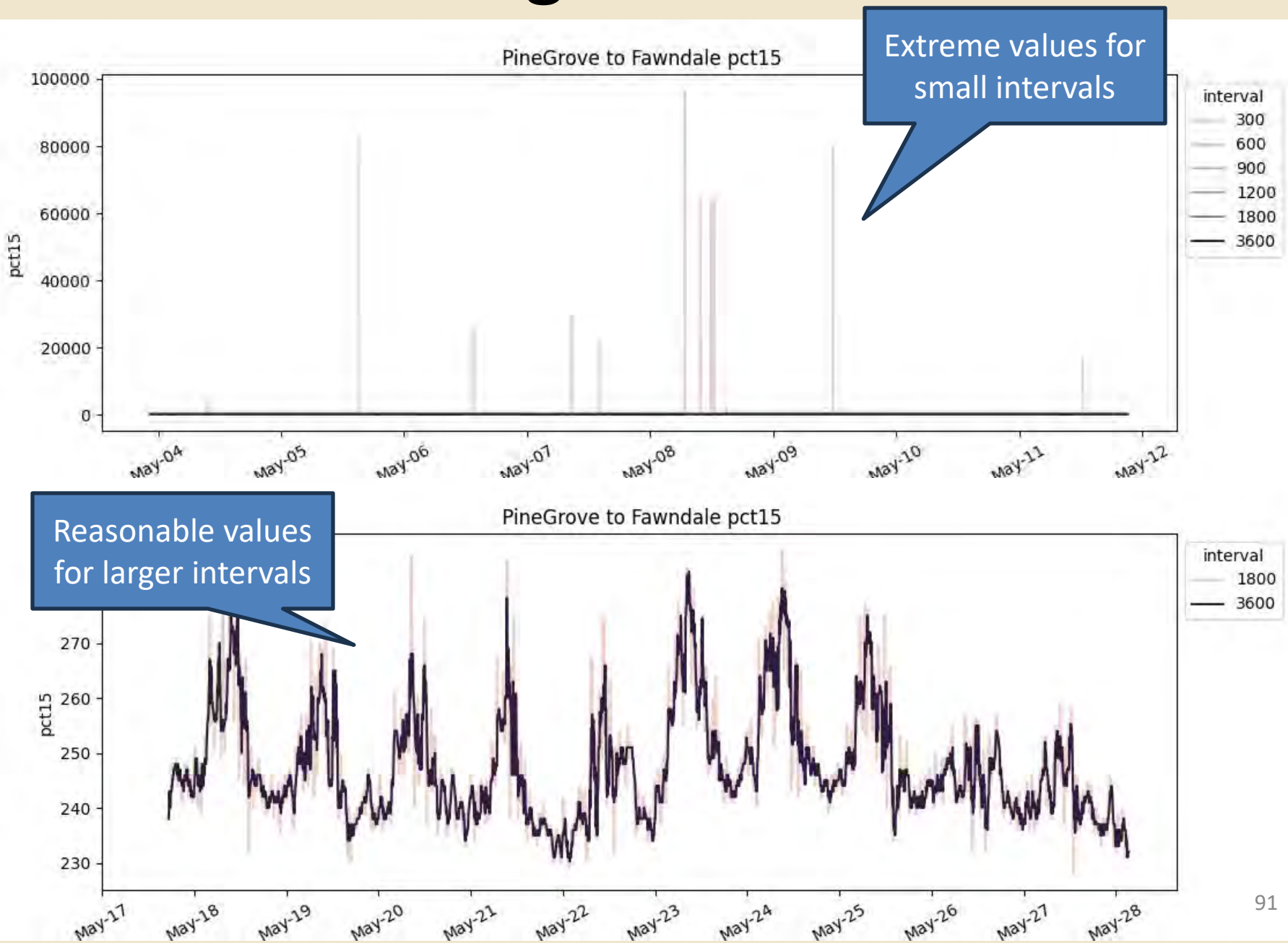
- Outliers
- Computation Time
- Data Wrangling

Challenges - Outliers

For small interval sizes, outliers dominated many intervals, particularly during chain-up events, resulting in extreme values for the summary statistics.

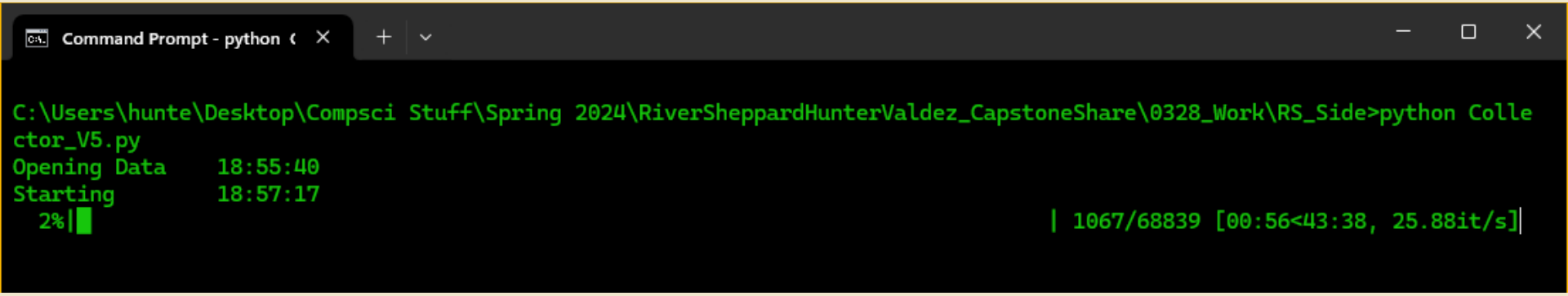
We subsequently focused on interval sizes of 30 minutes and 1 hour, striking a balance between usable data and bad data.

Challenges - Outliers



Challenges – (In)Efficiency

When working with larger datasets, our processing script became unusably slow, even on reasonable hardware.



Challenges - Efficiency

We addressed this by:

- consolidating our loops into one, resulting in an O(n) operation instead of $O(n^2)$.
- setting our dictionary to clear (old) values after a period of time to reduce memory use and computation time during the program's execution.

The final processing time for 8 months' worth of data became 50 minutes, whereas older scripts had been unable to finish in reasonable time.

(This was still inefficient, but it worked.)

Challenges – Data Wrangling

We struggled with extreme large travel times, and it took us a while to conjecture on what was causing them.

A challenge with this is that large travel times are valid during a chain-up event, which is what we are trying to characterize.

A poorly chosen cutoff value might exclude valid data.

Challenges – Data Wrangling

We speculated that some extreme values were caused by a scenario where a device passes the first sensor but then gets off the highway before the second sensor.

Then hours or even days later during a different trip or after getting back on the road for the same trip, the device passes the second sensor, making it look like it took an abnormally long time to travel a relatively short distance.

Another possibility was that a device read was made at one site but missed at the next on the initial trip.

Challenges – Data Wrangling

We attempted to resolve the issue of extreme values by removing addresses past a certain age from the dictionary, as those data points are not considered to be from a recent trip.

Results

Results were promising – delay was apparent. We found what we were looking for, green-lighting expansion to a larger group of sites and subsequent analysis.

We prepared to expand to larger group of sites: from 2 to 4.

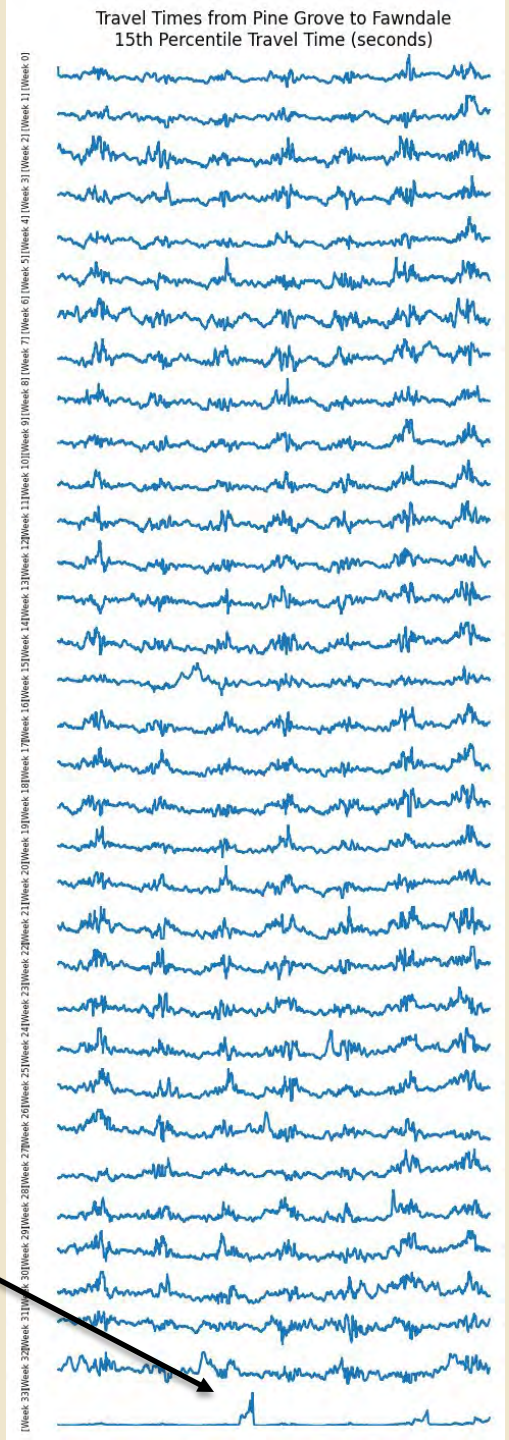
Results

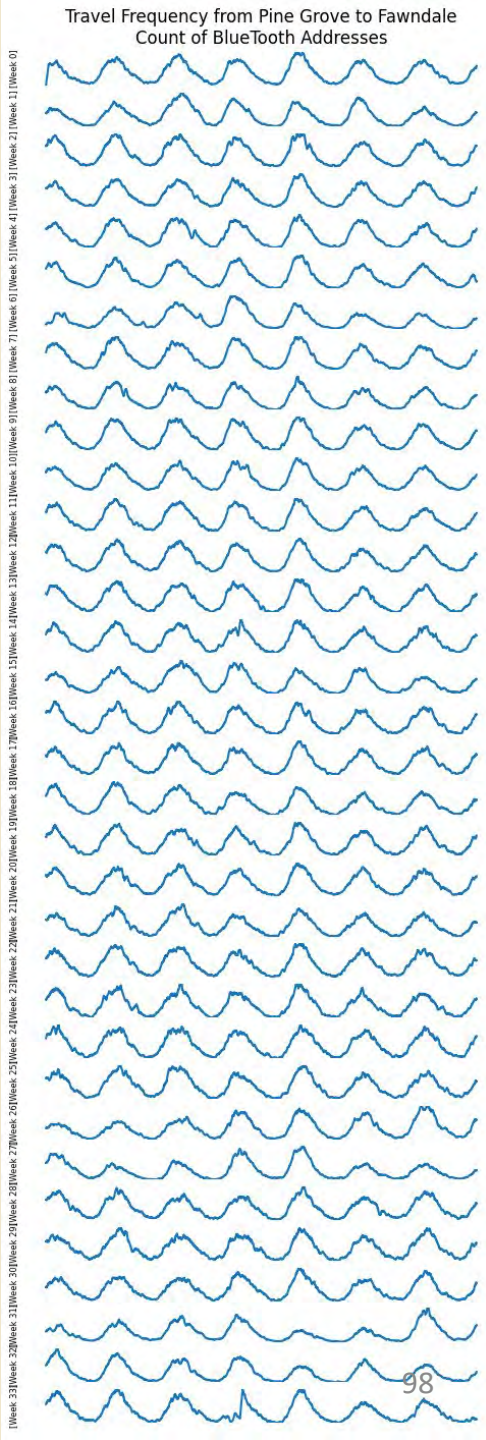
We split the data into week-long segments, making it easier to see several very clear points of delay.

We successfully detected periods experiencing delay by plotting travel time estimates for the entire period.

Here is a week where apparent delay occurred:

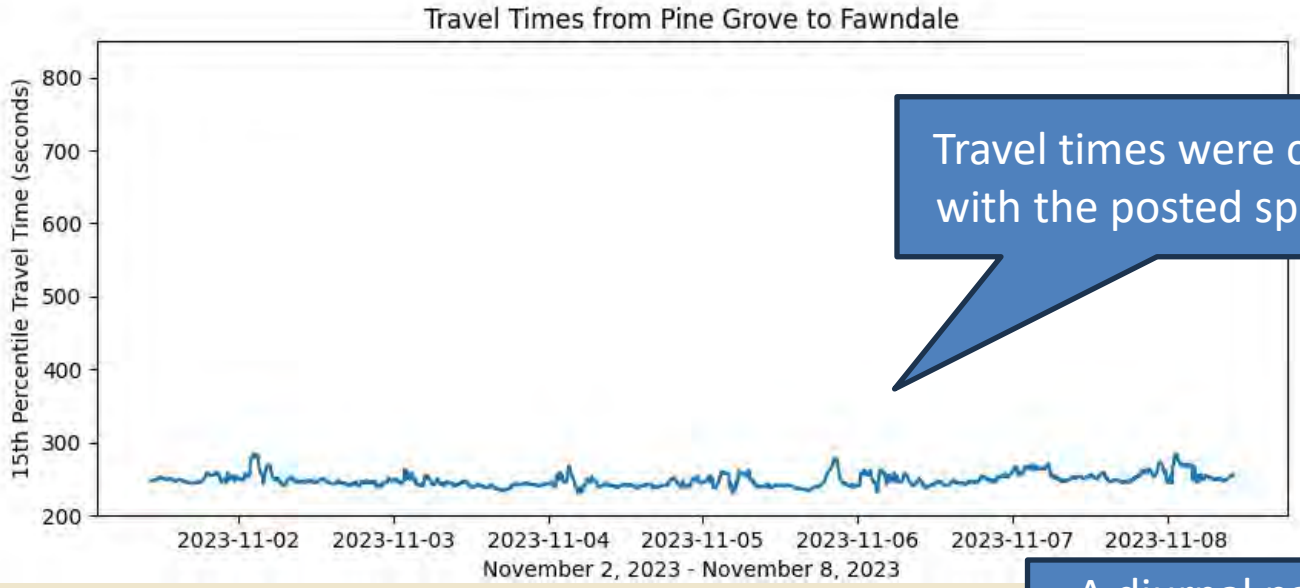
January 4th to 10th, 2024





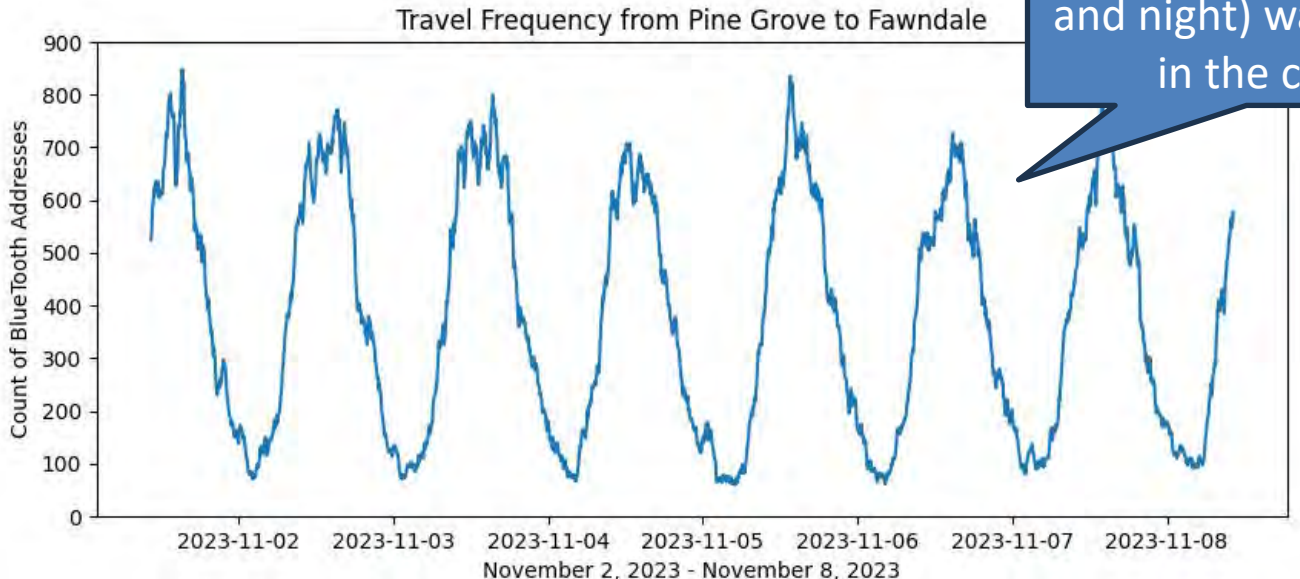
Normal Flow

Travel Time



Travel times were consistent with the posted speed limit.

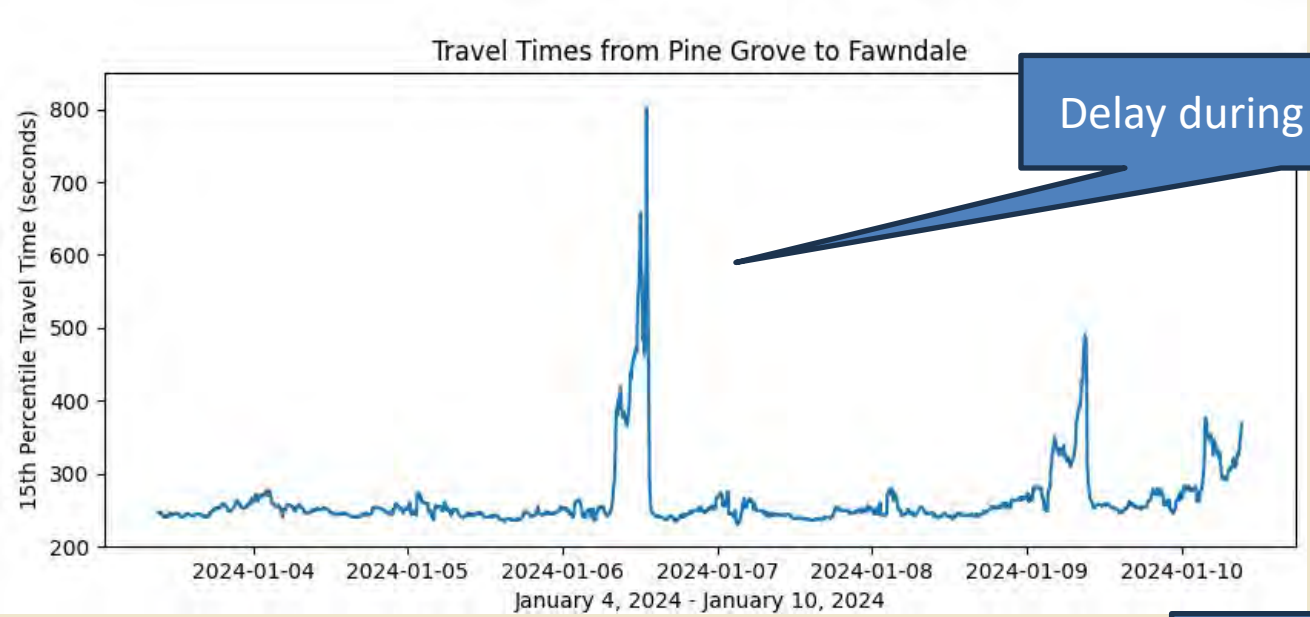
Paired Addresses



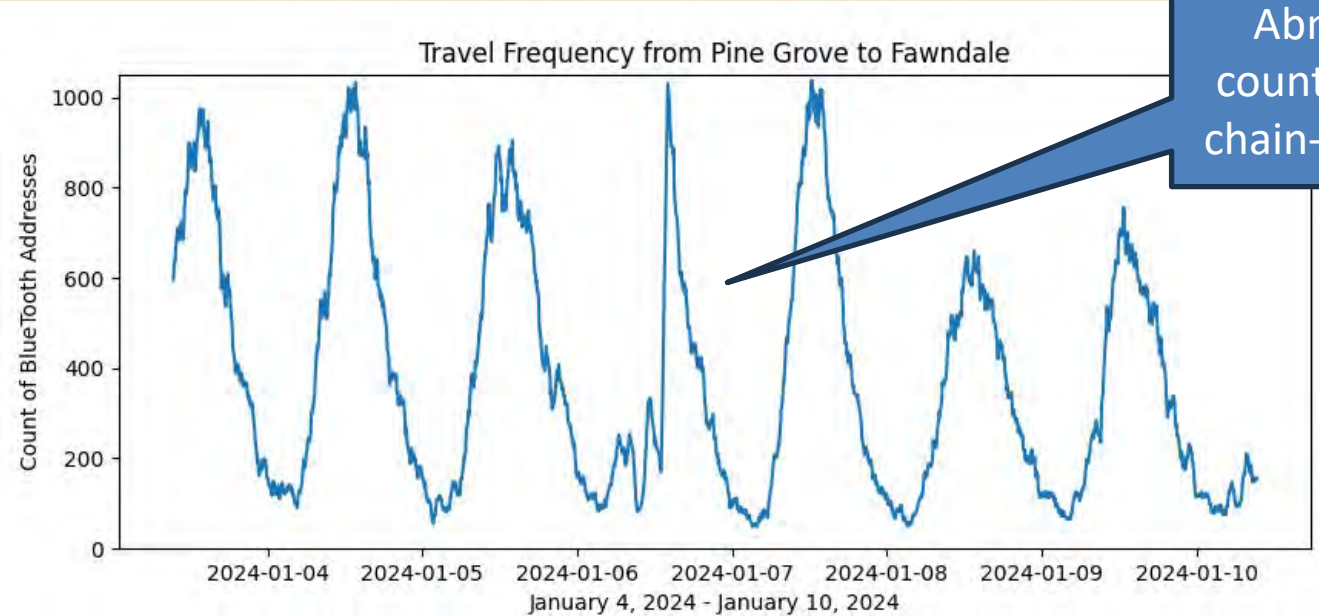
A diurnal pattern (day and night) was apparent in the counts.

Delay

Travel Time



Paired Addresses



Validation

CCTV images and chain control messages confirmed that the detected delay was real, and there was traffic backup at that time.

The backup started at Fawndale shortly after chain control went into effect, built up over time and extended past Wonderland and Mountain Gate.

When chain control ended, Fawndale traffic began to clear, followed by Wonderland and then Mountain Gate.

Validation

Chain Control Message	Time
All truck trailer combinations are being held at the chain control camper due to incidents or weather-related conditions.	8:23 AM
Vehicle Screening—All vehicles will be checked to make sure they have a full set of tire chains before being allowed to travel into areas where chains will be required.	10:00 AM
No chain controls are in effect at this time.	12:58 AM

	Fawndale	Wonderland	Mountain Gate	Pine Grove
Delay				
Clearing				
Cleared				

Early Proof of Concept Conclusions

At times, we found ourselves swimming in too much data:

- Interval size should be fixed. 30 and/or 60 minutes appear best.
- Stats get out of control fast, particularly in the presence of bad data. More work needed to be done to pin down the best statistical measures to represent data in the aggregate.
- We need to be careful about depending on stats, particularly in the presence of bad data.

Early Proof of Concept Conclusions

We demonstrated that it was possible to detect delays using the Bluetooth data. We took the initial data, processed it, and visually detected periods where delay occurred.

We felt that the project should move forward with more sites and into the development of a delay estimation algorithm.

Techxpo 2024
(Montana Tech Student Research Exposition)

Chain-up Delay Tracking and Estimation

Project Members: Dr. Douglas Galarus (mentor), River Sheppard, Hunter Valdez

Background

Interstate 15 between Redding, California and Lake Shasta frequently experiences delays due to bad weather and chain requirements. Our mentor Dr. Douglas Galarus is working with Caltrans (The California Department of Transportation) to predict travel delay time when chain requirements are in effect. We joined the project as data analysts and computer programmers, and our goal was to process raw data and detect delays. Our results will be used in future work to estimate delay times.



We were given data from Bluetooth sensors deployed along the highway to sense and record Bluetooth devices traveling on the highway, as well as the time at which devices were detected. We also had access to CCTV images taken from traffic cameras, and chain control messages and times.

Methodology

We started with a small set of data from two Bluetooth sensors, and performed data exploration and initial data processing. We wrote a processing script that converted the Bluetooth reads into summary data. We produced summary data in two forms: site summaries which record the number of unique and overall reads for each site, and a travel summaries with statistics for travel times between paired sites.

Our script processed data every five minutes, consolidating 15-minute, a 30-minute, and hour-long intervals. The range of intervals proved useful as short intervals were more responsive to events occurring throughout the day, but were sensitive to outliers whereas longer intervals were not.

We collected travel time statistics for two sets of Bluetooth data: one spanning approximately 1 week and a larger one spanning 8 months. Efficiency issues arose due to the size of the larger dataset, but we still managed to successfully produce statistics for the 8 month dataset.

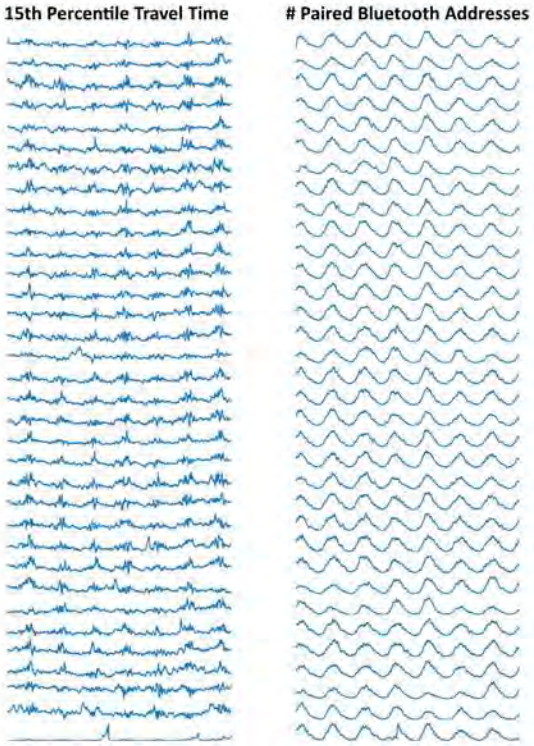
The transportation community commonly uses the 85th percentile speed as one of their primary metrics for flow. Due to the inverse relationship between speed and travel time, we utilized the 15th percentile of travel times which corresponds to the 85th percentile of speeds.

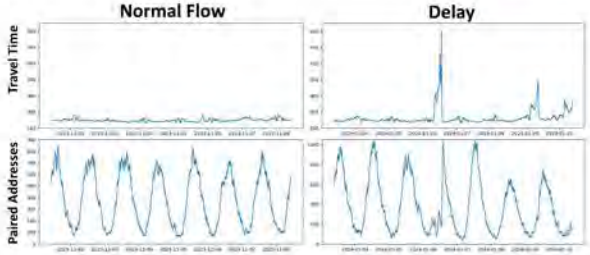
Results

We successfully detected periods experiencing delay by plotting travel time estimates for the entire period. After splitting the period into week-long segments, it became much easier to see several very clear points of delay. For instance, in the plots to the right is a period with normal flow, as well as a period with visible delay.

It is apparent that there are delays occurring during morning on January 6th. Cross-referencing the traffic cameras in the area, as well as the chain control messages confirm that the detected delay was genuine, and there was traffic backup at that time.

For this particular situation, a backup starts at Fawndale shortly after chain control goes into effect and builds up over time extending past Wonderland and Mountain Gate (though never quite reaching Pine Grove). When chain control ends, Fawndale traffic begins to clear, followed by Wonderland and then Mountain Gate.





Chain Control Messages on January 6, 2024

Time	Chain Control Message
8:23 AM	All truck trailer combinations are being held at the chain control camper due to incidents or weather related conditions.
10 AM	Vehicle Screening—All vehicles will be checked to make sure they have a full set of tire chains before being allowed to travel into areas where chains will be required.
12:58 AM	No chain controls are in effect at this time.



Conclusions

We wrote a processing script that can efficiently and accurately process a large amount of data, and then using the processed data we were able to detect a delay. Our current detection method is visual analysis of summary plots of the data, which demonstrates that it is possible to detect delay from Bluetooth data. We feel that the project will be able to move forward into the development of a delay estimation algorithm.

Credits

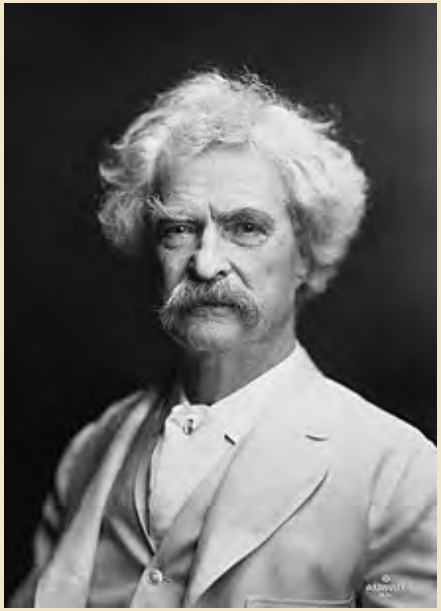
Thanks go to our mentor Dr. Douglas Galarus for his support, as well as Caltrans for providing the problem and related data.

“… lies, damned lies, and statistics …”

“… lies, damned lies, and statistics …”

"There are three kinds of lies: lies, damned lies, and statistics.“

Popularized by Mark Twain
(Correct attribution unknown.)



https://en.wikipedia.org/wiki/Mark_Twain#/media/File:Mark_Twain_by_AF_Bradley.jpg

https://en.wikipedia.org/wiki/Lies,_damned_lies,_and_statistics

DISCLAIMER:

Nobody lied and we believe our initial analysis was valid.

Data Mining

"If you look hard enough, you find stuff …

That thing is called Data Mining

and beware."

-Lisa Goldberg, UC Berkeley

We found what we were looking for …

We found what we were looking for, so we assumed all was good.

We found what we were looking for …

We found what we were looking for, so we assumed all was good.

Beware …

Part 2: Validation, Expansion, Bad Data

Bad Data

Recall the struggles the team had with extreme large travel times?

Bad Data

Some extreme small (implausible) travel times were also encountered.

These too were discounted as outliers that could be ignored because the data appeared to be valid in the aggregate.

We ignored these because we found what we were looking for.

Bad Data

Some extreme small (implausible) travel times were also encountered.

These too were discounted as outliers that could be ignored because the data appeared to be valid in the aggregate.

We ignored these because we found what we were looking for.

Beware …

Validation, Expansion, Bad Data

Student:

- Jacob Sririman, Paid Intern - Summer 2024

Task:

- Expand from two sites (Pine Grove and Fawndale) to four sites and then twelve sites.

Bad Data

Problems became more apparent in the data – impossible travel times.

Summary statistics yielded more unusable, impossible values.

Bad Data

My student was stuck.

He could not explain what was going on with the data, but it became apparent that this was a big problem that could not be ignored.

Bad Data

It reached an (oh shoot) moment where I (Galarus) had to drop everything to get to the bottom of the problem.

Bad Data

It reached an (oh shoot) moment where I (Galarus) had to drop everything to get to the bottom of the problem.



Bad Data

I suspected there was an issue with timestamps, and I quickly developed a methodology to examine the problem.

Bad timestamps and clock issues were suspected as the problem.

Observed Times on Devices

Time deviations were observed via comparison of times reported through device web interfaces with desktop time.

While not exact, this approach was close enough to see differences.

Real time data observations showed timestamps that were off by several minutes or more from actual time.

See subsequent discussion of time zone settings.

Observed Times on Devices

The following deviations are based on observations made at approximately 8:20 AM PDT August 1st, 2024.

Site	Observed Deviation from Actual Time
Pit River Bridge	-8 min 8 sec
Fawndale	-1 min 20 sec
Wonderland	+6 min 7 sec
Mountain Gate	**+13 min 50 sec**
Pine Grove	+3 min 32 sec
I5-SR273	+2 min 53 sec
I5-SR299	+1 min 26 sec
I5-SR44	+10 min 3 sec
Hartnell	-2 min 43 sec
South Bonnyview	**-7 min 27 sec**
Knighton	+8 min 13 sec
Riverside	+6 min 59 sec

Observed Times on Devices

Realize that our analysis was and continues to be conducted using historical data logged locally on the sensors.

We were not looking at the data in real time at this point other than casual observation when connecting to the devices to download bulk historical data.

Timestamps were assumed to be correct.

Observed Times on Devices

We had many questions, conjectures and concerns.

One question was why did the initial analysis appear to be correct?

We even questioned whether this could be a stopped-clock being right twice a day situation – that the data from both Pine Grove and Fawndale was wrong, but consistently wrong, yielding what appeared to be a correct result when differences were taken.

Observed Times on Devices

The end of summer was approaching as was the bad weather season.

Not only did it appear that we had lost good historical data, but we risked losing the potential to collect data at a critical time.

NTP and GPS

All devices reported settings corresponding to an NTP server on the Caltrans network.

Separate testing was done to query this NTP server for current time remotely over VPN to the Caltrans network and over a slow, remote home internet connection.

In all cases, the NTP server reported times within 1-2 seconds of times reported on the local desktop computer.

If I could query the NTP server via VPN and get a usable response, why wasn't it working for the sensors?

NTP and GPS

It was unclear whether NTP or GPS or some combination was working to adjust times on the devices.

GPS is onboard on the devices.

We did not have time to further analyze GPS interactions in the data. It is possible that attempts were made by devices to update their clocks using GPS. We assumed such attempts would be made every day or at most every week or so.

Time Zones

While not necessarily a contributing factor, two devices had their time zone configured to UTC-7 US & Canada Mountain/Mexico Sonora: Pit River Bridge and South Bonnyview.

These were the last two sites brought online.

All other sites were set to UTC-8: US & Canada Pacific/Mexico Baja California.

Time Zones

Daylight savings time did not appear to be accounted for with display of local time.

At the time we did this analysis, daylight savings time was in effect, so local time on the devices should have been UTC-7 PDT.

Our assumption was that observations were recorded with UTC epoch timestamps. We confirmed this via our analysis of the data.

As such, deviations in time zone settings should not impact the historical data. It would only impact display on the devices.

Further Analysis

After discovering anomalies in computed travel times, we conducted the following analysis to characterize the problem.

This analysis helped to show apparent clock shift and drift over time.

The Observed Times on Devices reported above confirmed clock problems.

This analysis further characterizes it.

Further Analysis

Observations were selected within a given time interval for pairs of sites.

Observations were paired across sites using MAC addresses.

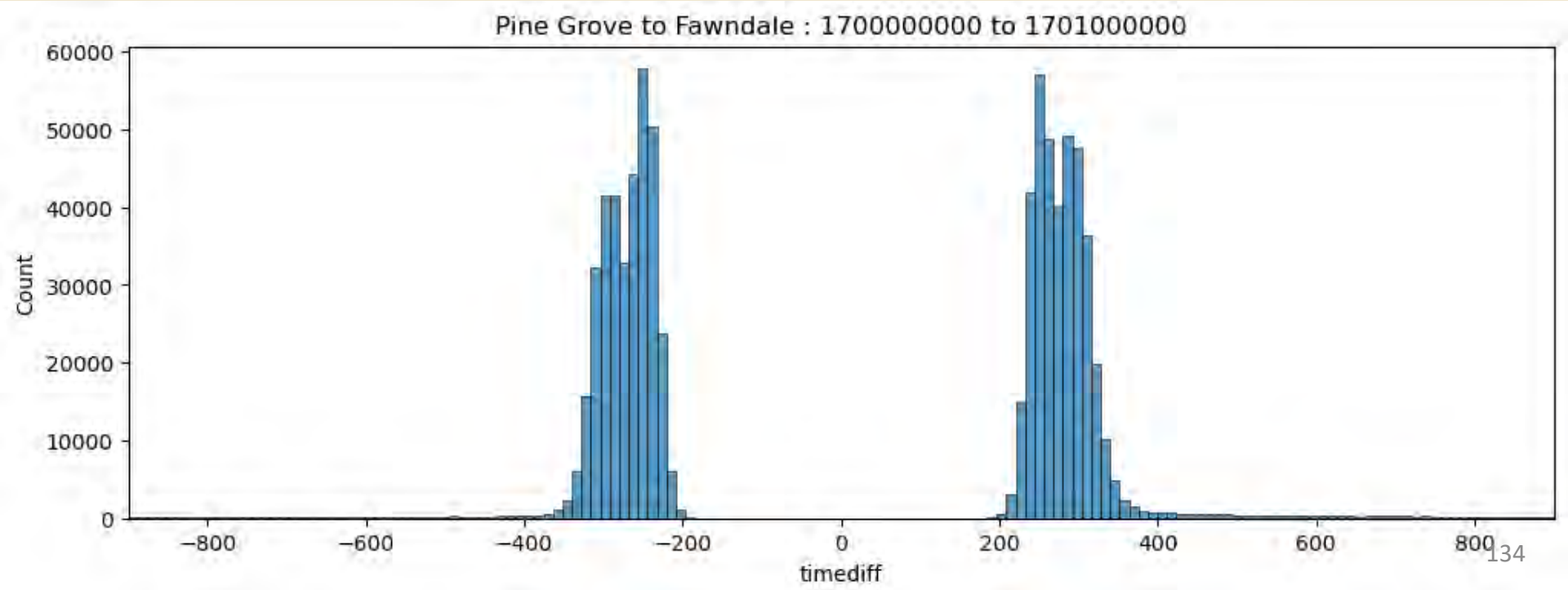
Time differences were computed by subtracting the timestamp for the south-most site from the timestamp for the north-most site.

Positive time differences (should) correspond to northbound travel and negative differences (should) correspond to southbound travel.

Expected patterns were observed in the distribution of these time differences.

Good Data Example

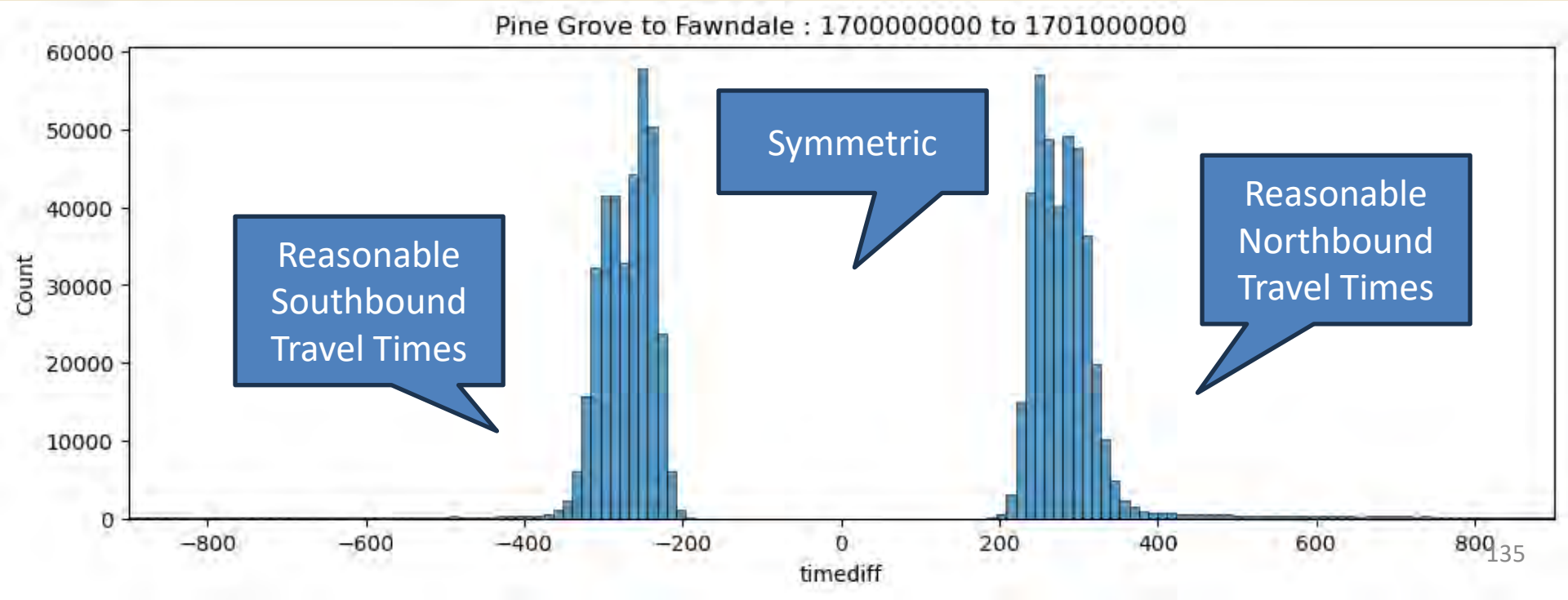
The distribution of travel times for Pine Grove and Fawndale between 1700000000 UTC epoch (11/14/2023 2:13:20 PM) to 1701000000 UTC epoch (11/26/2023 4:00:00 AM) appeared to show good data.



Good Data Example

Pine Grove to Fawndale: 5-mile segment length.

Expected travel time: 277 sec = 4 min 37 sec @ 65 mph



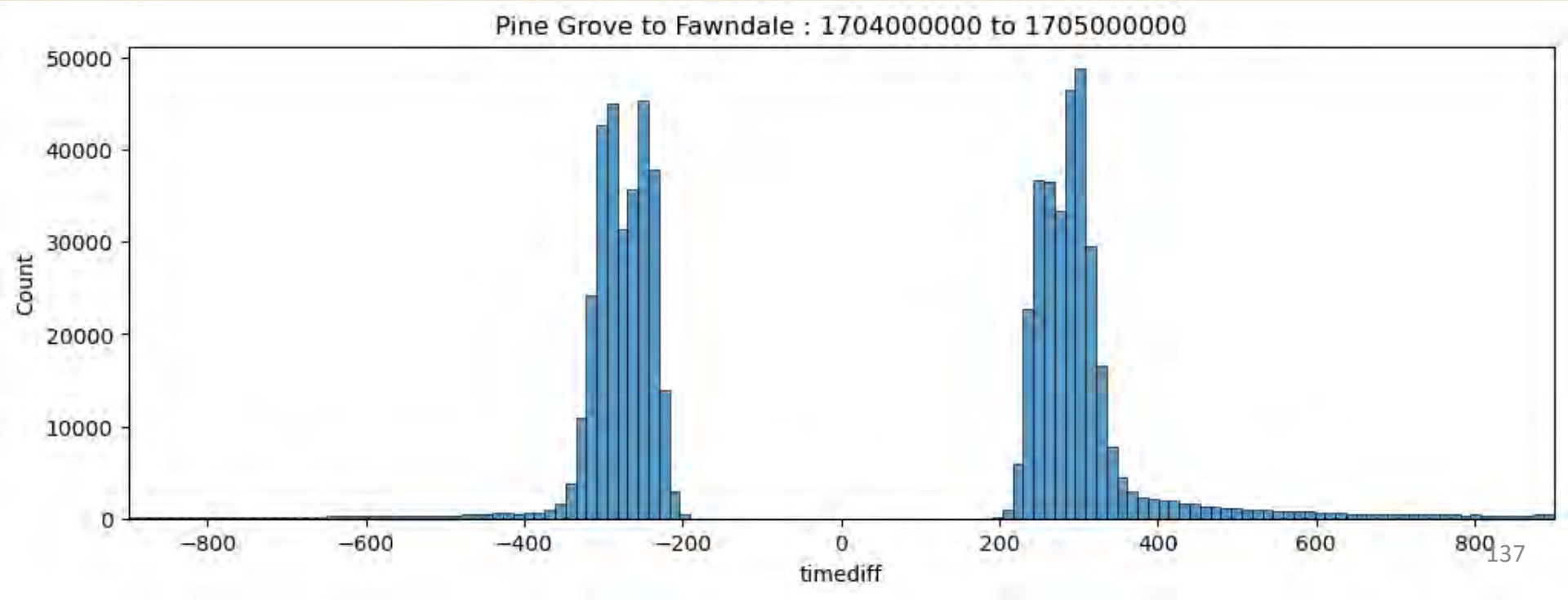
Good Data Example

This data exhibited expected characteristics:

- Southbound traffic falls to the left of the origin (negative values).
- Northbound traffic falls to the right of the origin (positive values).
- Travel times are distributed around expected travel times at the posted speed limit.
- The distributions are roughly symmetric about the origin relative to each other. This is expected assuming comparable volume, including vehicle types, and conditions.
  - Differing volumes could yield differences.
  - Differing conditions (weather, work zones, etc.) could yield differences.

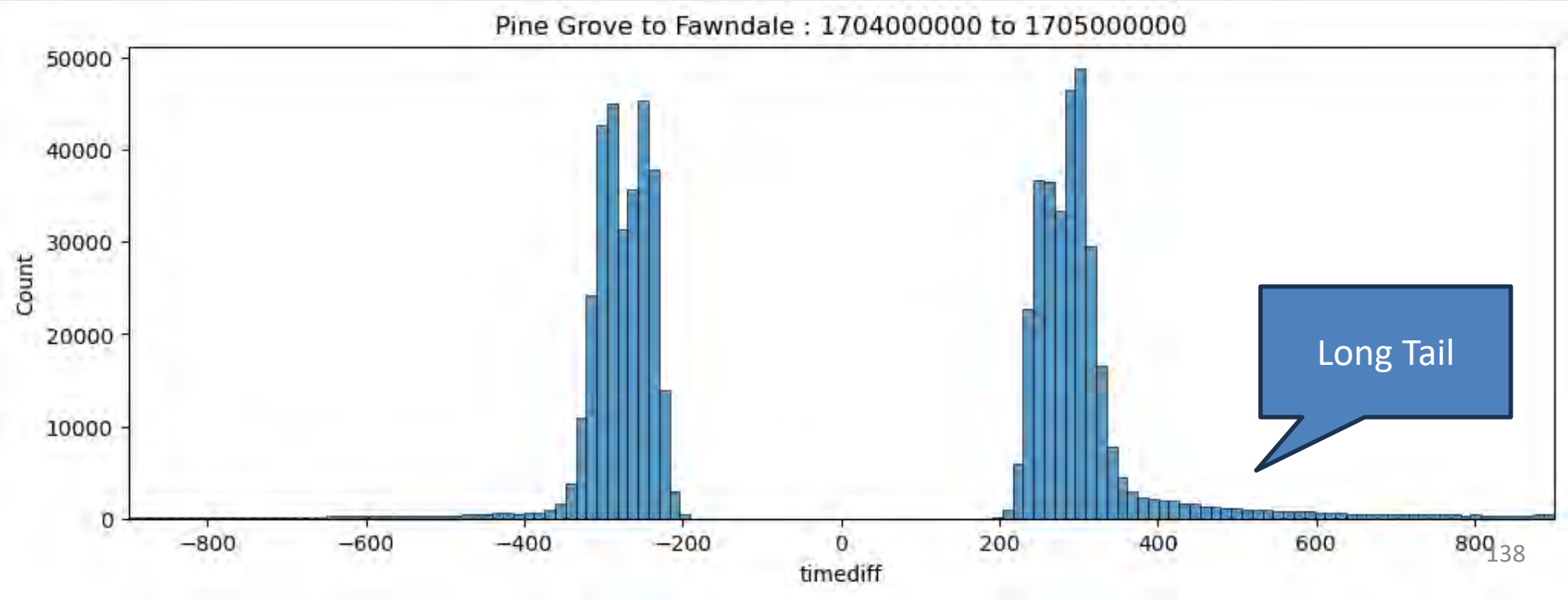
More Good Data

The travel times for Pine Grove and Fawndale between from 1704000000 UTC epoch (12/30/2023 9:20:00 PM Pacific) to 1705000000 UTC epoch (1/11/2024 12:06:40 PM Pacific) appeared to show good data. NOTE: This time-period overlaps with the chain-up event we previously analyzed.



More Good Data

Notice the prominent long tail on right (Northbound) side. This presumably corresponds to delay from the chain up event.



Bad Data

These examples showed expected behavior. I.e., good data.

Subsequent examples showed what might have initially appeared to be good data but eventually the data became obviously bad.

This was a consequence of incorrect times on the devices, clock drift, and instantaneous shifts in times.

Bad Data

Issues were observed and documented relative to the expected pattern and over time:

- Drift: gradual drift of the distribution in one direction over time. Likely due to clock drift on one or both sensors.

- Shift: abrupt shift of the distribution at a point in time. Possibly due to update of individual device time via NTP or GPS, although shifts did not appear to result in correct times.

Bad Data

Our basic assumption for the calculation of travel times was that positive times are northbound, negative times are southbound.

A reasonable window of times would then be used to clip observations for subsequent calculation of mean, percentiles, or similar.

This is the approach we used originally to estimate travel times, and it yielded anomalous results.

An incorrectly located distribution, either because of shift or drift as described above, makes the computed travel times incorrect.

Clock Issues - Shift

All sites appeared to experience shift.

Shifts appeared to occur at least once every several months.

Large shifts did not appear to yield correct timestamps, i.e., did not appear to successfully synchronize clocks.

Most shifts appeared to worsen the timestamps relative to actual time.

Since our methodology involved comparison of paired sites, shifts could be to correct time for an individual site and still yield incorrect travel time estimates due to a still incorrect time at the other site.

Clock Issues - Drift

The following sites appeared to experience drift:

- Pit River Bridge
- Fawndale
- Pine Grove
- I5-SR273

Data from pairs of sites that included these sites showed a continuous drift in travel time estimates.

We found it interesting and odd that data from Pine Grove and Fawndale appeared to be correct over months of initial data collection and analysis, then both appeared to drift and experience shifts.

Bad Data – Pine Grove to Fawndale

Distance: 5 miles

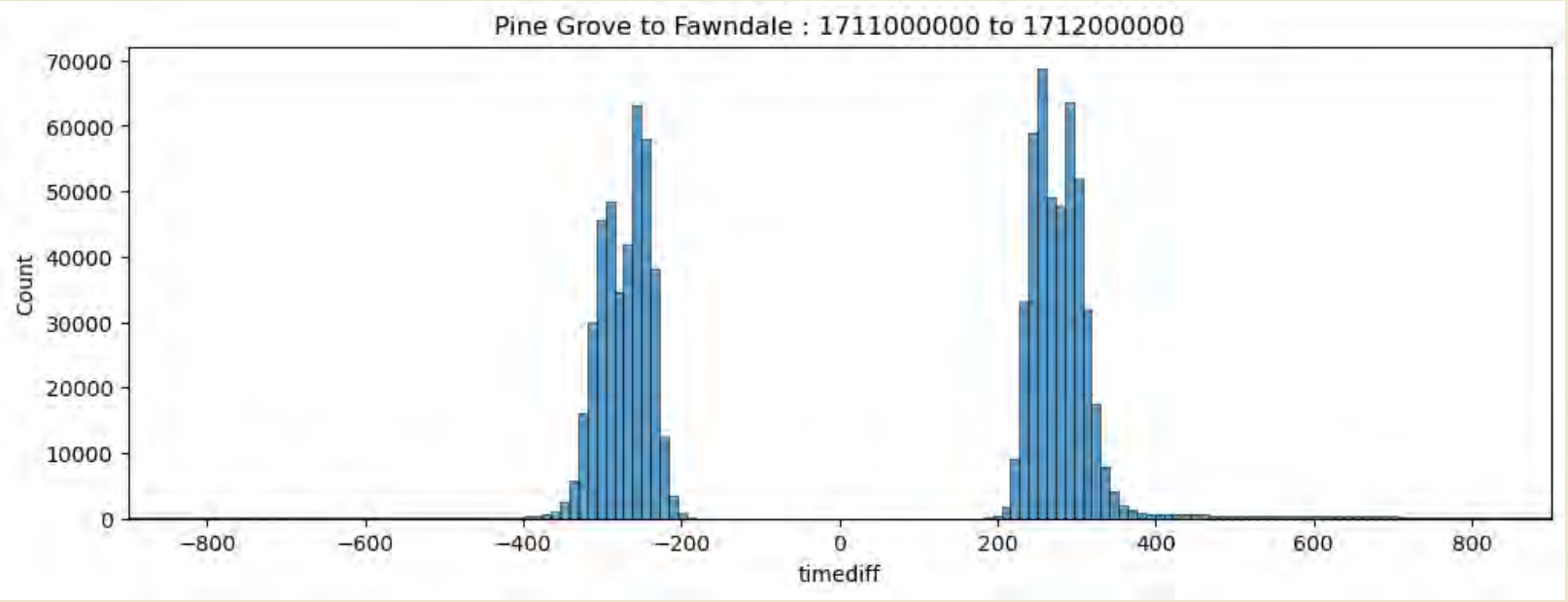
Expected Travel Time: 277 sec = 4 min 37 sec @ 65 mph

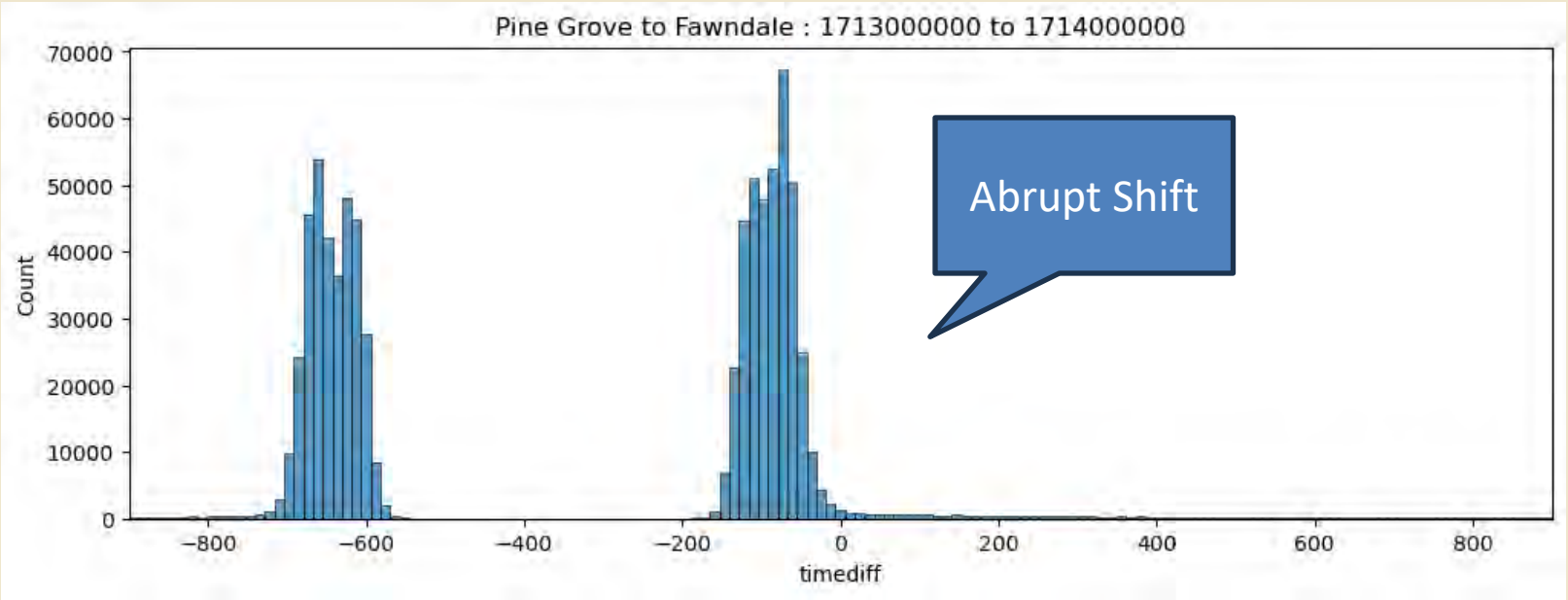
- Travel time estimates appeared correct and stable from UTC epoch 1700000000 (11/14/2023 2:13:20 PM) to UTC epoch 1712000000 (4/1/2024 12:33:20 PM).

- A time shift of approximately -350 seconds occurred between UTC epoch 1712000000 (4/1/2024 12:33:20 PM) and UTC epoch 1713000000 (4/13/2024 2:20:00 AM). Estimated travel times were now obviously incorrect because nearly all estimated travel times were negative.

- Estimated travel times remained incorrect but stable through UTC epoch 1720000000 (7/3/2024 2:46:40 AM).

Bad Data – Pine Grove to Fawndale





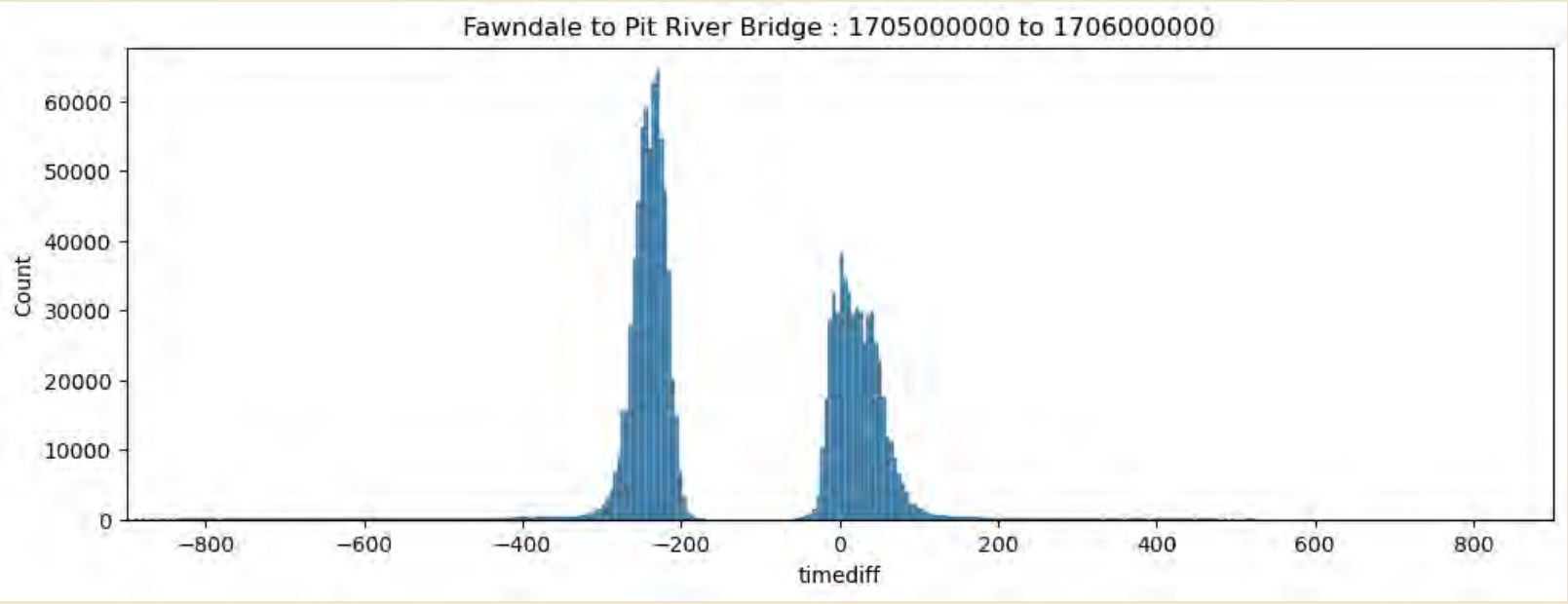
Bad Data – Fawndale to Pit River Bridge

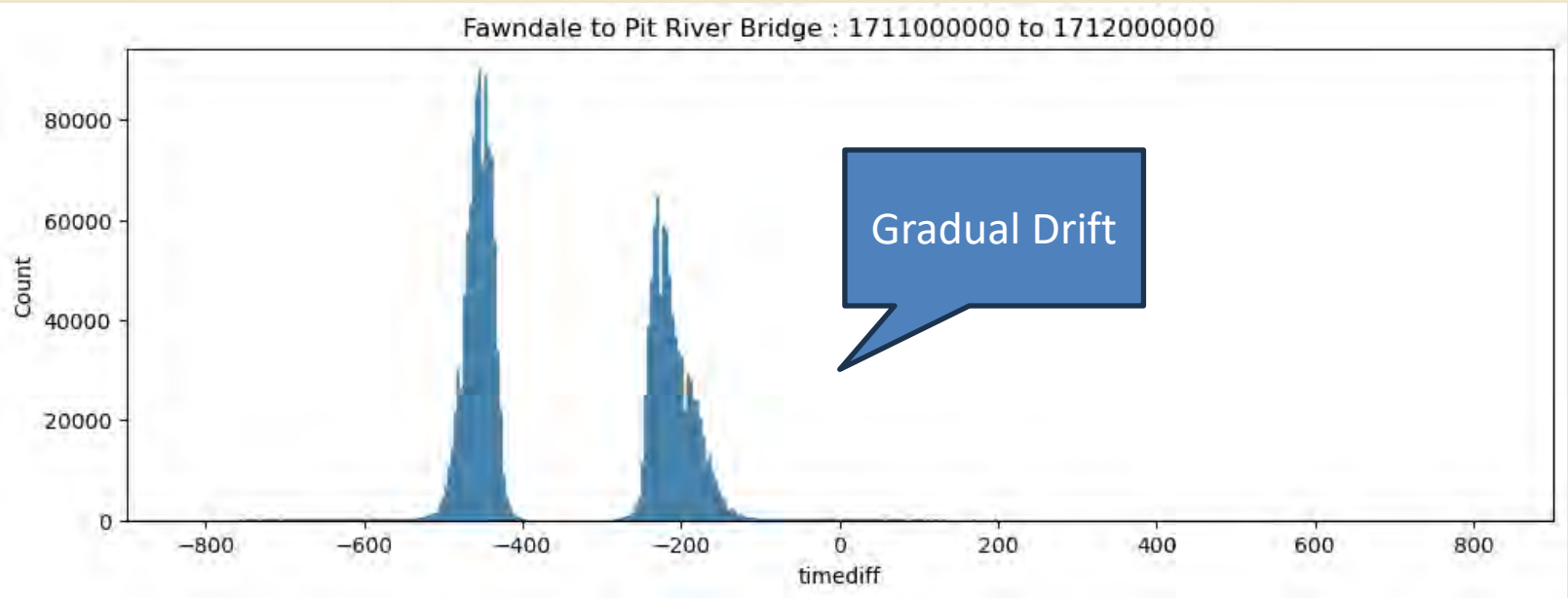
Distance: 2.1 miles

Expected Travel Time: 116 sec = 1 min 56 sec @ 65 mph

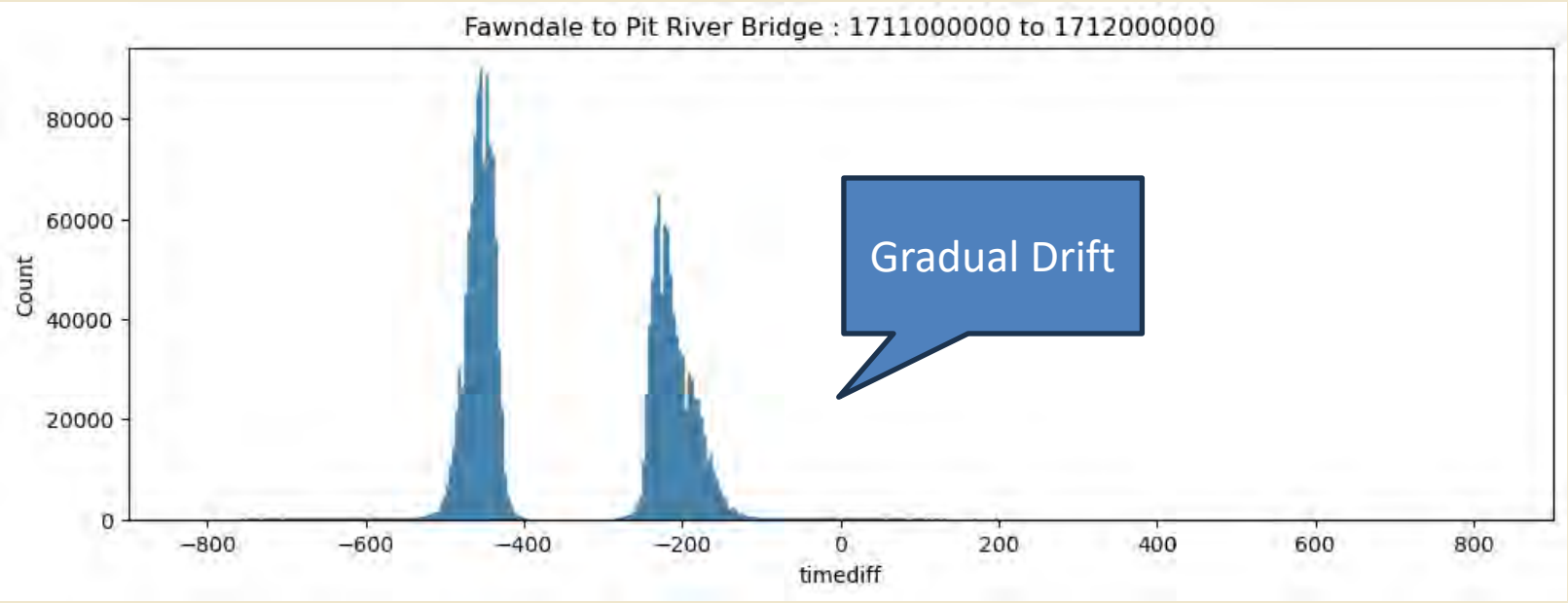
- Travel time estimates are shifted in the negative direction and are obviously incorrect at the start: UTC epoch 1705000000 (1/11/2024 11:06:40 AM).
- Travel time estimates gradually drift in the negative direction from UTC epoch 1705000000 (1/11/2024 11:06:40 AM) to 1712000000 (4/1/2024 12:33:20 PM).
- Travel time estimates are shifted in a positive direction by approx. +300 sec. between UTC epoch 1712000000 (4/1/2024 12:33:20 PM) and 1713000000 (4/13/2024 2:20:00 AM).
- Travel time estimates resumed gradually drifting in the negative direction from UTC epoch 1713000000 (4/13/2024 2:20:00 AM) to 1720000000 (7/3/2024 2:46:40 AM).

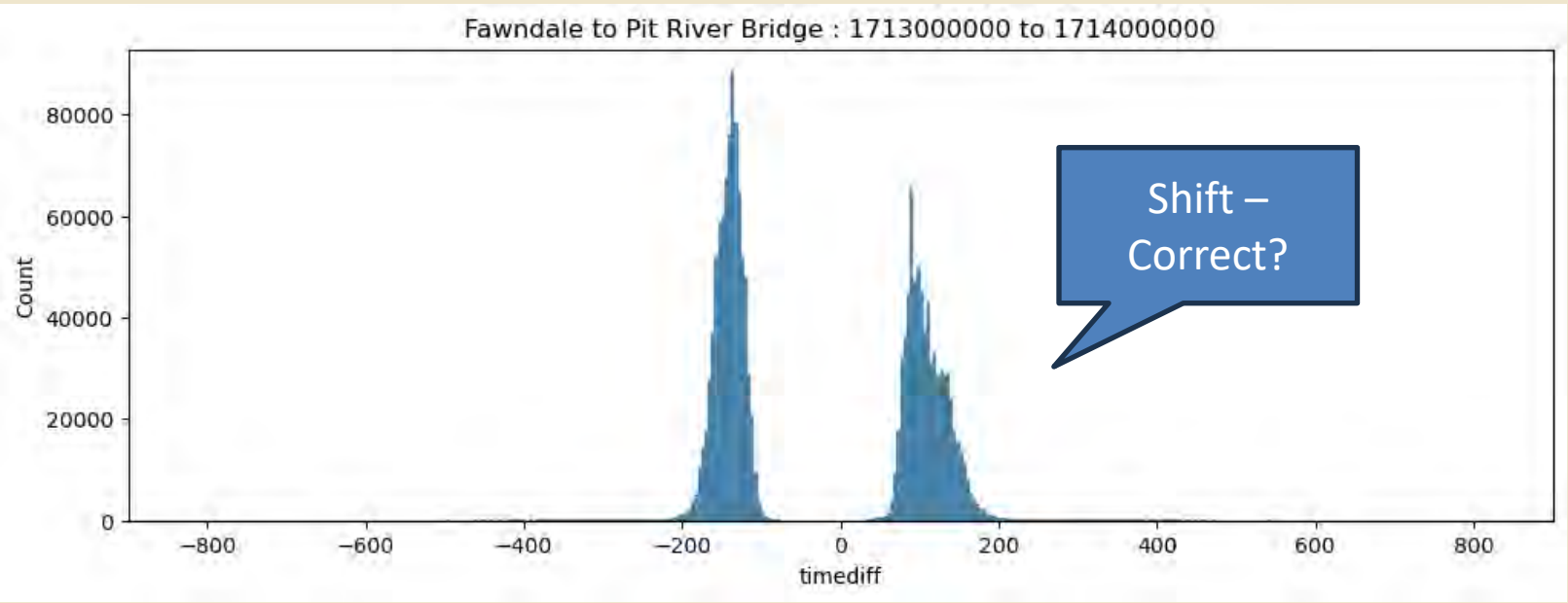
Bad Data – Fawndale to Pit River Bridge





Bad Data – Fawndale to Pit River Bridge





Bad Data Conclusions

If left as-is, data from these devices would not be usable.

This put data collection for the upcoming 2024-5 bad weather season in jeopardy.

Device clocks and timestamps needed to be as close to real time as possible.

It was critical that timestamps be consistent across devices so site-to-site travel times could be accurately computed.

Bad Data Conclusions

We acknowledge that it might be possible to post-process data from pairs of sites to account for incorrect clock times because relative position of northbound and southbound travel time estimates remain spaced by a near constant amount equal to the sum of expected northbound and southbound travel time.

However, such correction should not be necessary and would be prone to further error, even if only for the sake of analysis of the data already collected.

Correct times on devices was the only solution.

Bad Data Conclusions

Caltrans worked with the vendor to rectify the problem.

We also enabled Wi-Fi collection. More is better, right?

Part 3: Bad Weather, Good Data

Part 3: Bad Weather, Good Data

Students:

- Jacob Sririman
- Reese Lester

Fall 2024 – Spring 2025

Part 3: Bad Weather, Good Data

Finally, good data from a bad weather season?

Results were promising – delay was apparent. Efforts were made to automatically detect delay.

More needed to be done to formalize.

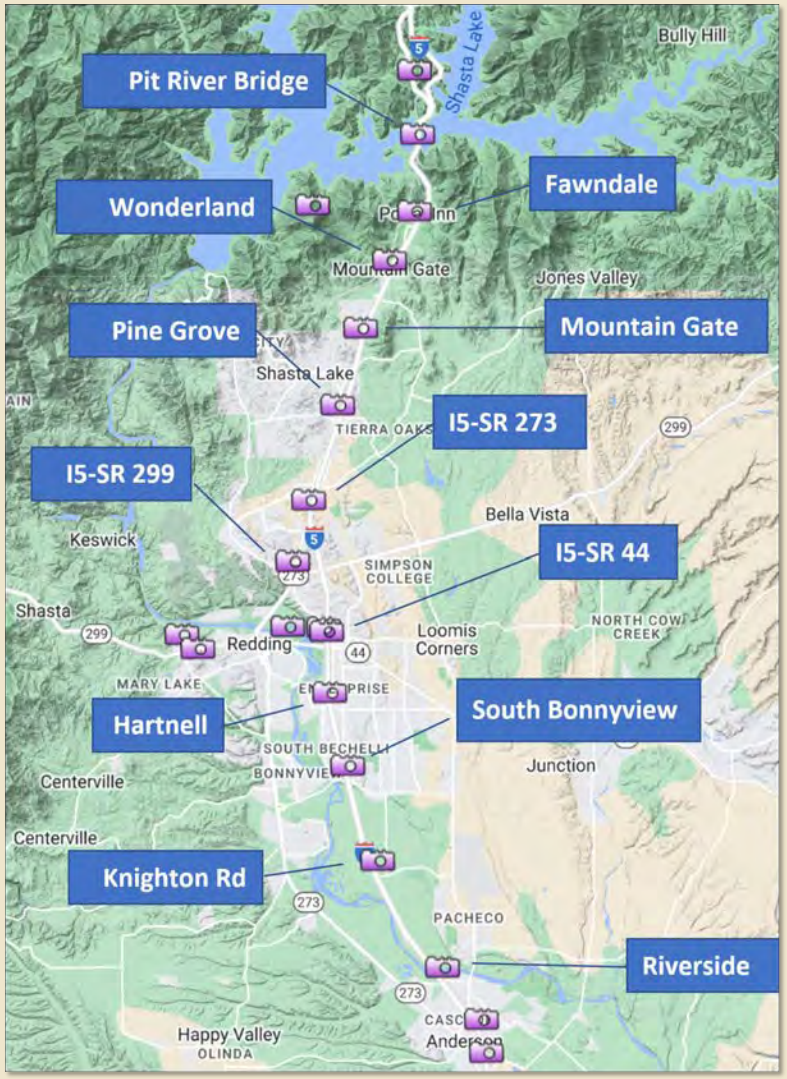
Methodology

Data

All 12 sensors were used.

Sensors read the MAC addresses of Bluetooth and Wi-Fi devices. (Wi-Fi was enabled after correcting the clock problems.)

Historical data was used for analysis. It was stored in files containing MAC addresses, type (BTLE/BTE/WIFI) and timestamps.



Data Extraction

A script was developed to more efficiently extract the data from historical data files.

Variables of interest included device type, timestamp, and MAC address.

Data Processing

To compute travel times between sites, we did the following:

1. Given two different sites, match MAC addresses that appear at both sites.
2. Using timestamps of these instances, compute elapsed time (time difference).
3. We set a time limit (12 hours) for MAC addresses (devices) to move between sites. Travel times longer than this limit are ignored.

Data Processing

We were interested in how travel times change over time.

To analyze this:

- We computed percentiles of travel times for 5-minute increments.
- We again used 15^{th} percentile travel times corresponding to 85^{th} percentile speeds.

Delay Detection

Previously, our method for detecting a delay was visual:

- Travel time plots showed delays graphically.
- CCTV camera images confirmed delays

We wanted a way to numerically detect and characterize delays in a more efficient manner in anticipation of a delay prediction algorithm.

Delay Detection Algorithm

Delay Detection Algorithm

1. Sliding Window Mean
2. Exponential Moving Average
3. Z-Score Normalization
4. Spike Detection
5. Return to Normal

Sliding Window Mean

We applied a moving average (with window size = 100 most-recent individual travel times) to smooth the raw travel time data

This helped reduce noise to put a greater emphasis on large shifts.

Exponential Moving Average (EMA)

An EMA was computed from the previous moving average using a smoothing factor.

The EMA gave higher weight to more recent instances, making it more likely to catch a delay with extremely quick onset.

We use smoothing factor of 0.1, determined empirically to work in this context.

$$EMA[i] = smoothing_{factor} \times means[i] + \left(1 - smoothing_{factor}\right) \times EMA[i-1]$$

Z-Score Normalization

Each EMA value (x) in the time series was normalized:

$$Z = \frac{x - \mu}{\sigma}$$

$$\mu = \text{Mean}$$

$$\sigma = Standard\ Deviation$$

Spike Detection

The normalized data makes it easier to detect spikes in travel times.

We set our threshold to Z = 1.75 to detect major delays.

The Z-threshold is low because of how we "smoothed" our data.

Return to Normal

We were also interested in determining when a delay is over (when travel times return to "normal“.

The algorithm keeps track of a window of values from before the delay. The average is our baseline value.

Once points return to within a tolerance (10%) of the baseline value, we deem the delay over.

Results

The delays identified by our algorithm were confirmed using images, plots, and chain control message data.

November Backup Event

On November 19, 2024, at 3:14 PM, chain control came into effect for trucks due to inclement weather.

This caused a significant slowdown, going several miles south of Fawndale.

On Nov 20 at 7:00 AM, the interstate was closed to all vehicles.

By early morning Nov 21, traffic was backed up all the way into Redding.

Chain Restrictions

Date	Time	Status	Chain Control Restriction at Fawndale
11/19/2024	3:08 PM	R-0	No chain controls are in effect at this time.
11/19/2024	3:14 PM	TS	All trucks must stop at the chain check point, Caltrans is currently screening for chains. Drivers must have maximum chains in their possession in order to proceed. Trucks without chains will be turned around. Permit loads are prohibited over the summit.
11/19/2024	6:18 PM	VS	Vehicle Screening - All vehicles will be checked to make sure they have a full set of tire chains before being allowed to travel into areas where chains will be required.
11/19/2024	8:13 PM	TH	All truck trailer combinations are being held at the chain control camper due to incidents or weather-related conditions.
11/20/2024	7:03 AM	RC	Closed to traffic.
11/20/2024	7:49 PM	VM	A traffic control is in effect to meter vehicles at the chain check point in order to reduce traffic congestion in the mountain areas.
11/21/2024	3:38 AM	TS	All trucks must stop at the chain check point, Caltrans is currently screening for chains. Drivers must have maximum chains in their possession in order to proceed. Trucks without chains will be turned around. Permit loads are prohibited over the summit.
11/21/2024	8:58 AM	R-0	No chain controls are in effect at this time.

Detected Delay

```
Spikes in travel time for traffic from Wonderland to Fawndale
Start of spike:
2024/11/19-12:25 -0800
End of spike:
2024/11/21-08:45 -0800

Spikes in travel time for traffic from Mountain Gate to Wonderland
Start of spike:
2024/11/21-02:25 -0800
End of spike:
2024/11/21-08:10 -0800

Spikes in travel time for traffic from Pine Grove to Mountain Gate
Start of spike:
2024/11/21-00:40 -0800
End of spike:
2024/11/21-09:10 -0800

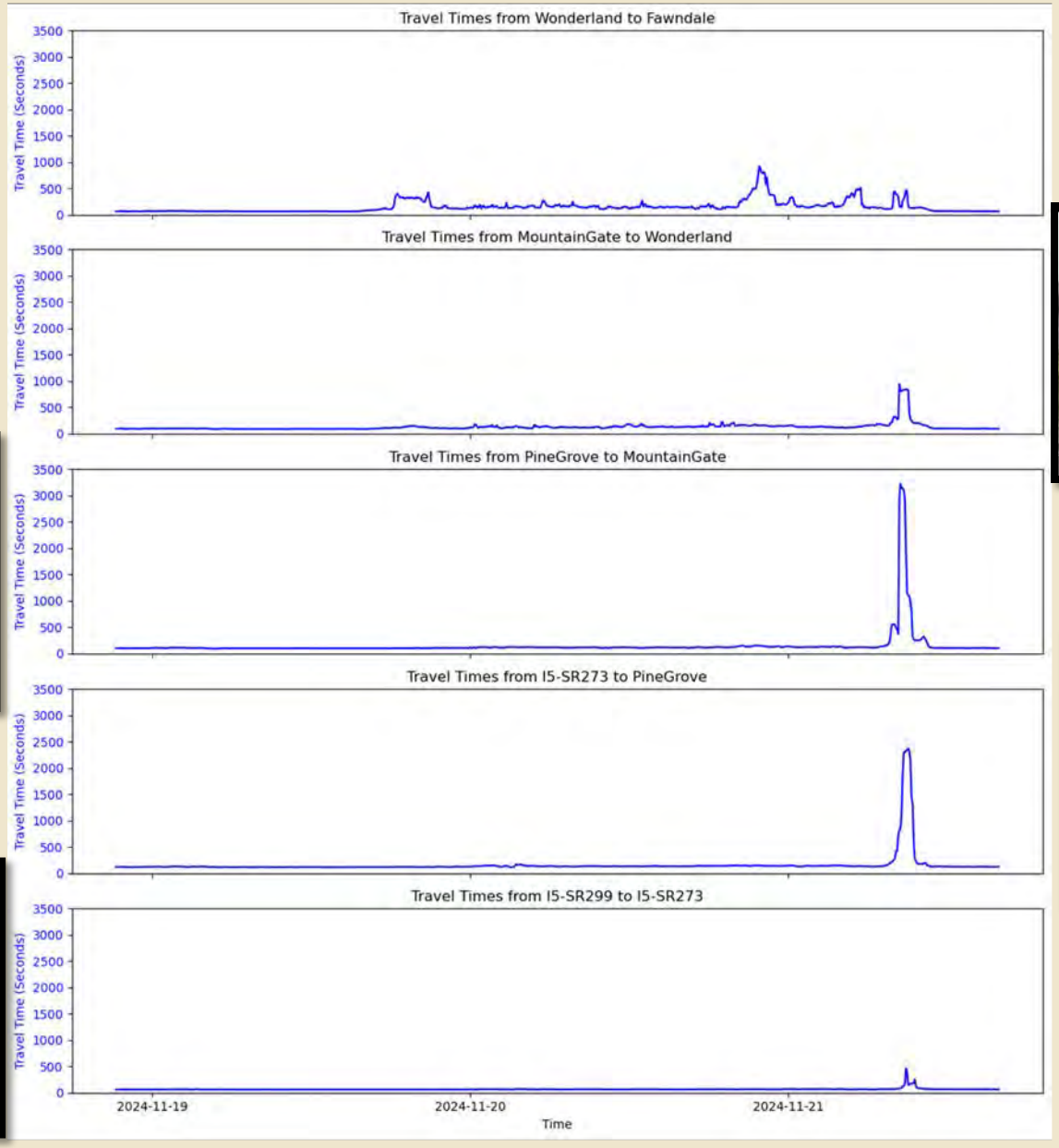
Spikes in travel time for traffic from I5-SR273 to Pine Grove
Start of spike:
2024/11/21-00:30 -0800
End of spike:
2024/11/21-09:20 -0800
```

Detection Compared to Chain Restrictions

Date	Time	Status
11/19/2024	3:08 PM	R-0
11/19/2024	3:14 PM	TS
11/19/2024	6:18 PM	VS
11/19/2024	8:13 PM	TH
11/20/2024	7:03 AM	RC
11/20/2024	7:49 PM	VM
11/21/2024	3:38 AM	TS
11/21/2024	8:58 AM	R-0

```
Spikes in travel time for traffic from Wonderland to Fawndale
Start of spike:
2024/11/19-12:25 -0800
End of spike:
2024/11/21-08:45 -0800
Spikes in travel time for traffic from Mountain Gate to Wonderland
Start of spike:
2024/11/21-02:25 -0800
End of spike:
2024/11/21-08:10 -0800
Spikes in travel time for traffic from Pine Grove to Mountain Gate
Start of spike:
2024/11/21-00:40 -0800
End of spike:
2024/11/21-09:10 -0800
Spikes in travel time for traffic from I5-SR273 to Pine Grove
Start of spike:
2024/11/21-00:30 -0800
End of spike:
2024/11/21-09:20 -0800
```

Detection Compared to CCTV Images





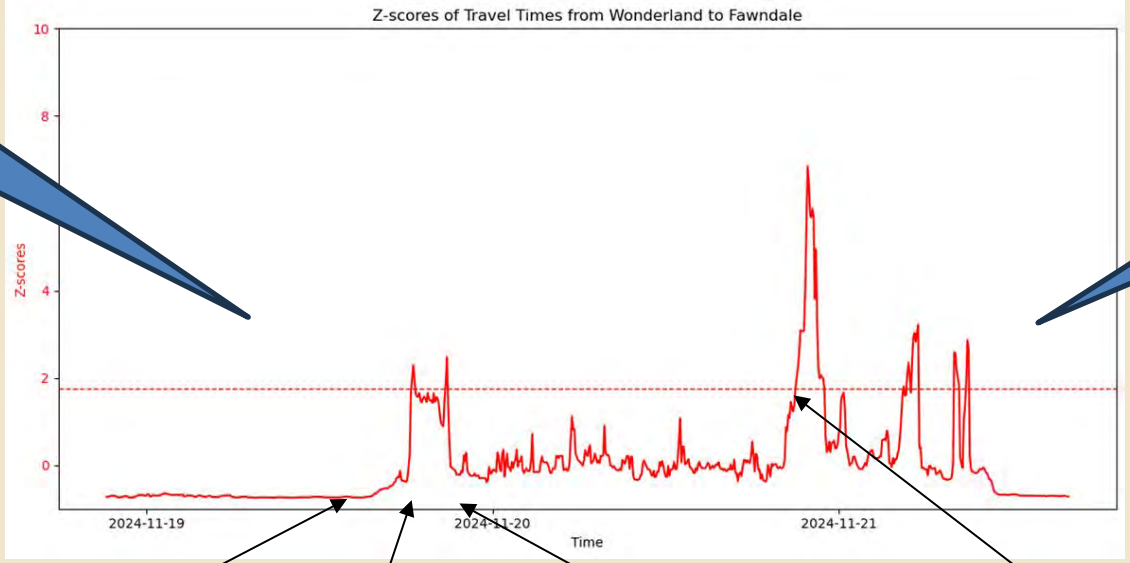






Detection Compared to CCTV Images

Beginning of the delay, shortly before chain control comes into effect …



After the road closed, the backup increased significantly.









Deliverables

(Student Work Fall 2024 – Spring 2025)

Deliverables

(Student Work Fall 2024 – Spring 2025)

This work was part of a larger project

Others working on this project in the future would need to effectively use what was produced.

The eventual end goal is to produce a delay prediction algorithm

Quantitatively characterizing the extend of the delay was considered a necessary first step.

Data Collection/Processing Scripts

We produced a reusable and memory-efficient script to process data directly from the Bluetooth/WIFI device sensor data, into CSV files:

- Easily callable by other, subsequent scripts.
- Could be used for future data.

We wrote a script to compute pairwise travel times among all sites:

- Produced percentiles of travel times.
- Configured to be reusable for future data.

Delay Detection Algorithm Script

The algorithm we developed worked directly on the percentile data that we computed.

This script could be run on any new data in that format, for any window or size of data.

The code could handle multiple spikes, so it could be used to look at a long-term window of travel times.

```
Spikes in travel time for traffic from I5-SR273 to Pine Grove
Start of spike:
2024/11/21-00:30 -0800
End of spike:
2024/11/21-09:20 -0800
Start of spike:
2025/02/05-03:10 -0800
End of spike:
2025/02/05-13:40 -0800
Start of spike:
2025/02/07-04:40 -0800
End of spike:
2025/02/07-12:30 -0800
```

Data Quality – Issues Faced

- During the summer we encountered strange artifacts in the data
  - Impossibly fast travel times, abnormally slow travel times, unusually skewed distributions, etc.
- Focus was shifted to diagnosing and fixing the issue.
- The sensors deployed in California weren't connecting properly to an NTP server.
- As a result, clock drift and clock shift occurred, making for incorrect timestamps.
- Caltrans worked with the sensor vendor to fix the problem.
- We lost a chunk of data but were able to remedy the issue before the following winter, rescuing subsequent data collection efforts.

Data Quality

- After the summer data quality issues, we diligently checked quality of data.
- At each step of the pipeline, we checked average values of travel times vs expected, and distributions.
- We didn't encounter any more major data quality issues during winter data collection.

Conclusions

We expanded on previous work by being able to detect delays quantitatively.

We developed reusable code to assist future members of this project.

We felt we were one step closer to having a delay prediction algorithm that can be used by CALTRANS.

Conclusions

Don’t jump too quickly into developing an algorithm. The data needs to be correct, and we need ground truth as a basis for evaluation. We still did not have this.

Techxpo 2025
(Montana Tech Student Research Exposition)

Chain-Up Delay Tracking and Estimation
for Interstate 5 in Northern California

Project Team: Jacob Sriraman, Reese Lester, Dr. Douglas Galarus (mentor)

Background

When chain controls are in place on northbound I-5 north of Redding, CA, vehicles are required to chain up near Fawndale, and there can be a backup of trucks for 5 miles or more. Determining accurate delay times that could be displayed on changeable message signs (CMS) before the backup starts could reduce the wait times and backup length, which will improve safety within this corridor.





The purpose of this project is to use data from 12 Caltrans-deployed Bluetooth sensors that log time and MAC address, and to use the data collected by these devices in conjunction with chain control status and other data to develop an algorithm to estimate travel time/delay through the affected area.



This project will directly benefit travelers on Interstate 5 north of Redding, California, and along all of Interstate 5 from Southern California to Washington State. The results are expected to be of benefit to other states that operate chain-up sites.

Methodology

We were given time-stamped sensor data from Bluetooth and Wi-Fi devices traveling along the highway. We also used CCTV images from traffic cameras, and chain control messages and times. We wrote scripts to compute travel times by pairing MAC addresses across sites. It is common n the transportation industry to use 85th percentile speeds, so we computed 15th percentile travel times.

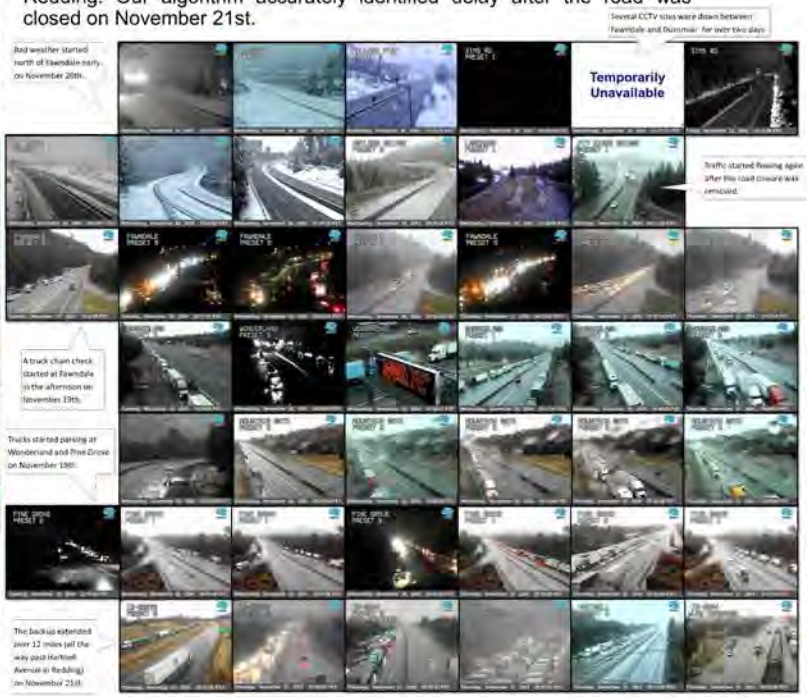
We developed a preliminary detection algorithm that identifies significant spikes in travel time by applying a sliding window and an exponential moving average to smooth the data, followed by Z-score computations to find statistically significant delays. Once a spike is detected, the algorithm waits until travel times return to "normal" to track both the onset and resolution of delays.

This approach accurately identifies the start and end of each spike.

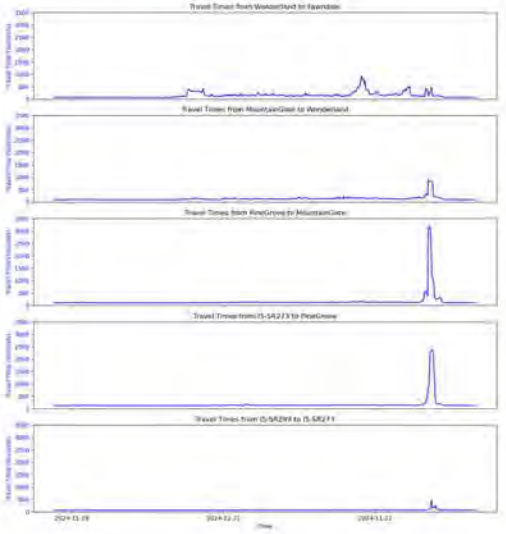
Results

Previously the only way we were able to detect delay events was visually, using plots. We have improved on this using our delay-detection algorithm. The accuracy of our algorithm was validated using timestamps from chain control messaging, as well as CCTV images from those times to visually confirm that delay is happening.

Our algorithm detected backup at Fawndale starting on November 19, 2024. Over the next two days, traffic was much slower than usual until the morning of November 21st, when our algorithm picked up extreme backup further south, all the way through Pine Grove, into and nearly past Redding. Our algorithm accurately identified delay after the road was closed on November 21st.







Date	Time	Status	Chain Control Restriction at Fawndale
11/19/2024	3:08 PM	R-0	No chain controls are in effect at this time.
11/19/2024	3:14 PM	TS	All trucks must stop at the chain check point, Caltrans is currently screening for chains. Drivers must have maximum chains in their possession in order to proceed. Trucks without chains will be turned around. Permit loads are prohibited over the summit.
11/19/2024	6:18 PM	VS	Vehicle Screening - All vehicles will be checked to make sure they have a full set of tire chains before being allowed to travel into areas where chains will be required.
11/19/2024	8:13 PM	TH	All truck trailer combinations are being held at the chain control camper due to incidents or weather related conditions.
11/20/2024	7:03 AM	RC	Closed to traffic.
11/20/2024	7:49 PM	VM	A traffic control is in effect to meter vehicles at the chain check point in order to reduce traffic congestion in the mountain areas.
11/21/2024	3:38 AM	TS	All trucks must stop at the chain check point, Caltrans is currently screening for chains. Drivers must have maximum chains in their possession in order to proceed. Trucks without chains will be turned around. Permit loads are prohibited over the summit.
11/21/2024	8:58 AM	R-0	No chain controls are in effect at this time.

Conclusions

Our delay prediction algorithm appears to be reliable relative to actual chain control status. Being able to characterize the delay quantitatively puts us a step closer to a useable delay prediction algorithm.

Credits: Thanks go to our mentor Dr. Galarus for his support, as well as the California Department of Transportation (Caltrans) for providing the problem and related data. This project is sponsored by Caltrans and the Western States Rural Transportation Consortium.

Part 4: ITE 2025 Presentation

ITE 2025 Presentation

We were invited to present a poster (eventually a full presentation) at ITE 2025 in Orlando.

We used this as an opportunity to document the November 2024 Chain-up Event in complete detail to explain the problem and set the stage for future work.

We also made an observation that would lead us towards Ground Truth.

Documenting the November 2024 Chain-Up Incident

ITE 2025 Poster

Chain-Up Delay Tracking and Estimation for Interstate 5 in Northern California

Dr. Douglas Galarus, Associate Professor, Montana Tech; Jeremiah Pearce, P.E., Chief, Office of ITS Engineering and Support, Caltrans, District 2
Montana Tech Students: Emily Martin, Jacob Sriraman, Reese Lester, River Sheppard, Hunter Valdez

Background

When chain controls are in effect on Interstate 5 north of Redding, CA, vehicles are required to chain up near Fawndale and there can be a backup of trucks extending 5 miles or more. Determining accurate delay times and displaying them on changeable message signs (CMS) before the backup starts could reduce the wait times and backup length, and improve safety within this corridor.



The purpose of this project is to use data from 12 Caltrans-deployed Bluetooth and Wi-Fi sensors that log time and MAC address, and to use the data collected by these devices in conjunction with chain control status and other data to develop an algorithm to estimate travel time/delay through the affected area.

This project will directly benefit travelers on Interstate 5 north of Redding, California, and along all of Interstate 5 from Southern California to Washington State. The results are also expected to benefit other states that operate chain-up sites.



Methodology

Sensors log time-stamped MAC addresses from Bluetooth and Wi-Fi devices traveling along the highway. MAC addresses are paired across sensor sites and 15th percentile travel times are computed. Other measures include counts of paired MAC addresses and percentage of MAC addresses paired. These measures characterize delay between sites and will be used in conjunction with chain control status to develop an algorithm to estimate delay. CCTV camera images are used for visual confirmation and further site analysis.

Data from a chain control event between November 19th and November 21st, 2024 was used for characterization of delay and investigation of measures as indicators of backup and delay.

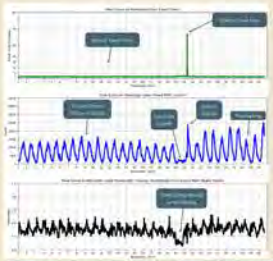
November 2024 Fawndale Chain Control Event

Date	Time	Status	Chain Control Restriction at Fawndale
11/19/2024	3:08 PM	R-1[1]	No chain controls are in effect at this time.
11/19/2024	3:14 PM	T5	All trucks must stop at the chain check point. Caltrans is currently screening for chains. Drivers must have maximum chains in their possession in order to proceed. Trucks without chains will be turned around. Permit loads are prohibited over the summit.
11/19/2024	5:15 PM	V5	Vehicle Screening - All vehicles will be checked to make sure they have a full set of tire chains before being allowed to travel into areas where chains will be required.
11/19/2024	6:11 PM	T4	All truck tractor combinations are being told at the chain control canyon due to incidents or weather related conditions.
11/20/2024	7:03 AM	RC	Closed to traffic.
11/20/2024	7:49 PM	VM	A traffic control is in effect to cause vehicles to circulate chock-boxes in order to reduce traffic congestion in the mountain areas.
11/21/2024	3:38 AM	T1	All trucks must stop at the chain check point. Caltrans is currently screening for chains. Drivers must have maximum chains in their possession in order to proceed. Trucks without chains will be turned around. Permit loads are prohibited over the summit.
11/21/2024	8:58 AM	R-1[1]	No chain controls are in effect at this time.

Event Data

Data from Pine Grove and Mountain Gate, located several miles south of Fawndale, show the impact on travel during the November 2024 Fawndale Chain Control Event:

- Travel time spikes when Chain Control is lifted on November 21st.
- Travel is at a standstill throughout November 20th and into early November 21st.



For Further Information Contact:
dgalarus@mtech.edu
jeremiah.pearce@dot.ca.gov

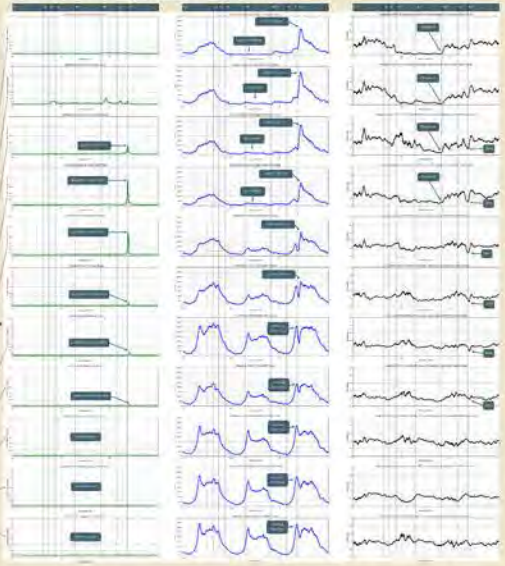
Conclusions

The sensor data appears to capture important information characterizing chain control events at Fawndale including travel time, stopped traffic, and length of the impacted area. We are confident that this data can be used to develop a real-time delay estimation algorithm.

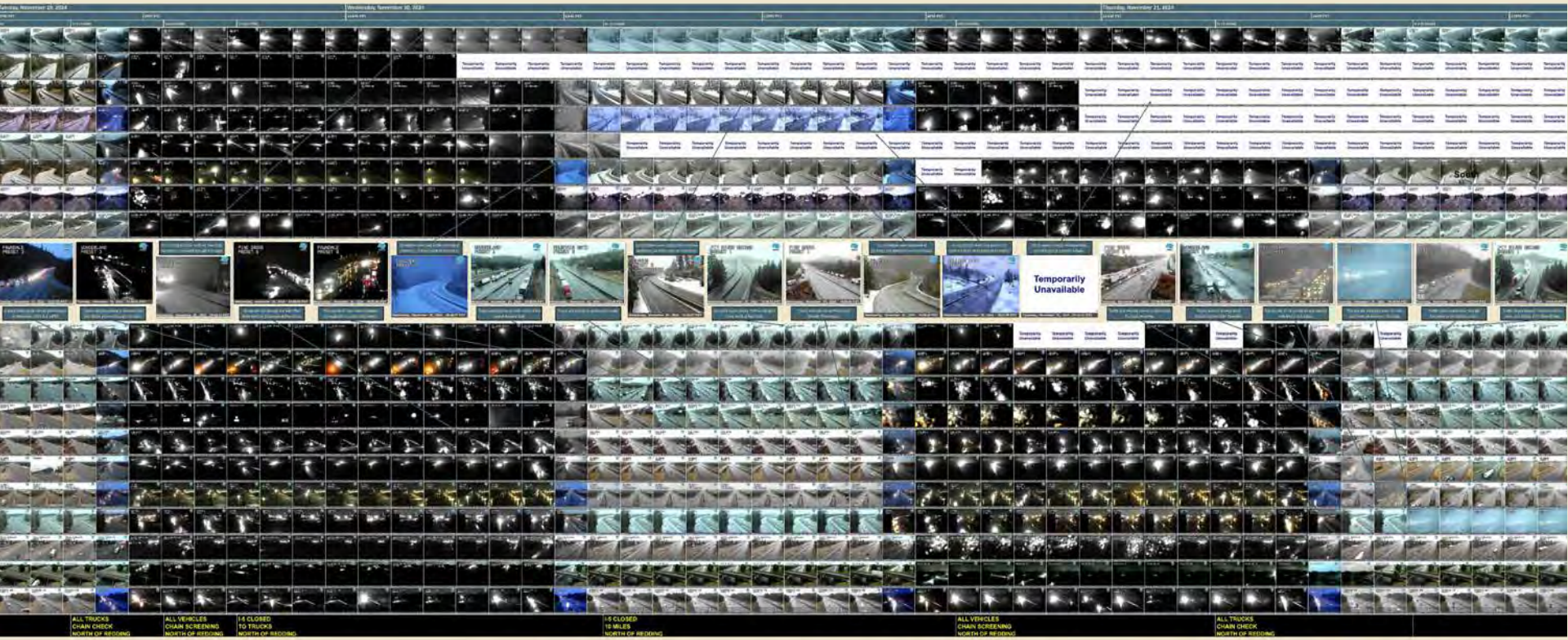
Next Steps

Chain control events from the remainder of the 2024-2025 and the 2025-2026 bad weather seasons will be used to develop and test the algorithm.





ITE 2025 Poster



Methodology

Data from a chain control event between November 19th and November 21st, 2024, was used for characterization of delay and investigation of measures as indicators of backup and delay.

November 2024 Fawndale Chain Control Event

Date	Time	Status	Chain Control Restriction at Fawndale
11/19/2024	3:08 PM	R-0	*No chain controls are in effect at this time.*
11/19/2024	3:14 PM	TS	*All trucks must stop at the chain check point. Caltrans is currently screening for chains. Drivers must have maximum chains in their possession in order to proceed. Trucks without chains will be turned around. Permit loads are prohibited over the summit.*
11/19/2024	6:18 PM	VS	*Vehicle Screening - All vehicles will be checked to make sure they have a full set of tire chains before being allowed to travel into areas where chains will be required.*
11/19/2024	8:13 PM	TH	*All truck trailer combinations are being held at the chain control camper due to incidents or weather-related conditions.*
11/20/2024	7:03 AM	RC	*Closed to traffic.*
11/20/2024	7:49 PM	VM	*A traffic control is in effect to meter vehicles at the chain check point in order to reduce traffic congestion in the mountain areas.*
11/21/2024	3:38 AM	TS	*All trucks must stop at the chain check point. Caltrans is currently screening for chains. Drivers must have maximum chains in their possession in order to proceed. Trucks without chains will be turned around. Permit loads are prohibited over the summit.*
11/21/2024	8:58 AM	R-0	*No chain controls are in effect at this time.*

November 2024 Fawndale Chain Control Event



Fawndale Chain Control
Status: TS

A truck chain check started at Fawndale on November 19th at 3:14PM.

November 2024 Fawndale Chain Control Event



Fawndale Chain Control
Status: TH

Trucks started parking at Wonderland and stayed parked through the night.

November 2024 Fawndale Chain Control Event



Fawndale Chain Control
Status: TH

Rain turned to snow north of Fawndale.
Conditions worsened through the night.

November 2024 Fawndale Chain Control Event



Trucks parked through the night, 5 miles south of Fawndale, at Pine Grove.

Fawndale Chain Control Status: TH

November 2024 Fawndale Chain Control Event



Fawndale Chain Control Status: TH

The backup at Fawndale continued throughout the chain restrictions.

November 2024 Fawndale Chain Control Event



Fawndale Chain Control Status: TH

Conditions were bad in the morning at Vollmers, 19 miles north of Fawndale.

November 2024 Fawndale Chain Control Event



Fawndale Chain Control
Status: RC

Trucks were parked on both sides of the road at Wonderland.

November 2024 Fawndale Chain Control Event



Fawndale Chain Control
Status: RC

Trucks were lined up at Mountain Gate.

November 2024 Fawndale Chain Control Event



Icy conditions were apparent by midday at Gibson, 24 miles north of Fawndale.

Fawndale Chain Control Status: RC

November 2024 Fawndale Chain Control Event



Fawndale Chain Control
Status: RC

No traffic was crossing Pit River Bridge,
2 miles north of Fawndale.

November 2024 Fawndale Chain Control Event



Fawndale Chain Control
Status: RC

Icy conditions were apparent at Vollmers late afternoon on Wednesday.

November 2024 Fawndale Chain Control Event



Fawndale Chain Control
Status: RC

Icy conditions were also present at
Pollard Flat, 23 miles north of Fawndale.

November 2024 Fawndale Chain Control Event



Fawndale Chain Control
Status: RC

Trucks were parked at Pine Grove through Wednesday.

November 2024 Fawndale Chain Control Event



Fawndale Chain Control
Status: VM

Many cameras became unavailable, possibly due to a power outage.

November 2024 Fawndale Chain Control Event



Fawndale Chain Control
Status: TS

Traffic was moving slowly at Pine Grove Thursday morning.

November 2024 Fawndale Chain Control Event



Fawndale Chain Control
Status: TS

Traffic was still backed up at
Wonderland at 9AM Thursday.

November 2024 Fawndale Chain Control Event



Fawndale Chain Control
Status: R-0

The backup at I-5 and SR-44 was packed with trucks and autos.

November 2024 Fawndale Chain Control Event



Fawndale Chain Control
Status: R-0

The backup extended over 12 miles past Hartnell Avenue in Redding.

November 2024 Fawndale Chain Control Event



Fawndale Chain Control
Status: R-0

Traffic continued to flow through Fawndale as the backup cleared.

November 2024 Fawndale Chain Control Event



Fawndale Chain Control
Status: R-0

Traffic finally flowed in both directions over Lake Shasta at Pit River Bridge.

November 2024 Event Data

Data from Pine Grove and Mountain Gate, located several miles south of Fawndale, show the impact on travel during the November 2024 Fawndale Chain Control Event:

- Travel time spiked when Chain Control was lifted on November 21st.

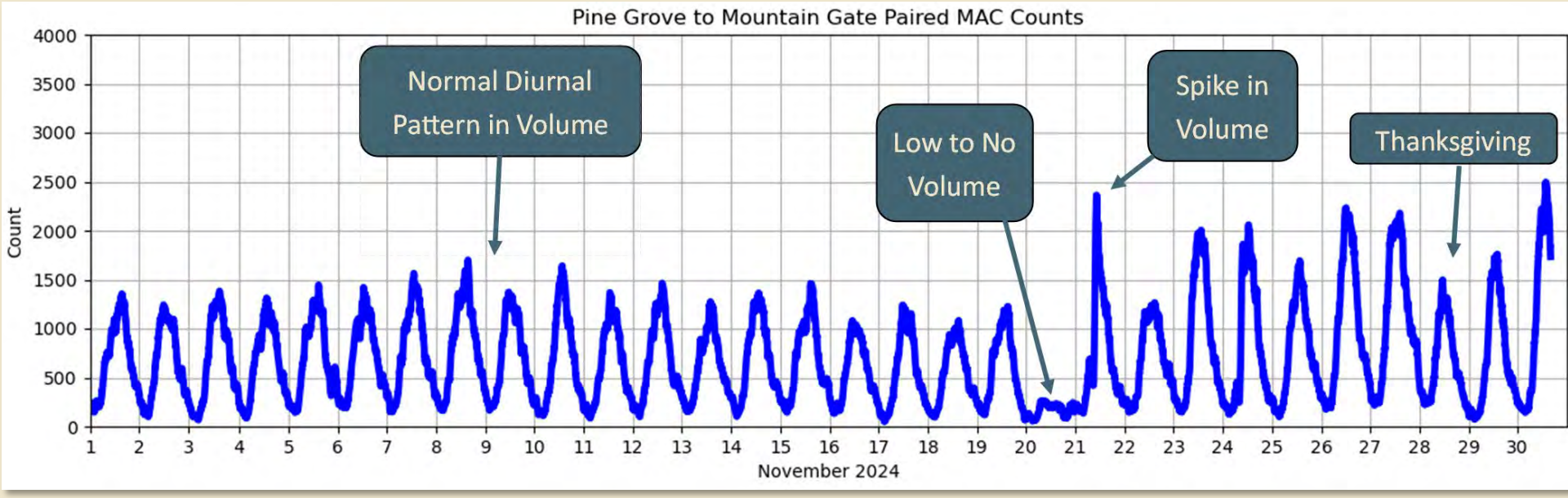
- Travel was at a standstill throughout November 20th and into early November 21st.

November 2024 Event Data

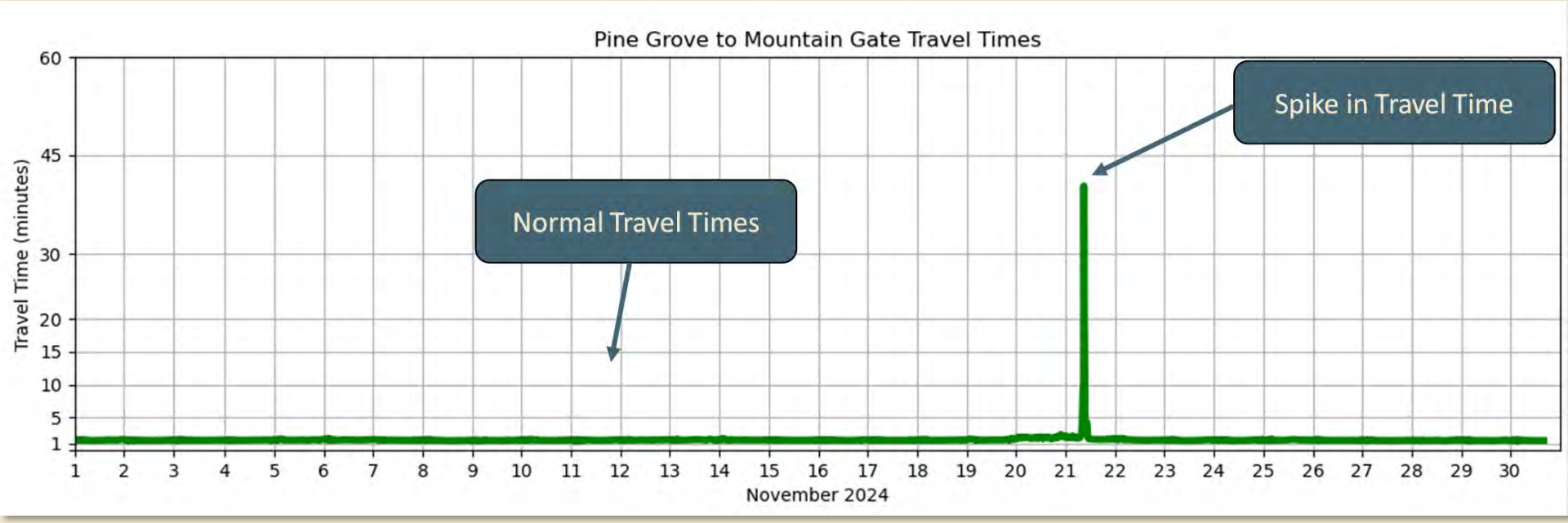
We had been looking at the data in the same way from the start of the project – plots of aggregate travel times along with counts of pairs as a proxy for volume.

For ITE 2024, we included several representative plots of this data.

November 2024 Event Data



November 2024 Event Data



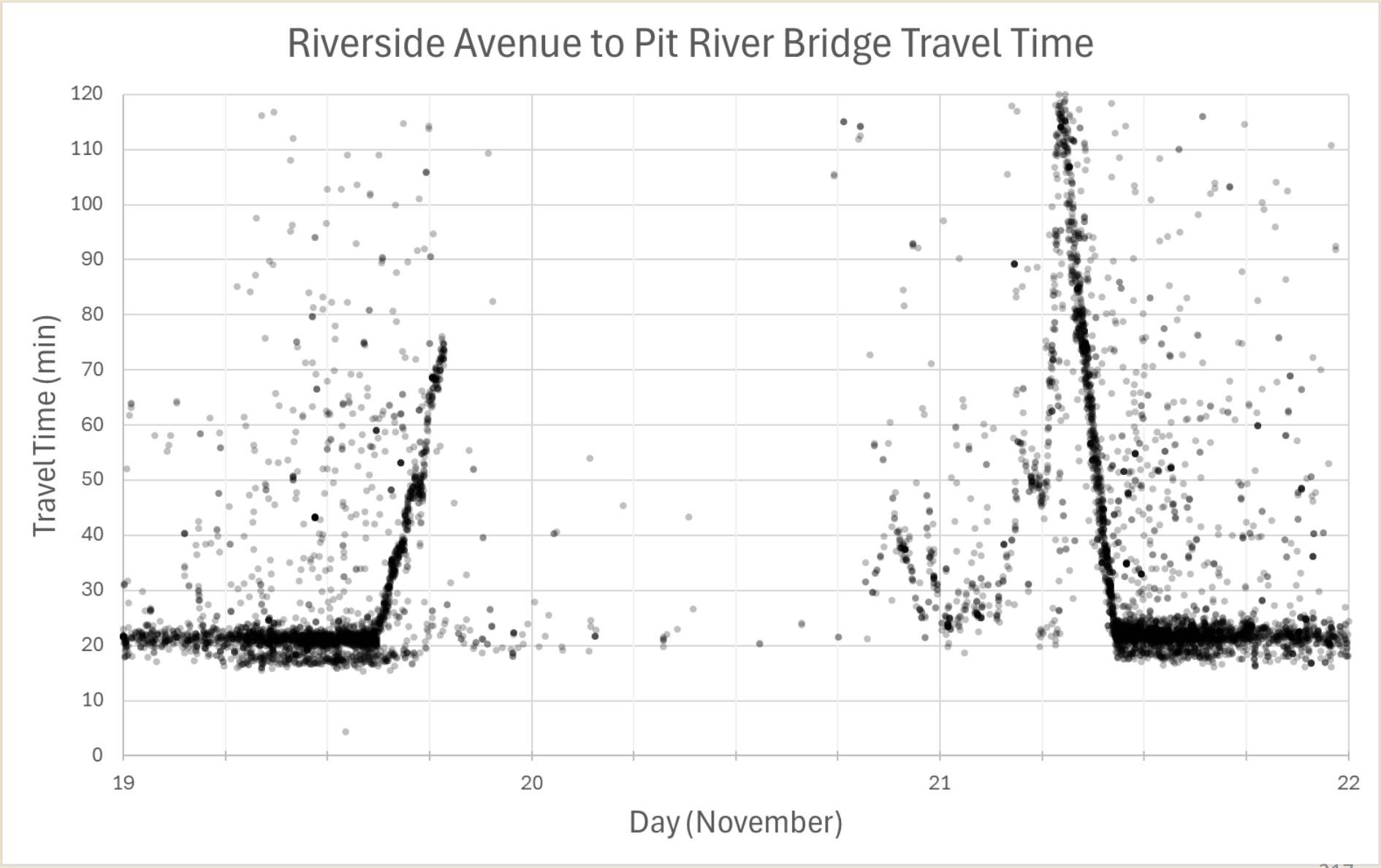
November 2024 Event Data

We added a plot that showed the following:

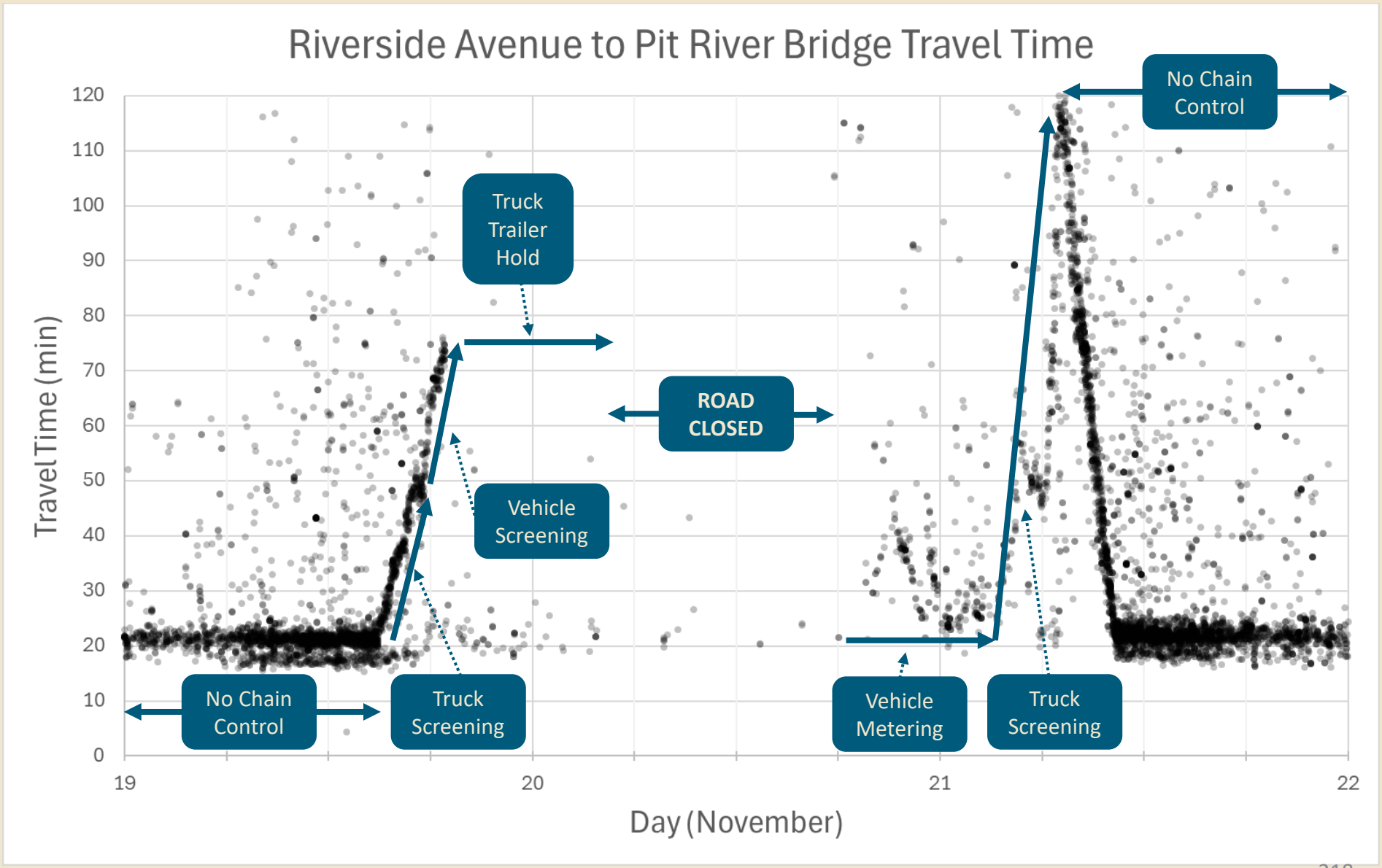
- Travel times between Riverside and Pit River Bridge
- Individual Device Travel Times

This plot showed what we thought to be ground truth. But was it real? Subsequent work would investigate this.

November 2024 Event Data



November 2024 Event Data



Next Steps

Determine if this an accurate depiction of Ground Truth and attempt to characterize it with aggregate measures.

To this point we had computed aggregates and assumed they represented Ground Truth because validation with CCTV and Chain Control messages confirmed what was saw. We needed to be more rigorous.

Data quality needed to be questioned again – trust nothing.

Part 5: In Search of Ground Truth

In Search of Ground Truth

Students:

- Emily Martin
- Jason Decker

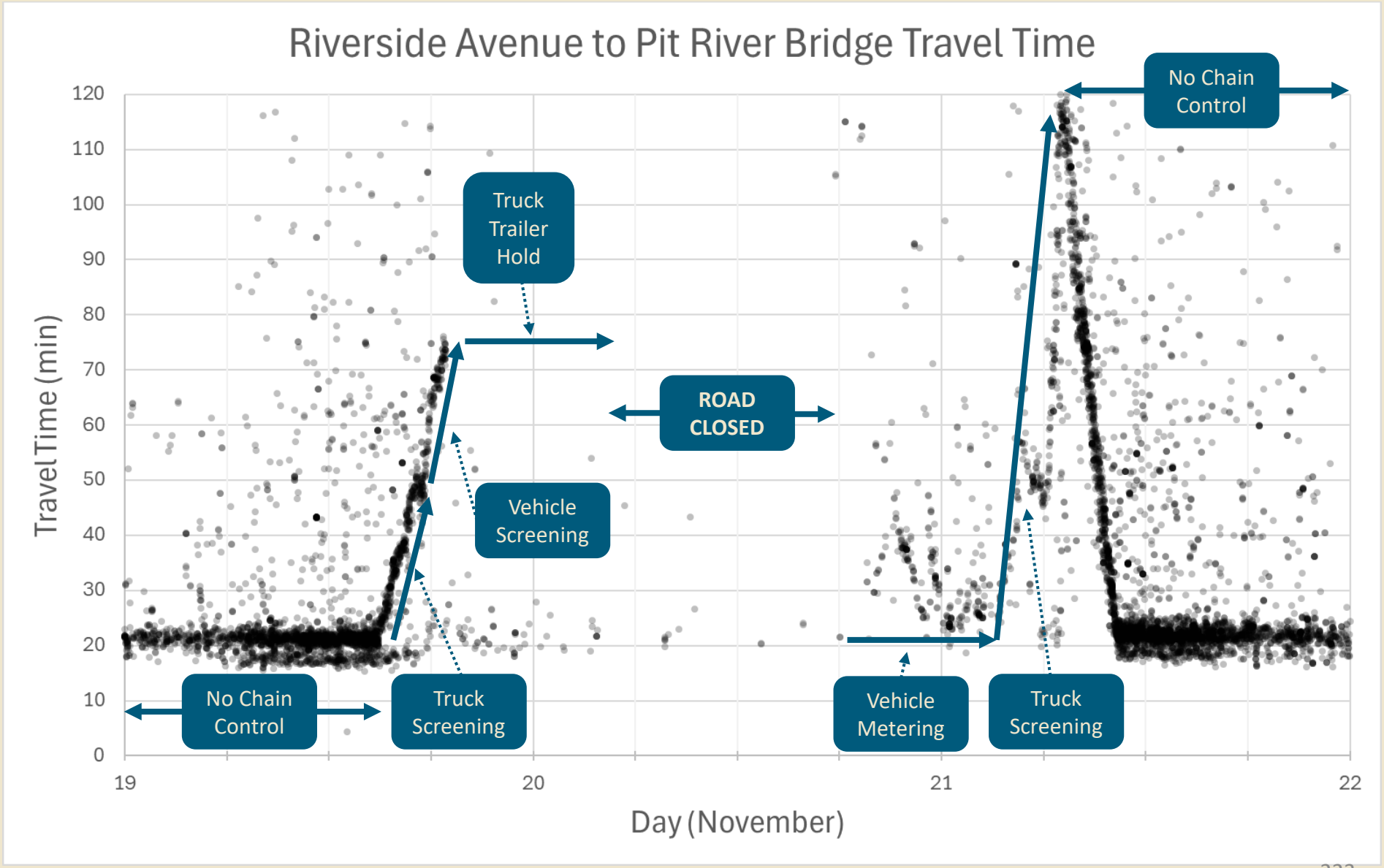
Summer 2025 – April 2026

Delay was apparent in the data, but what were the real travel times?

What is Ground Truth?

The Missing Piece – Ground Truth

Is this real? Does it show Ground Truth?

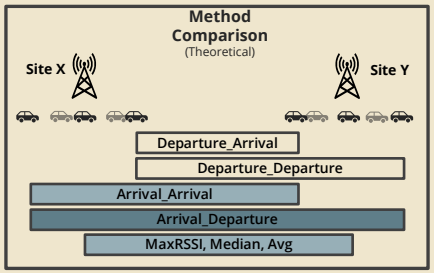


Objectives

1. Develop a data-processing framework for MAC address data and create summary measures to estimate vehicle travel time and speed.

2. Use the processed historical dataset to establish a ground-truth benchmark for evaluating and supporting real-time delay predictions during extreme weather events.

Process



Individual Device Reads

Data Wrangling & Cleaning

Visit
consecutive single-device reads at a site with gaps of no more than 15 minutes

Ground Truth
real devices traveling during real events
Paired Devices

Individual Travel Times & Speeds

Tuning Event November 2024

Summary Measures
representative values of travel time & speed

Percentiles
robust method for imperfect data

Chain Control Status

CCTV Images

Visualization & Validation
matching summary measures to data patterns and known information

Testing Event February 2025

Baseline for Future Algorithm Comparison
50th & 75th percentiles

Individual Device Reads (visits)

Sensor data device reads are cleansed and stored into two data files: processed data files and visits data files.

Relevant sensor data device reads consists of a timestamp, organization unique identifier (OUI), media access control (MAC) address, device, received signal strength indicator (RSSI), and device type.

A visit consists of consecutive single-device reads at a site with gaps of no more than 15 minutes.

Additional data is derived from the relevant sensor data to help determine a visit, travel times (average, median, arrival), speeds, and maximum RSSI readings.

Paired Devices

A paired device consists of a MAC address verified device with readings for consecutive sites (site pair).

The primary method of calculating travel time (TT) and speed (S) uses the maxRSSI time at both sites in the current pair. Additional methods have been evaluated, but this method appears to provide the most meaningful results.

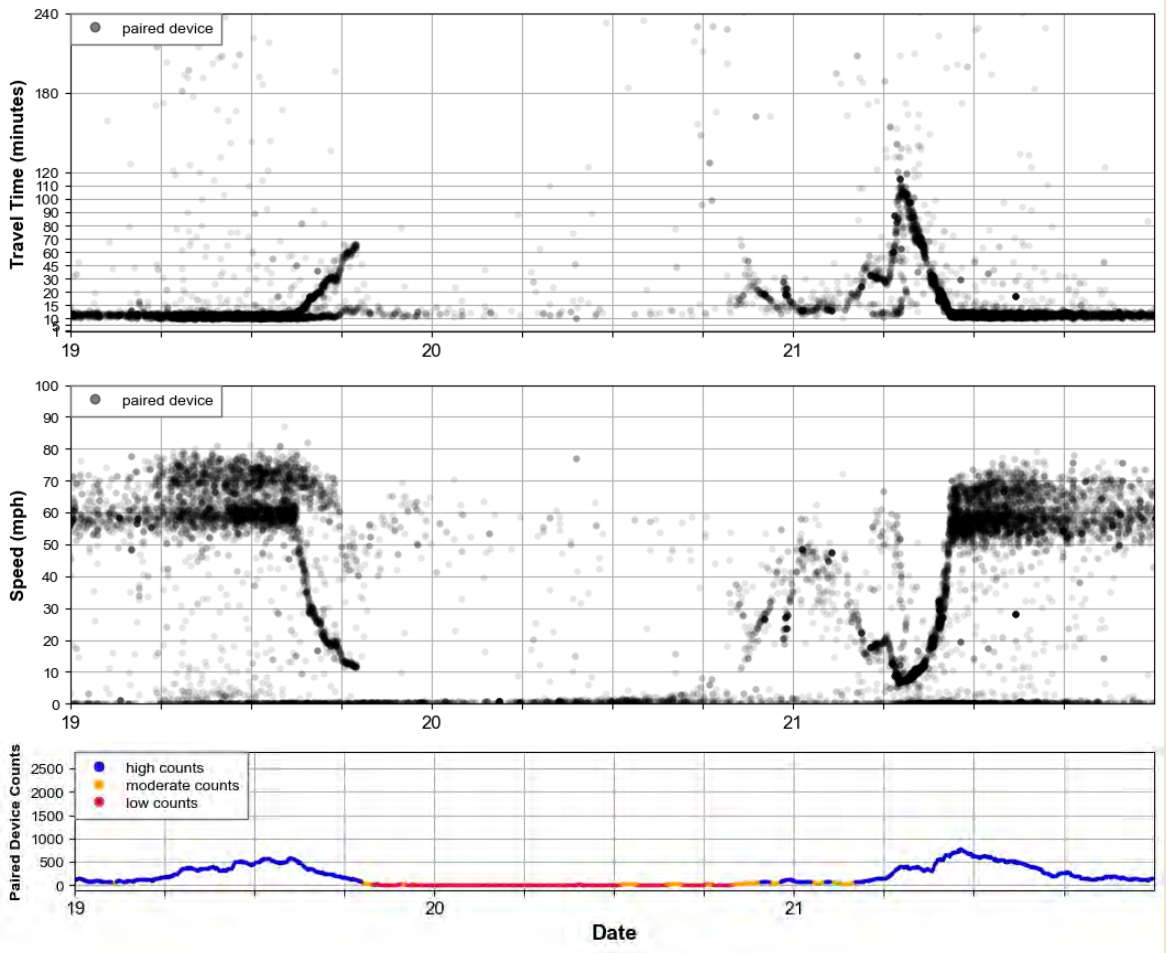
TT = SiteYMethodTime – SiteXMethodTime

S = Miles/TT

Speeds are masked to only include values > 0 and <= 130 miles per hour. Negative speeds indicate south bound traffic (these values are removed).

Speed vs Travel Time

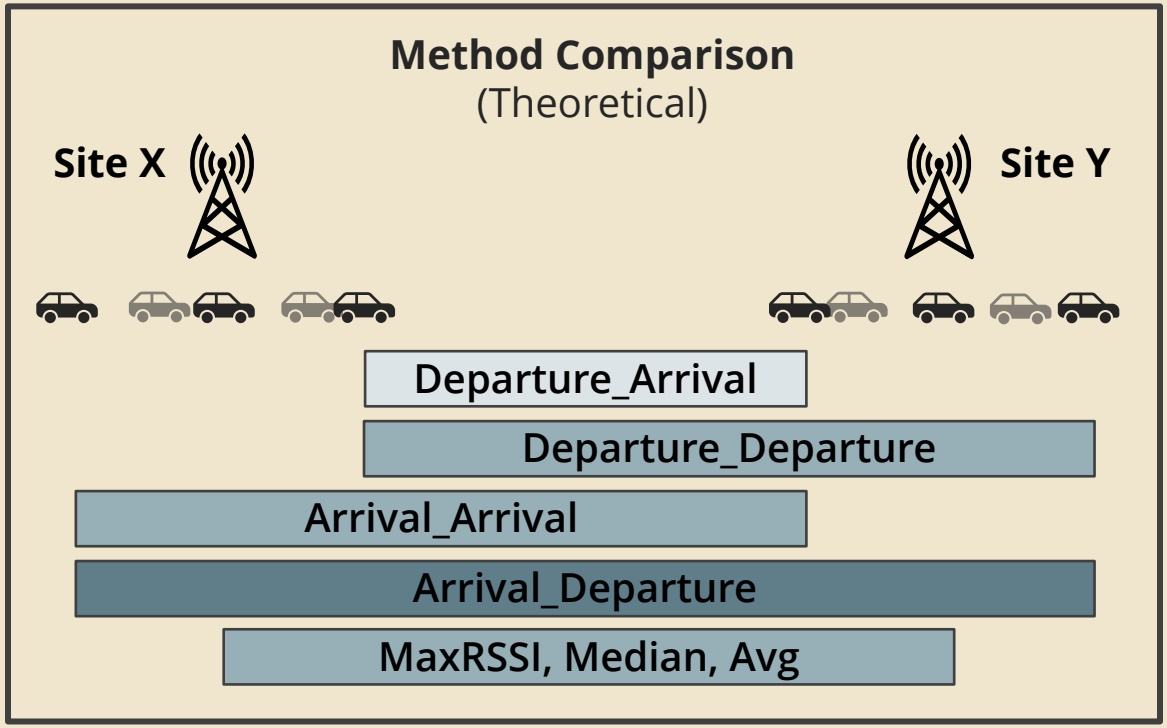
Speed and travel time are inversely related. Speed is useful for visualizing delays, as it decreases toward zero during delays. Travel time is the primary metric of interest and target outcome for this project.



Method Comparison

We evaluated multiple travel time and speed calculation methods.

The ability to implement any method wa saved within the project file pipeline.



Spearman Correlation

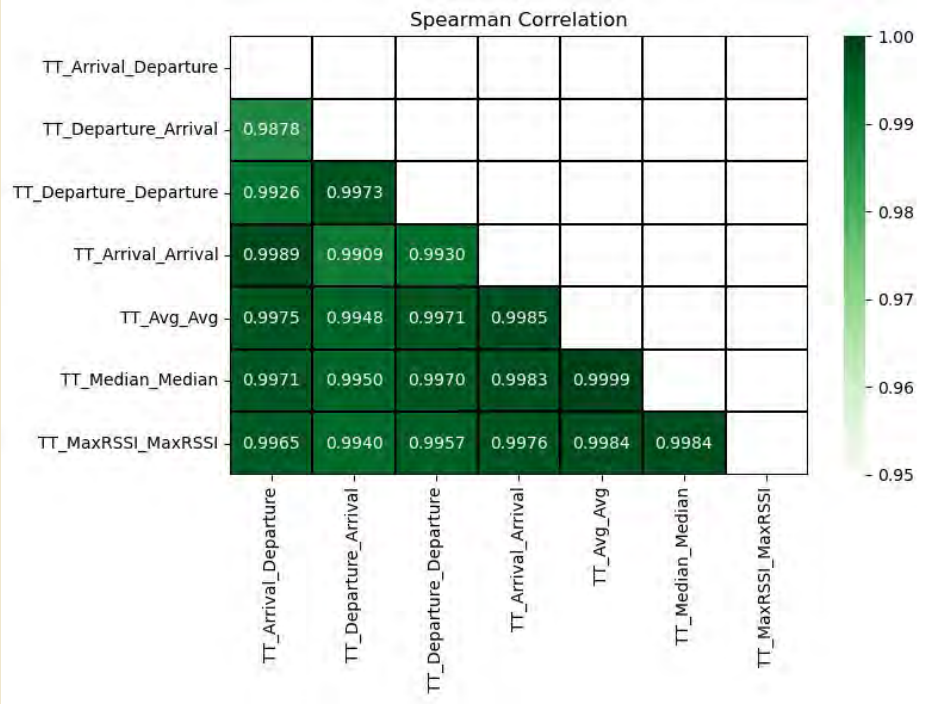
Measure agreement in trip rankings between methods:

- All methods show a strong positive association (~0.987-1.00)
- Strong evidence of consistent rankings across methods (p-value ~0.000)
- Methods rank trips in nearly the same order.
- Does not assess differences in absolute travel times.

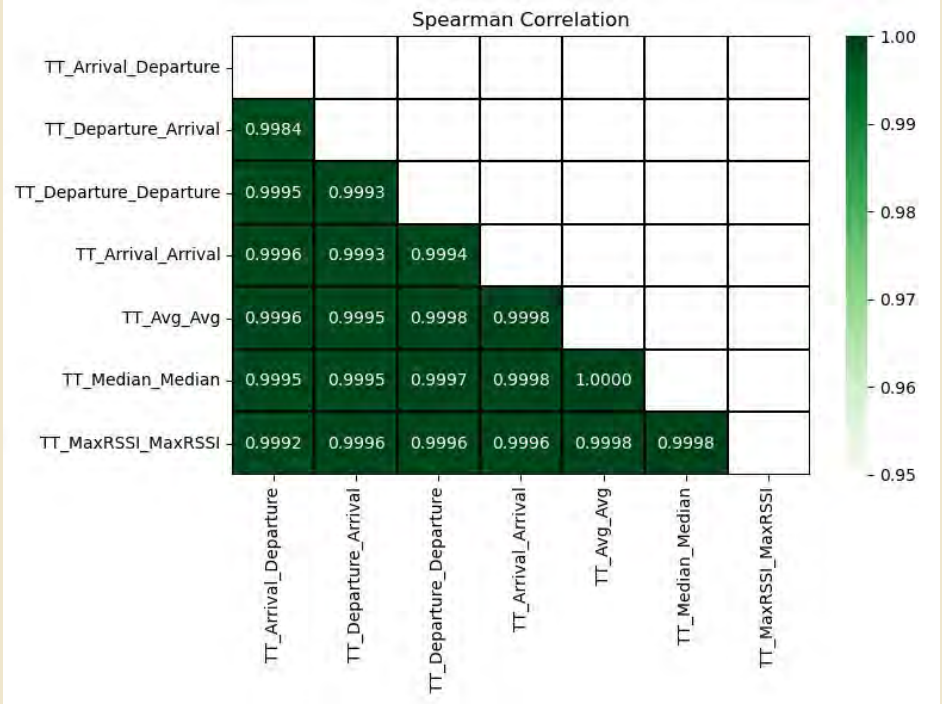
Additional validation methods may be addressed in future work.

Spearman Correlation

Fawndale to Pit River Bridge



Wonderland to Pit River Bridge



Summary Measures

We wanted to find representative values of travel time at specific points in time.

Percentiles:

- Based on the relative position of data points within the dataset
- Robust method for summarizing imperfect data
- Less affected by outliers and skewness than the mean

Visualization & Validation

Validate the summary measures qualitatively using:

- observed patterns in the paired device data
- chain control status records
- closed-circuit television (CCTV) images

Method Tuning & Testing

November 2024 Event

- Development and tuning of the data-processing framework
- Selection of representative summary measures for estimating travel time: 50th & 75th Percentiles

February 2025 Event

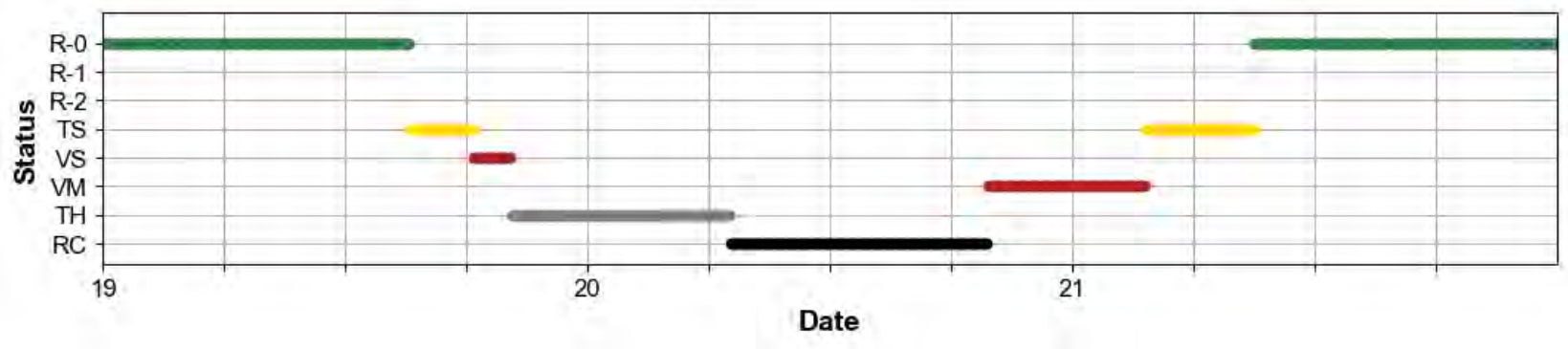
- Evaluation of the tuned framework and selected summary measures

Restriction Levels

Legend	Status Code	Description
	R-0	No chain controls are in effect at this time.
	R-1	Chains, traction devices or snow tires are required on the drive axle of all vehicles except four wheel or all wheel drive vehicles.
	R-2	Chains or traction devices are required on all vehicles except four wheel / all wheel drive vehicles with snow treaded tires on all wheels.
	TS	All trucks must stop at the chain check point, Caltrans is currently screening for chains. Drivers must have maximum chains in their possession in order to proceed. Trucks without chains will be turned around. Permit loads are prohibited over the summit.
	VS	All vehicles will be checked to make sure they have a full set of tire chains before being allowed to travel into areas where chains will be required.
	VM	A traffic control is in effect to meter vehicles at the chain check point in order to reduce traffic congestion in the mountain areas.
	TH	All truck trailer combinations are being held at the chain control camper due to incidents or weather-related conditions.
	RC	Road closed to traffic.

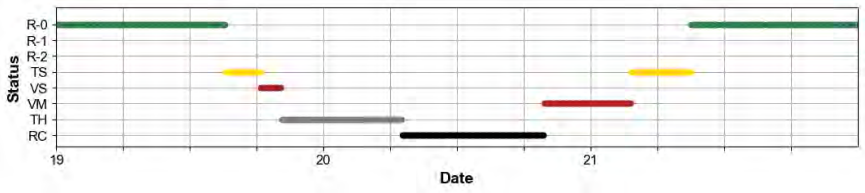
Tuning Event – November 2024

Chain Control Status

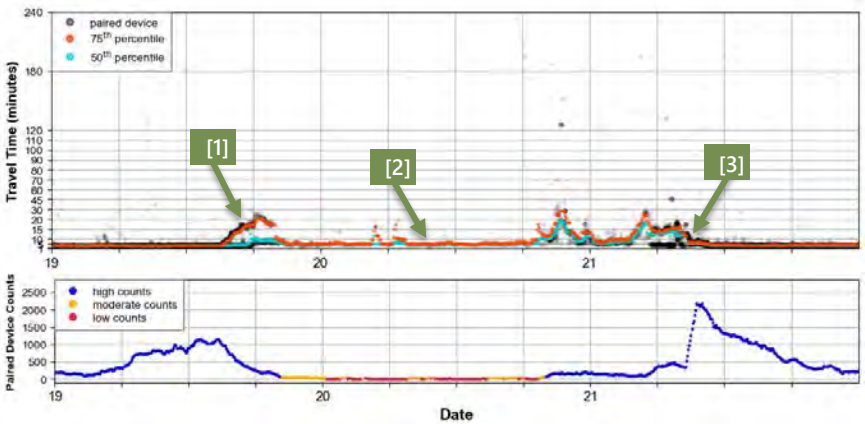


Tuning Event – November 2024

Chain Control Status



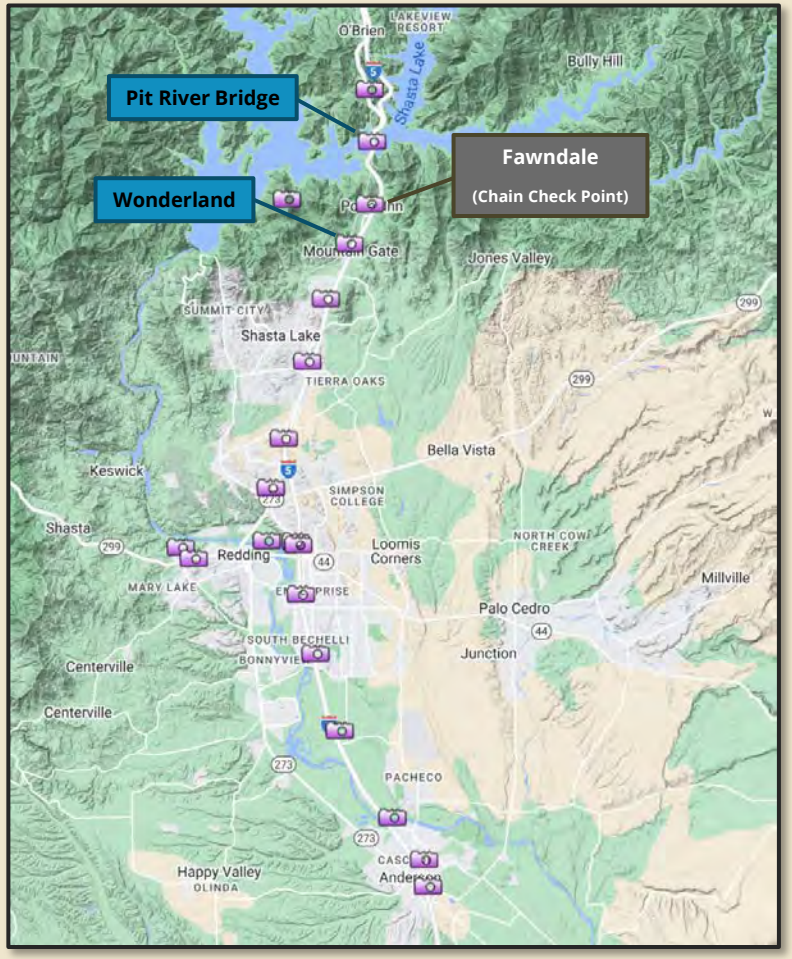
Wonderland to Pit River Bridge





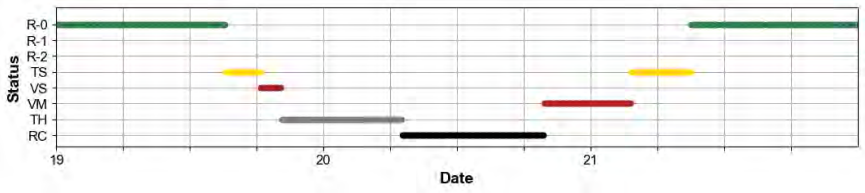




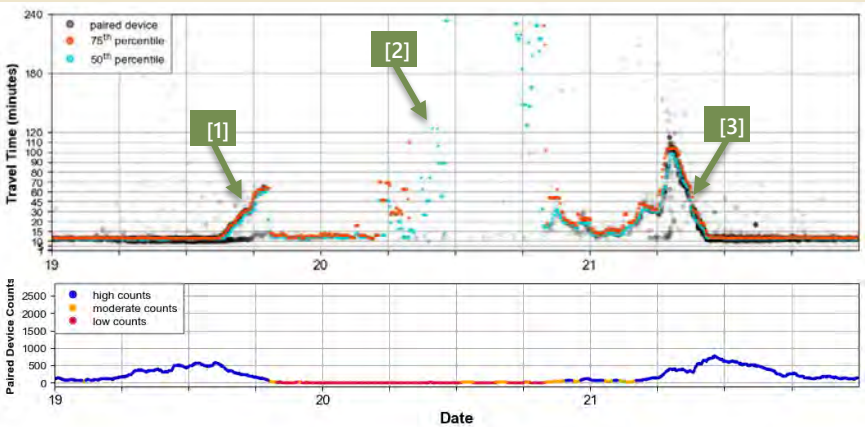


Tuning Event – November 2024

Chain Control Status



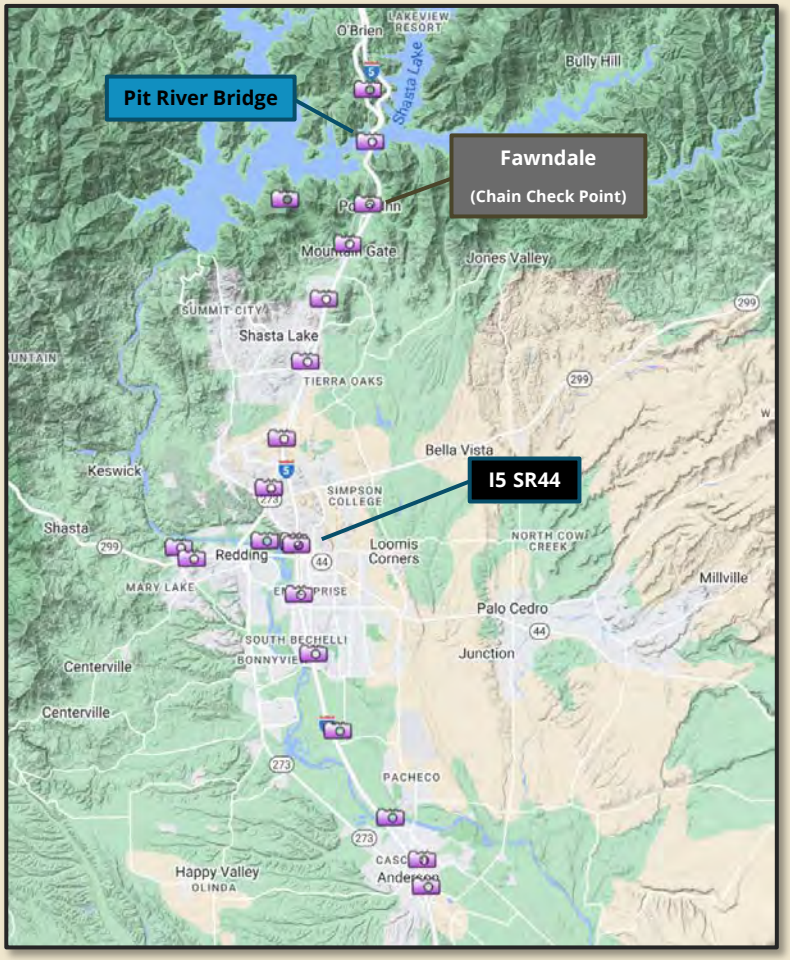
I5-SR44 to Pit River Bridge





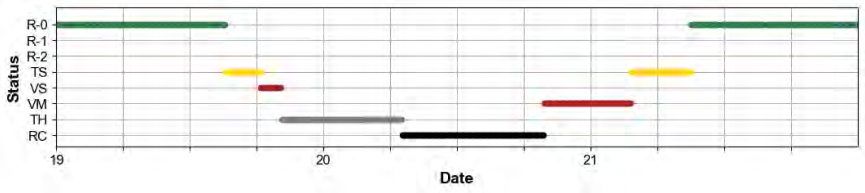




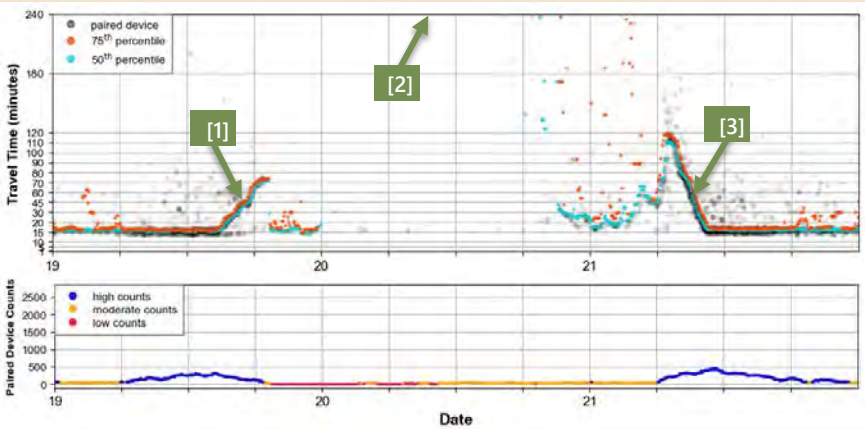


Tuning Event – November 2024

Chain Control Status



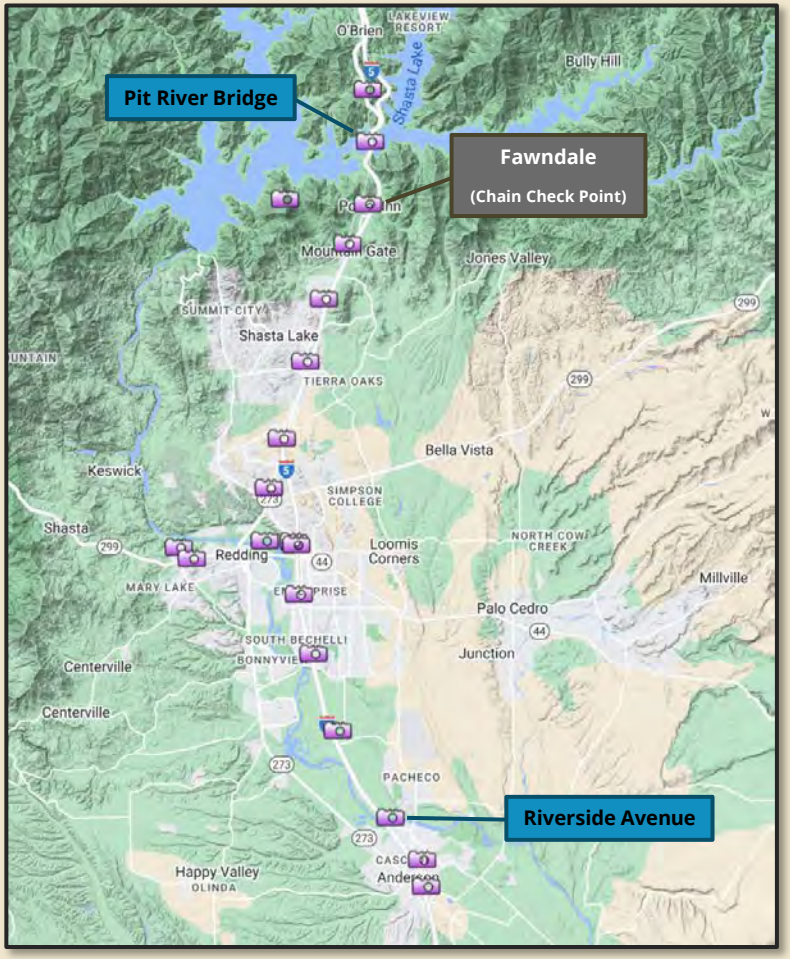
Riverside to Pit River Bridge





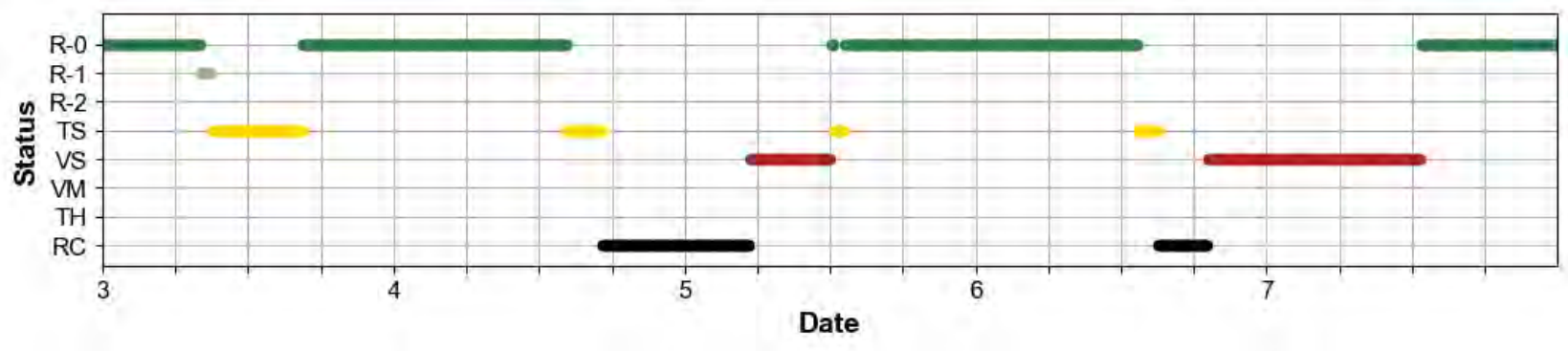






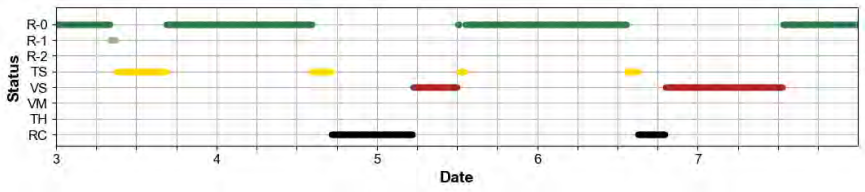
Testing Event – February 2025

Chain Control Status

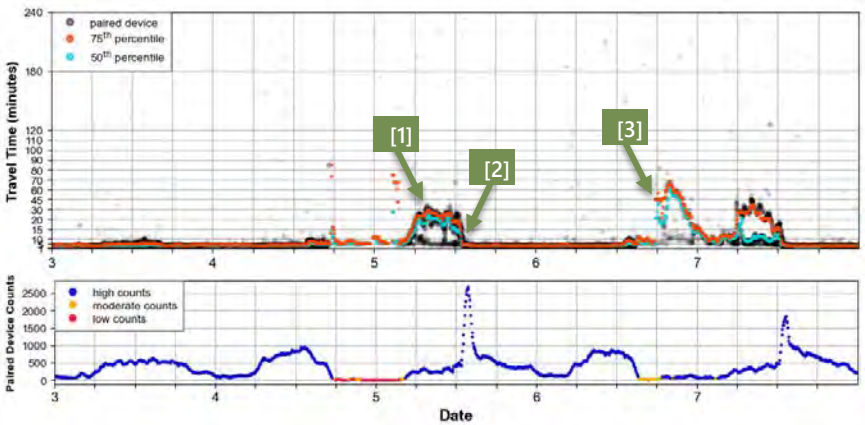


Testing Event – February 2025

Chain Control Status



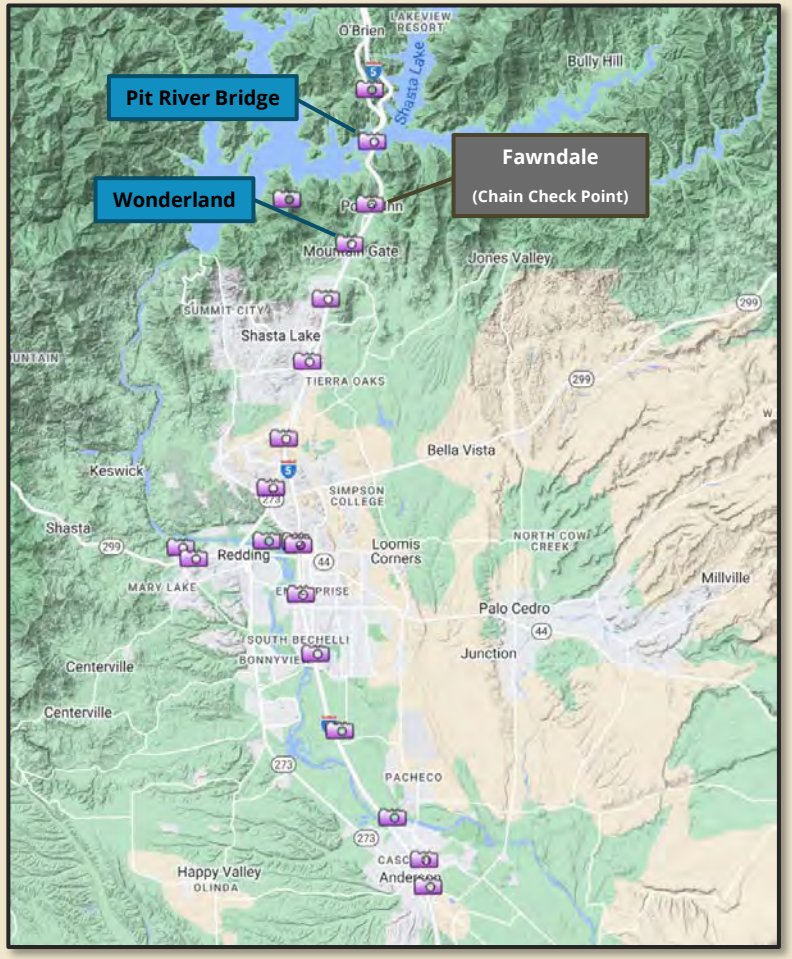
Wonderland to Pit River Bridge





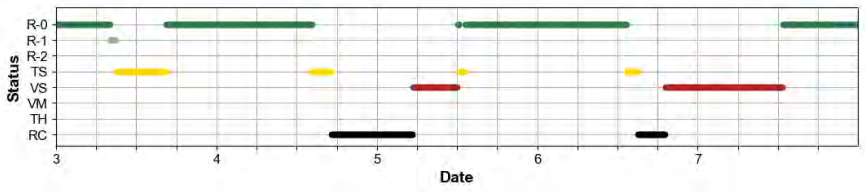




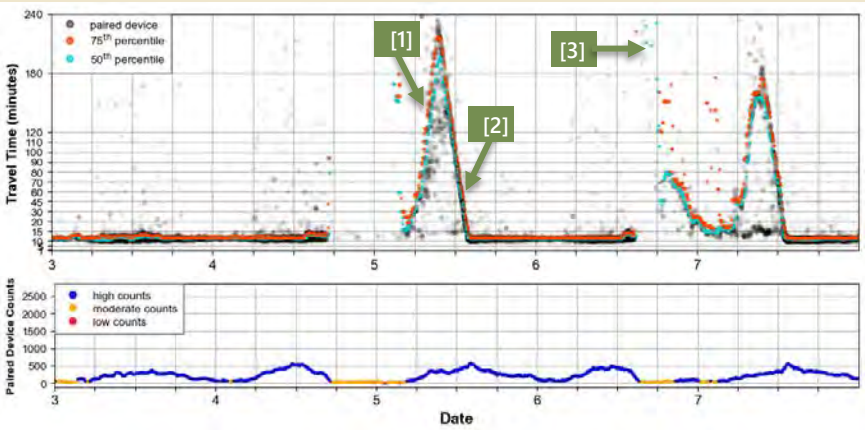


Testing Event – February 2025

Chain Control Status



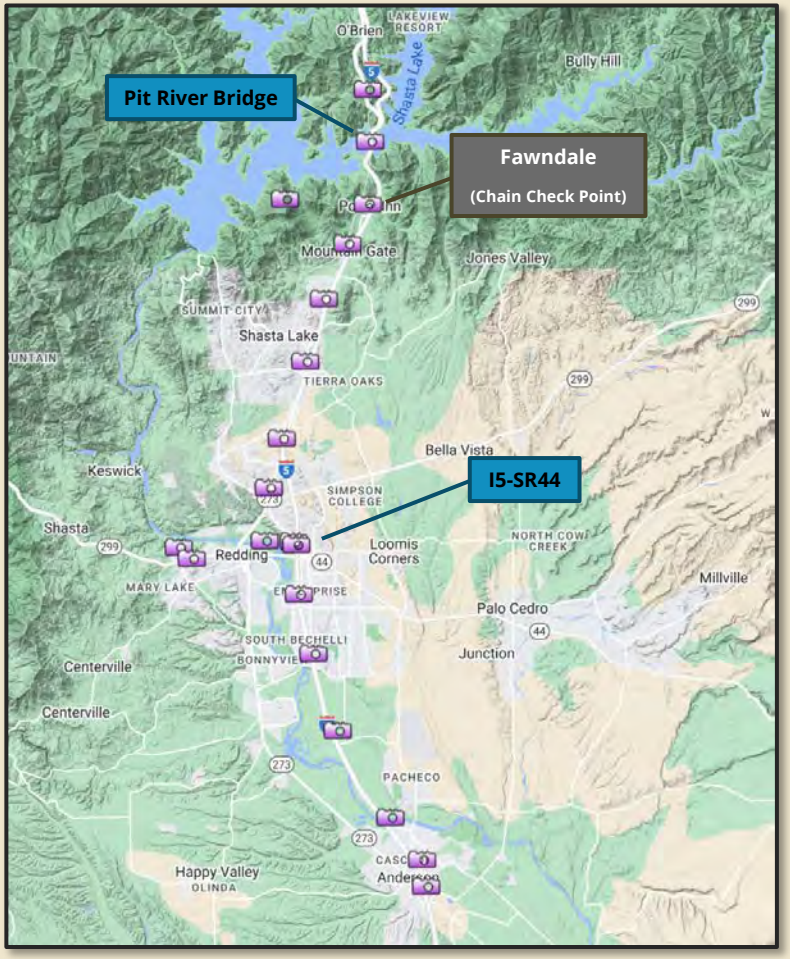
I5-SR44 to Pit River Bridge





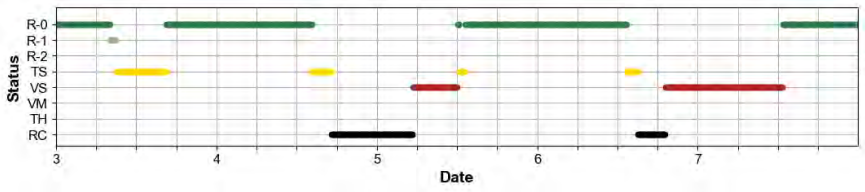




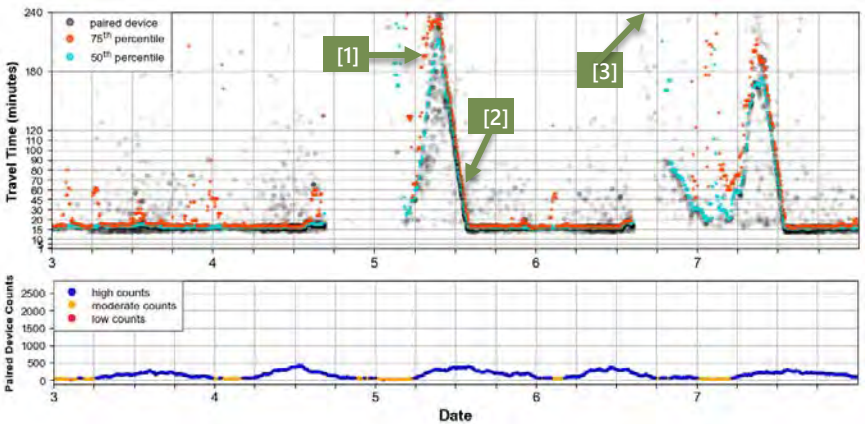


Testing Event – February 2025

Chain Control Status



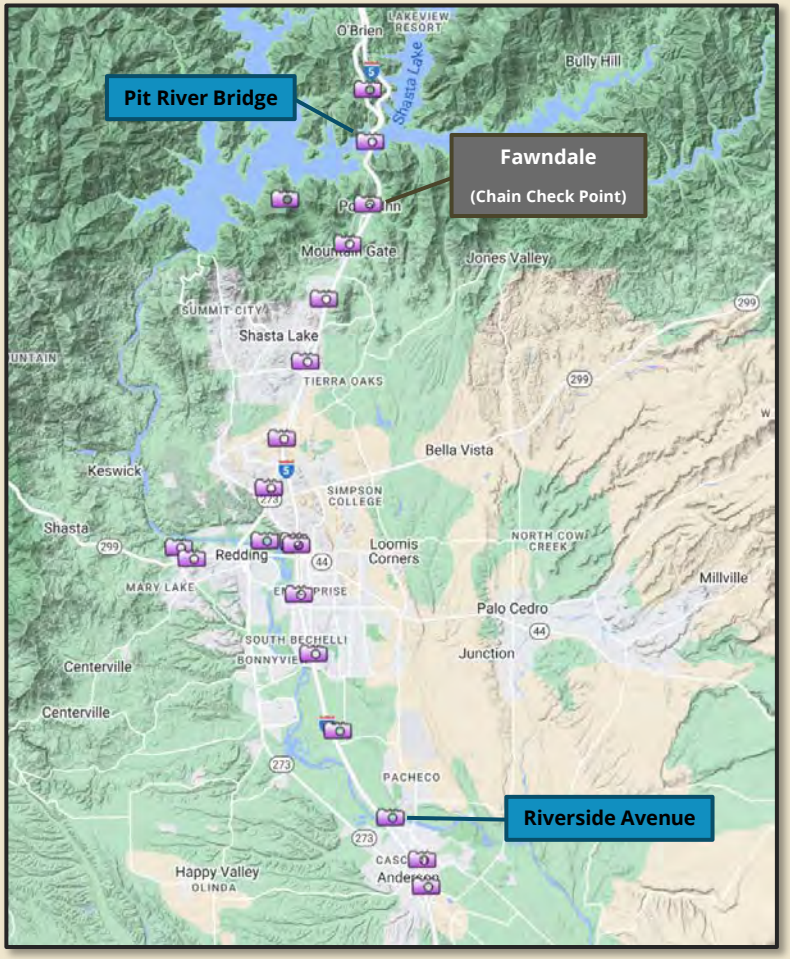
Riverside to Pit River Bridge











Results

Percentile summary measures were consistent with trends observed in the Paired Device data.

Tuning of the November 2024 event produced parameters that visually perform well on the February 2025 event, indicating generalizability despite limited data.

The 75th percentile performs best for northern sites, while the 50th percentile is more appropriate for south sites, likely due to commuter dominated traffic.

Conclusions

Percentiles may provide a reliable ground-truth benchmark for summarizing estimated travel time and speed.

Differences between north and south sites highlight the need for further tuning and calibration.

This framework successfully establishes a baseline that will support future development and evaluation of real-time delay prediction algorithms.

Techxpo 2026
(Montana Tech Student Research Exposition)

Chain-Up Delay Estimation for Interstate 5 in Northern California: Ground Truth Data Processing and Evaluation

MONTANA TECHNOLOGICAL UNIVERSITY

Project Team: Jason Decker, Emily Martin, Joseph Opitz, Dr. Douglas Galarus

Background

- **Location:** I-5 north of Redding, CA, serves as a major transportation corridor with limited alternative routes.
- **Chain Control:** A traffic restriction at Fawndale requires northbound vehicles to use or install approved traction devices based on road conditions.

Legend	Status Code	Description
	R-0	No chain controls are in effect at this time.
	R-1	Chains, traction devices or snow tires are required on the drive axle of all vehicles except four wheel or all wheel drive vehicles.
	R-2	Chains or traction devices are required on all vehicles except four wheel / all wheel drive vehicles with snow treaded tires on all wheels.
	TS	All trucks must stop at the chain check point. Caltrans is currently screening for chains. Drivers must have maximum chains in their possession in order to proceed. Trucks without chains will be turned around. Permit loads are prohibited over the summit.
	VS	All vehicles will be checked to make sure they have a full set of tire chains before being allowed to travel into areas where chains will be required.
	VM	A traffic control is in effect to meter vehicles at the chain check point in order to reduce traffic congestion in the mountain areas.
	TH	All truck trailer combinations are being held at the chain control camper due to incidents or weather-related conditions.
	RC	Road closed to traffic.

- **Monitoring:** Caltrans operates 12 sensors along I-5 that collect MAC addresses from traditional Bluetooth, Bluetooth Low Energy, and Wi-Fi devices.



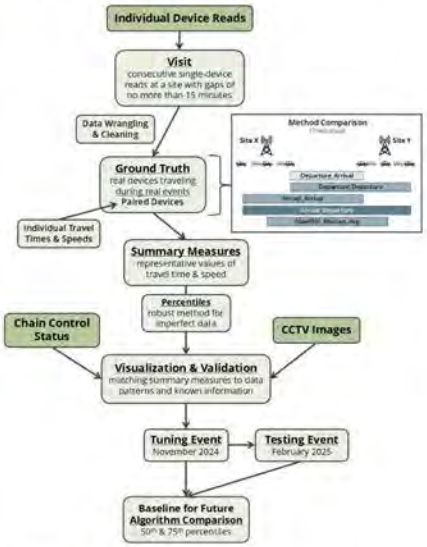
Problem Statement

- Chain control restrictions during extreme weather events can result in **backups** of 10 miles or more.
- Providing **accurate delay information** to drivers before backups form can reduce wait times, shorten queues, and improve safety.





Methodology



Objectives

1) Develop a **data-processing framework** for MAC address data and create summary measures to estimate vehicle travel time and speed.
2) Use the processed historical dataset to **establish a ground-truth benchmark** for evaluating and supporting real-time delay predictions during extreme weather events.

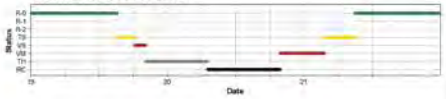
Results

- Percentile summary measures are **consistent** with trends observed in the Paired Device data.
- Tuning of the Nov'24 event produced parameters that visually **perform well** on the Feb'25 event, indicating generalizability despite limited data.
- The **75th percentile** performs best for northern sites, while the **50th percentile** is more appropriate for south sites, likely due to commuter dominated traffic.

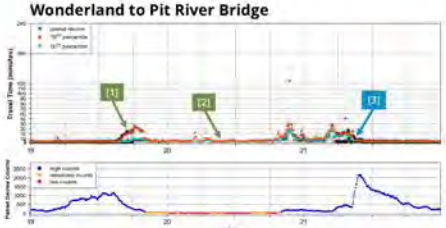
Results: Tuning

November 2024

Chain Control Status

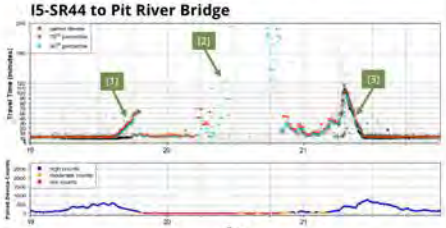


Wonderland to Pit River Bridge





I5-SR44 to Pit River Bridge

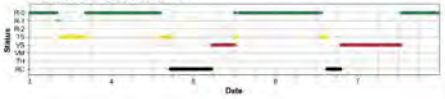




Results: Test

February 2025

Chain Control Status



Wonderland to Pit River Bridge





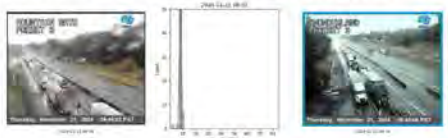
I5-SR44 to Pit River Bridge





Animation

Distribution of Individual Device Speeds Over Time



Conclusions

- **Percentiles** provide a **reliable ground-truth benchmark** for summarizing estimated travel time and speed.
- Differences between north and south sites highlight the need for **further tuning and calibration**.
- This framework **successfully establishes a baseline** that will support future development and evaluation of real-time delay prediction algorithms.

Credits: This research is generously sponsored by the California Department of Transportation (Caltrans) and Western States Rural Transportation Consortium and would not have been possible without the support of our mentor Dr. Galarus.

Part 6: Confirming Ground Truth

Part 6: Confirming Ground Truth

Galarus

April – May 2026

Delay was apparent in the data, but what were the real travel times?

More work needed to be done on this.

In Depth on Ground Truth Travel Times

The Details:

- Data Wrangling / Cleaning, Preprocessing
- Origin-Based Characterization of Travel time from A to B. Travel time when departing A, not when arriving at B.
- Too many parameters.
- This involves a lot of work – part of the reason why collecting your own data has gone out of vogue.

Visits





Visits

A first step in processing the original historical data for analysis is the calculation of what we call a visit.

A visit is a set of one or more consecutive reads of an individual device at a given site.

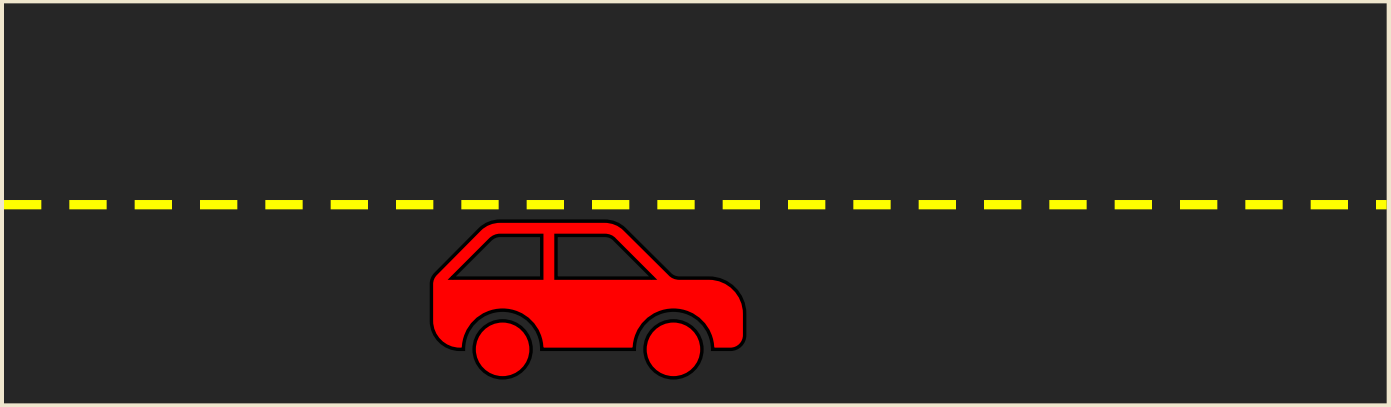
Multiple reads can occur at a site, particularly during chain-up events. With the prior approach of using the most-recent observation per device and site, this was largely ignored.

With historical data, this is valuable information that can and should be processed. But how?

Visits



Normal Flow – One read occurs as the car passes Site X.

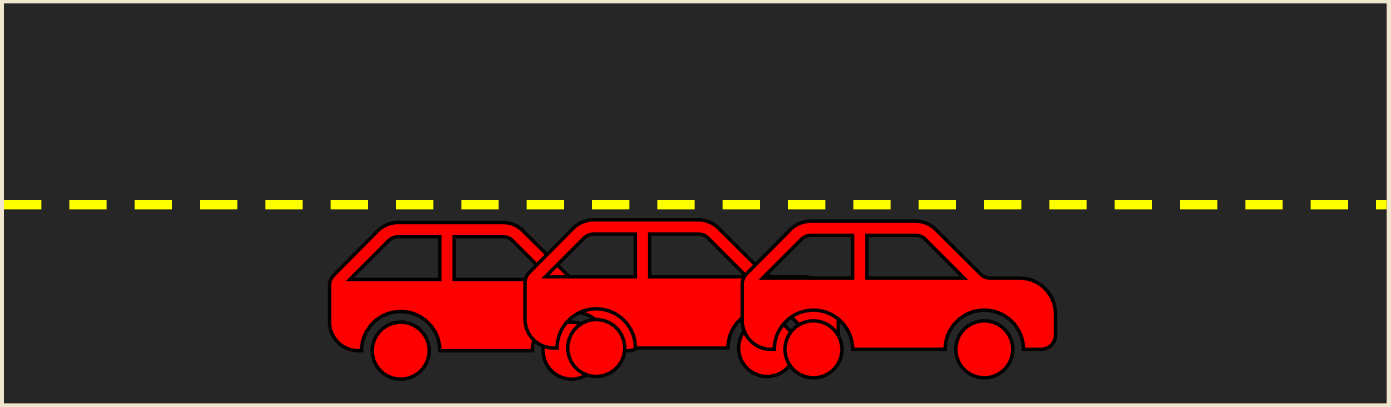


Consider a single car driving past Site X. Assume there is a single (Bluetooth) device in the car.

Visits



Normal Flow – Several reads occur as the car passes Site X.

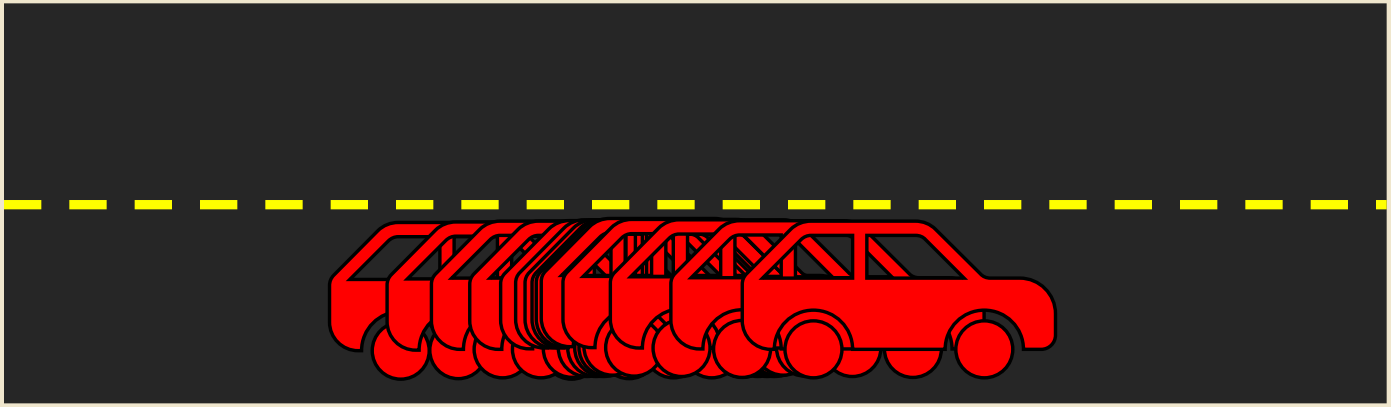


Consider a single car driving past Site X. Assume there is a single (Bluetooth) device in the car.

Visits

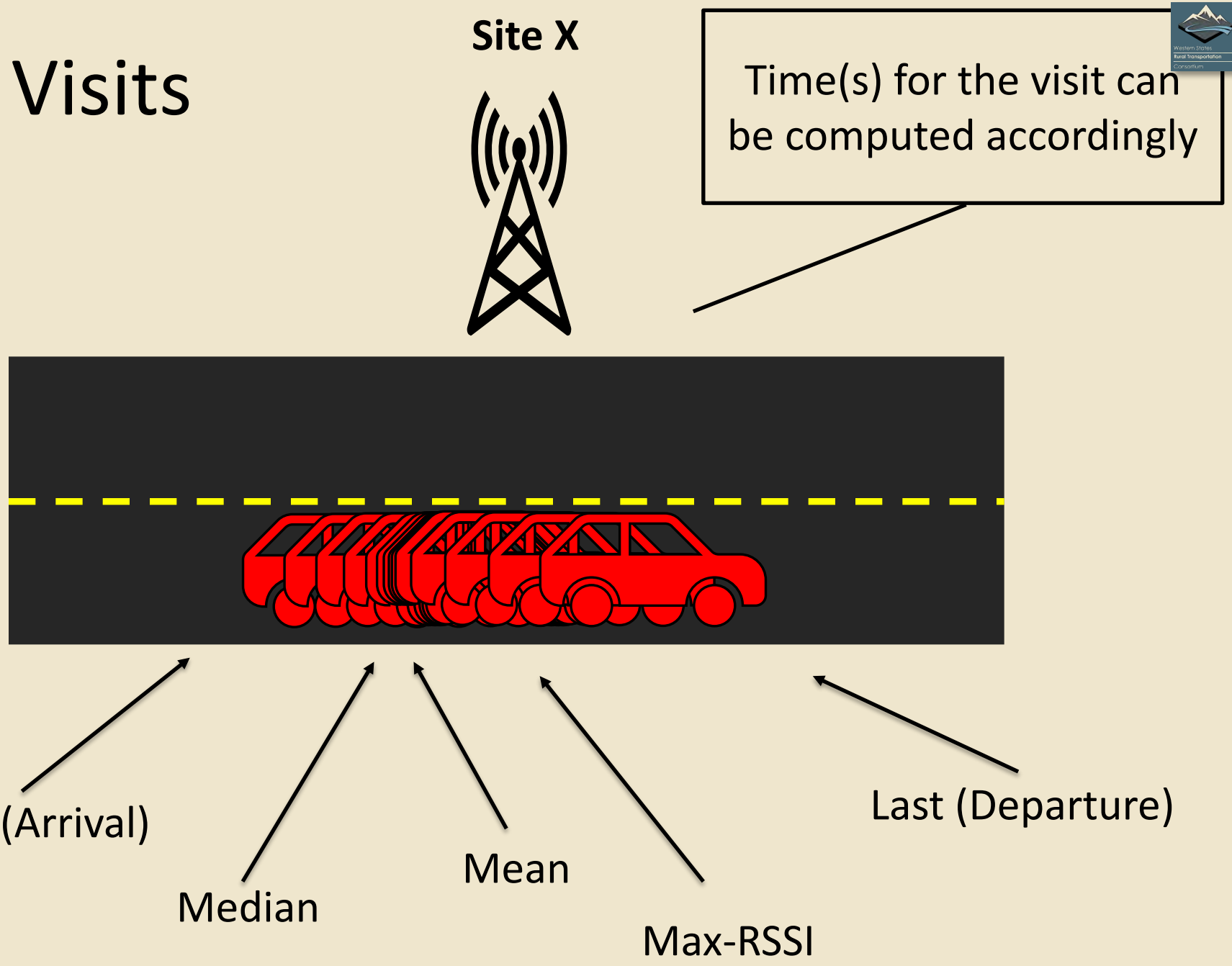


Traffic slowed or stopped – Numerous reads occur as the car is in proximity to Site X.



Consider a single car driving past Site X. Assume there is a single (Bluetooth) device in the car.

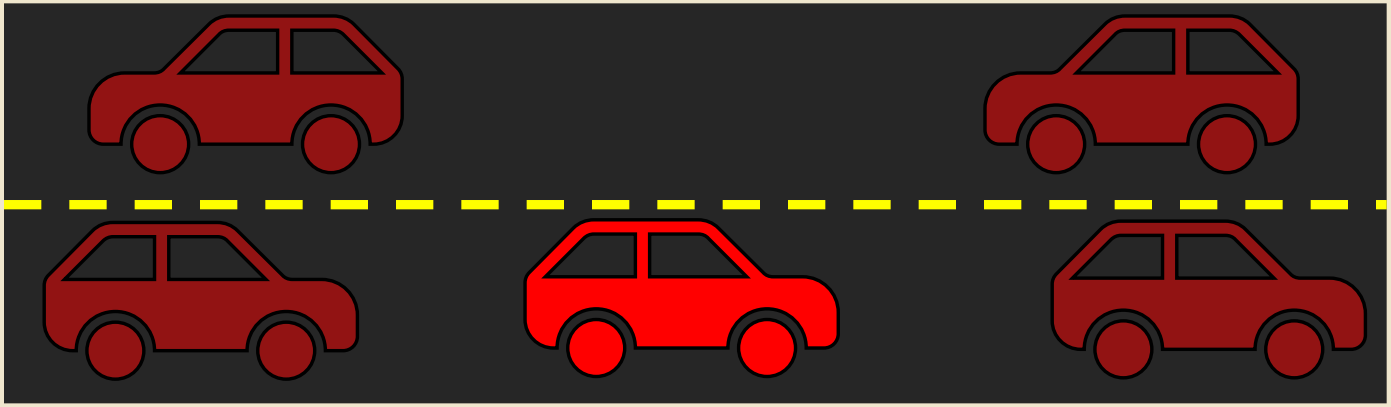
Visits


Site X
Time(s) for the visit can be computed accordingly
First (Arrival)
Median
Mean
Max-RSSI
Last (Departure)

Visits



Multiple reads occur as the car passes Site X multiple times on multiple trips.



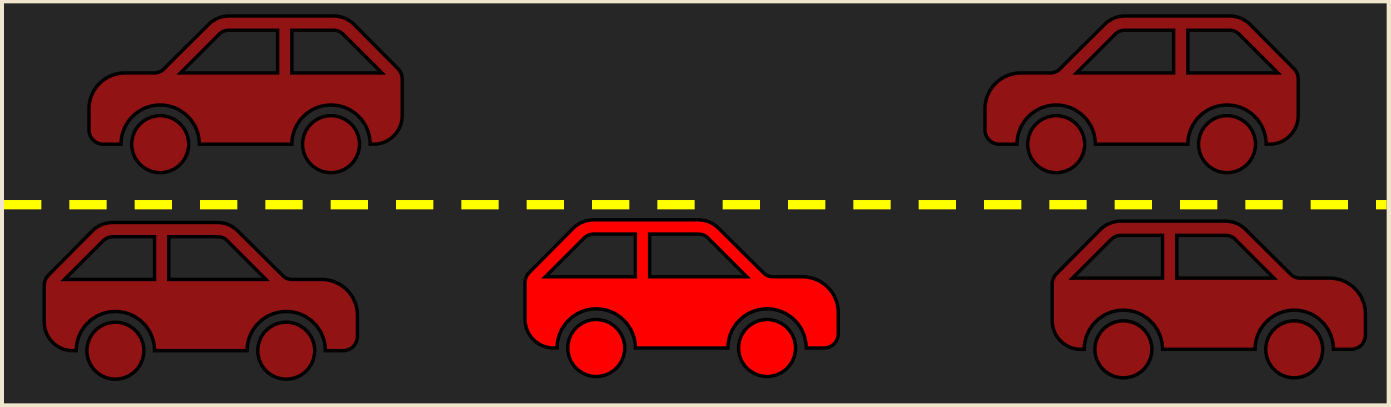
Vehicles (devices) may pass by Site X in multiple trips. The reads from these trips should be separated into visits.

Visits

Site X



Multiple reads occur as the car passes Site X multiple times on multiple trips.



To distinguish trips, we chose a Time Gap of 15 minutes. If the gap between reads exceeds this, then it is considered a new visit.

How to compute travel time?

The most basic calculation of travel time is the following:

Travel Time for Device D from Site X to Site Y

=

Time @ Site Y – Time @ Site X

We assume Device D visited Site X and then Site Y.

How to compute travel time?

The most basic calculation of travel time is the following:

Travel Time for Device D from Site X to Site Y

=

Time @ Site Y – Time @ Site X

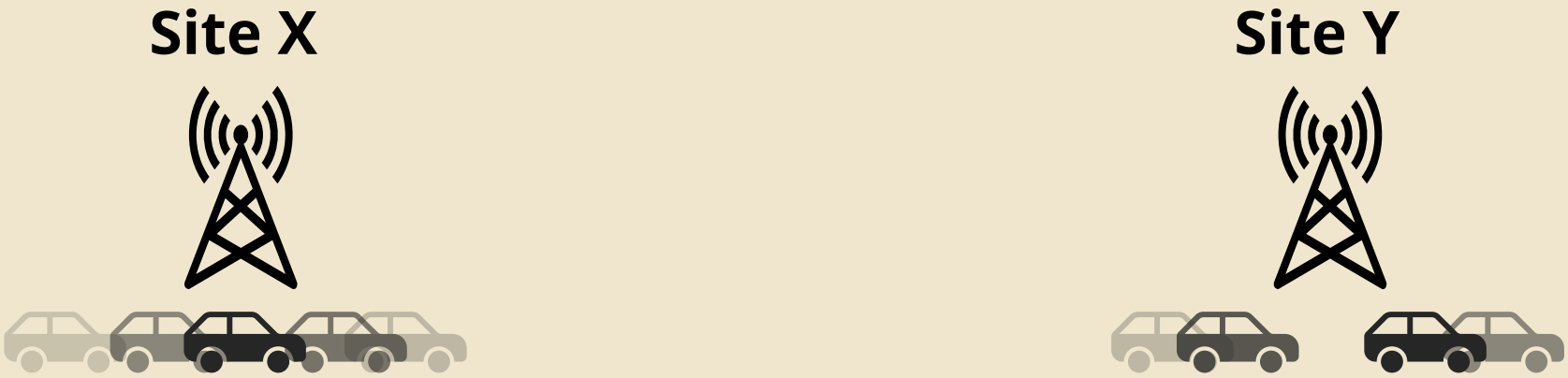
We assume Device D visited Site X and then Site Y.

What times are used here? We can choose from:

- First (Arrival), Median, Mean, Max-RSSI, Last (Departure)

We can could different combinations between Site X and Site Y. Which is best? Does it matter?

How to compute travel time?



- Departure to Arrival
- Departure to Departure
- Arrival to Arrival
- Arrival to Departure
- MaxRSSI to MaxRSSI
- Median to Median
- Mean to Mean

How to compute travel time?

While there is a difference in the ways to compute the times for a visit, we chose to use Max-RSSI for the following reasons:

- Max-RSSI intuitively corresponds to point at which the device passed closest to the sensor.
- Max-RSSI intuitively falls in the middle of a set of multiple reads.
- Max-RSSI yields a time at which there was an actual read of the device. Mean and Median can produce times that are close to but not the time of an actual read.

How to compute travel time?

Now consider the calculation of travel time based on multiple devices traveling along the roadway.

We assume times for individual devices are the Max-RSSI times.

Travel Time Computation

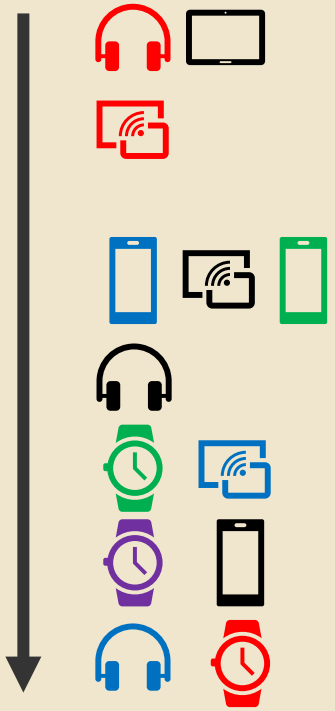


Time at Site X

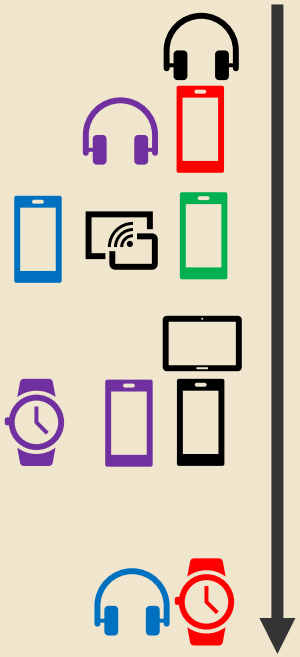
Consider multiple devices in proximity to Site X and Site Y over time. Some are in cars driving between Site X and Site Y.

How do we estimate travel time between Site X and Site Y at Time t?

Time at Site Y



Travel Time Computation



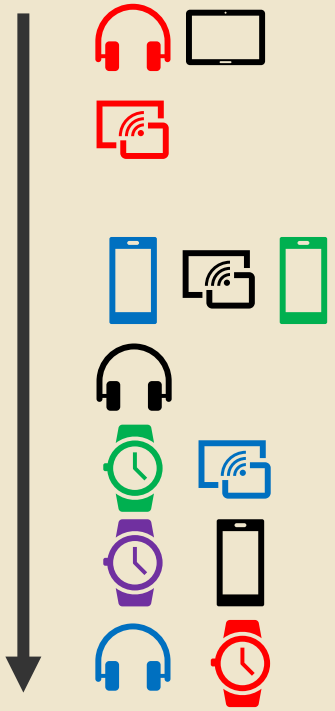
Time at Site X

Time t

For a vehicle at Site X at Time t, we want to know: How long will it take to get to Site Y?

With the historical data we can compute how long it took to get from Site X to Site Y at or near Time t.

Time at Site Y



How to compute travel time?

IMPORTANT:

What we are describing here is what we refer to as Origin or Departure-based travel time.

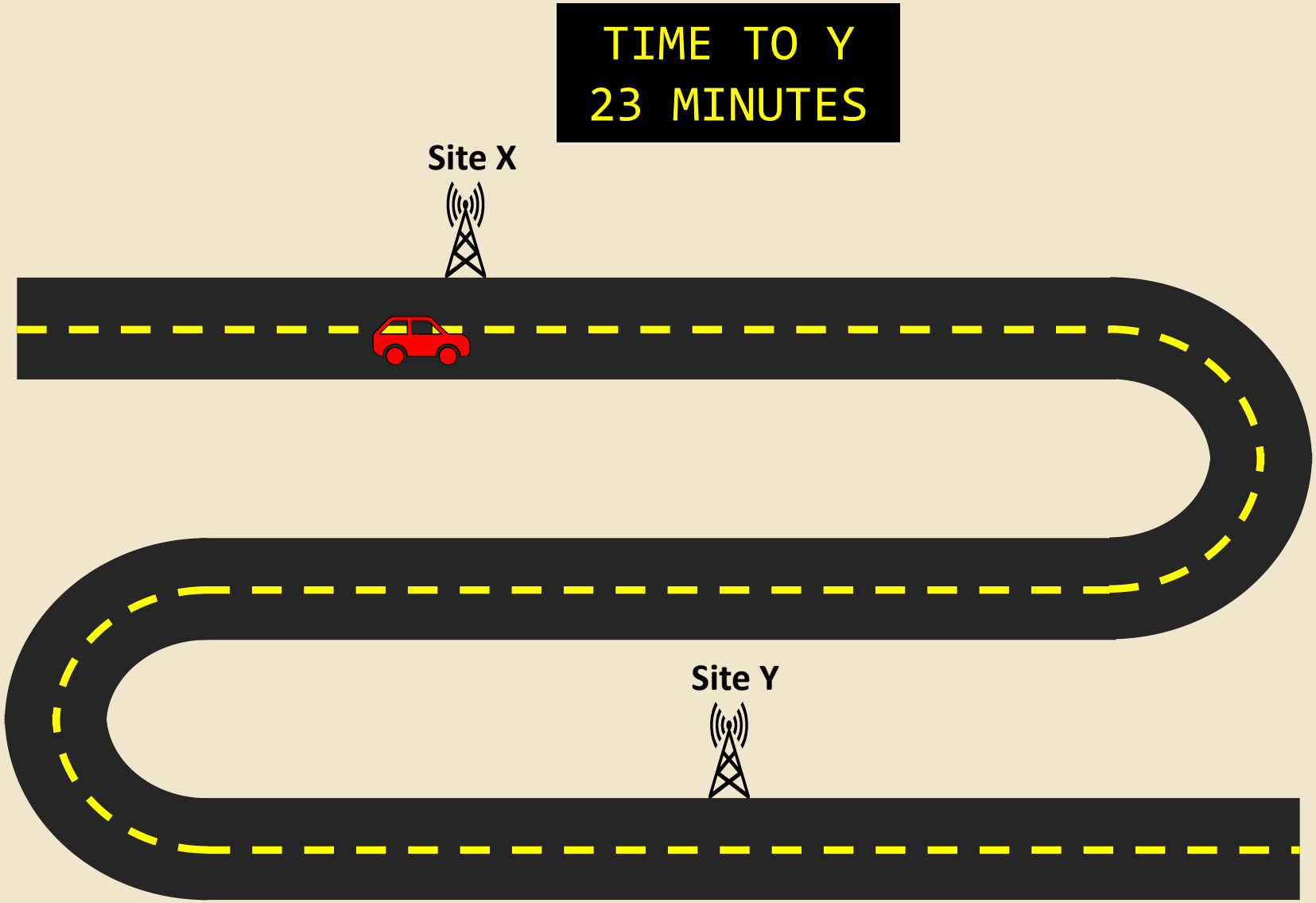
These travel times correspond to travel times from Site X to Site Y when at Site X at Time t.

In other words, these are the travel times that should have been shown at Site X at Time t for travel to Site Y. Ground Truth.

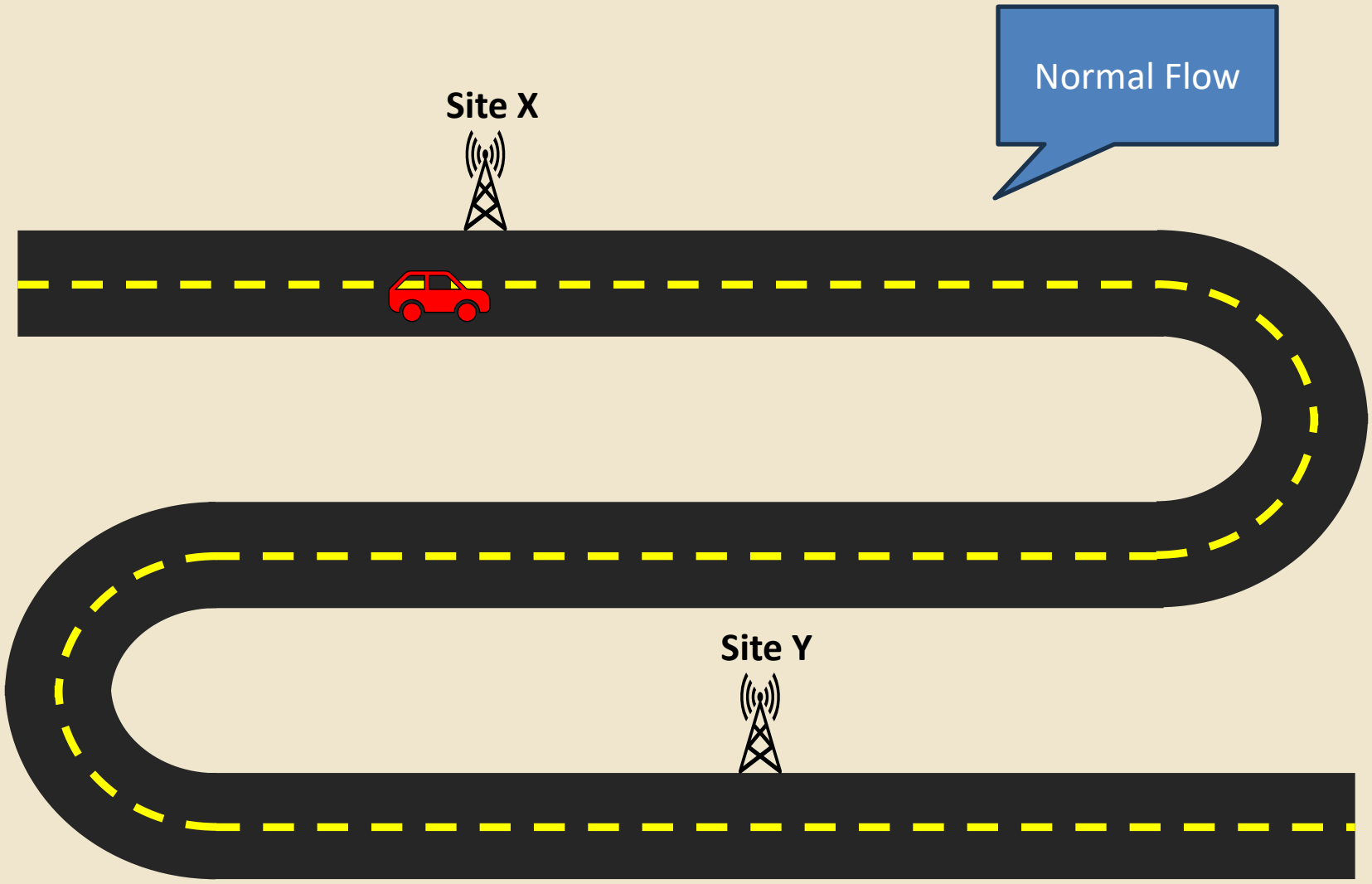
I.e.,

How long would it take to get from Site X to Site Y when at Site X?

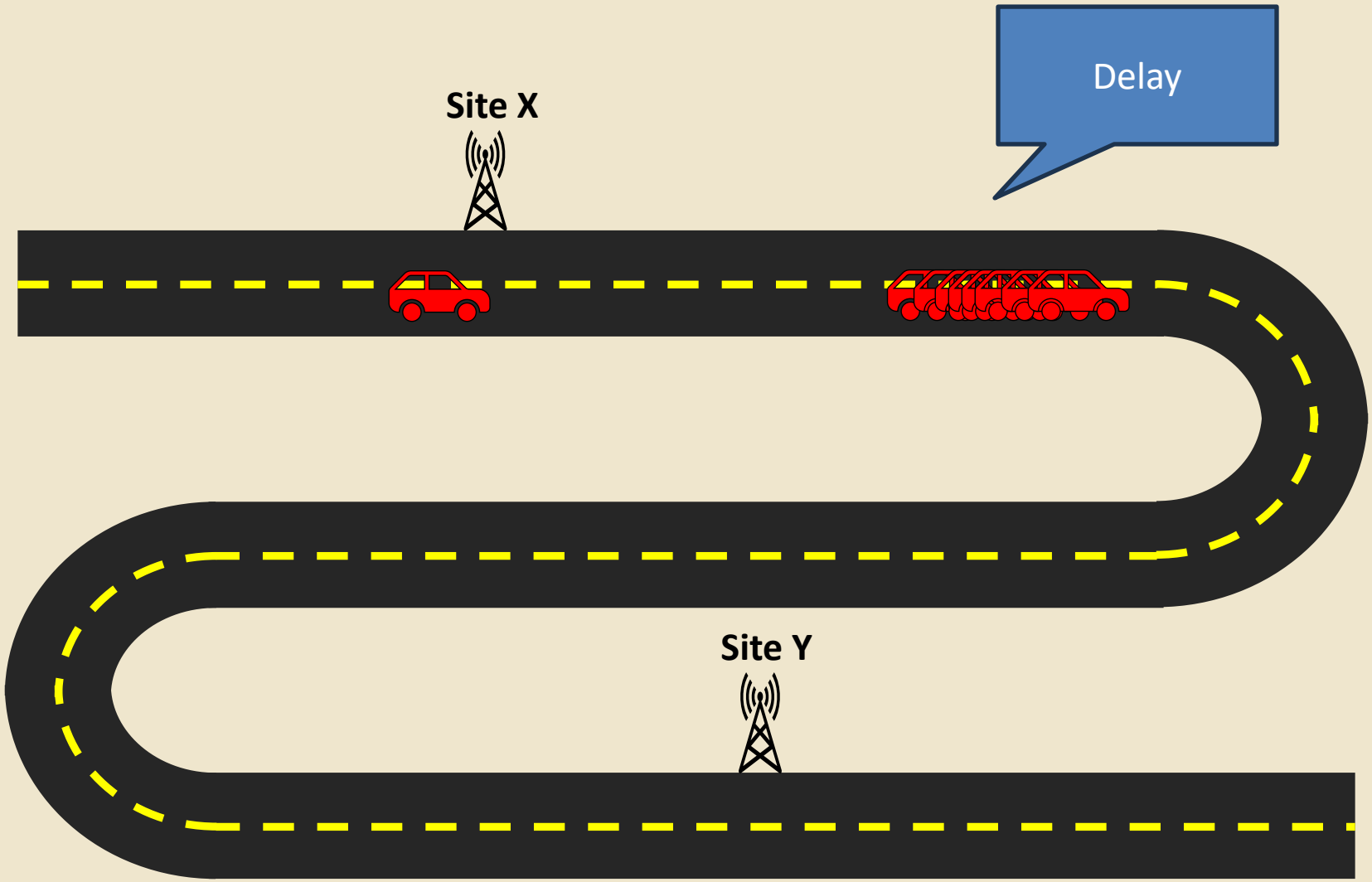
Estimated Travel Time



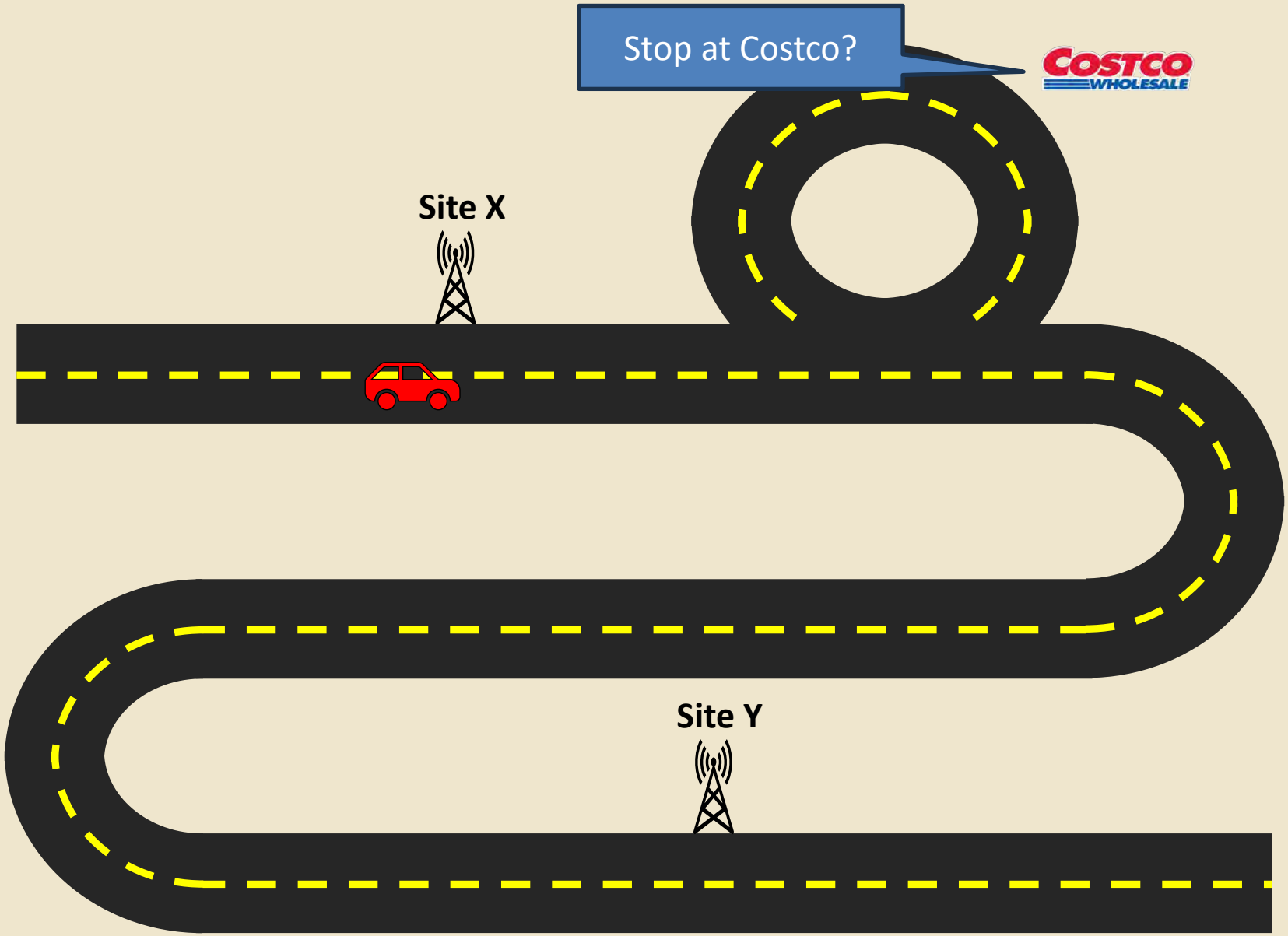
Travel Time – Considerations



Travel Time – Considerations



Travel Time – Considerations



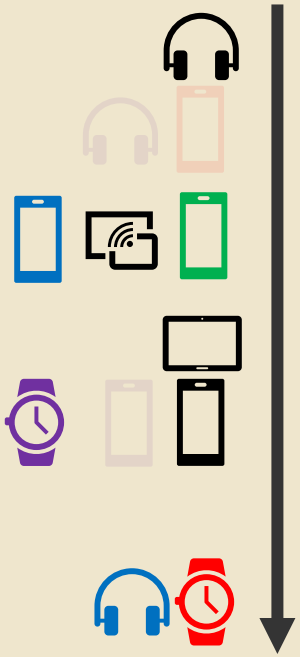
How to compute travel time?

IMPORTANT:

These Origin/ Departure –based travel times can be computed using historical data to give us (past) ground truth.

The real-time situation is different – see later slides.

Travel Time Computation

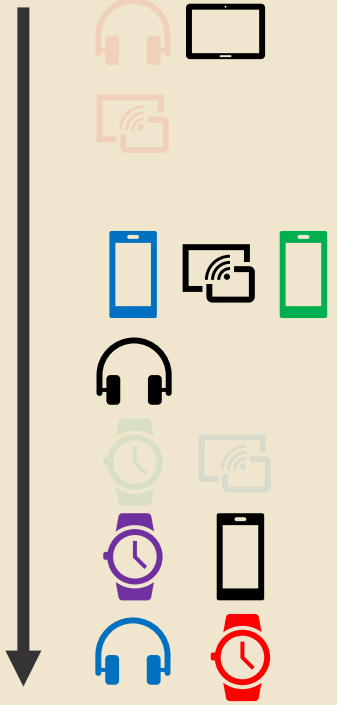


Time at Site X

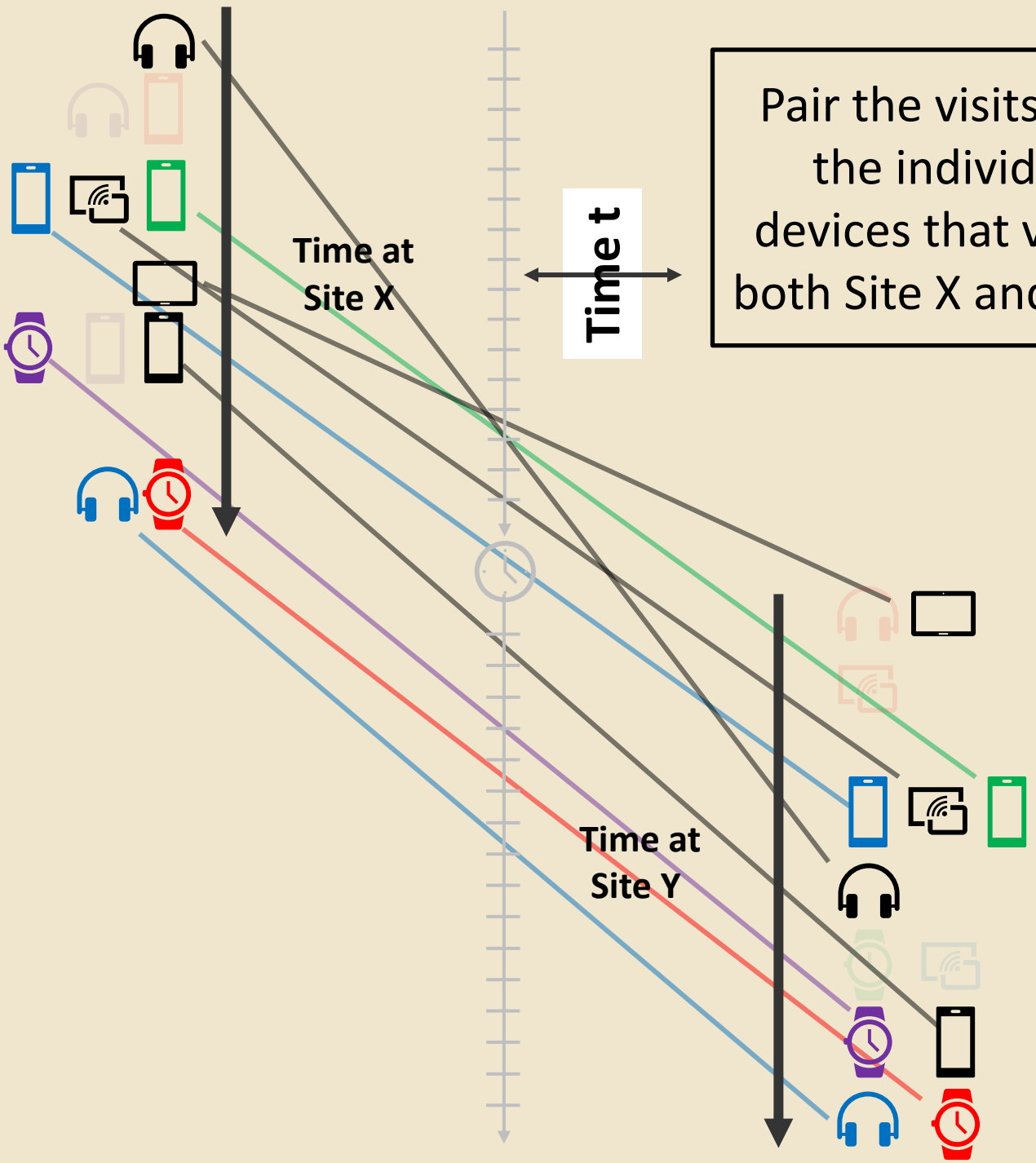
Time t

Identify devices that were read at Site X in proximity to Time t (within 30 minutes) that also visited Site Y.

Time at Site Y

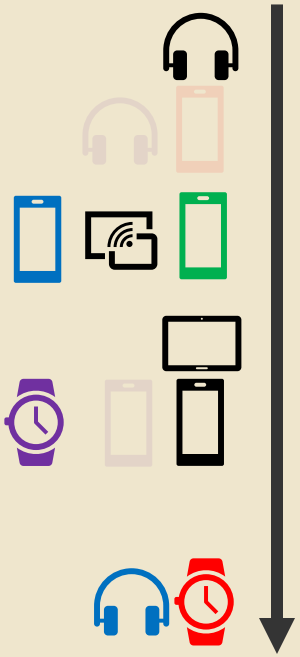


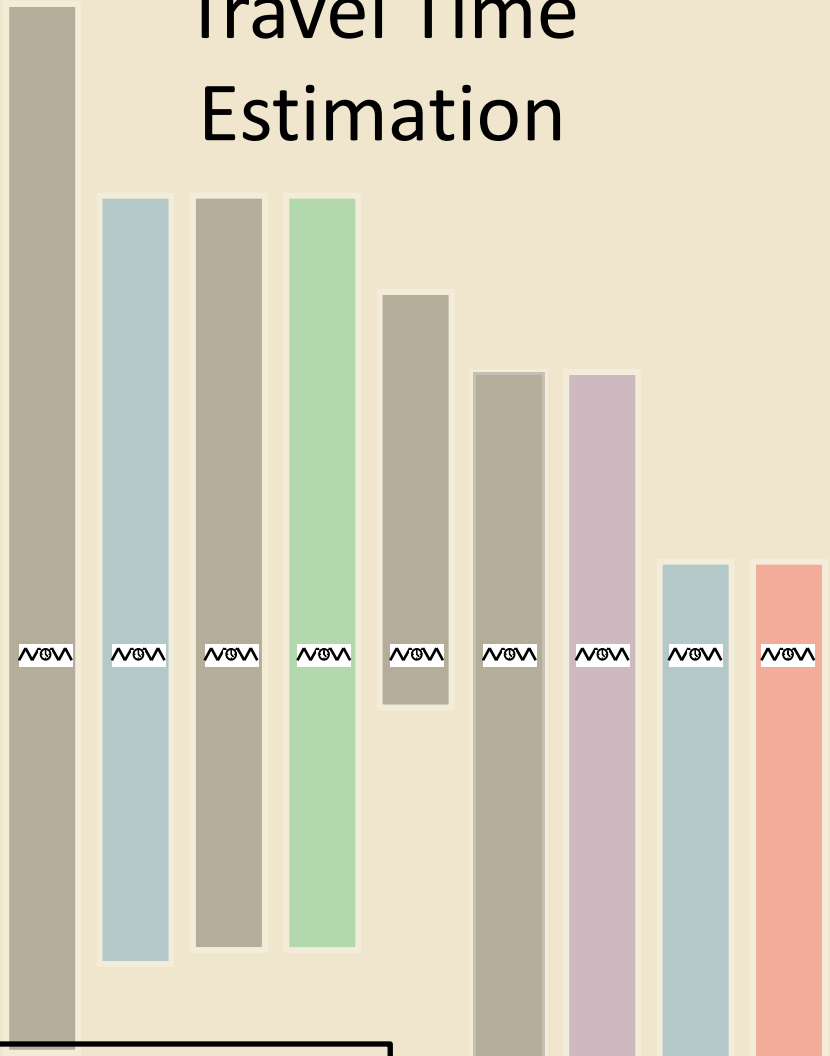
Travel Time Estimation

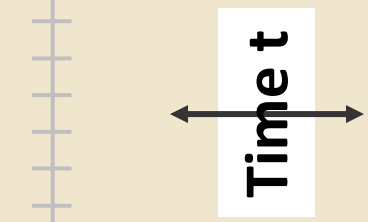


Pair the visits from the individual devices that visited both Site X and Site Y

Travel Time Estimation



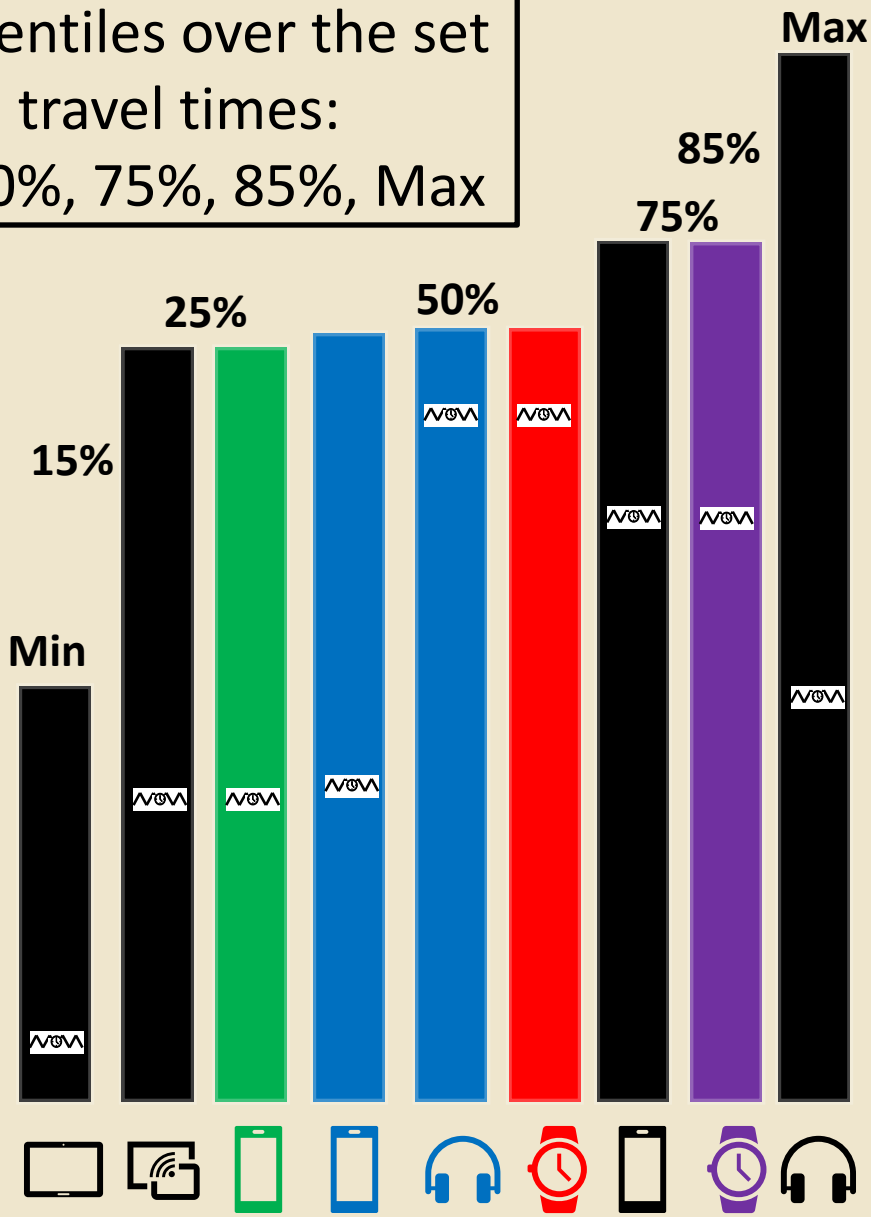




For each device, compute the difference between the time at Site Y and the time at Site X. These are the individual travel times.

Travel Time Estimation

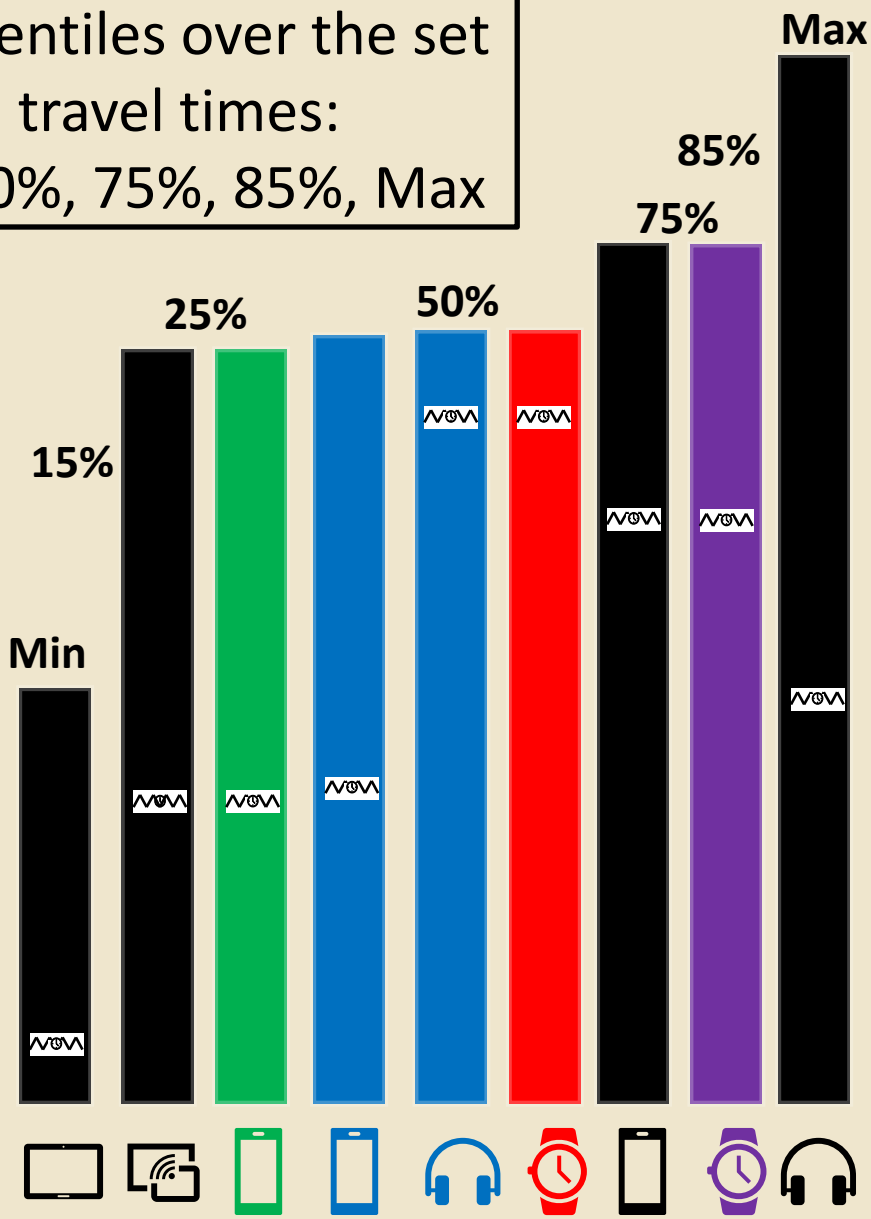
We compute percentiles over the set of individual travel times:
Min, 15%, 25%, 50%, 75%, 85%, Max



Travel Time Estimation

We compute percentiles over the set of individual travel times:
Min, 15%, 25%, 50%, 75%, 85%, Max

Which to use?



How to compute travel time in real time?

IMPORTANT:

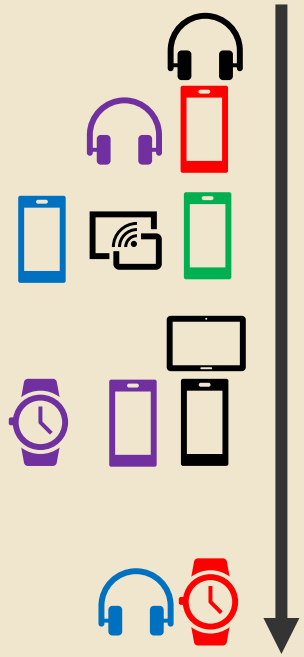
The Origin/ Departure –based travel times are computed using historical data to give us (past) ground truth.

The real-time situation is different.

For the real-time situation, we do not know actual individual travel times from Site X to Site Y until vehicles (devices) reach Site Y.

Destination / Arrival –based travel times are computed similarly based on time of arrival at Y.

Travel Time Estimation



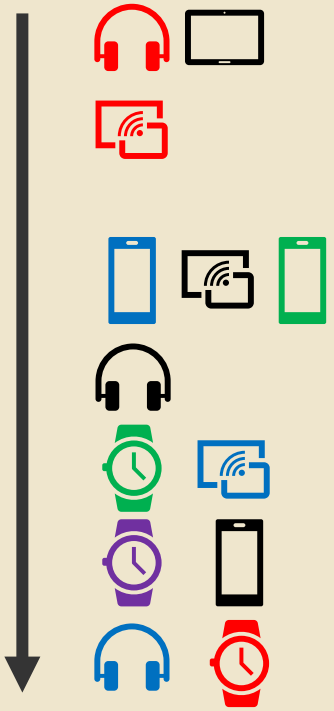
Time at Site X

We can use the historical data to compute how long it took to get from Site X to Site Y at or near Time t.

For a vehicle at Site Y at Time t, we can compute: How long did it take to get to Site Y from Site X?

Time t

Time at Site Y



How to compute travel time in real time?

IMPORTANT:

There will be a lag between Destination / Arrival –based travel times that are computed based on time of arrival at Y versus Origin/ Departure –based travel times that are computed time of departure from X.

The lag will be greater when there is delay versus normal flow.

Adjacent Sites vs. Collective Travel Times

We had been looking at speeds and travel times between adjacent sites. This didn't tell the whole story and didn't give us a good indication of the collective travel times across the larger area.

We had also been thinking in terms of the real-time situation and were trying to model it. We needed to step back and think differently about ground truth.

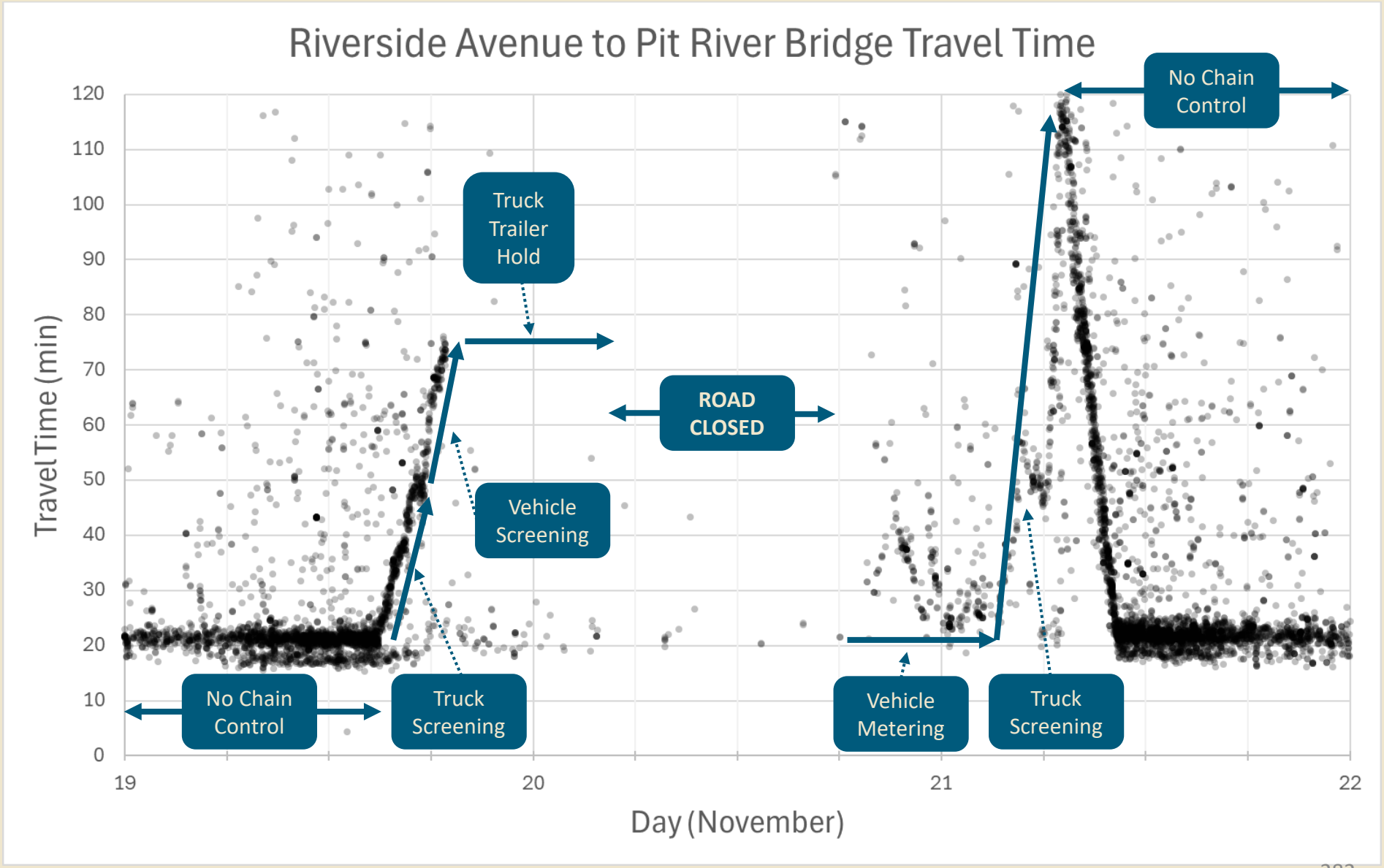
Because we have historical data, we can look at longer runs across the entire area and characterize travel times within. Doing so can give us what we were looking for – the best indication of ground-truth travel times.

Apply to Formalize Ground Truth

We will use Riverside Avenue to Pit River Bridge to formalize Ground Truth by analyzing individual devices. This covers our study corridor from start to finish.

Then we will try to determine aggregates (percentiles) that match the patterns from the individual devices.

Is this real? Does it show Ground Truth?



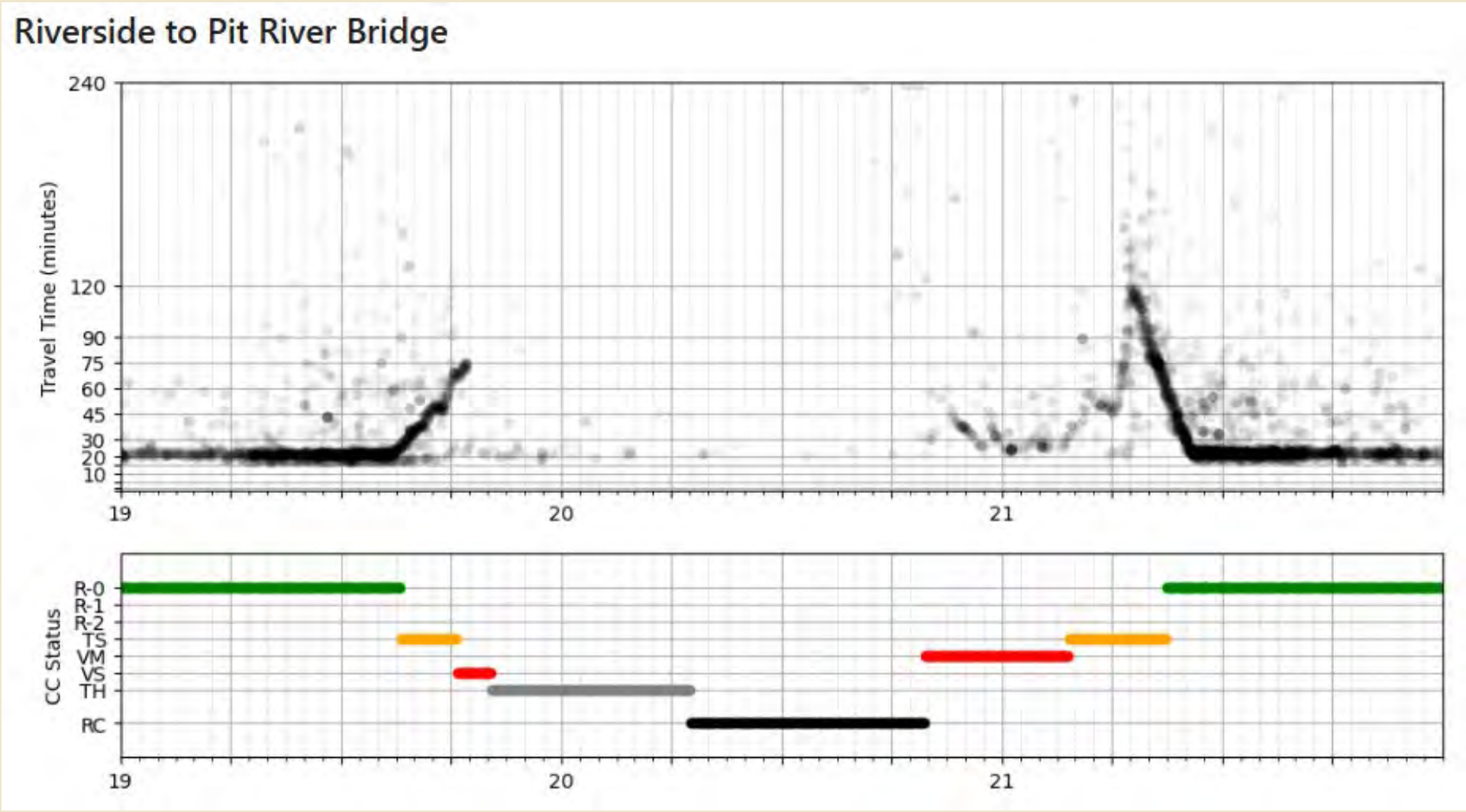
Examine Paired Device Plots

Using Origin-Based Travel Times –

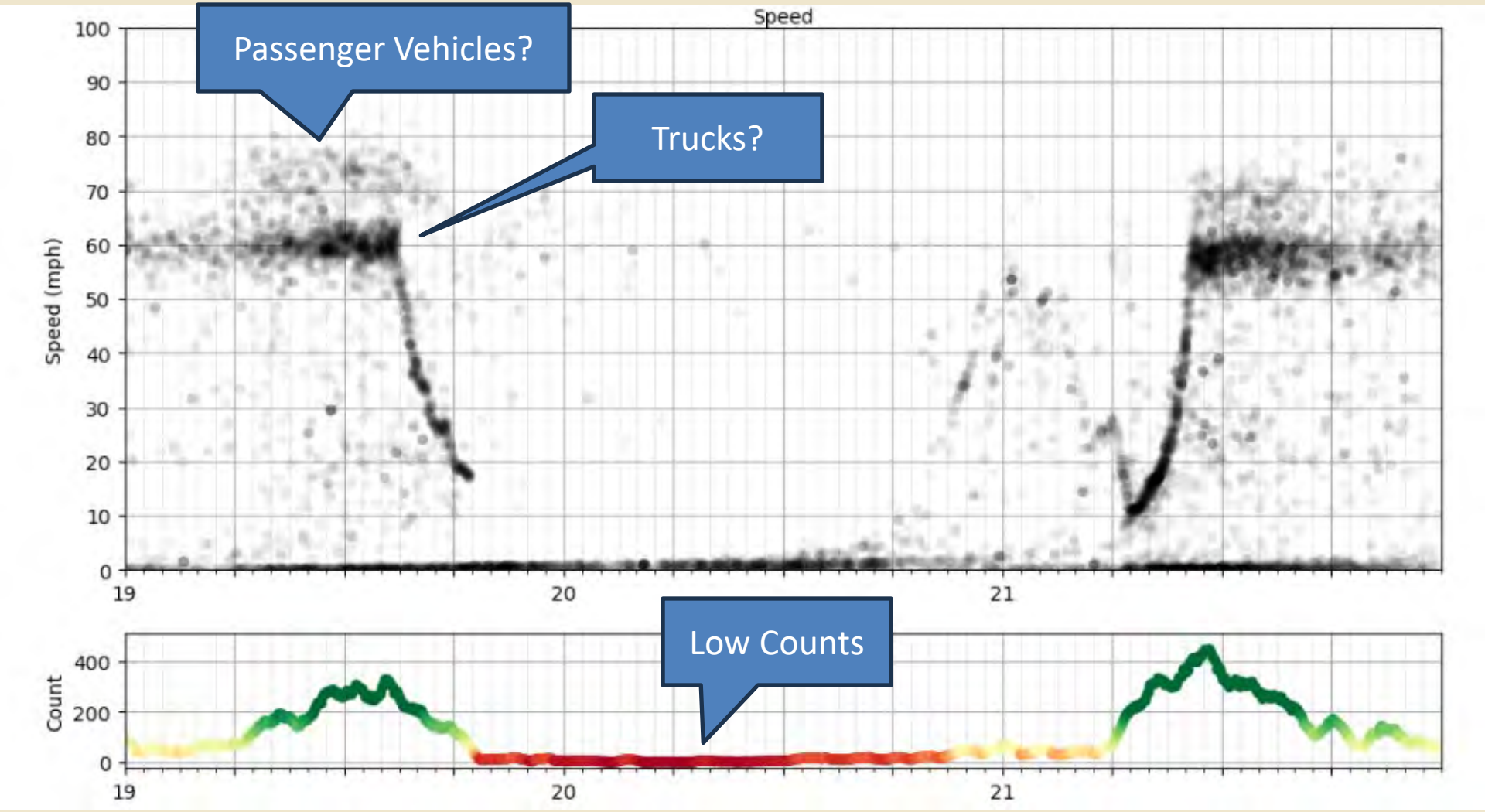
What was the travel time from A to B when at A?

We use the Max RSSI reading, middle ground, which corresponds to a real time that is intuitively the time when the device passes the sensors.

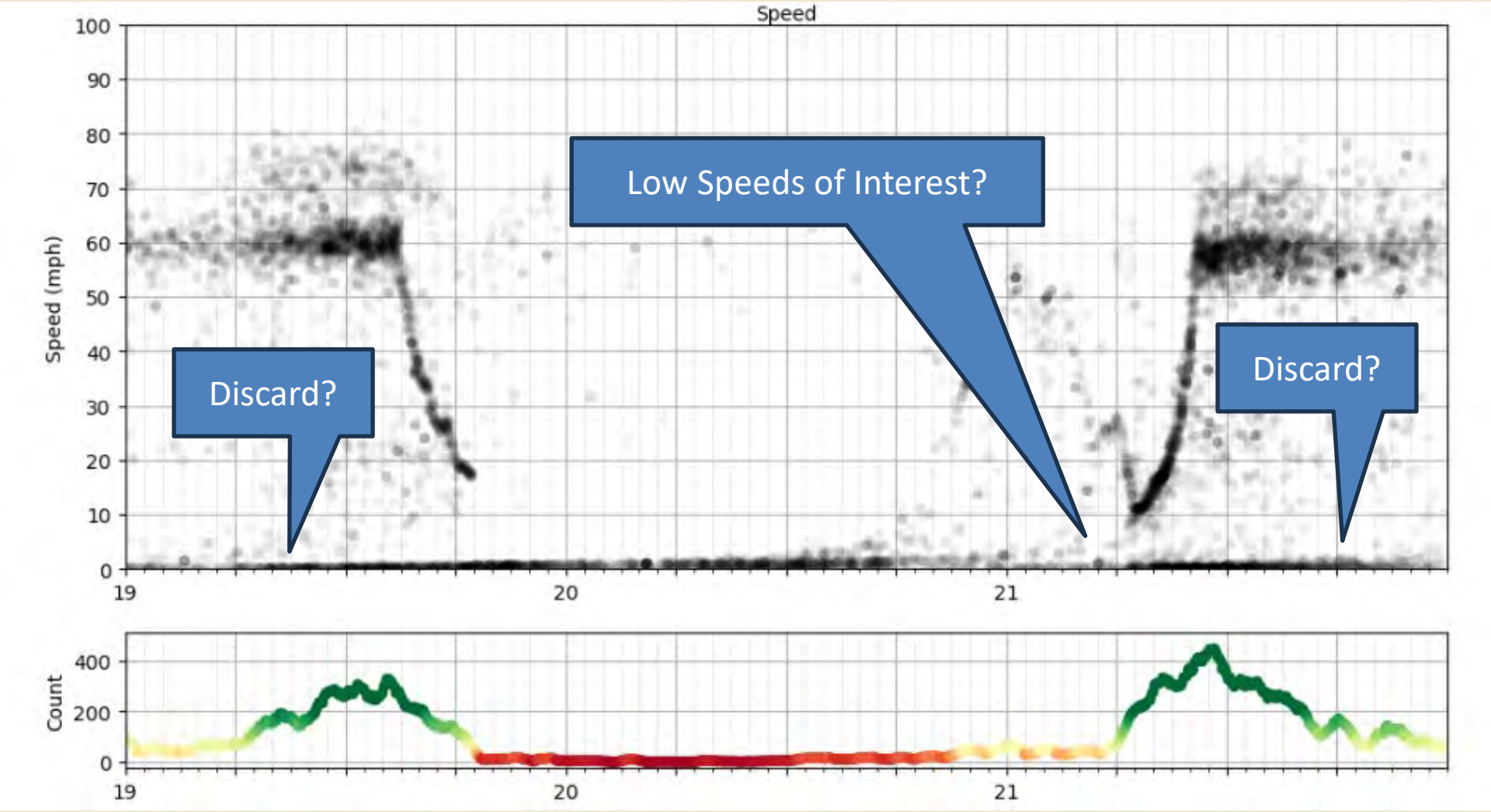
Paired Device Plots – Travel Time



Paired Device Plots – Speed

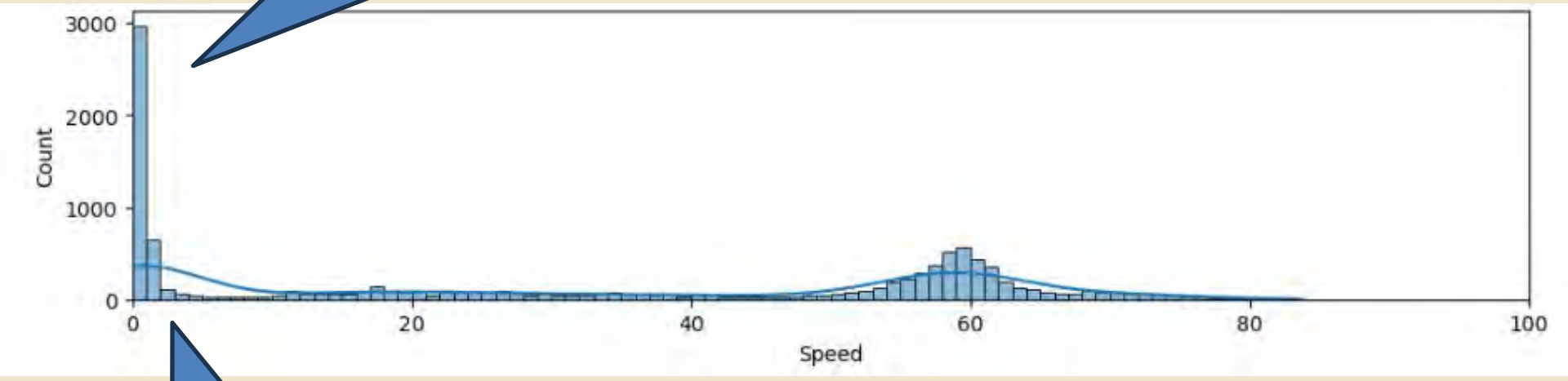


Paired Device Plots – Speed



Distribution of Speeds

A lot of low speeds – some may be interest while others logically should be discarded.



Should a simple cutoff be used to remove these or is something else needed to address this?

This impact statistics, including percentiles.

Examine Through-Traffic Paired Device Plots

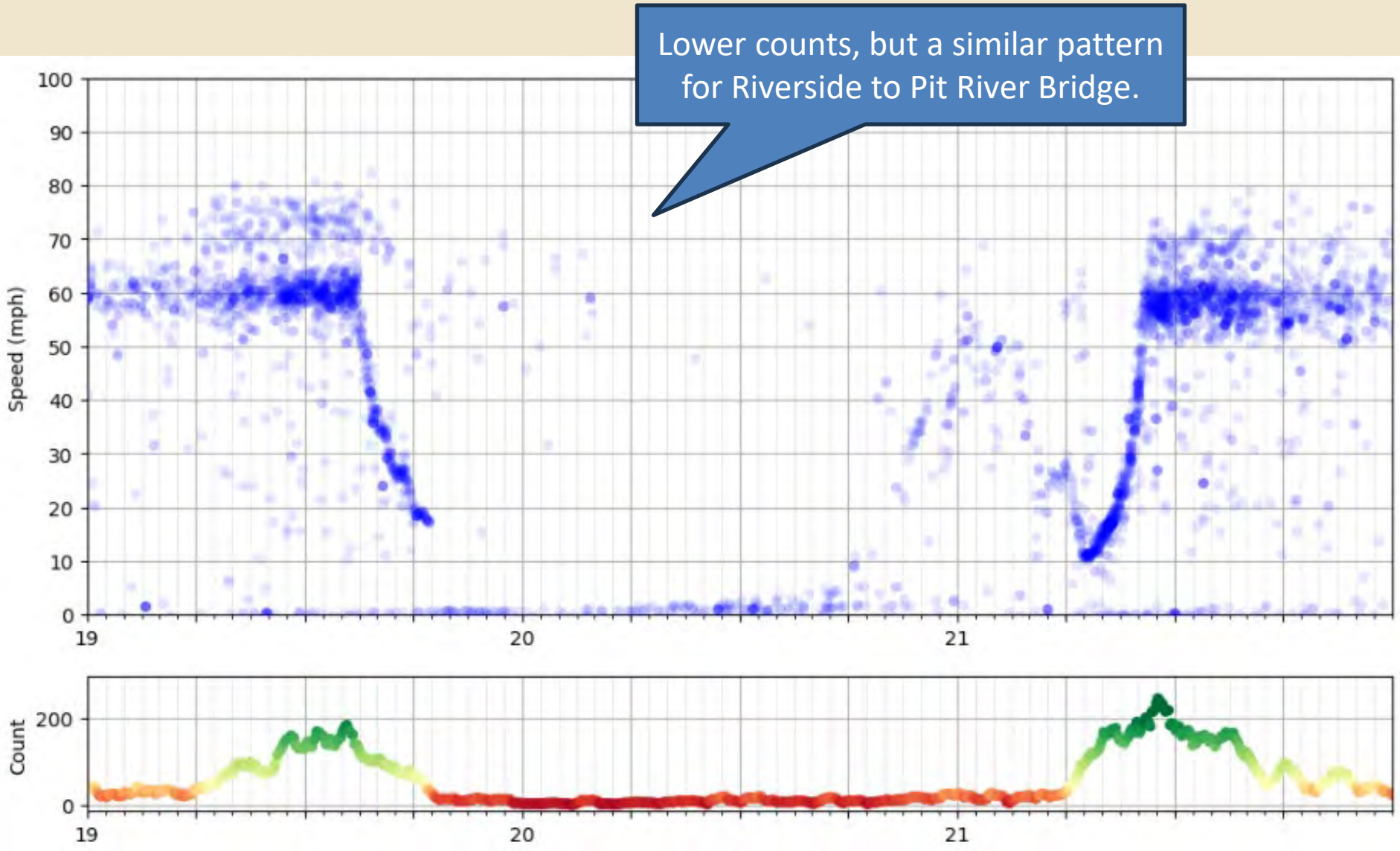
Pairing devices between shorter segments includes all pairings, including and sometimes dominated by local traffic that does not traverse the entire corridor.

What if we examine devices that are read at all 12 sensor locations?

Our first thought was that there would not be enough of these to be use. Upon further examination, we found that there were over 50,000 such device trips that occurred in November 2024, and the associated pairings provide useful insight into through traffic. This is the traffic we are most interested in.

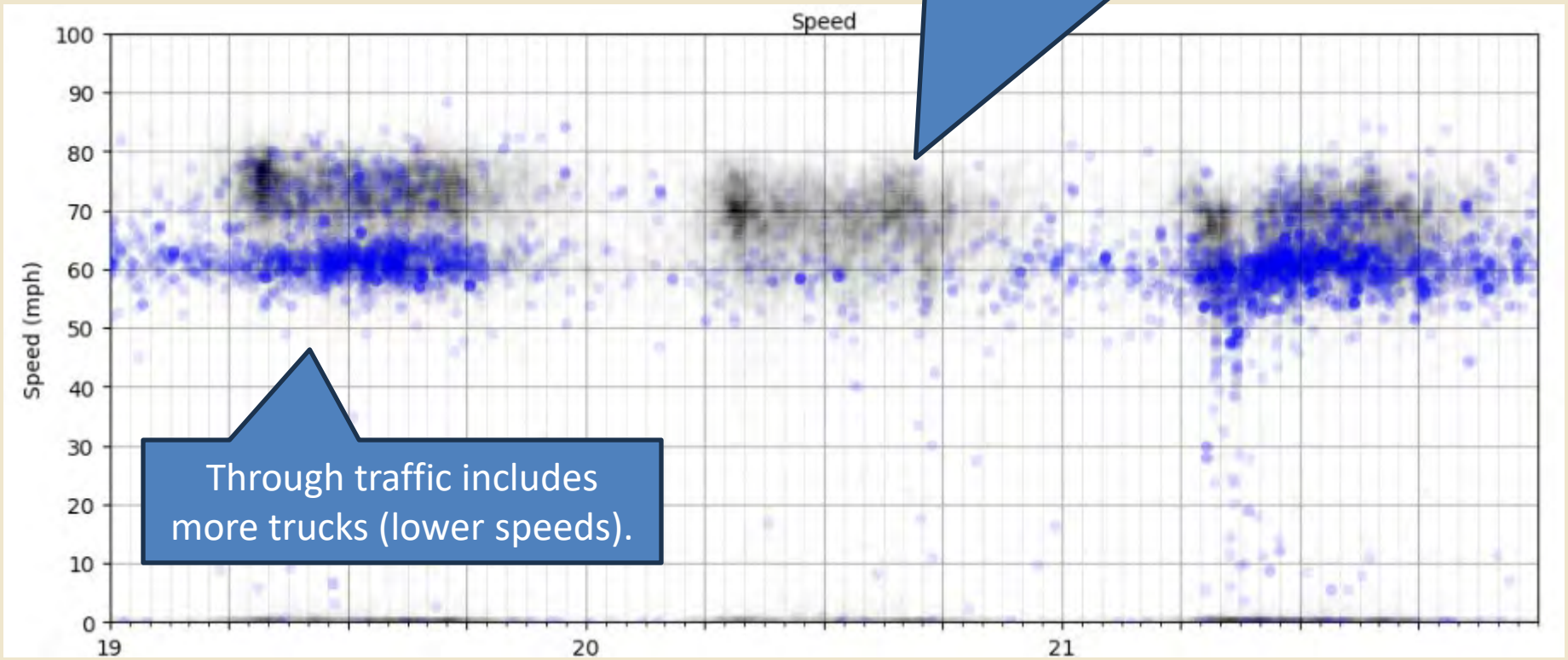
Through Traffic Paired Device Plot – Speed

Riverside to Pit River Bridge



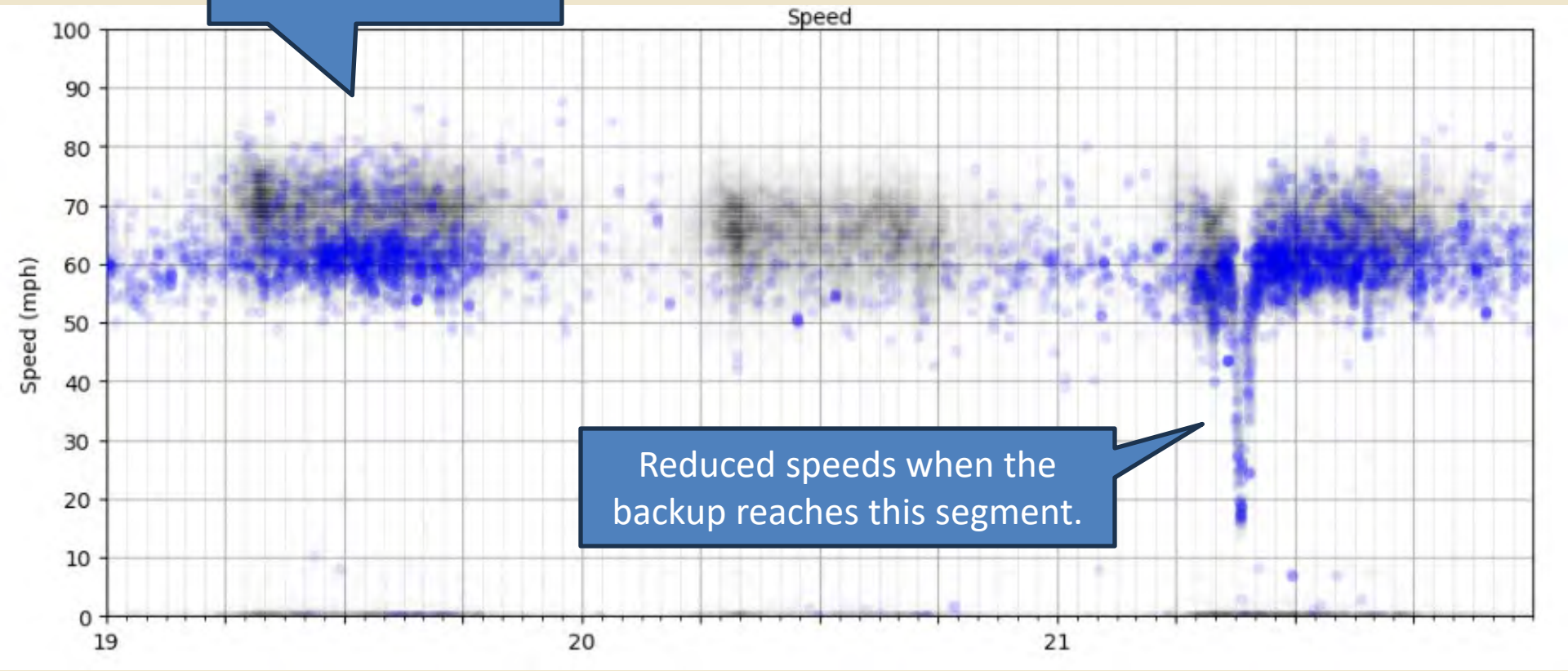
Through Traffic Paired Device Plot – Speed

Riverside to Knighton Rd (The Southernmost Segment)



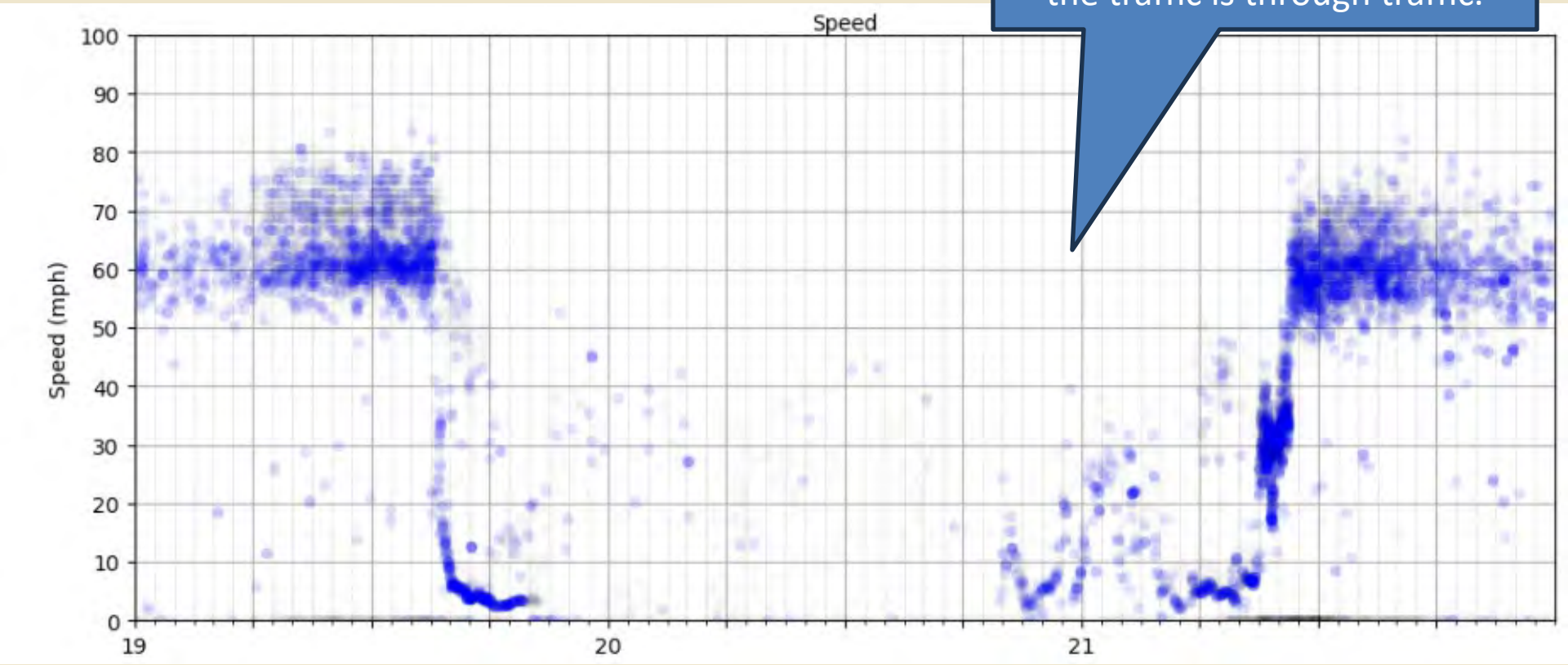
Through Traffic Paired Device Plot – Speed

South Bonnyview to Hartnell (Also a Southern Segment)



Through Traffic Paired Device Plot – Speed

Wonderland to Fawndale (Northern Segment)



What else could we do to get to Ground Truth?

What else could we do with this data to get to Ground Truth?

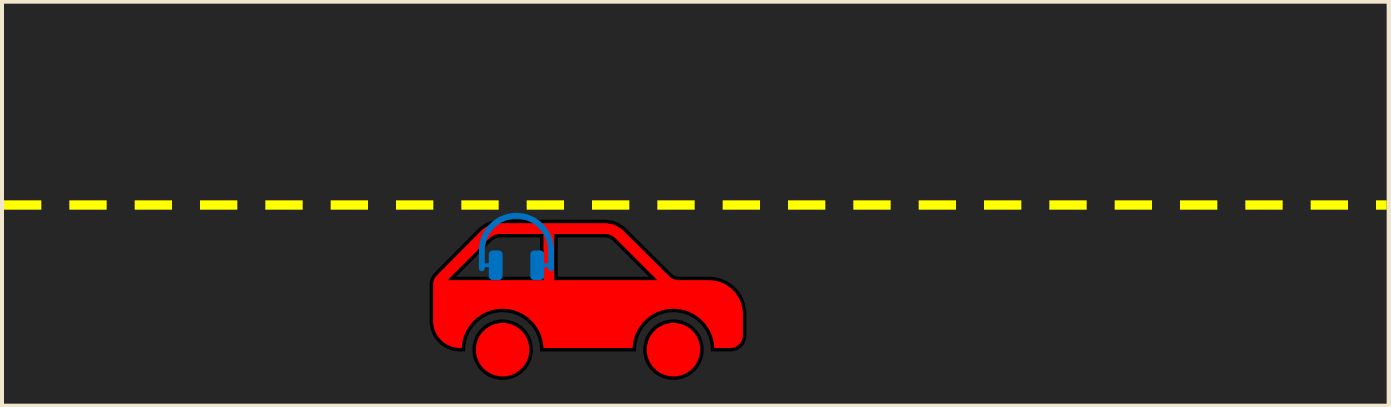
What else could we do to get to Ground Truth?

What else could we do with this data to get to Ground Truth?

Ride along with some of the (representative) devices …



ALL VEHICLES
CHAIN SCREENING
NORTH OF REDDING



What else could we do to get to Ground Truth?

If we could go back in time, we could drive through the corridor and measure travel times firsthand.

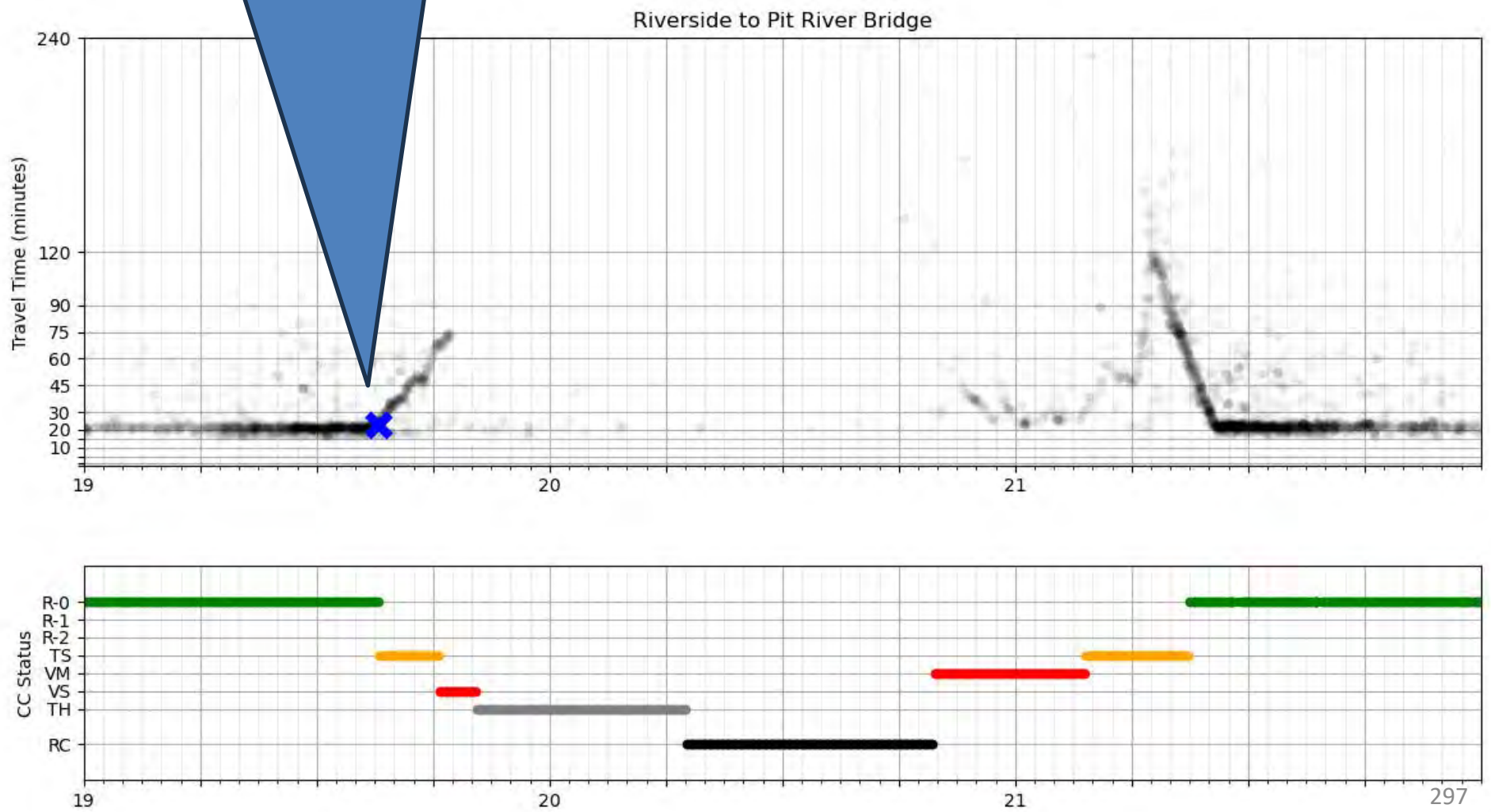
We did the next best thing – we tracked individual devices through the corridor at representative points in time.

Track Individual Devices through the Corridor

To further attempt to determine if these patterns represent Ground Truth, we tracked devices through the corridor and validated what we saw against speed plots and CCTV images.

Track Individual Device : BTLECAPT 3c:68:16:XX:XX:XX

This device was at Riverside when restrictions were initiated at Fawndale and made it through the corridor in near normal time.



Track Individual Device : BTLECAPT 3c:68:16:XX:XX:XX

Date	Time	Site	Speed	Travel Time
November 19, 2024	03:09:10 PM	Riverside	64 mph	2 min 48 sec
November 19, 2024	03:11:58 PM	Knighton Rd	64 mph	2 min 16 sec
November 19, 2024	03:14:14 PM	South Bonnyview	64 mph	1 min 41 sec
November 19, 2024	03:15:55 PM	Hartnell	63 mph	1 min 26 sec
November 19, 2024	03:17:21 PM	I5-SR44	61 mph	1 min 52 sec
November 19, 2024	03:19:13 PM	I5-SR299	69 mph	1 min 8 sec
November 19, 2024	03:20:21 PM	I5-SR273	67 mph	2 min 9 sec
November 19, 2024	03:22:30 PM	Pine Grove	60 mph	1 min 54 sec
November 19, 2024	03:24:24 PM	Mountain Gate	61 mph	1 min 46 sec
November 19, 2024	03:26:10 PM	Wonderland	**27 mph**	2 min 55 sec
November 19, 2024	03:29:05 PM	Fawndale	42 mph	2 min 58 sec
November 19, 2024	03:32:03 PM	Pit River Bridge	**TOTAL**	**22 min 53 sec**

The speed from Wonderland to Fawndale was about half of normal speed.

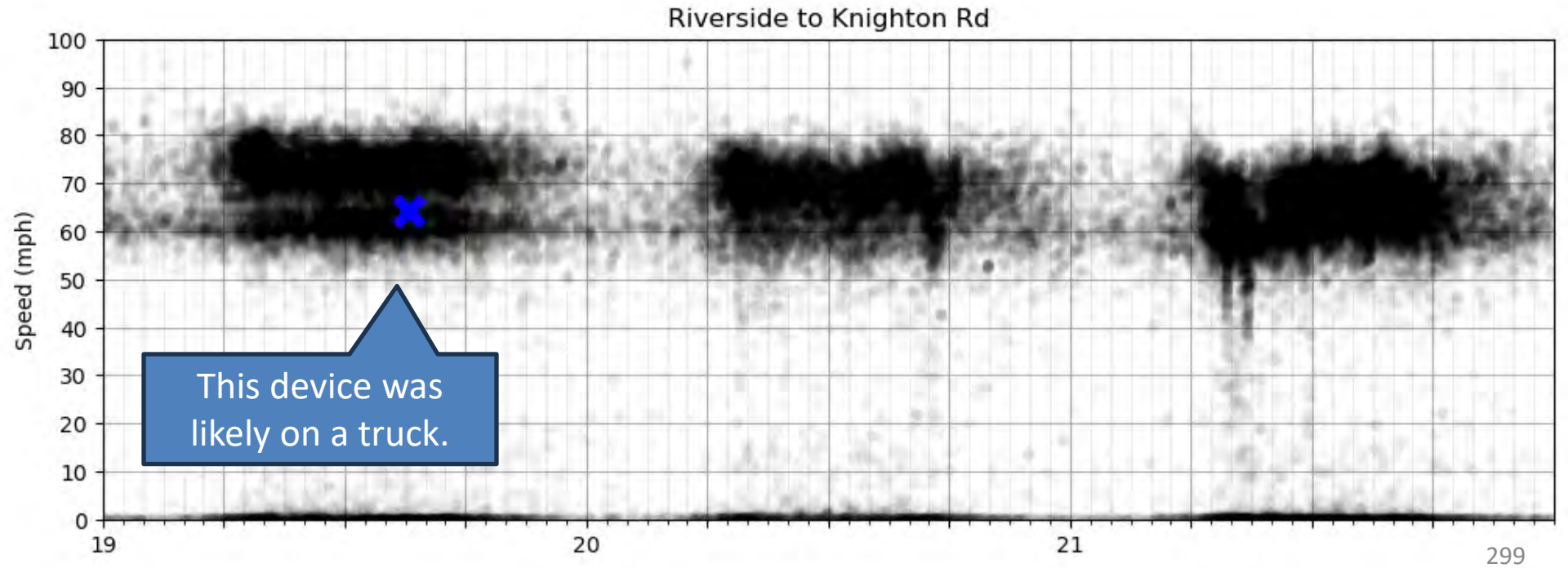


Riverside to Knighton Rd
Speed: 64 mph
Travel Time: 2 min 48 sec



Riverside
November 19, 2024
03:09:10 PM

Knighton Rd
November 19, 2024
03:11:58 PM



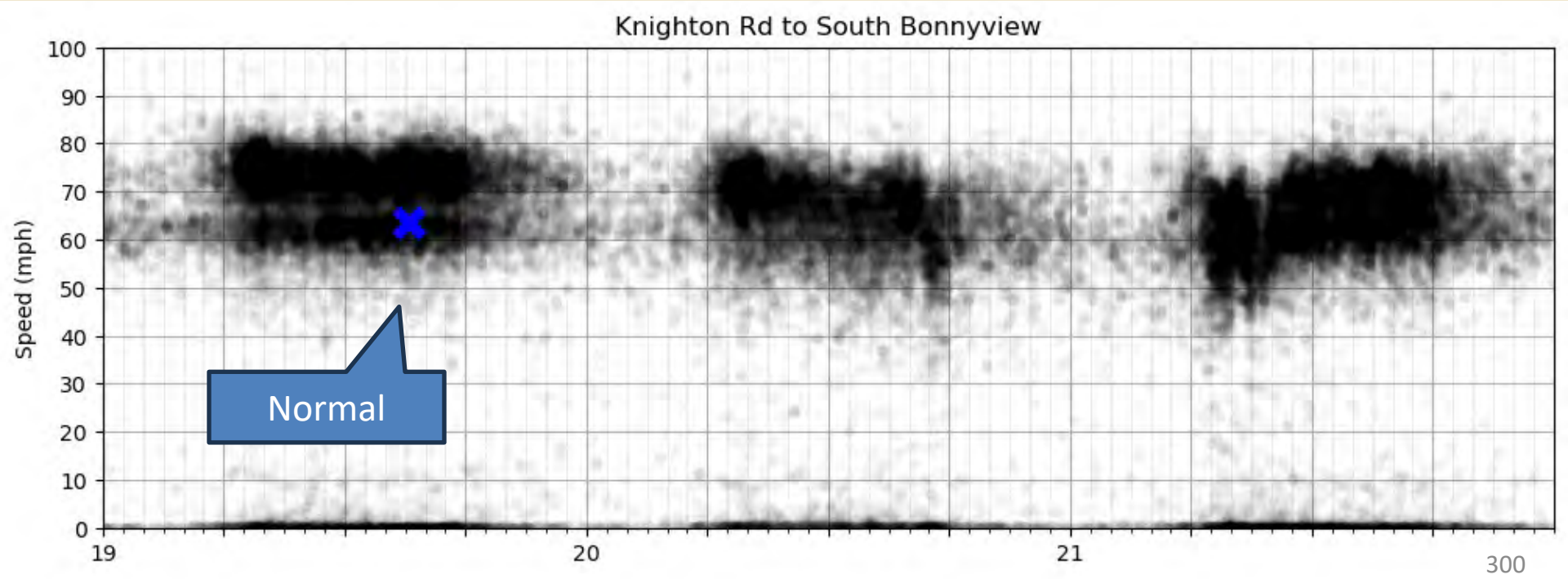


Knighton Rd to South Bonnyview
Speed: 64 mph
Travel Time: 2 min 16 sec



Knighton Rd
November 19, 2024
03:11:58 PM

South Bonnyview
November 19, 2024
03:14:14 PM



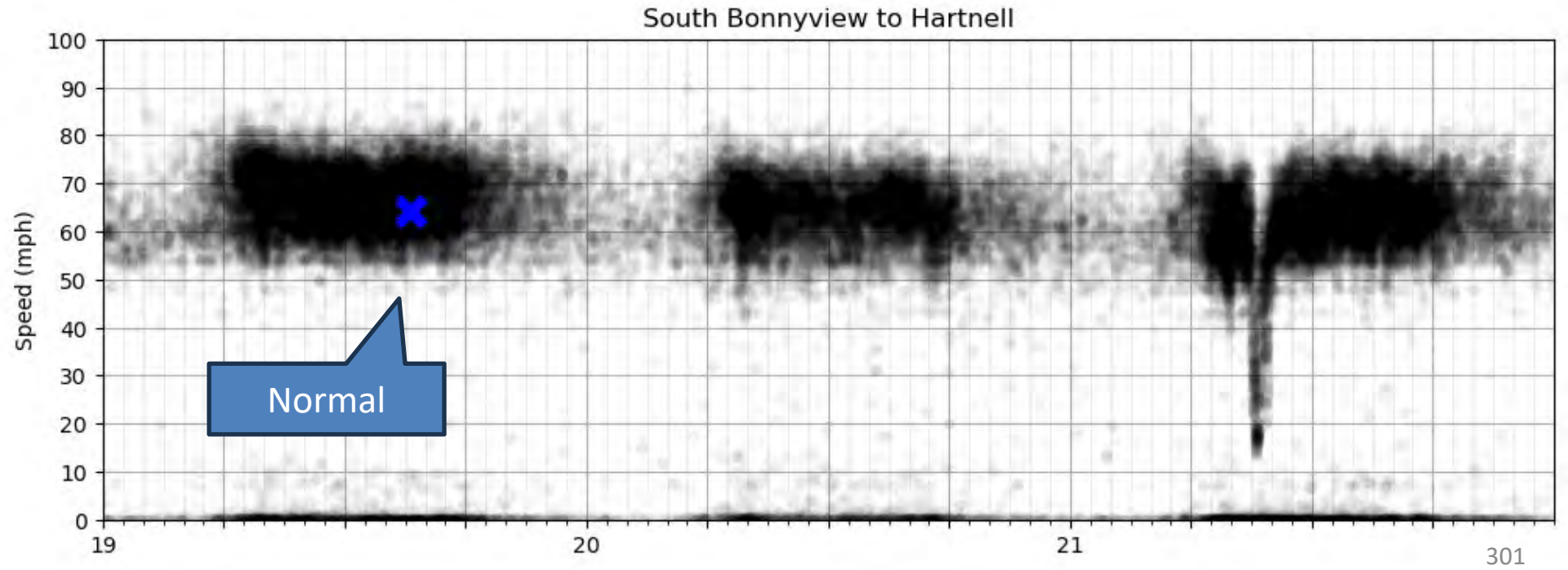
South Bonnyview to Hartnell
Speed: 64 mph
Travel Time: 1 min 41 sec





South Bonnyview
November 19, 2024
03:14:14 PM

Hartnell
November 19, 2024
03:15:55 PM



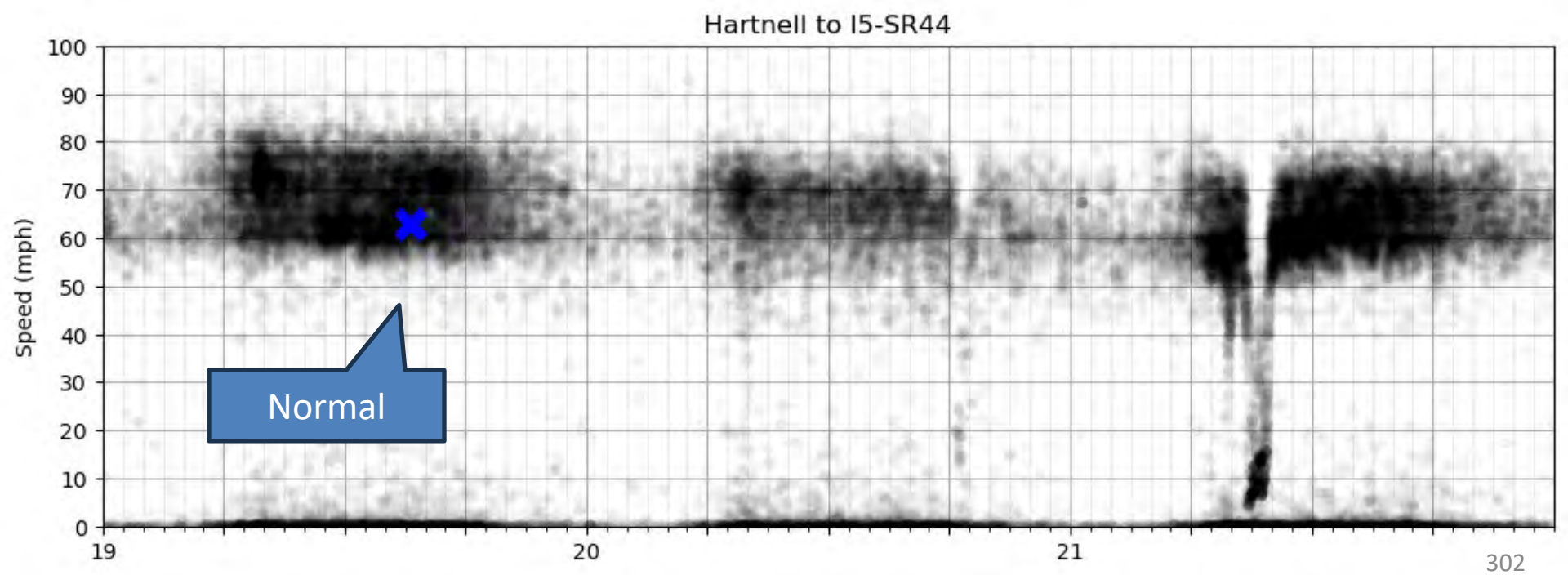


Hartnell to I5-SR44
Speed: 63 mph
Travel Time: 1 min 26 sec



Hartnell
November 19, 2024
03:15:55 PM

I5-SR44
November 19, 2024
03:17:21 PM



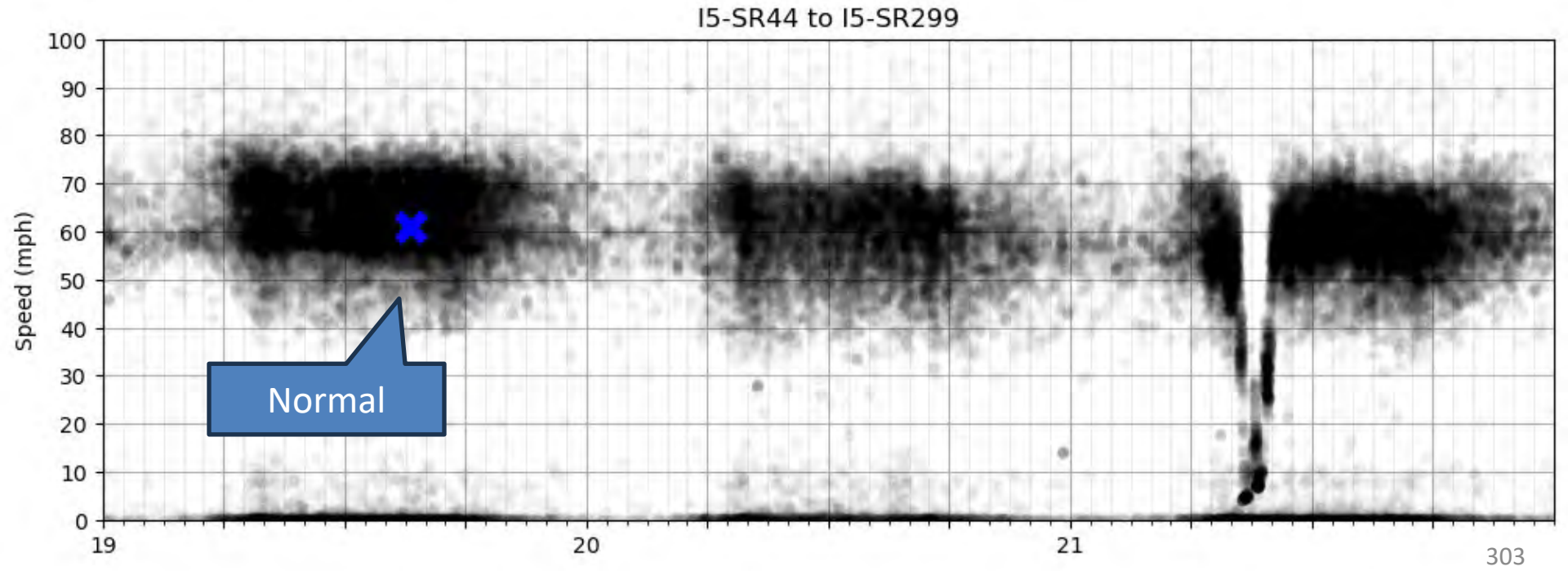


I5-SR44 to I5-SR299
Speed: 61 mph
Travel Time: 1 min 52 sec



I5-SR44
November 19, 2024
03:17:21 PM

I5-SR299
November 19, 2024
03:19:13 PM



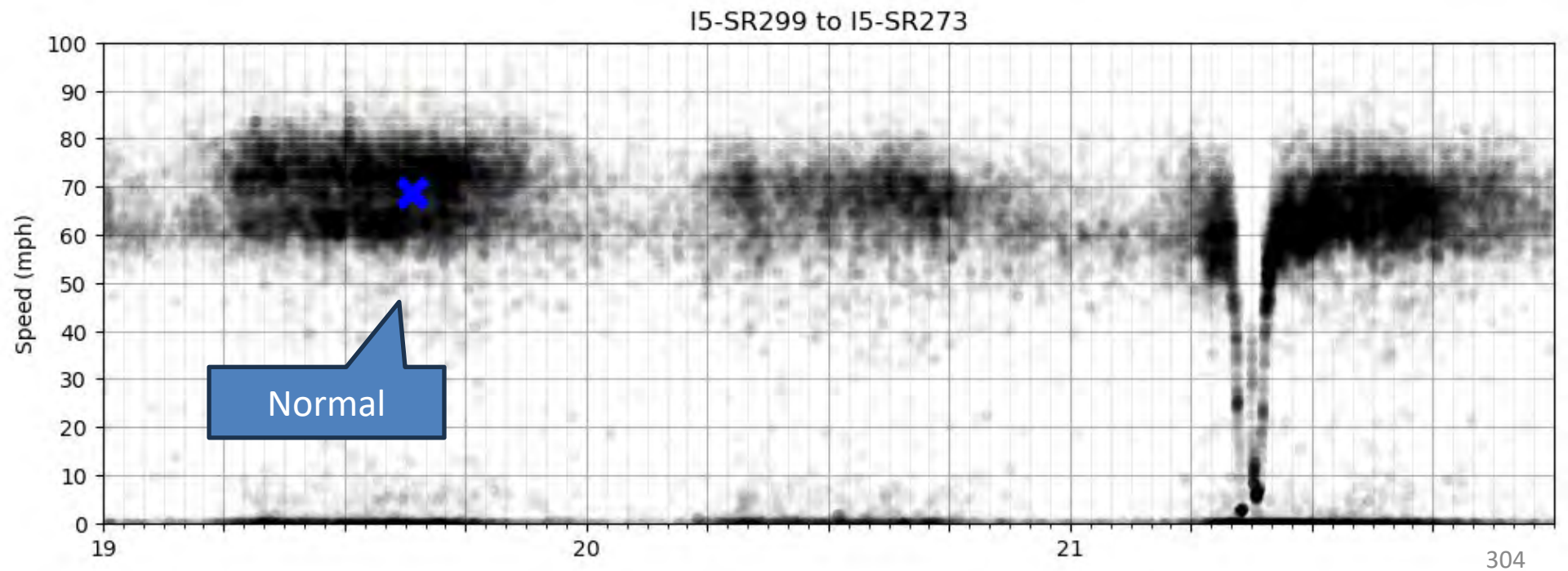
I5-SR299 to I5-SR273
Speed: 69 mph
Travel Time: 1 min 8 sec





I5-SR299
November 19, 2024
03:19:13 PM

I5-SR273
November 19, 2024
03:20:21 PM



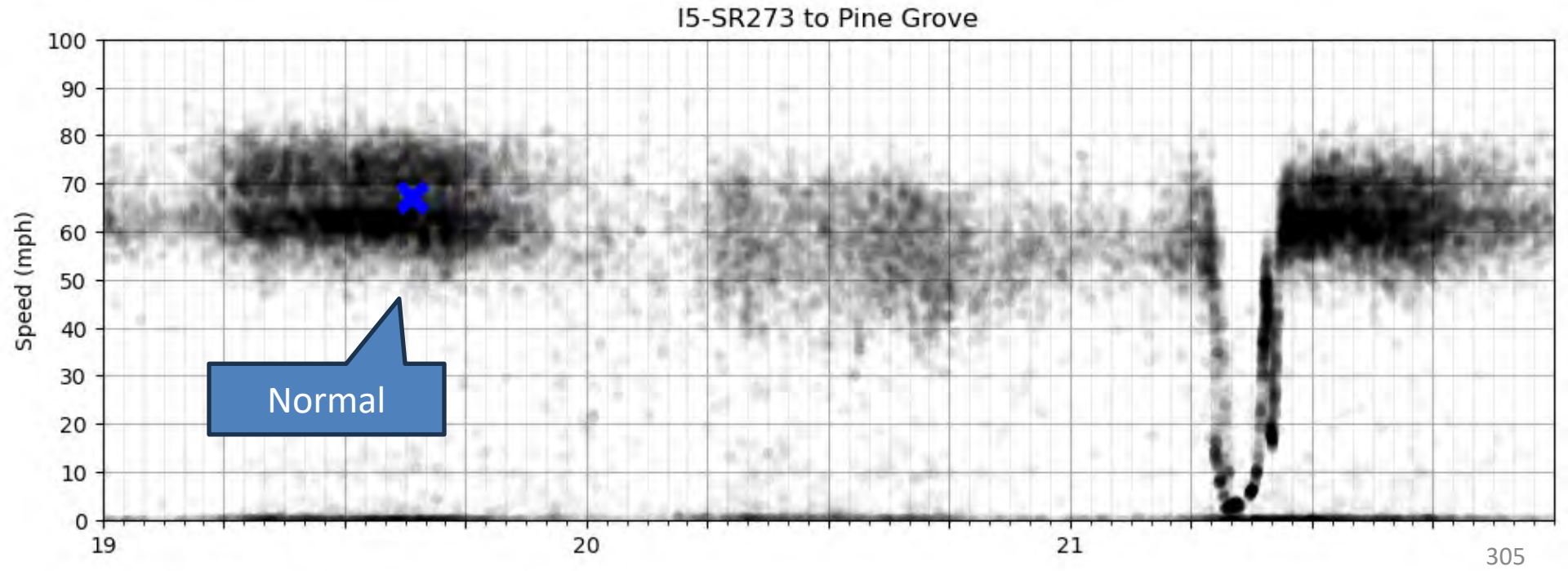


I5-SR273 to Pine Grove
Speed: 67 mph
Travel Time: 2 min 9 sec



I5-SR273
November 19, 2024
03:20:21 PM

Pine Grove
November 19, 2024
03:22:30 PM



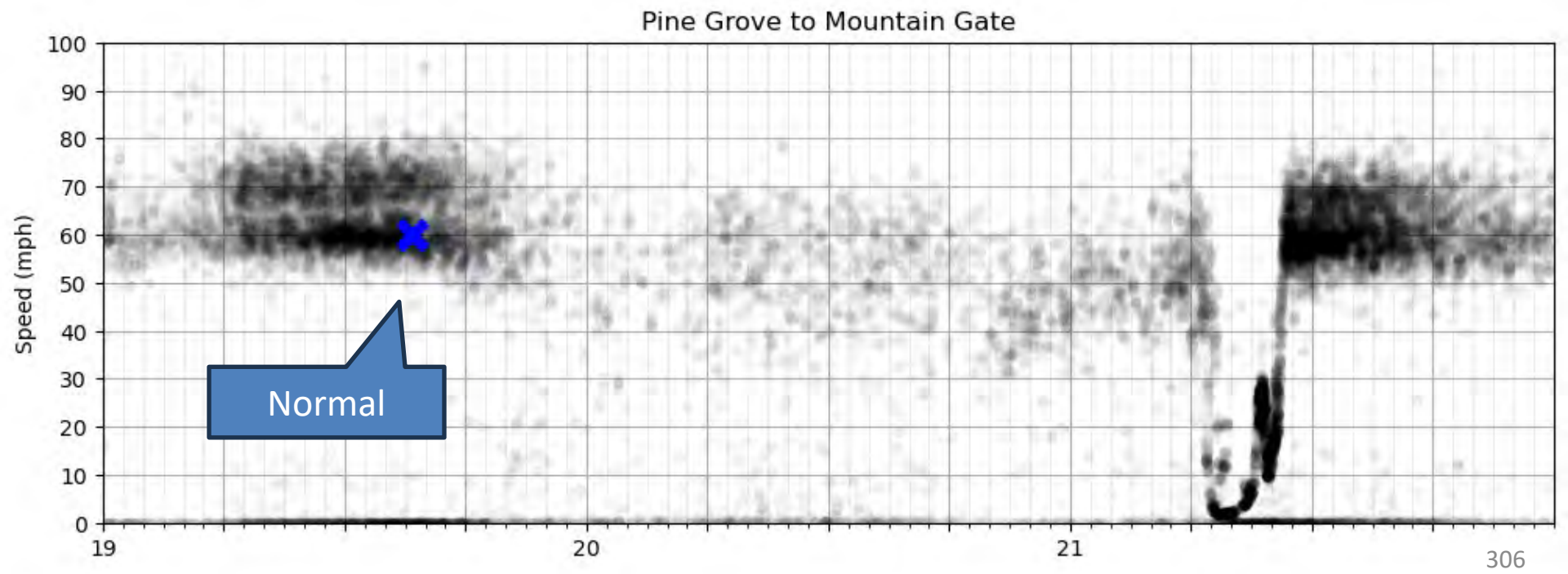


Pine Grove to Mountain Gate
Speed: 60 mph
Travel Time: 1 min 54 sec



Pine Grove
November 19, 2024
03:22:30 PM

Mountain Gate
November 19, 2024
03:24:24 PM



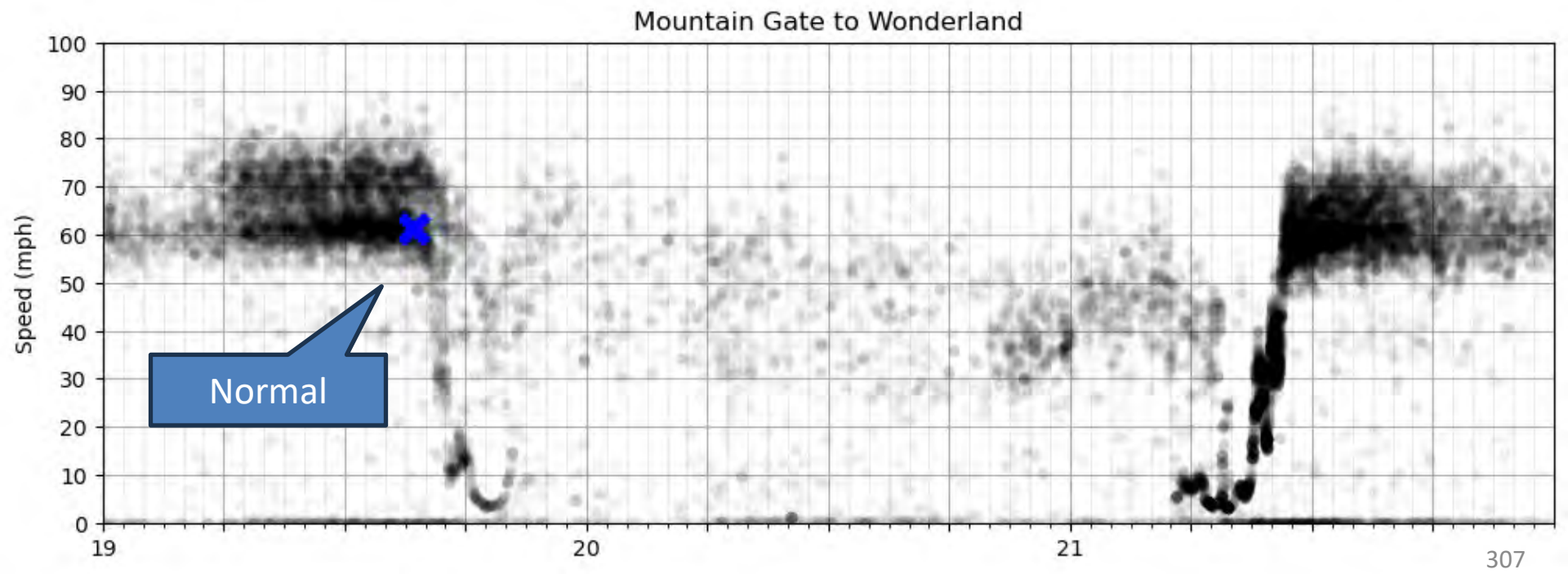


Mountain Gate to Wonderland
Speed: 61 mph
Travel Time: 1 min 46 sec



Mountain Gate
November 19, 2024
03:24:24 PM

Wonderland
November 19, 2024
03:26:10 PM





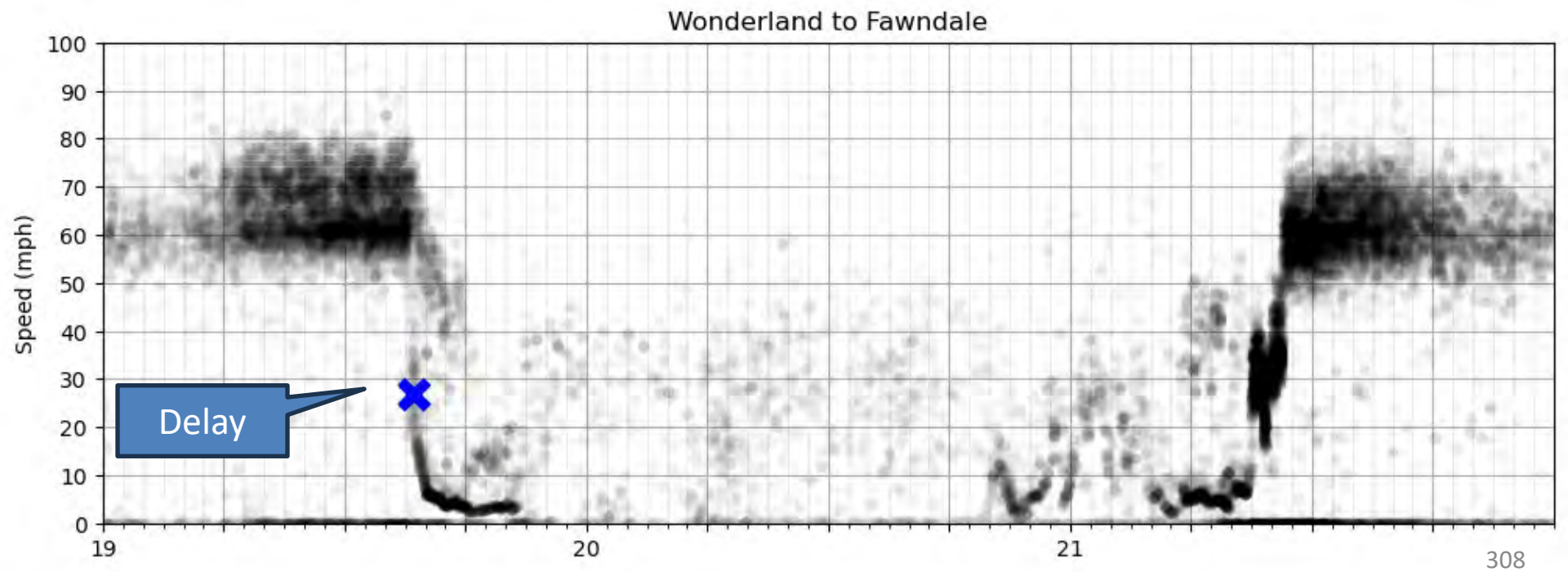
Wonderland to Fawndale
Speed: 27 mph
Travel Time: 2 min 55 sec

Delay



Wonderland
November 19, 2024
03:26:10 PM

Fawndale
November 19, 2024
03:29:05 PM





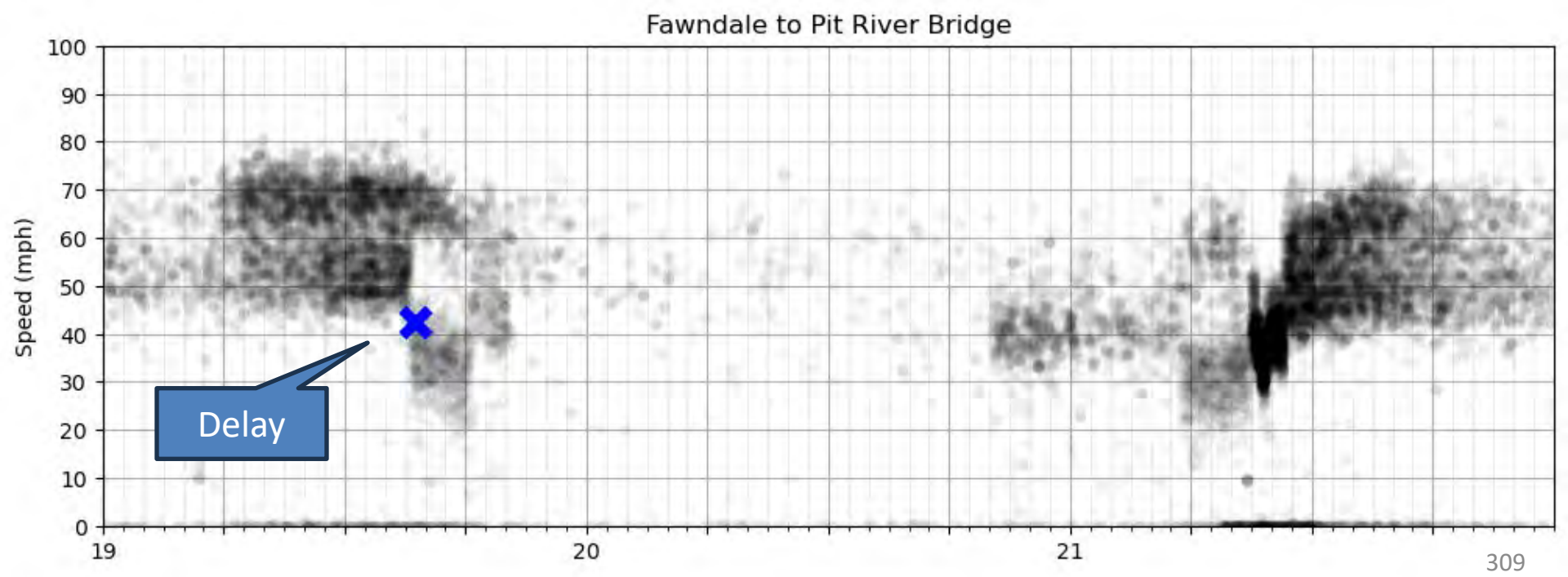
Fawndale to Pit River Bridge
Speed: 42 mph
Travel Time: 2 min 58 sec

Delay



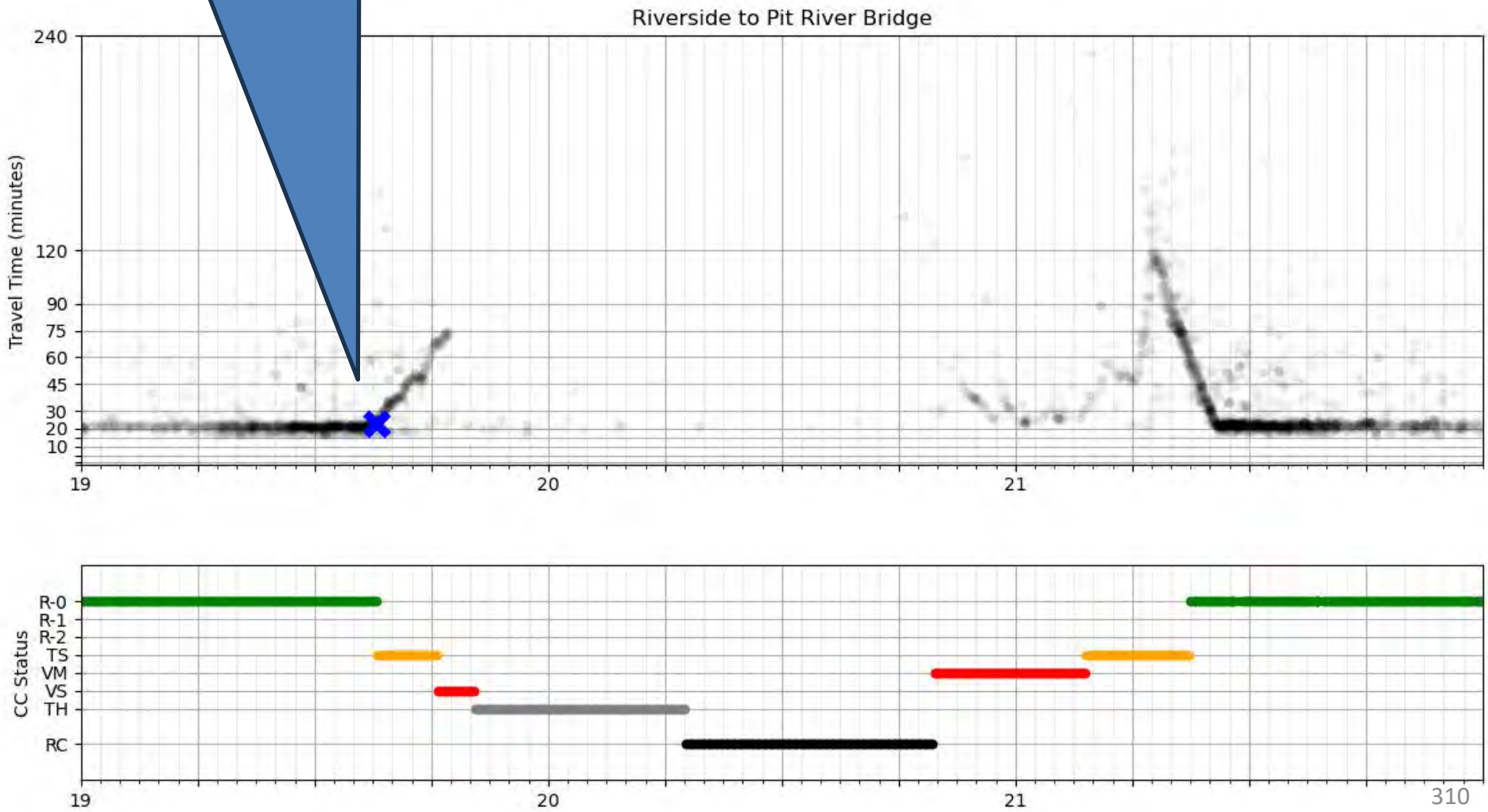
Fawndale
November 19, 2024
03:29:05 PM

Pit River Bridge
November 19, 2024
03:32:03 PM



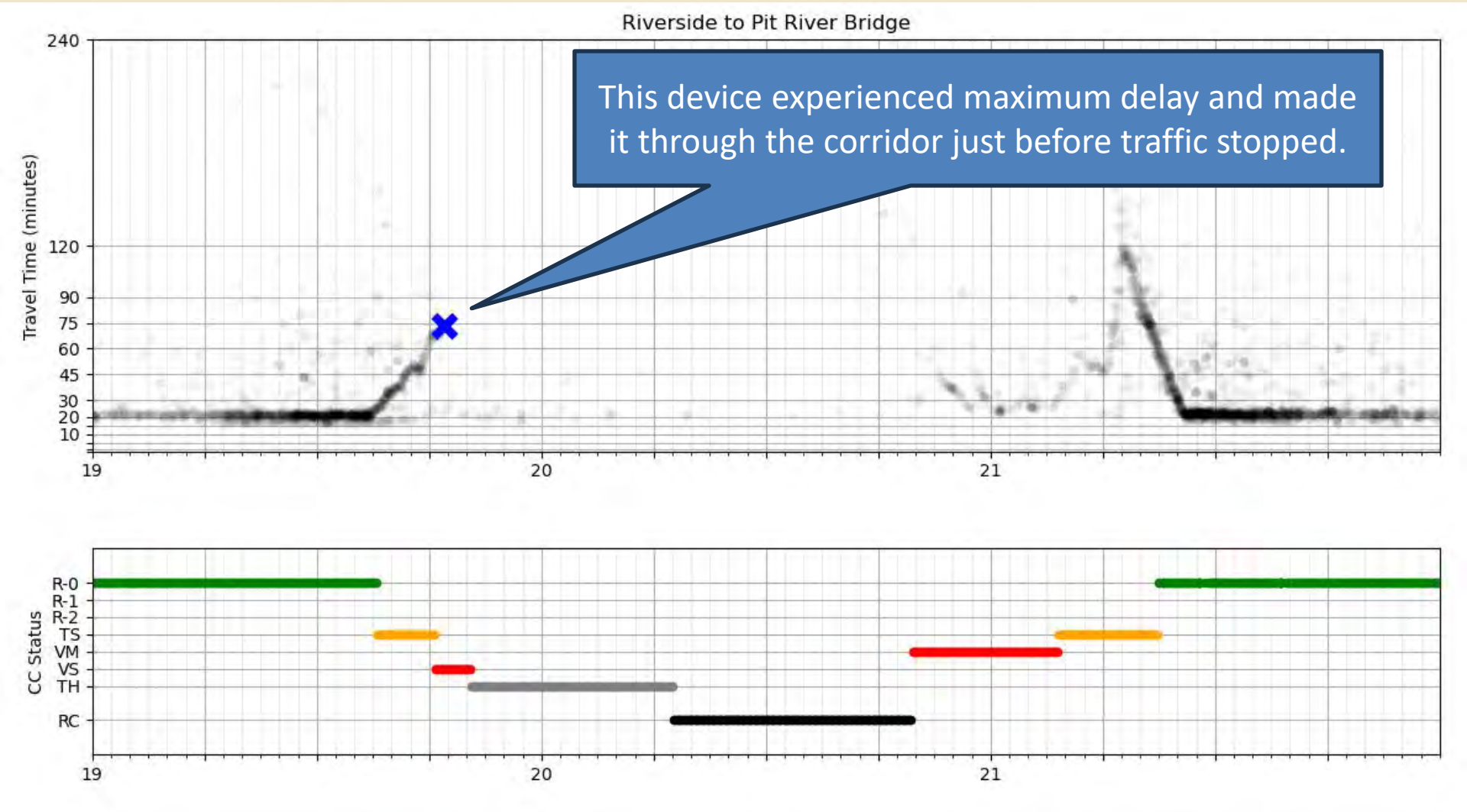
Track Individual Device : BTLECAPT 3c:68:16:XX:XX:XX

This device and travel time appear to be real and represent Ground Truth.



Track Another Device : BTLECAPT c8:cf:5b:XX:XX:XX

Track Another Device : BTLECAPT c8:cf:5b:XX:XX:XX



Track Another Device : BTLECAPT c8:cf:5b:XX:XX:XX

Date	Time	Site	Speed	Travel Time
November 19, 2024	06:50:08 PM	Riverside	61 mph	2 min 58 sec
November 19, 2024	06:53:06 PM	Knighton Rd	60 mph	2 min 23 sec
November 19, 2024	06:55:29 PM	South Bonnyview	58 mph	1 min 52 sec
November 19, 2024	06:57:21 PM	Hartnell	60 mph	1 min 30 sec
November 19, 2024	06:58:51 PM	I5-SR44	57 mph	2 min 1 sec
November 19, 2024	07:00:52 PM	I5-SR299	64 mph	1 min 13 sec
November 19, 2024	07:02:05 PM	I5-SR273	61 mph	2 min 21 sec
November 19, 2024	07:04:26 PM	Pine Grove	58 mph	1 min 57 sec
November 19, 2024	07:06:23 PM	Mountain Gate	**3 mph**	**31 min 48 sec**
November 19, 2024	07:38:11 PM	Wonderland	**3 mph**	**22 min 29 sec**
November 19, 2024	08:00:40 PM	Fawndale	45 mph	2 min 47 sec
November 19, 2024	08:03:27 PM	Pit River Bridge	**TOTAL**	**73 min 19 sec**

Long delay between Mountain Gate and Wonderland and between Wonderland and Fawndale.

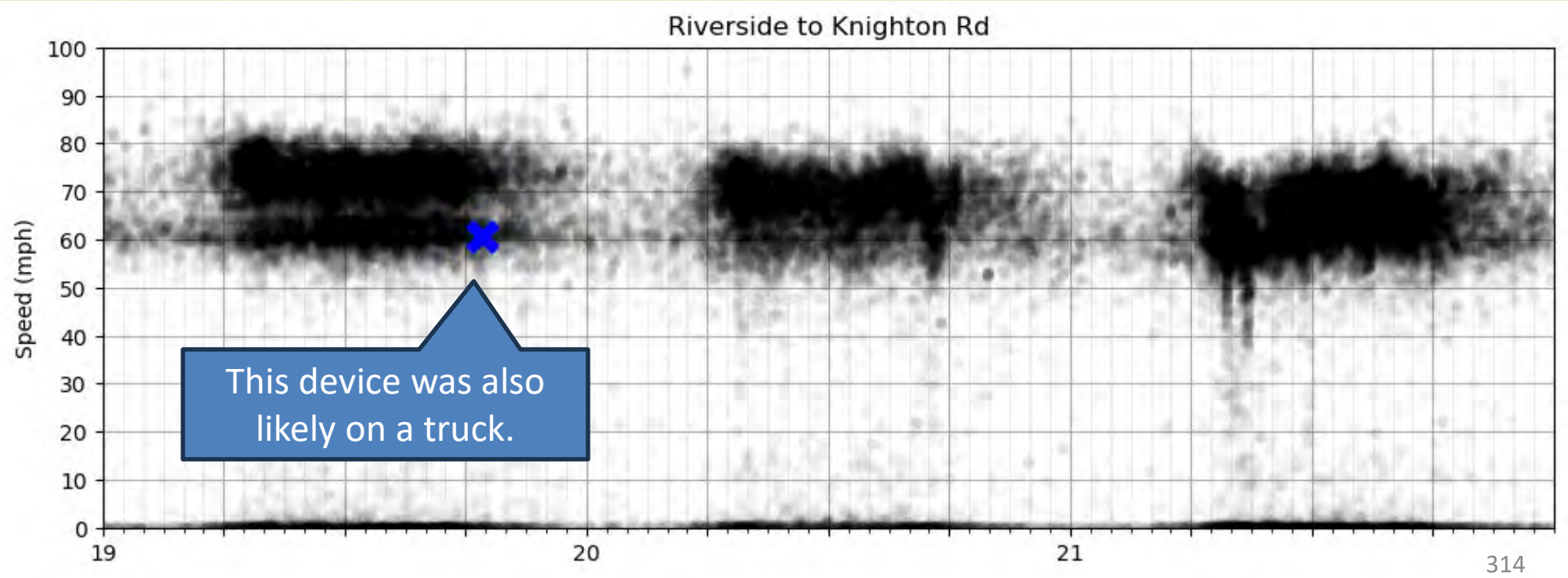


Riverside to Knighton Rd
Speed: 61 mph
Travel Time: 2 min 58 sec



Riverside
November 19, 2024
06:50:08 PM

Knighton Rd
November 19, 2024
06:53:06 PM



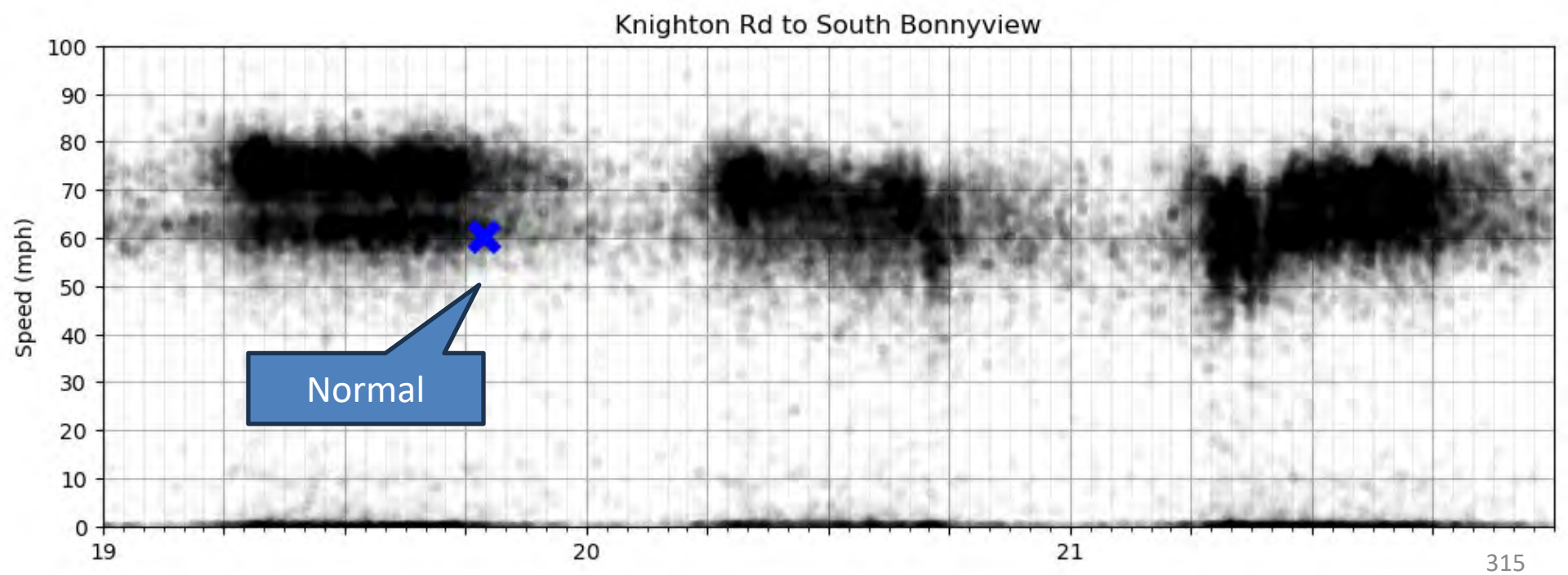


Knighton Rd to South Bonnyview
Speed: 60 mph
Travel Time: 2 min 23 sec



Knighton Rd
November 19, 2024
06:53:06 PM

South Bonnyview
November 19, 2024
06:55:29 PM



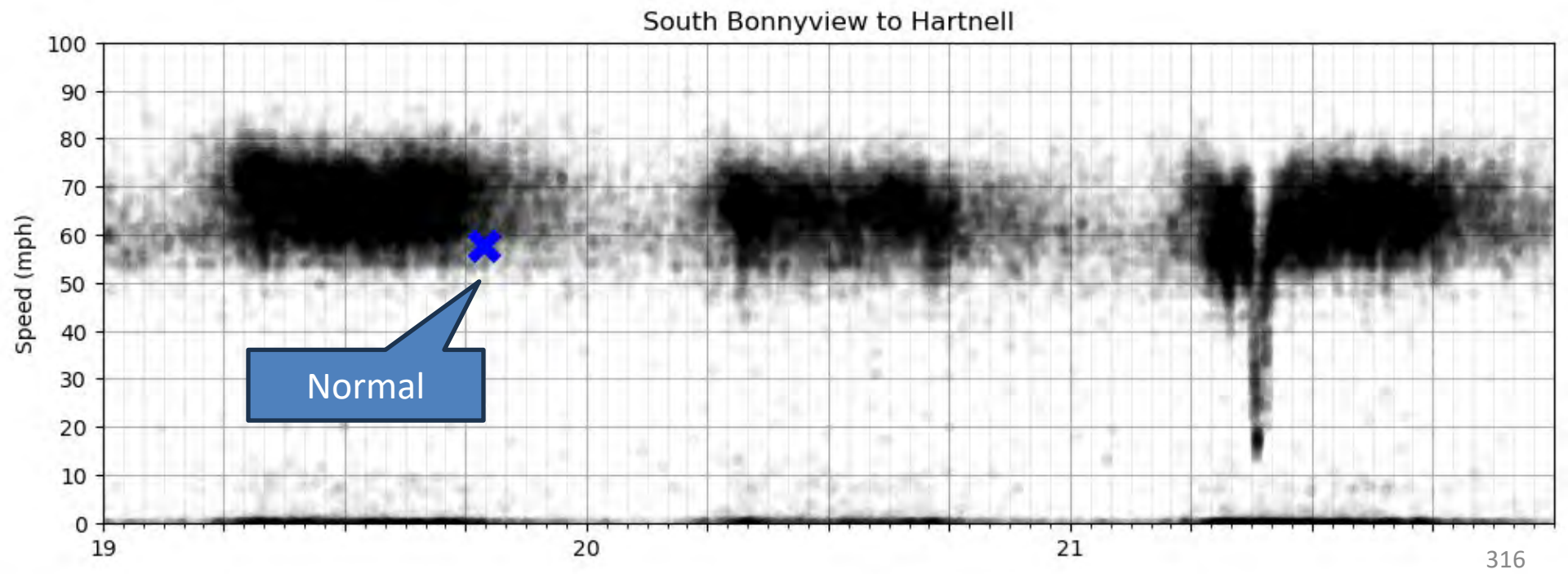


South Bonnyview to Hartnell
Speed: 58 mph
Travel Time: 1 min 52 sec



South Bonnyview
November 19, 2024
06:55:29 PM

Hartnell
November 19, 2024
06:57:21 PM



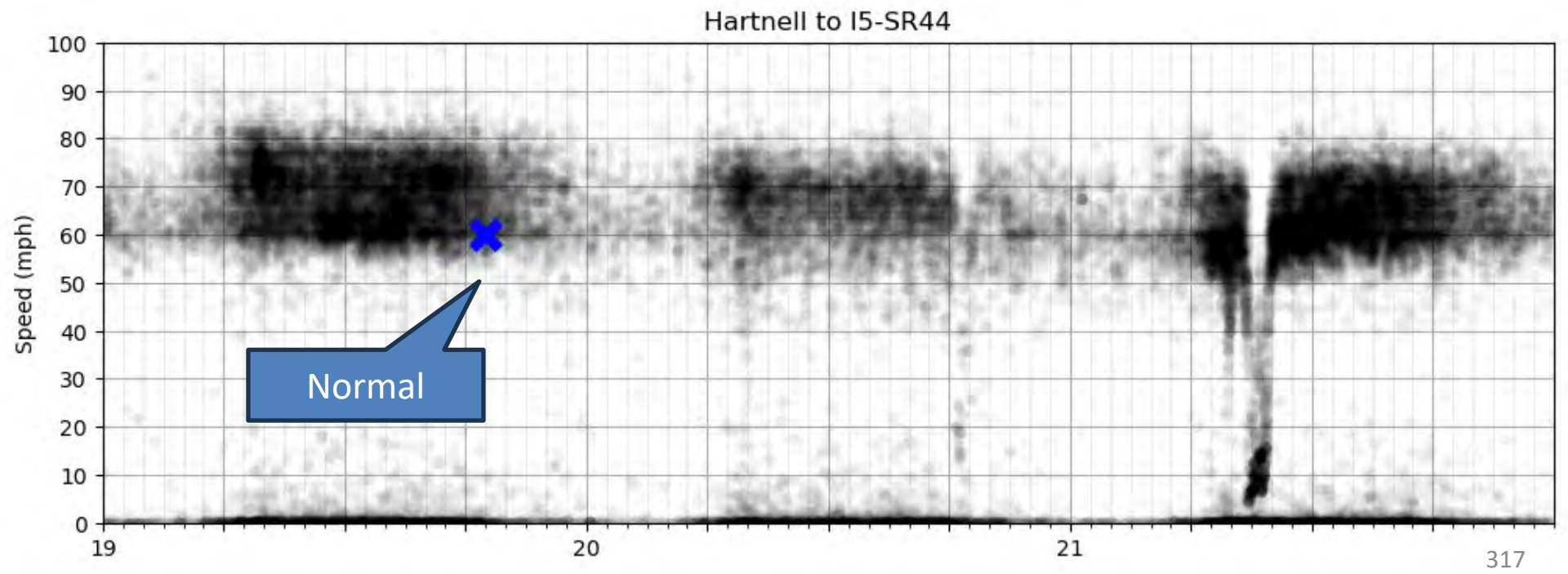


Hartnell to I5-SR44
Speed: 60 mph
Travel Time: 1 min 30 sec



Hartnell
November 19, 2024
06:57:21 PM

I5-SR44
November 19, 2024
06:58:51 PM



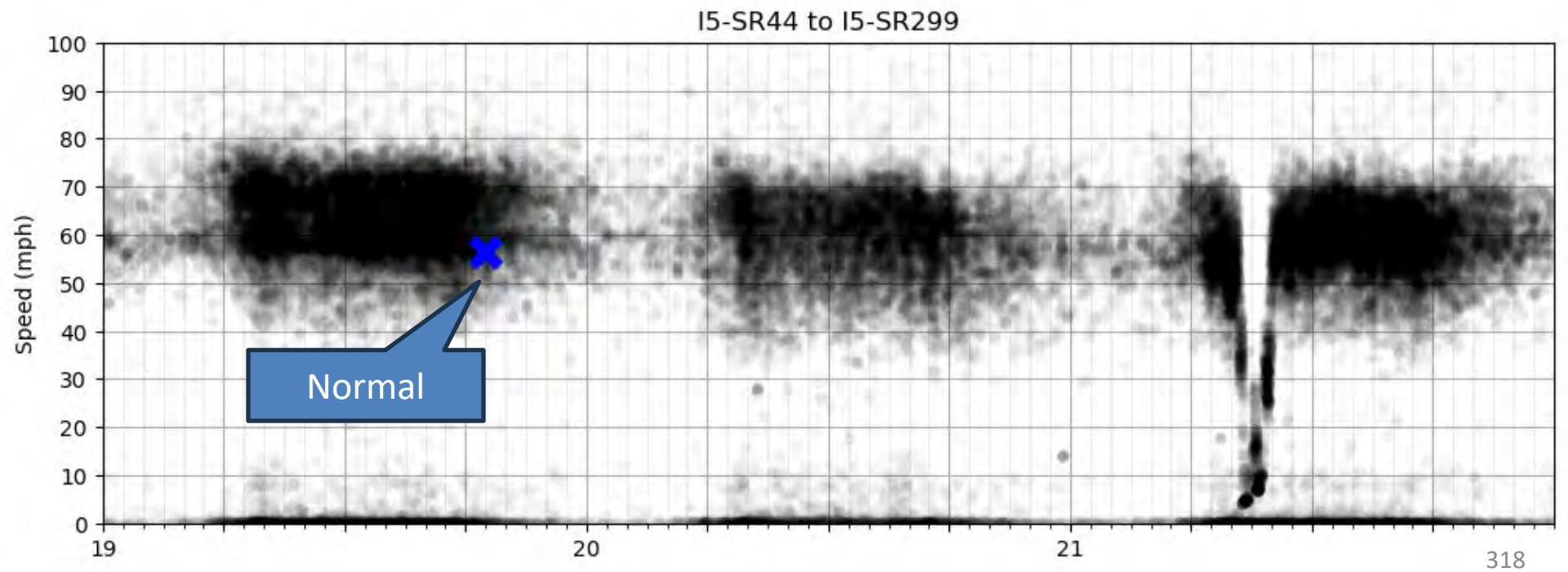


I5-SR44 to I5-SR299
Speed: 57 mph
Travel Time: 2 min 1 sec



I5-SR44
November 19, 2024
06:58:51 PM

I5-SR299
November 19, 2024
07:00:52 PM



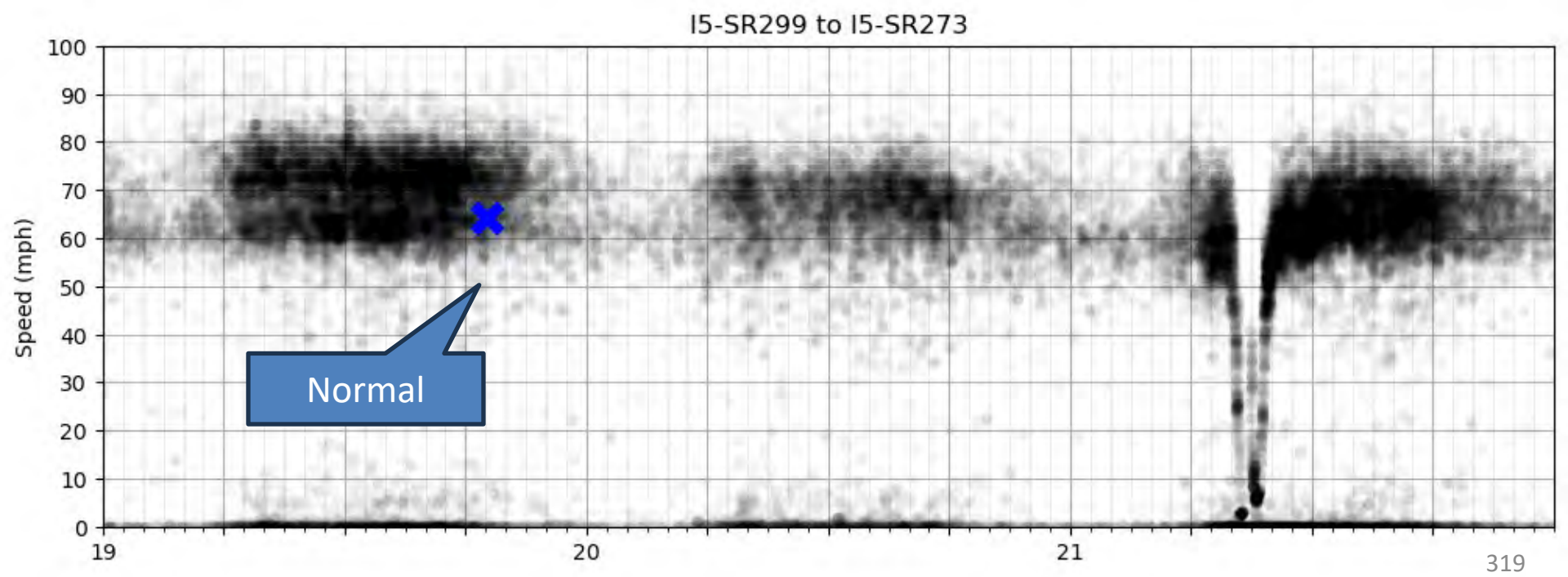
I5-SR299 to I5-SR273
Speed: 64 mph
Travel Time: 1 min 13 sec





I5-SR299
November 19, 2024
07:00:52 PM

I5-SR273
November 19, 2024
07:02:05 PM



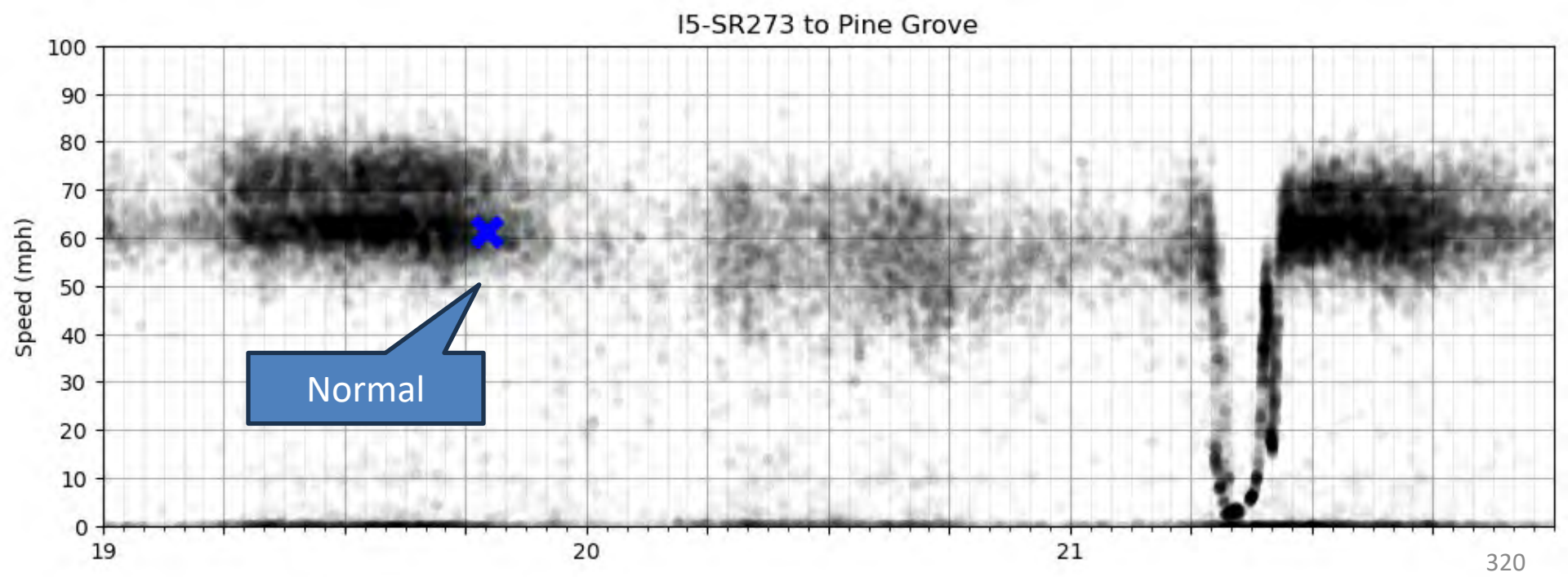


I5-SR273 to Pine Grove
Speed: 61 mph
Travel Time: 2 min 21 sec



I5-SR273
November 19, 2024
07:02:05 PM

Pine Grove
November 19, 2024
07:04:26 PM



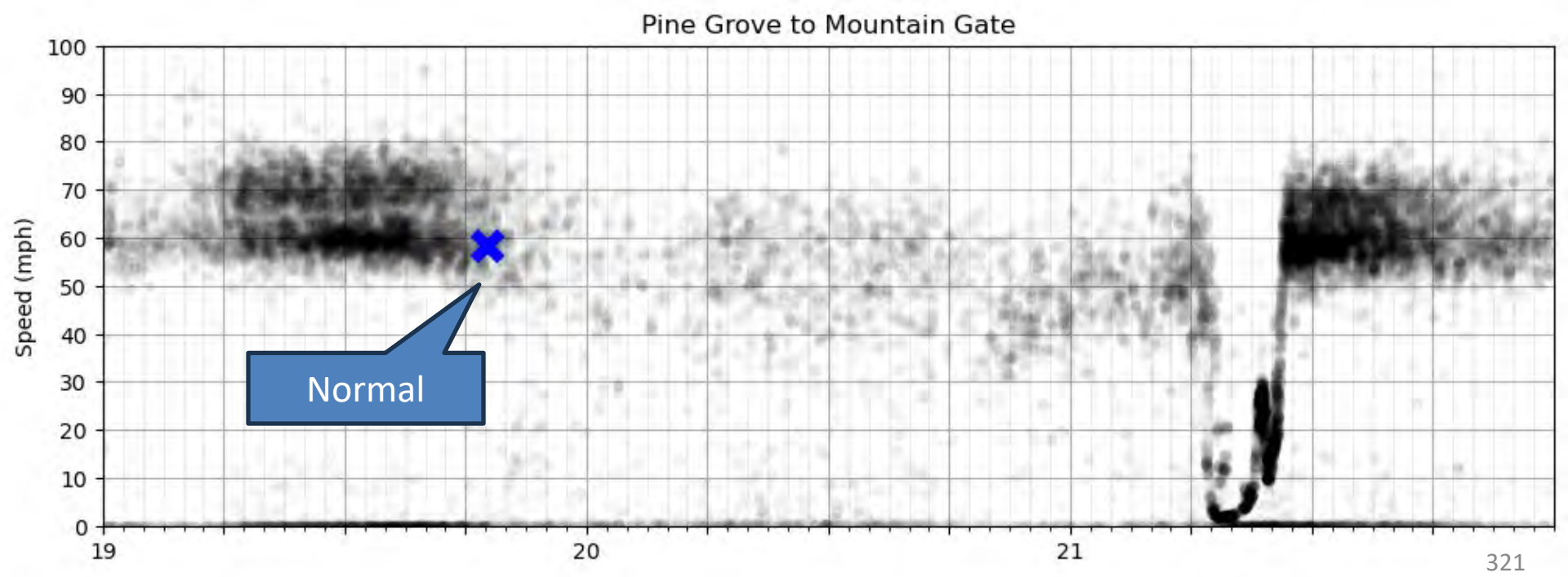


Pine Grove to Mountain Gate
Speed: 58 mph
Travel Time: 1 min 57 sec



Pine Grove
November 19, 2024
07:04:26 PM

Mountain Gate
November 19, 2024
07:06:23 PM





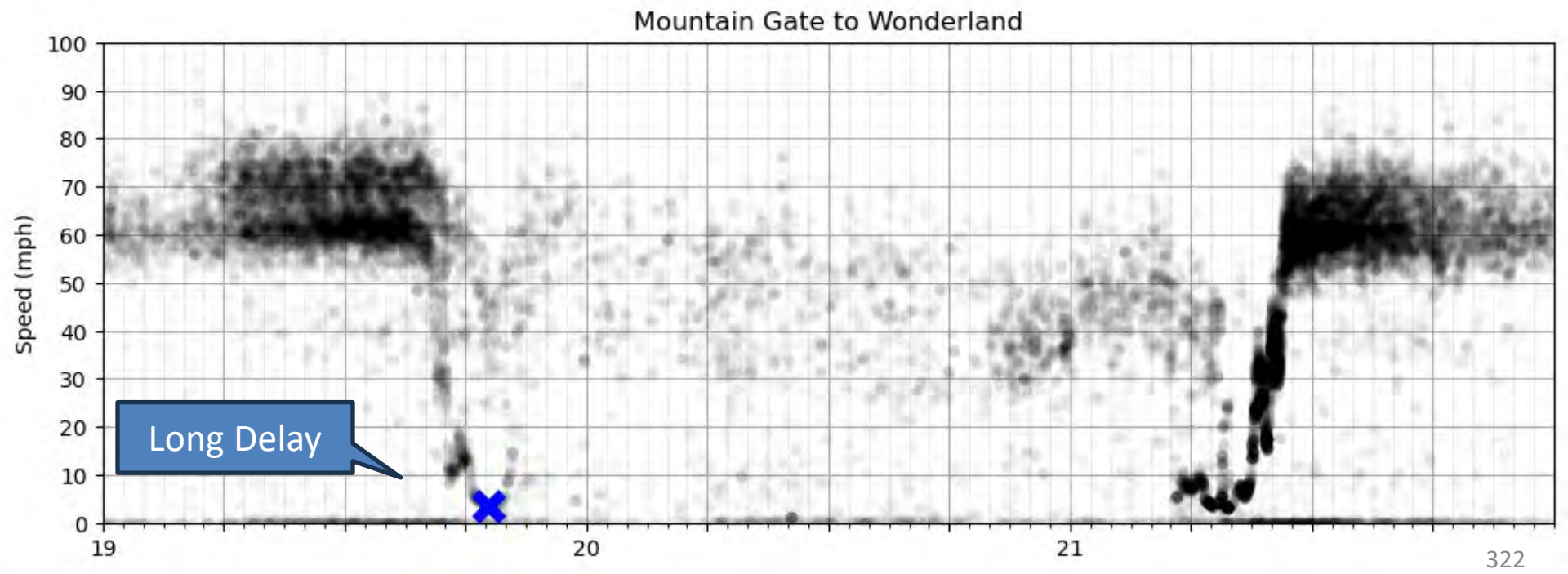
Mountain Gate to Wonderland
Speed: 3 mph
Travel Time: 31 min 48 sec

Long Delay



Mountain Gate
November 19, 2024
07:06:23 PM

Wonderland
November 19, 2024
07:38:11 PM





Wonderland to Fawndale
Speed: 3 mph
Travel Time: 22 min 29 sec

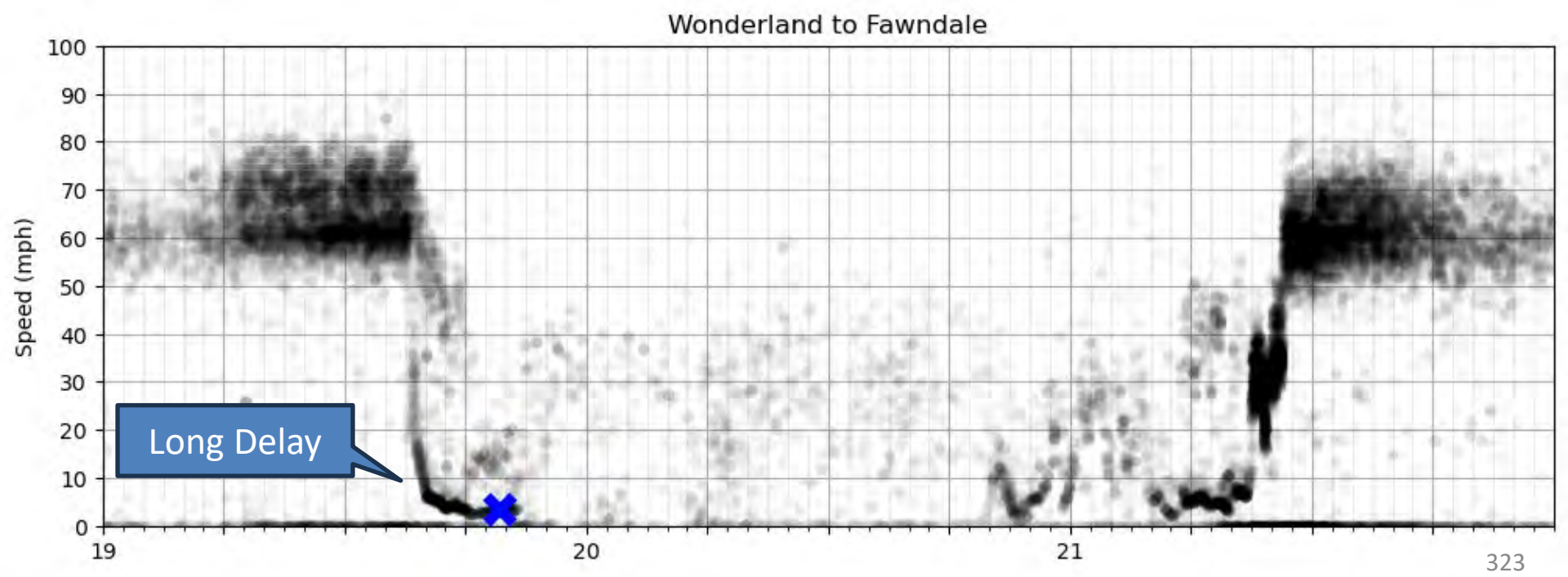
Long Delay

Long Delay



Wonderland
November 19, 2024
07:38:11 PM

Fawndale
November 19, 2024
08:00:40 PM





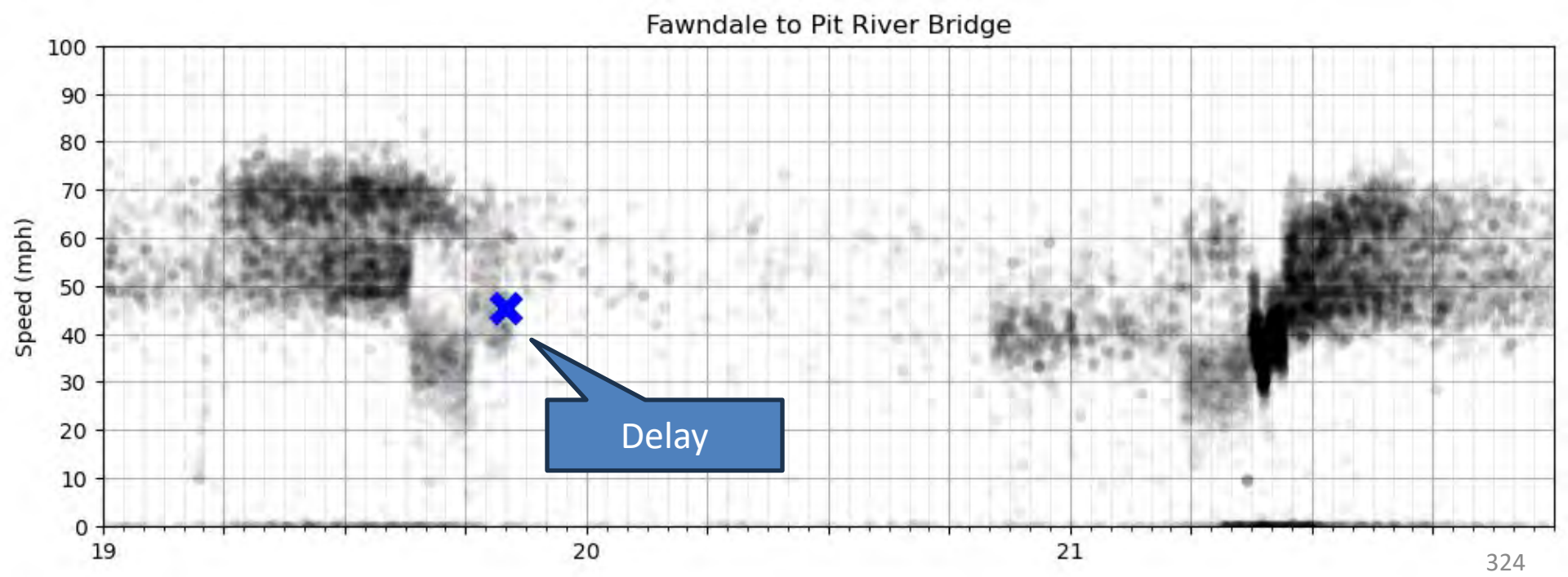
Fawndale to Pit River Bridge
Speed: 45 mph
Travel Time: 2 min 47 sec

Long Delay



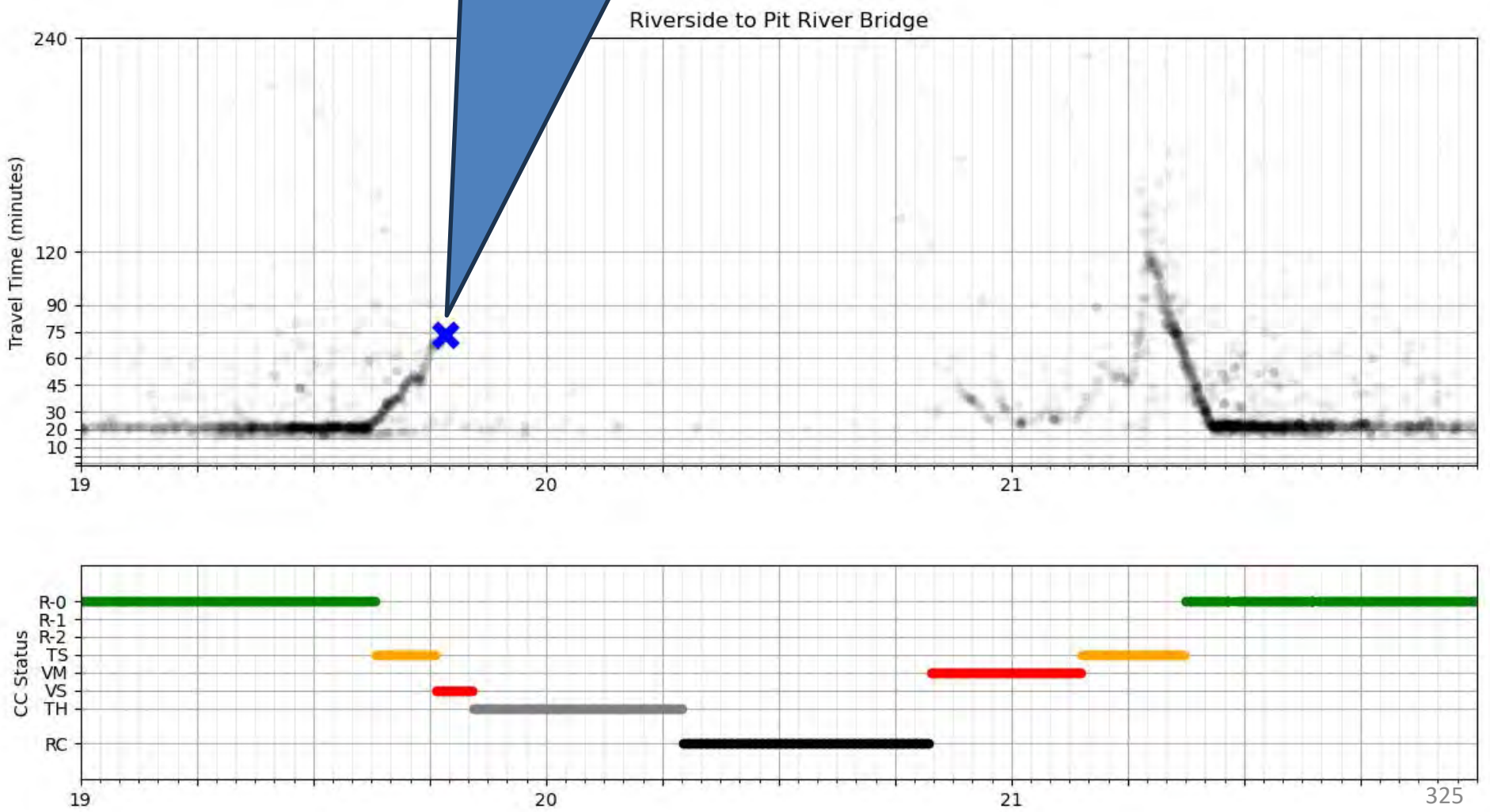
Fawndale
November 19, 2024
08:00:40 PM

Pit River Bridge
November 19, 2024
08:03:27 PM



Track Another Device : BTLECAPT c8:cf:5b:XX:XX:XX

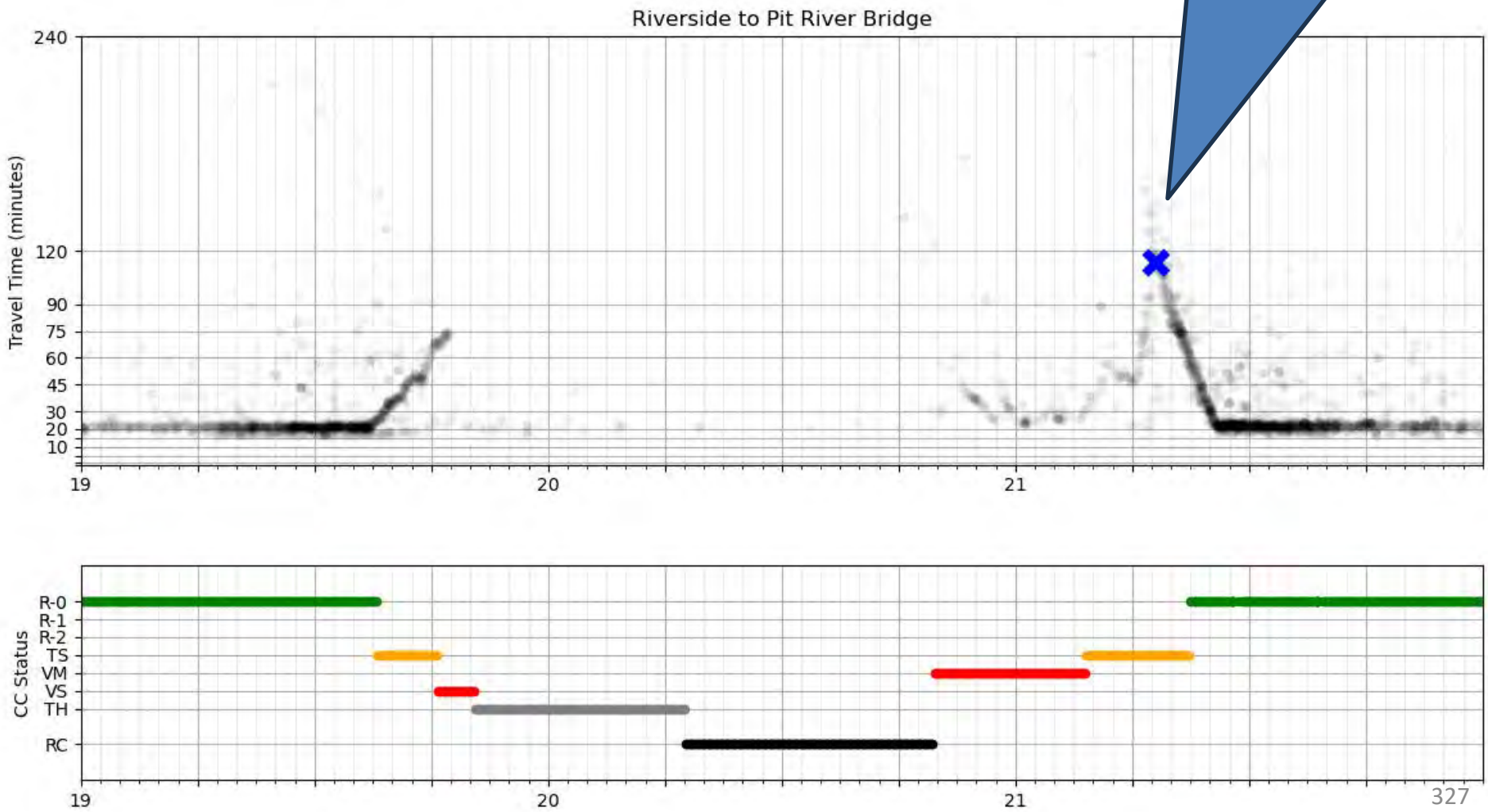
This device and travel time appear to be real and represent Ground Truth.



Track Another Device : BTLECAPT ea:34:fe:XX:XX:XX

Track Another Device : BTLECAPT ea:34:fe:XX:XX:XX

This device experienced maximum delay when restrictions were lifted.



Track Another Device : BTLECAPT ea:34:fe:XX:XX:XX

Date	Time	Site	Speed	Travel Time
November 21, 2024	07:11:10 AM	Riverside	59 mph	3 min 3 sec
November 21, 2024	07:14:13 AM	Knighton Rd	50 mph	2 min 54 sec
November 21, 2024	07:17:07 AM	South Bonnyview	59 mph	1 min 50 sec
November 21, 2024	07:18:57 AM	Hartnell	59 mph	1 min 31 sec
November 21, 2024	07:20:28 AM	I5-SR44	51 mph	2 min 13 sec
November 21, 2024	07:22:41 AM	I5-SR299	62 mph	1 min 16 sec
November 21, 2024	07:23:57 AM	I5-SR273	**8 mph**	**16 min 58 sec**
November 21, 2024	07:40:55 AM	Pine Grove	**2 mph**	**57 min 5 sec**
November 21, 2024	08:38:00 AM	Mountain Gate	**5 mph**	**20 min 30 sec**
November 21, 2024	08:58:30 AM	Wonderland	**22 mph**	**3 min 32 sec**
November 21, 2024	09:02:02 AM	Fawndale	47 mph	2 min 41 sec
November 21, 2024	09:04:43 AM	Pit River Bridge	**TOTAL**	**113 min 33 sec**

Long delay between I5-SR273 and Pine Grove, Pine Grove and Mountain Gate, Mountain Gate and Wonderland, and between Wonderland and Fawndale.

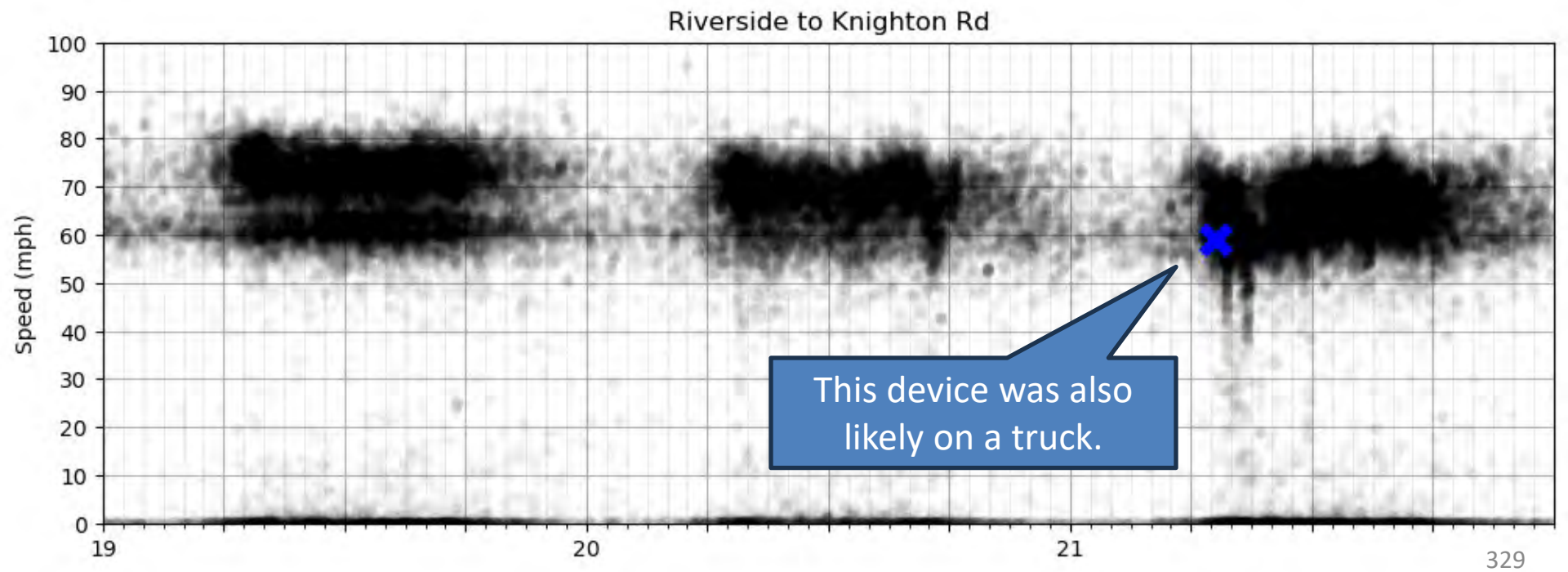


Riverside to Knighton Rd
Speed: 59 mph
Travel Time: 3 min 3 sec



Riverside
November 21, 2024
07:11:10 AM

Knighton Rd
November 21, 2024
07:14:13 AM



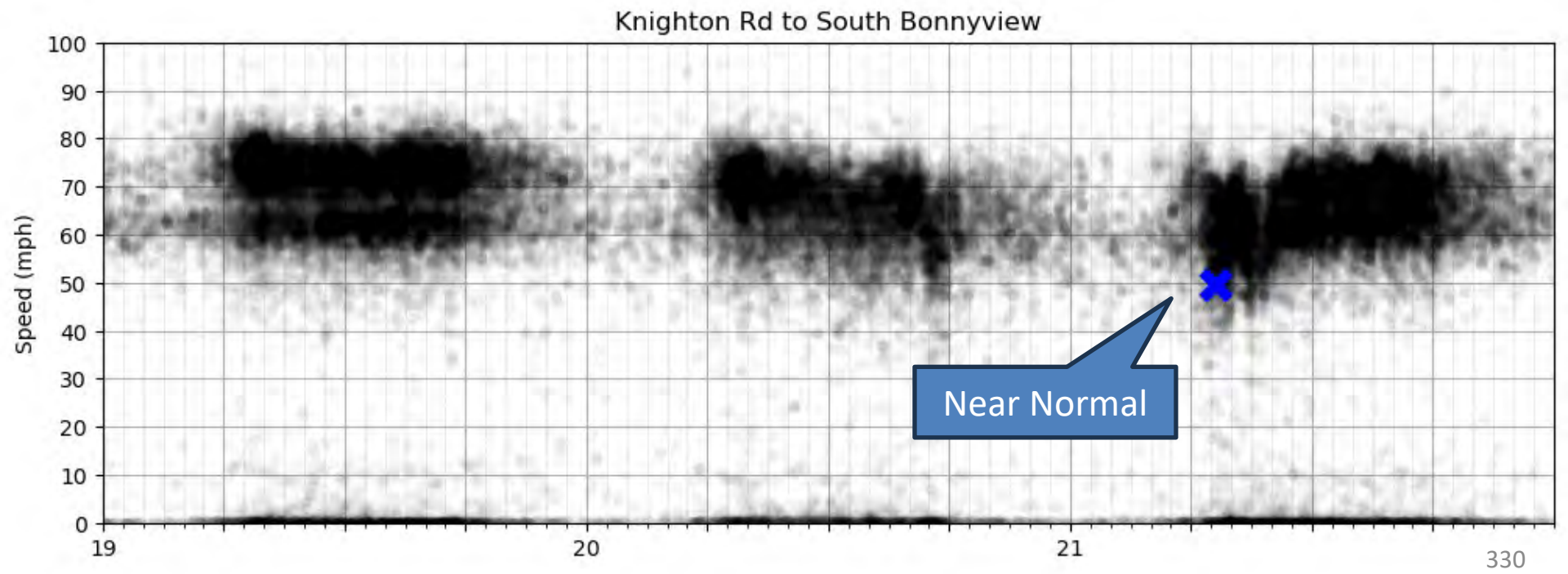


Knighton Rd to South Bonnyview
Speed: 50 mph
Travel Time: 2 min 54 sec



Knighton Rd
November 21, 2024
07:14:13 AM

South Bonnyview
November 21, 2024
07:17:07 AM



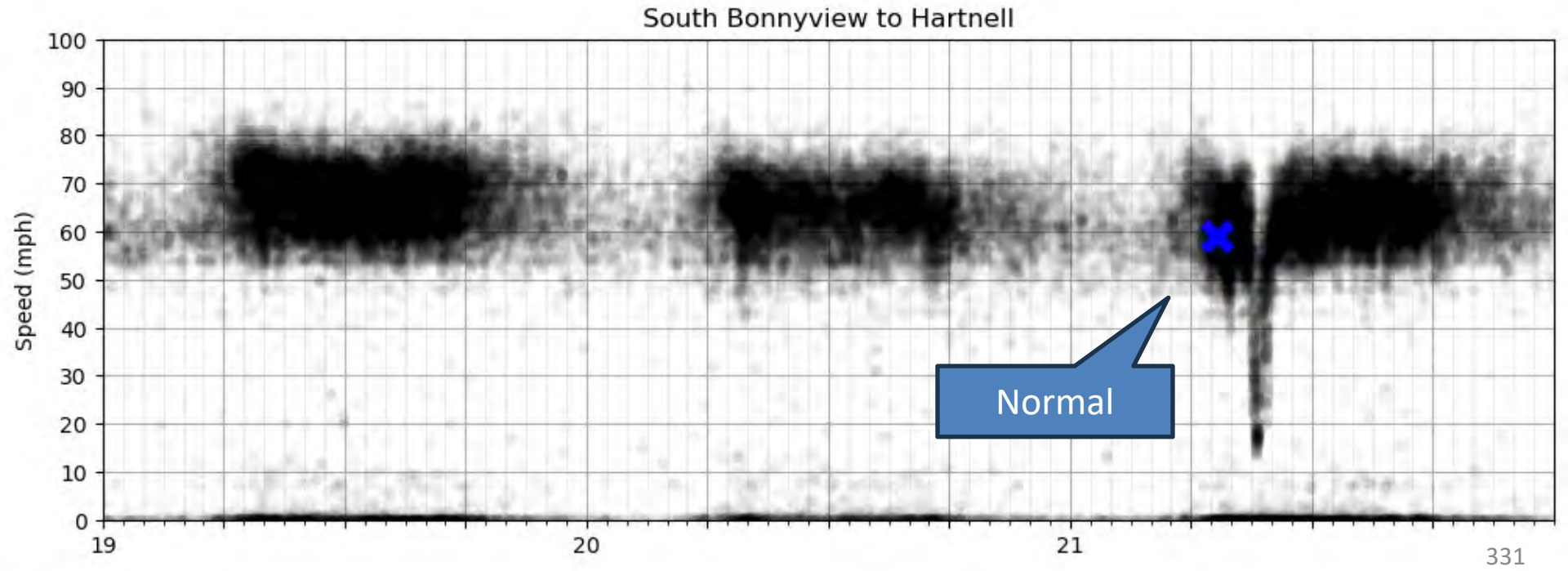


South Bonnyview to Hartnell
Speed: 59 mph
Travel Time: 1 min 50 sec



South Bonnyview
November 21, 2024
07:17:07 AM

Hartnell
November 21, 2024
07:18:57 AM



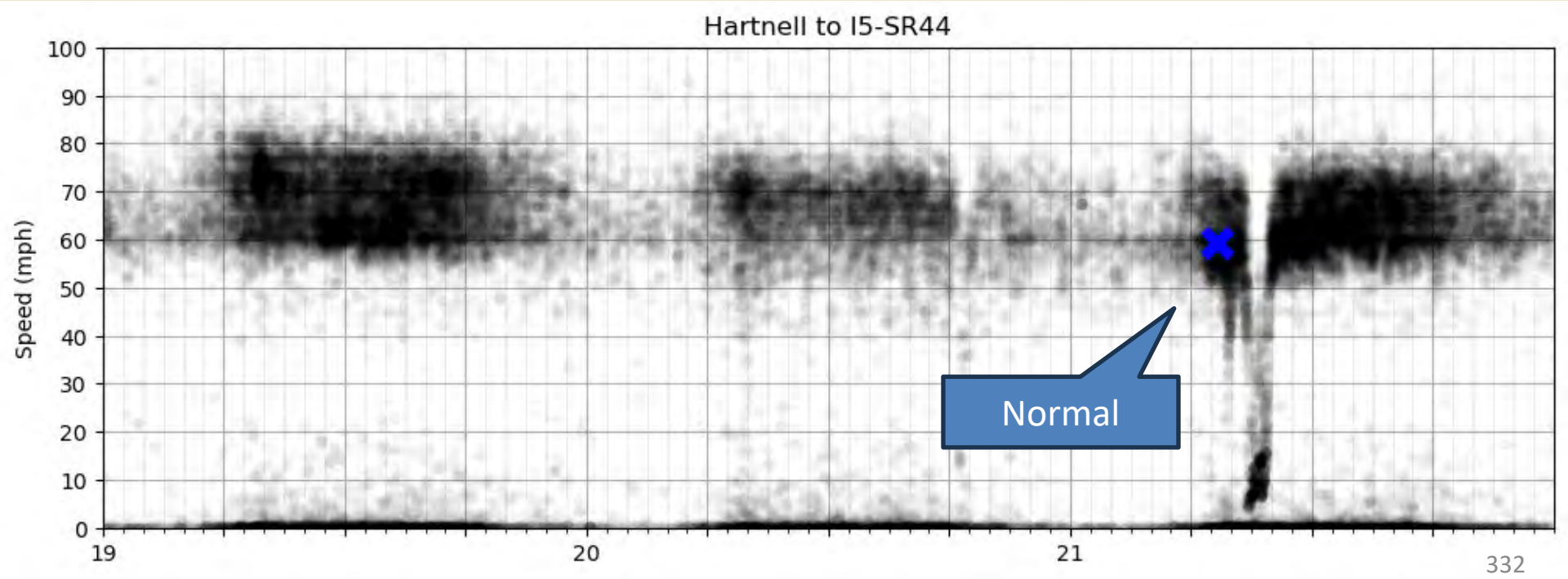


Hartnell to I5-SR44
Speed: 59 mph
Travel Time: 1 min 31 sec



Hartnell
November 21, 2024
07:18:57 AM

I5-SR44
November 21, 2024
07:20:28 AM



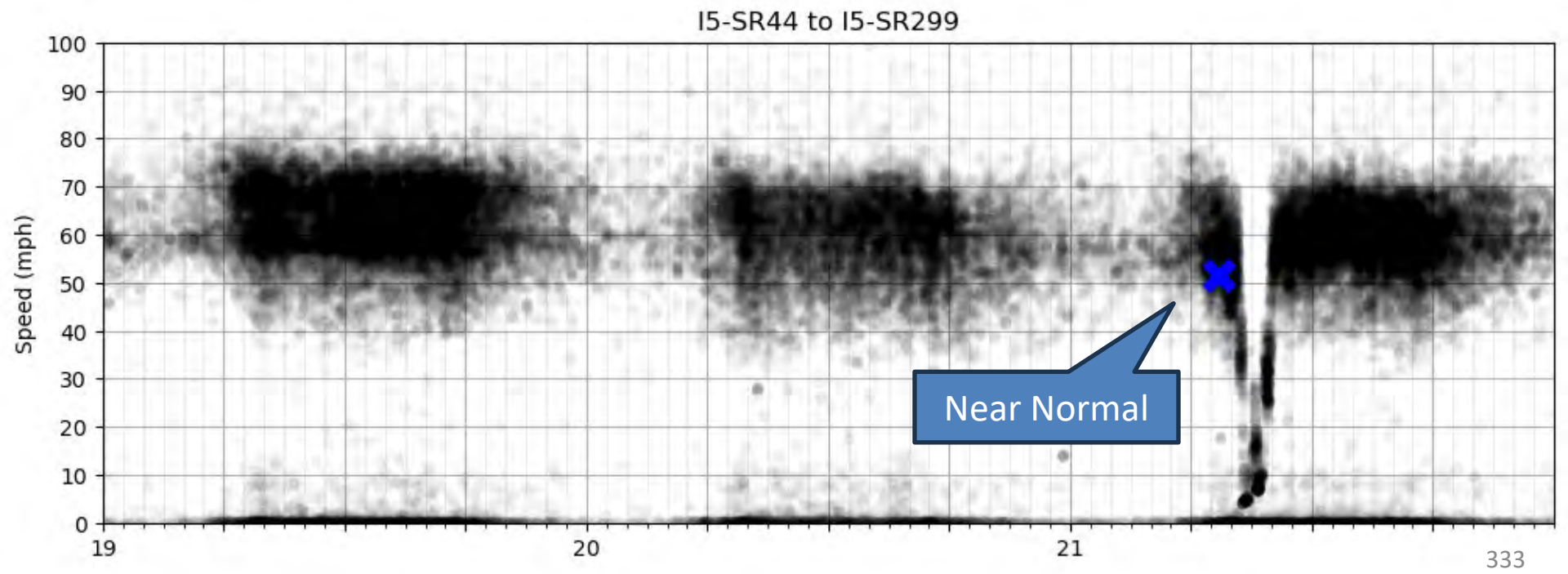


I5-SR44 to I5-SR299
Speed: 51 mph
Travel Time: 2 min 13 sec



I5-SR44
November 21, 2024
07:20:28 AM

I5-SR299
November 21, 2024
07:22:41 AM



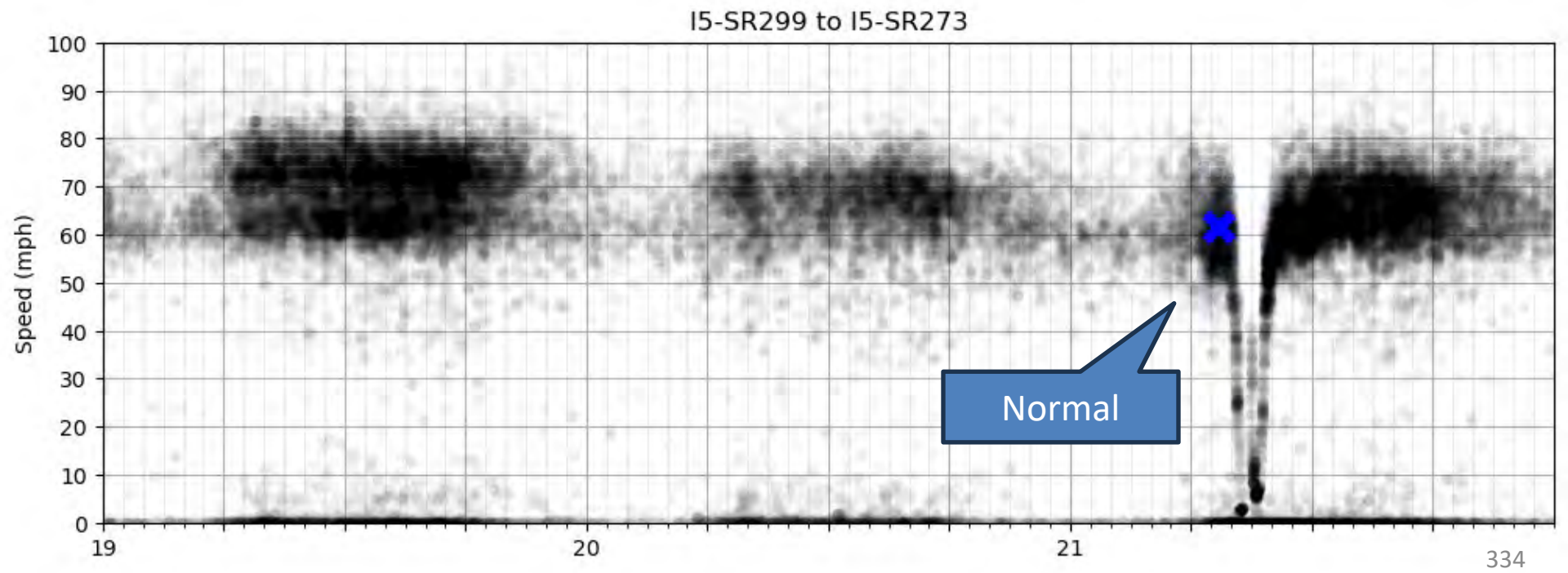
I5-SR299 to I5-SR273
Speed: 62 mph
Travel Time: 1 min 16 sec





I5-SR299
November 21, 2024
07:22:41 AM

I5-SR273
November 21, 2024
07:23:57 AM





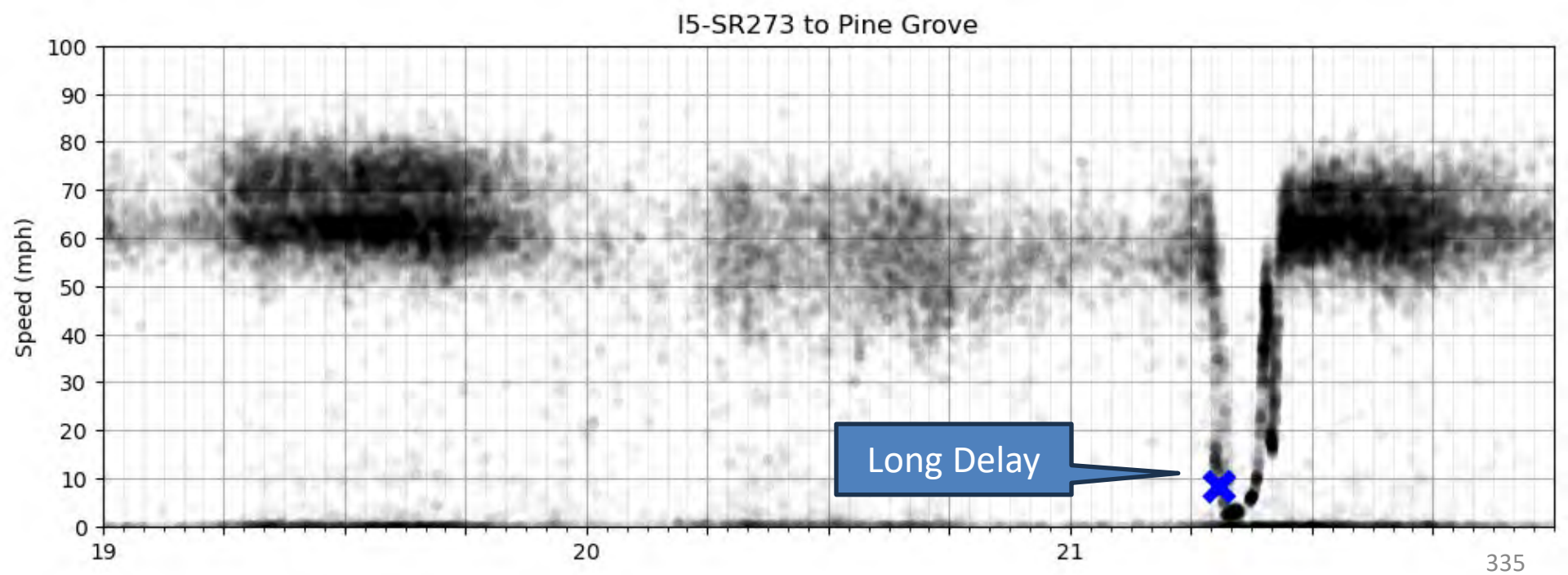
I5-SR273 to Pine Grove
Speed: 8 mph
Travel Time: 16 min 58 sec

Long Delay



I5-SR273
November 21, 2024
07:23:57 AM

Pine Grove
November 21, 2024
07:40:55 AM





Pine Grove to Mountain Gate
Speed: 2 mph
Travel Time: 57 min 5 sec

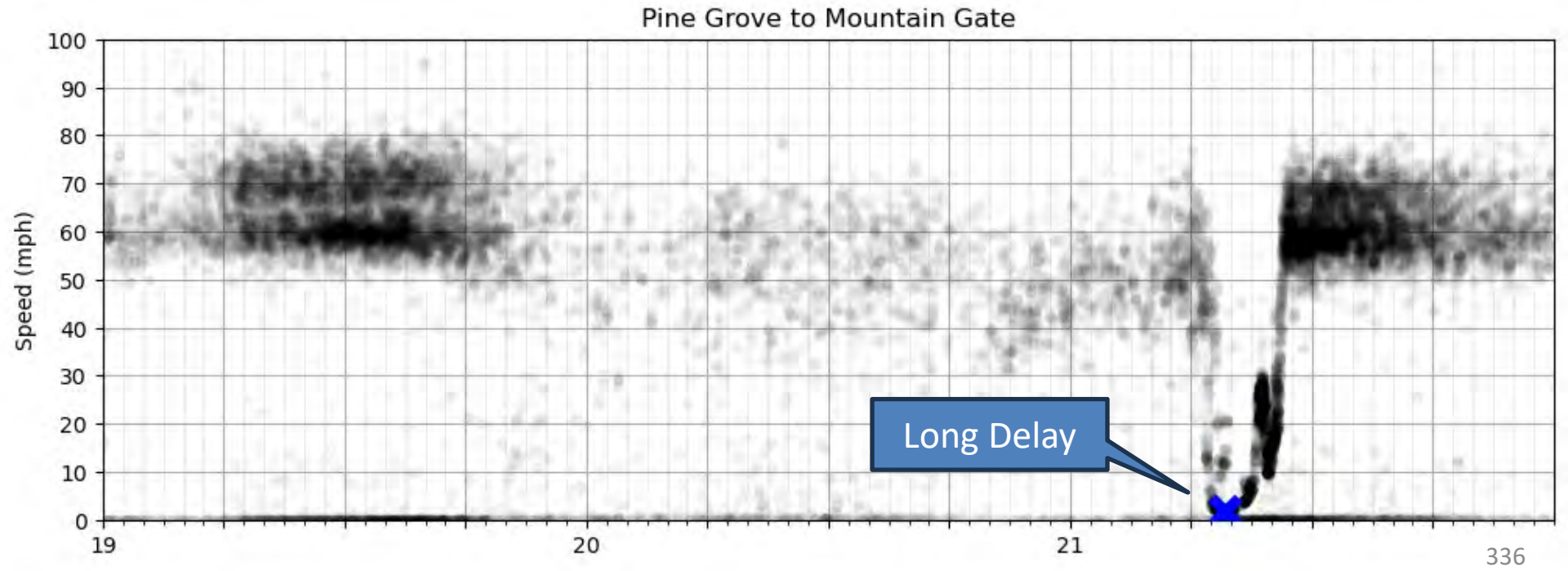
Long Delay

Long Delay



Pine Grove
November 21, 2024
07:40:55 AM

Mountain Gate
November 21, 2024
08:38:00 AM





Mountain Gate to Wonderland
Speed: 5 mph
Travel Time: 20 min 30 sec

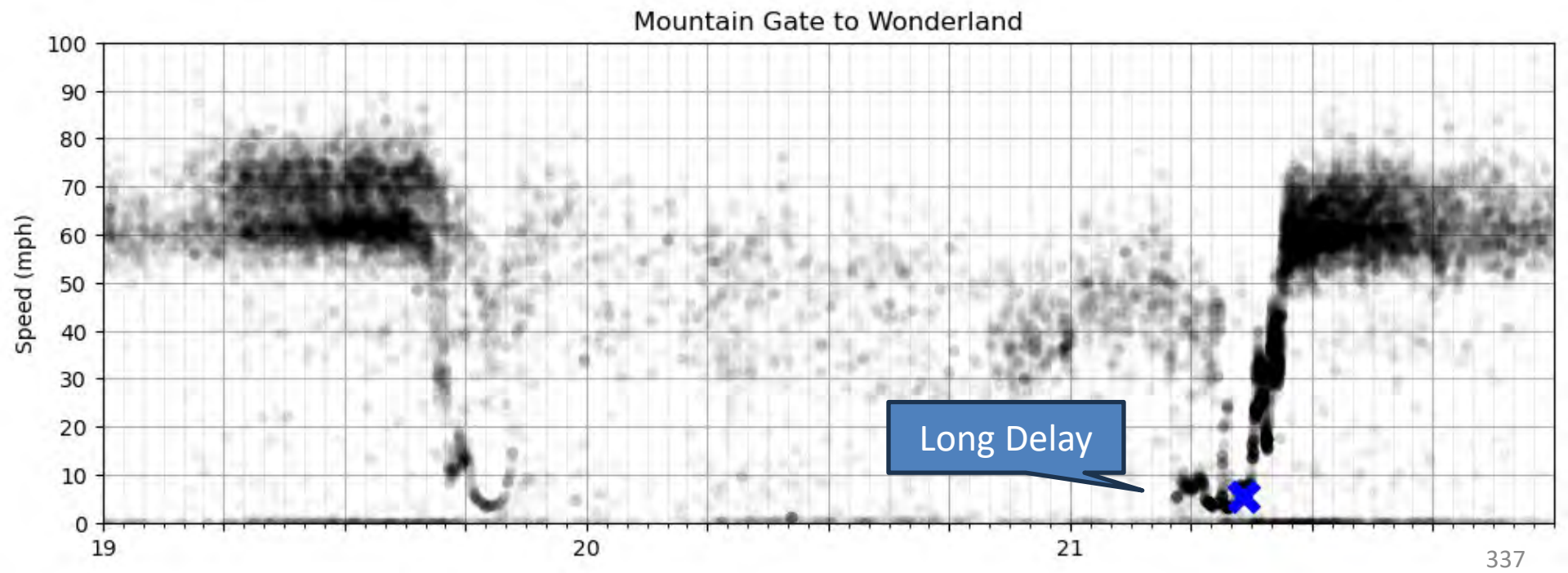
Long Delay

Long Delay



Mountain Gate
November 21, 2024
08:38:00 AM

Wonderland
November 21, 2024
08:58:30 AM





Wonderland to Fawndale
Speed: 22 mph
Travel Time: 3 min 32 sec

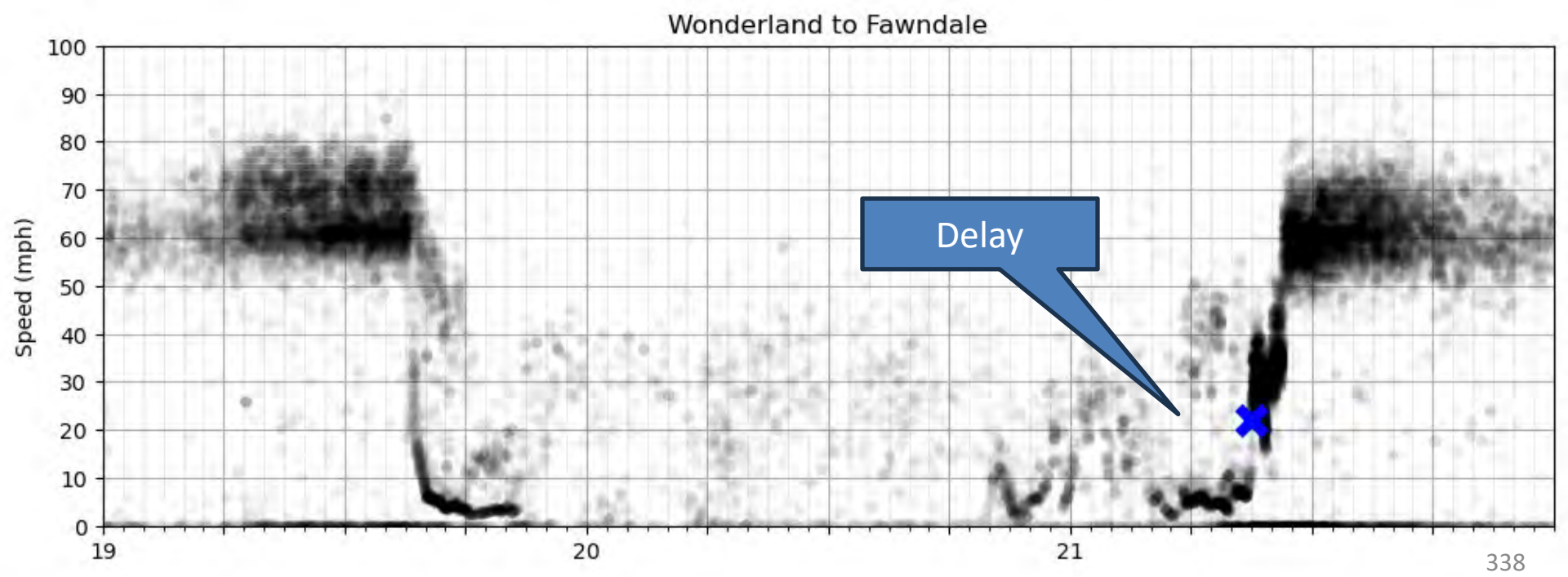
Long Delay

Delay



Wonderland
November 21, 2024
08:58:30 AM

Fawndale
November 21, 2024
09:02:02 AM



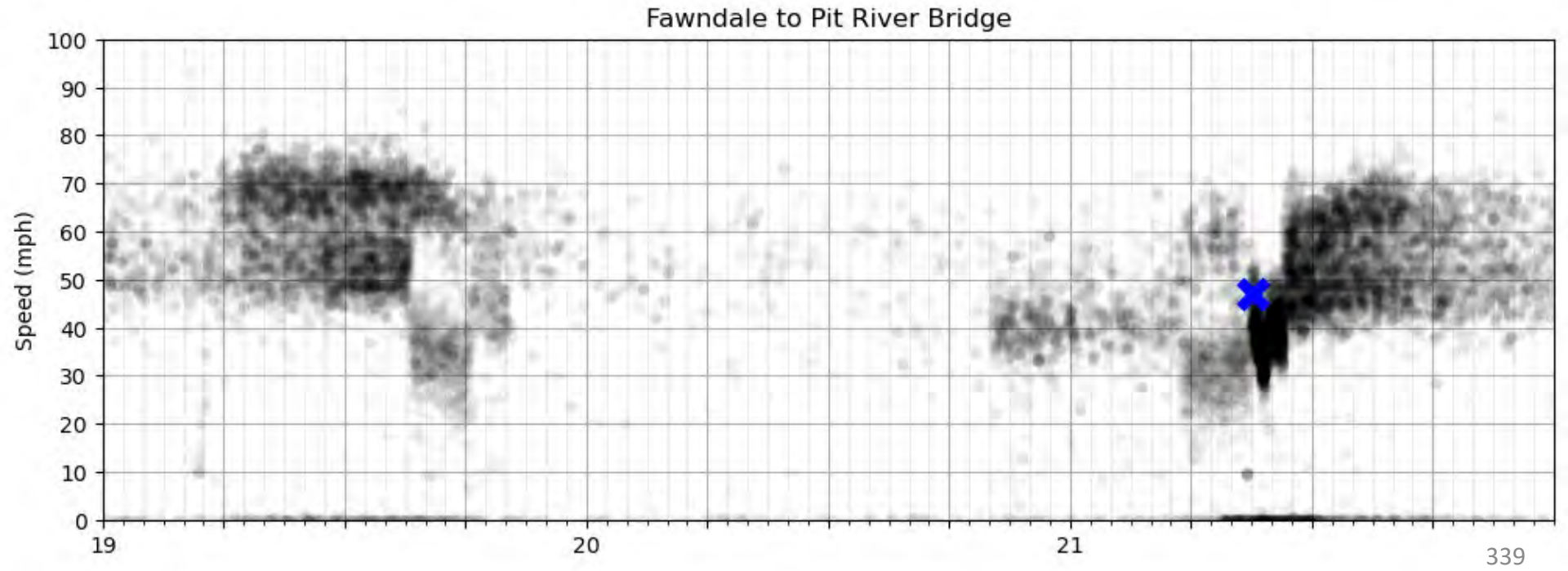


Fawndale to Pit River Bridge
Speed: 47 mph
Travel Time: 2 min 41 sec



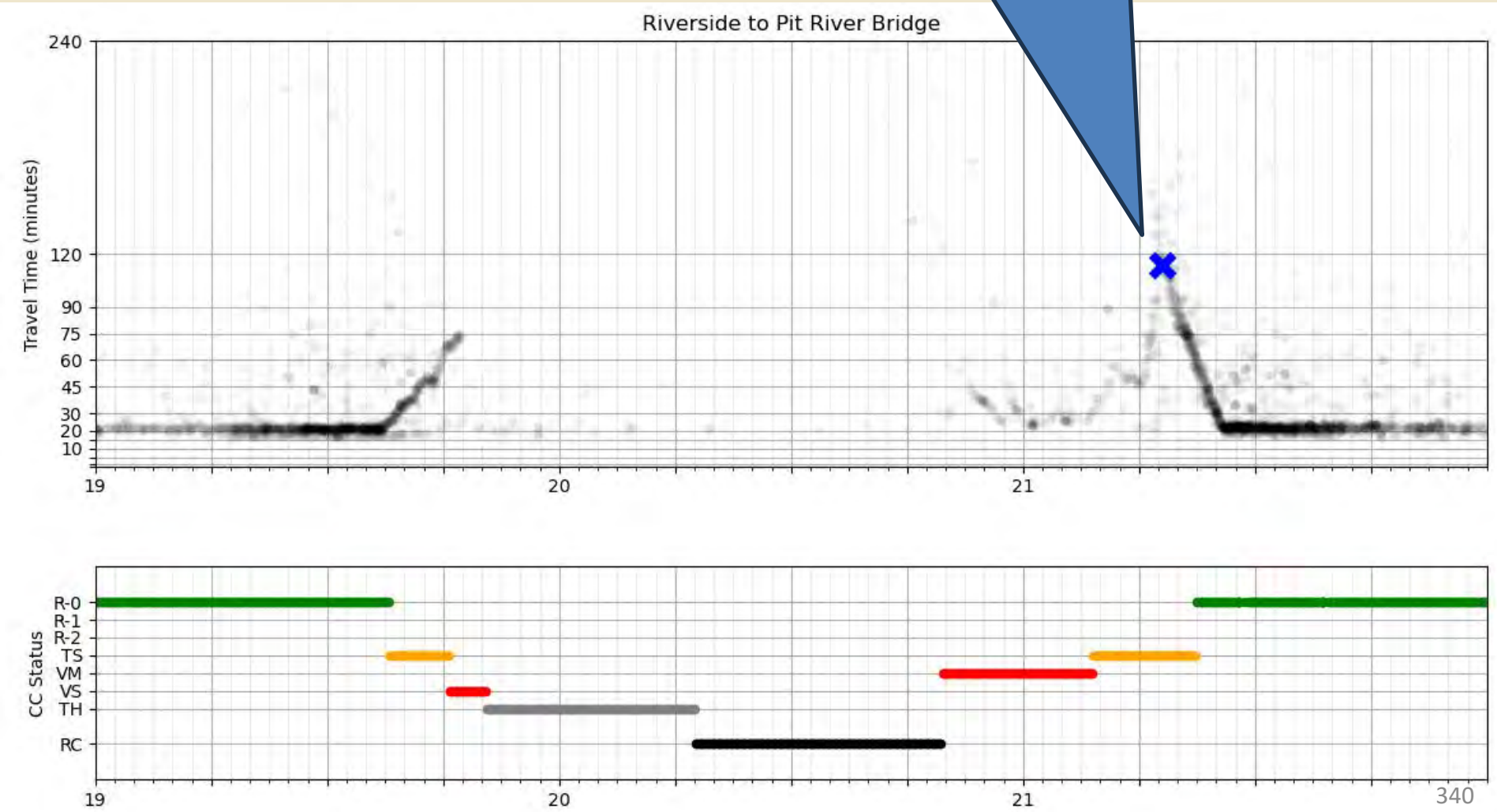
Fawndale
November 21, 2024
09:02:02 AM

Pit River Bridge
November 21, 2024
09:04:43 AM



Track Individual Device : BTLECAPT ea:34:fe:XX:XX:XX

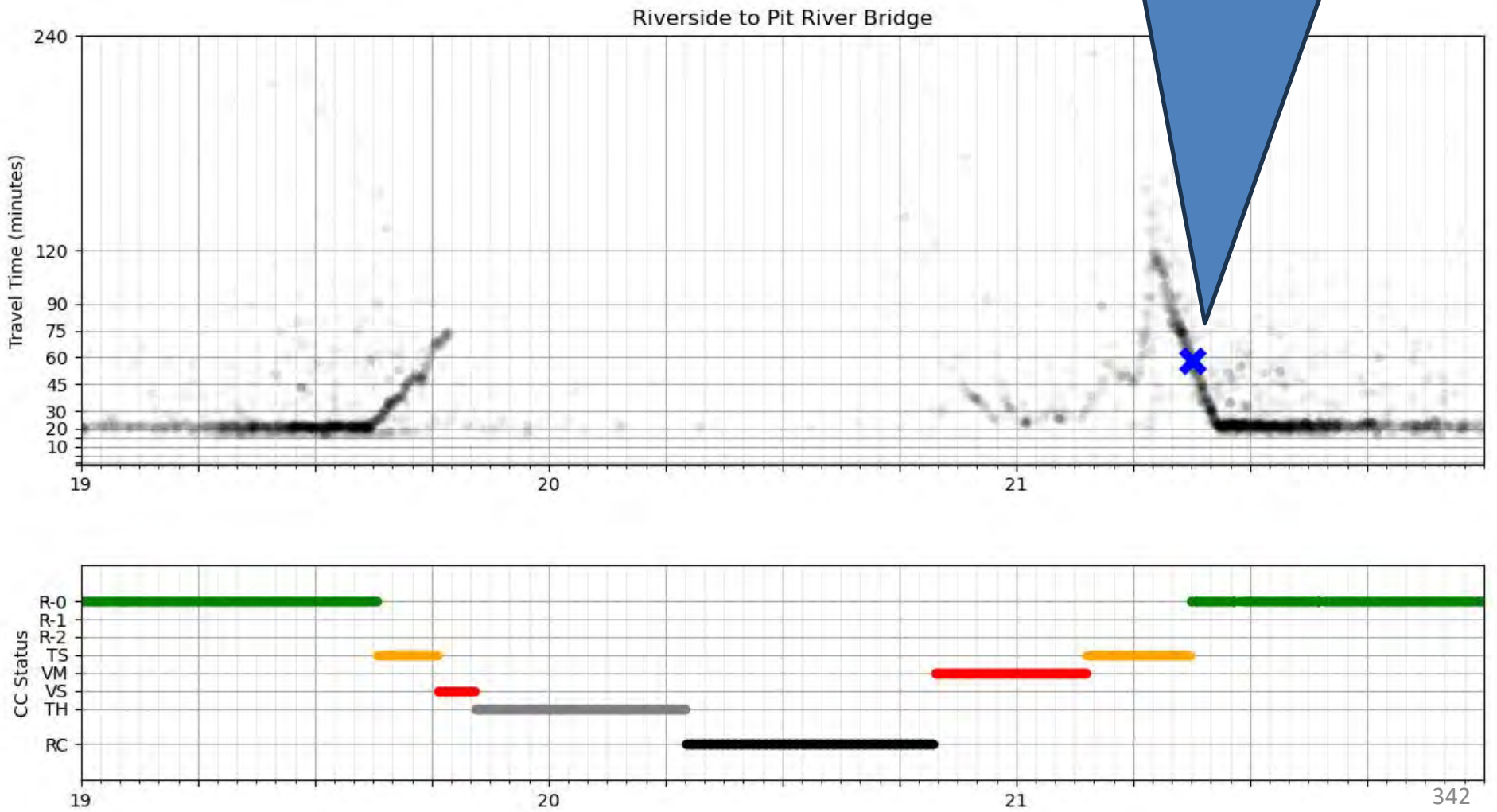
This device and travel time appear to be real and represent Ground Truth.



Track Another Device : BTLECAPT fa:ba:fb:XX:XX:XX

Track Individual Device : BTLECAPT fa:ba:fb:XX:XX:XX

This device experienced delay after restrictions were lifted. Delay was decreasing at this time.



Track Individual Device : BTLECAPT fa:ba:fb:XX:XX:XX

Date	Time	Site	Speed	Travel Time
November 21, 2024	09:01:44 AM	Riverside	64 mph	2 min 48 sec
November 21, 2024	09:04:32 AM	Knighton Rd	66 mph	2 min 10 sec
November 21, 2024	09:06:42 AM	South Bonnyview	**27 mph**	3 min 57 sec
November 21, 2024	09:10:39 AM	Hartnell	**10 mph**	8 min 54 sec
November 21, 2024	09:19:33 AM	I5-SR44	**7 mph**	16 min 7 sec
November 21, 2024	09:35:40 AM	I5-SR299	**37 mph**	2 min 7 sec
November 21, 2024	09:37:47 AM	I5-SR273	**38 mph**	3 min 47 sec
November 21, 2024	09:41:34 AM	Pine Grove	**15 mph**	7 min 30 sec
November 21, 2024	09:49:04 AM	Mountain Gate	**21 mph**	5 min 13 sec
November 21, 2024	09:54:17 AM	Wonderland	**29 mph**	2 min 39 sec
November 21, 2024	09:56:56 AM	Fawndale	**39 mph**	3 min 12 sec
November 21, 2024	10:00:08 AM	Pit River Bridge	**TOTAL**	**58 min 24 sec**

Delay extends all the way back to the segment between South Bonnyview and Hartnell.

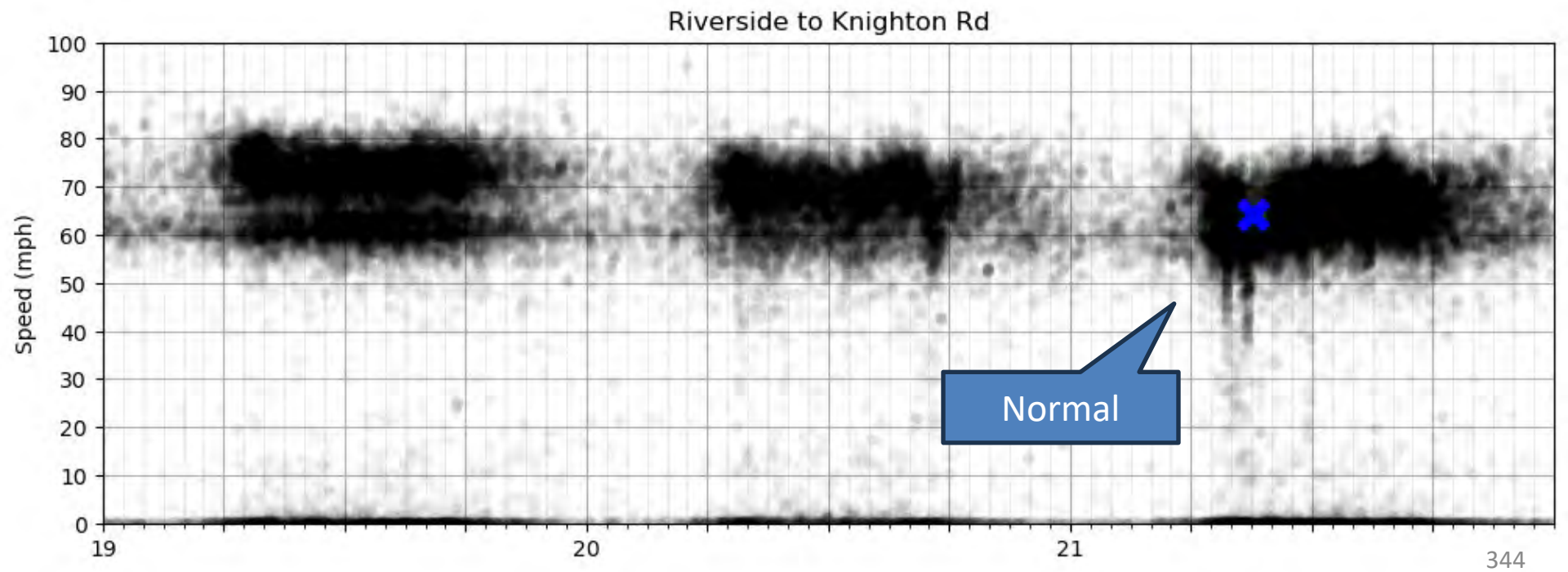


Riverside to Knighton Rd
Speed: 64 mph
Travel Time: 2 min 48 sec



Riverside
November 21, 2024
09:01:44 AM

Knighton Rd
November 21, 2024
09:04:32 AM



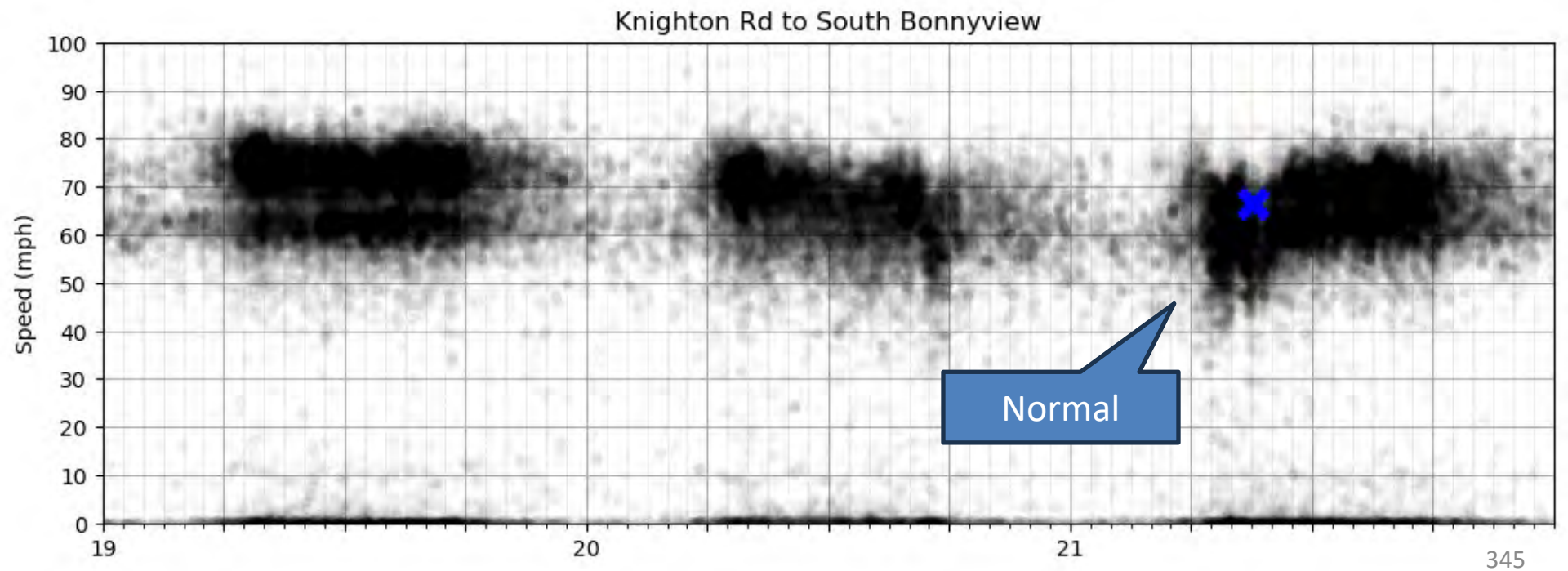


Knighton Rd to South Bonnyview
Speed: 66 mph
Travel Time: 2 min 10 sec



Knighton Rd
November 21, 2024
09:04:32 AM

South Bonnyview
November 21, 2024
09:06:42 AM





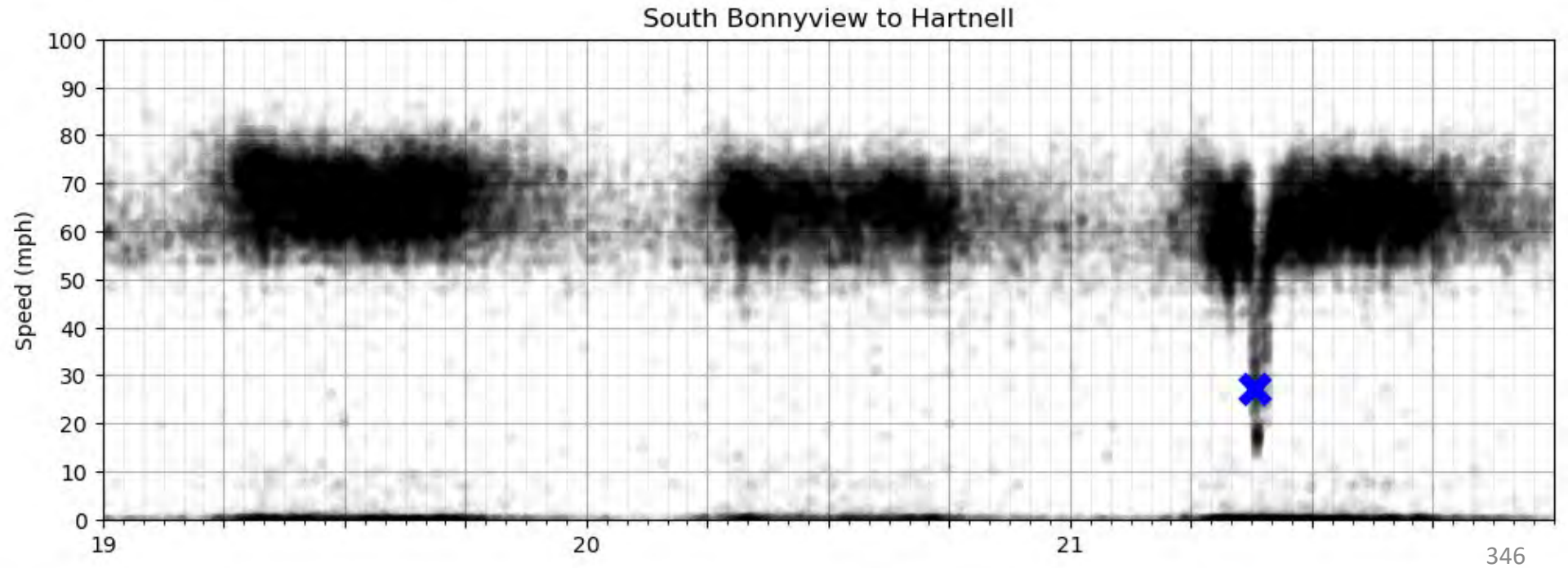
South Bonnyview to Hartnell
Speed: 27 mph
Travel Time: 3 min 57 sec

Delay



South Bonnyview
November 21, 2024
09:06:42 AM

Hartnell
November 21, 2024
09:10:39 AM





Hartnell to I5-SR44
Speed: 10 mph
Travel Time: 8 min 54 sec

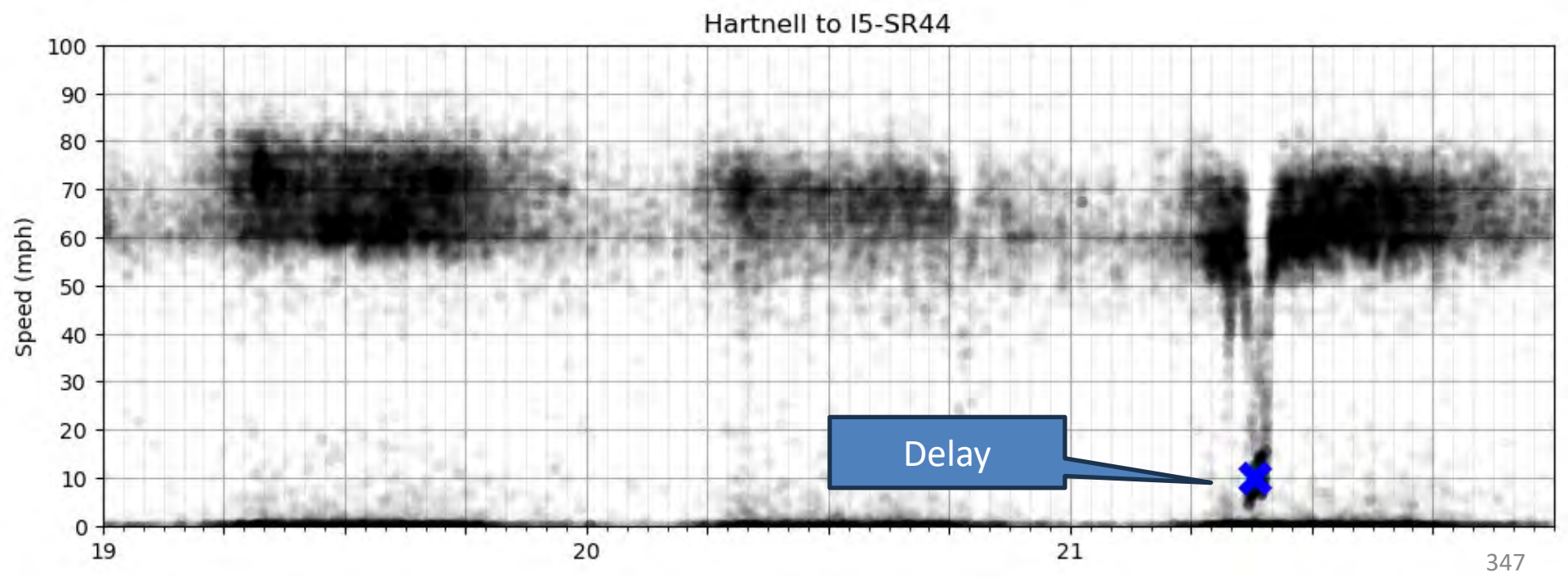
Delay

Delay



Hartnell
November 21, 2024
09:10:39 AM

I5-SR44
November 21, 2024
09:19:33 AM





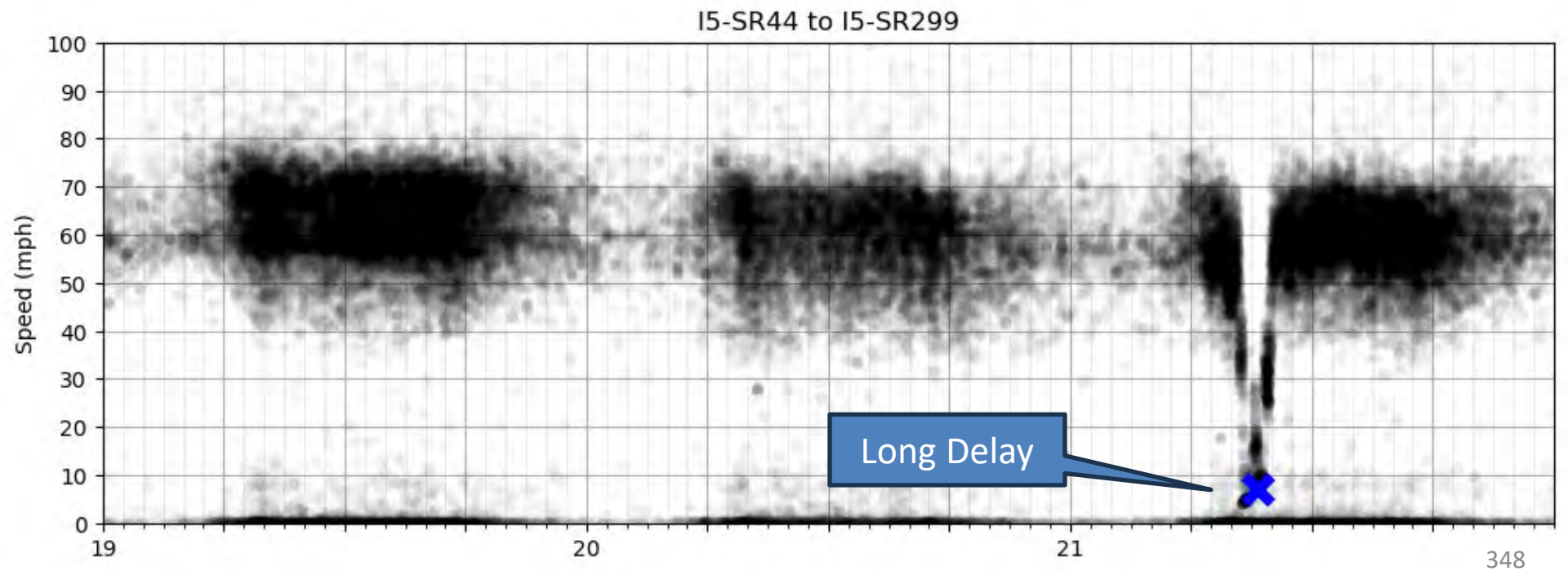
I5-SR44 to I5-SR299
Speed: 7 mph
Travel Time: 16 min 7 sec

Long Delay



I5-SR44
November 21, 2024
09:19:33 AM

I5-SR299
November 21, 2024
09:35:40 AM



I5-SR299 to I5-SR273
Speed: 37 mph
Travel Time: 2 min 7 sec

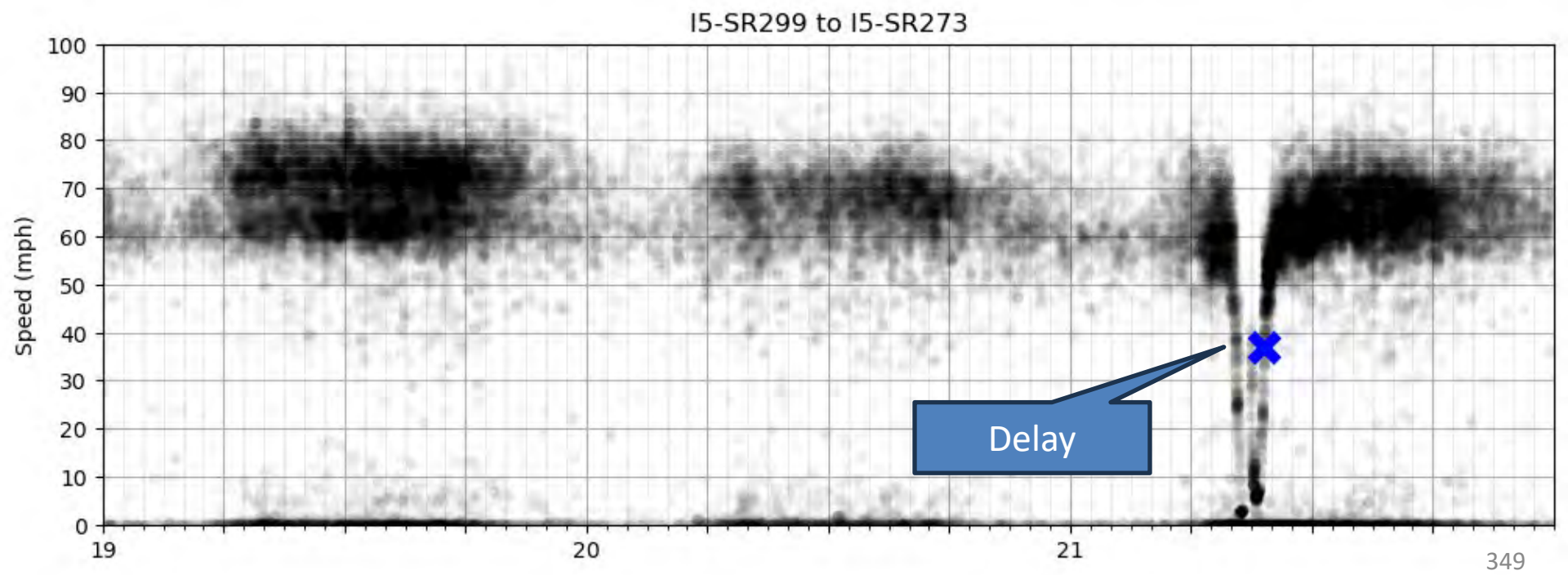


Delay



I5-SR299
November 21, 2024
09:35:40 AM

I5-SR273
November 21, 2024
09:37:47 AM





I5-SR273 to Pine Grove
Speed: 38 mph
Travel Time: 3 min 47 sec

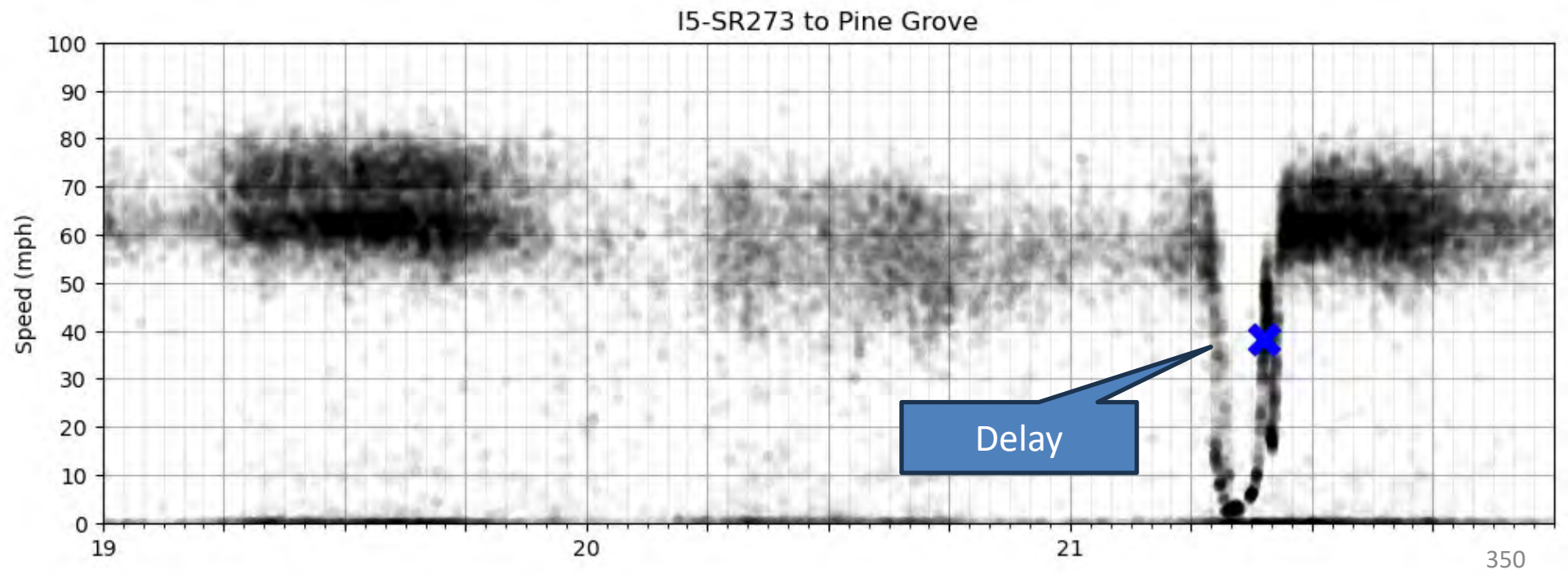
Delay

Delay



I5-SR273
November 21, 2024
09:37:47 AM

Pine Grove
November 21, 2024
09:41:34 AM





Pine Grove to Mountain Gate
Speed: 15 mph
Travel Time: 7 min 30 sec

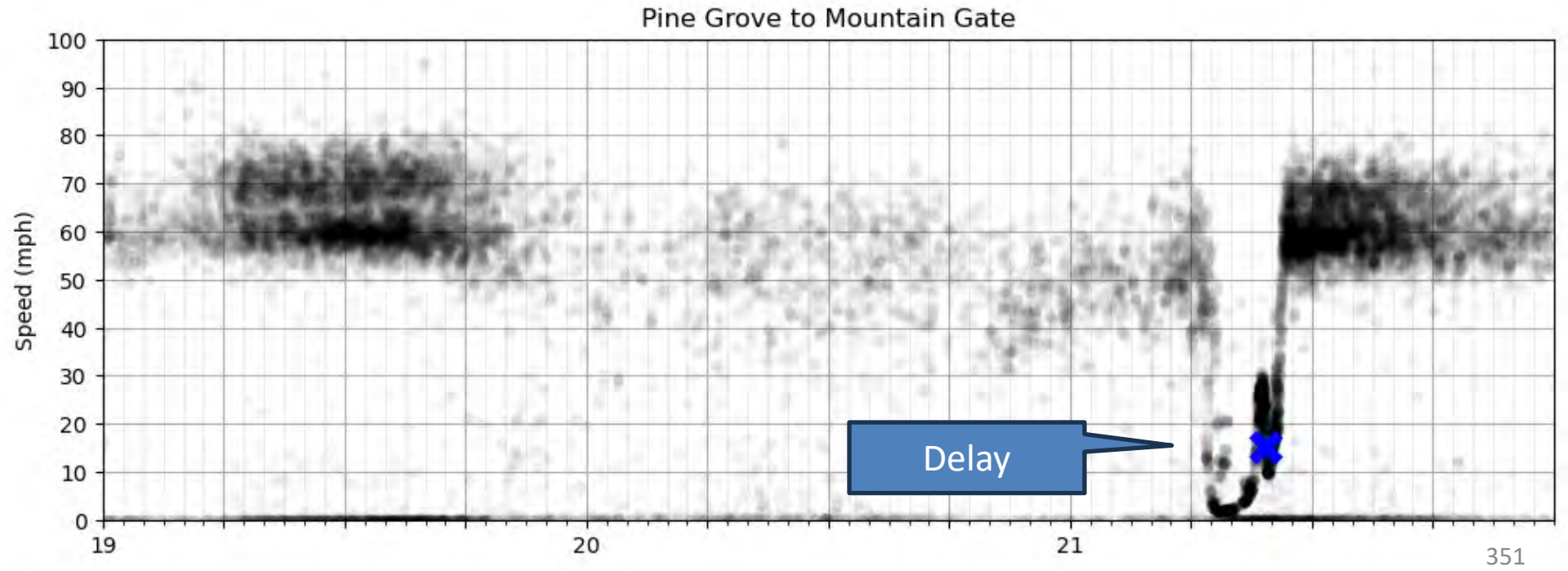
Delay

Delay



Pine Grove
November 21, 2024
09:41:34 AM

Mountain Gate
November 21, 2024
09:49:04 AM





Mountain Gate to Wonderland
Speed: 21 mph
Travel Time: 5 min 13 sec

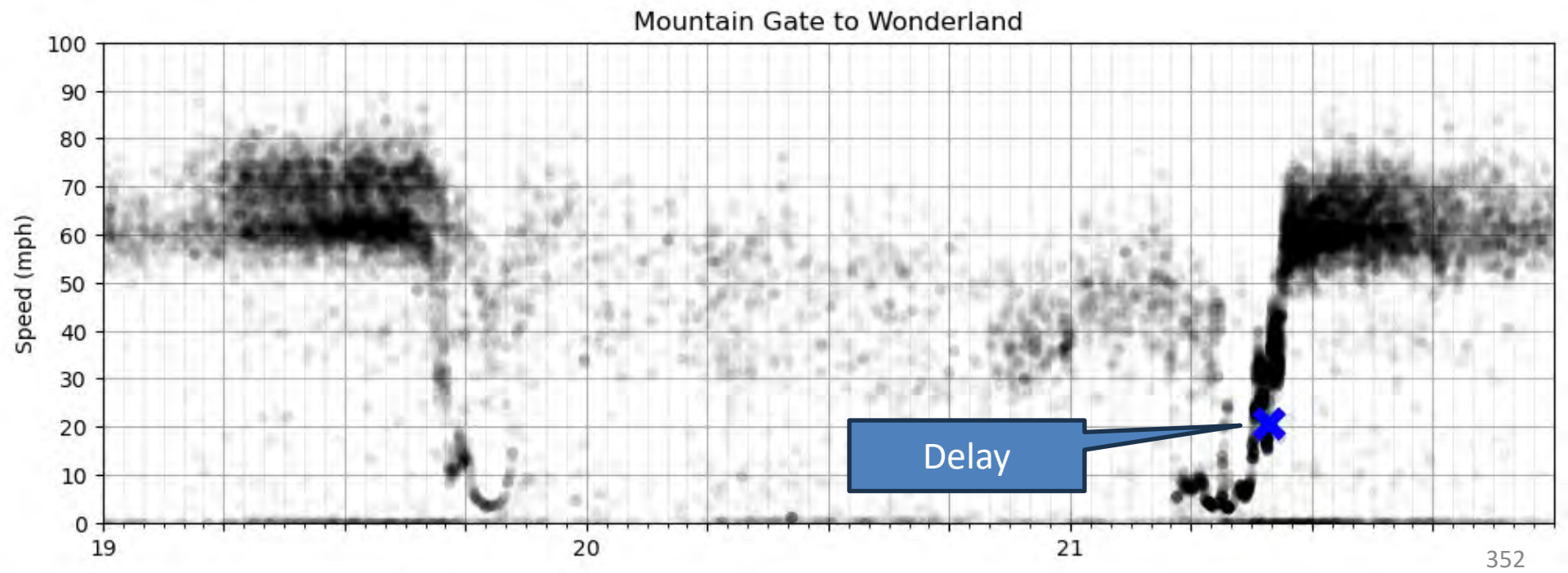
Delay

Delay



Mountain Gate
November 21, 2024
09:49:04 AM

Wonderland
November 21, 2024
09:54:17 AM





Wonderland to Fawndale
Speed: 29 mph
Travel Time: 2 min 39 sec

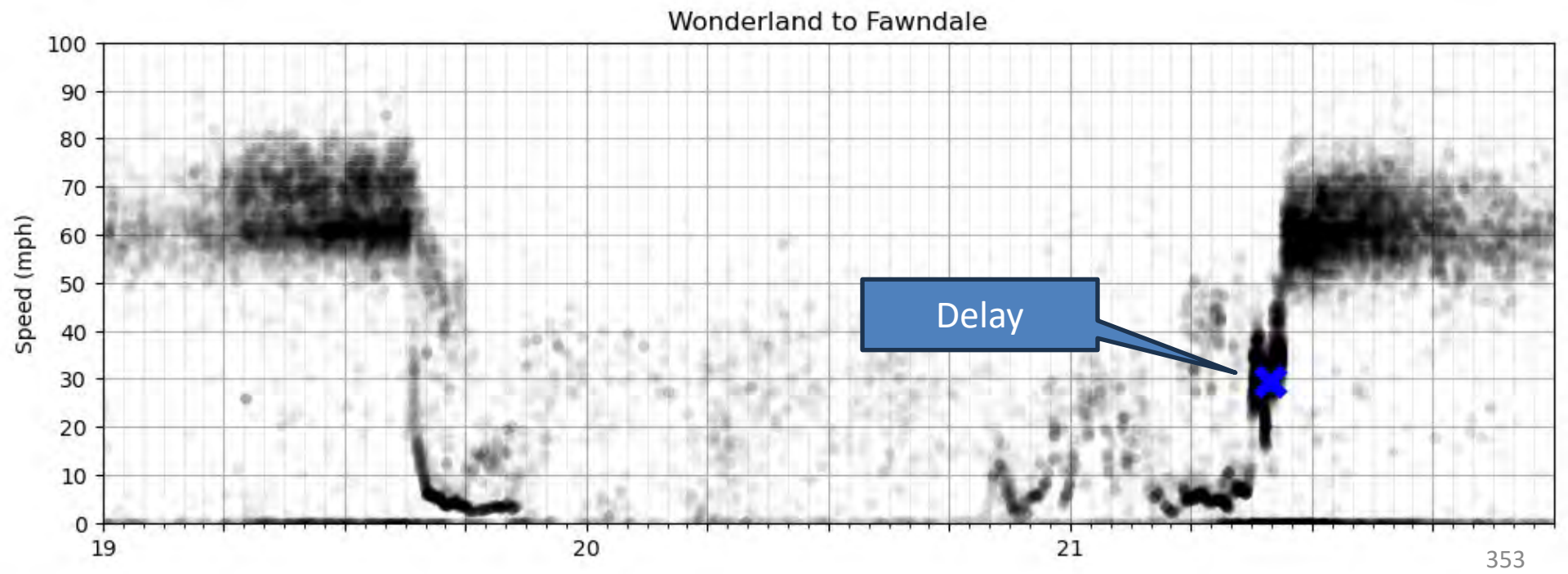
Delay

Delay



Wonderland
November 21, 2024
09:54:17 AM

Fawndale
November 21, 2024
09:56:56 AM





Fawndale to Pit River Bridge
Speed: 39 mph
Travel Time: 3 min 12 sec

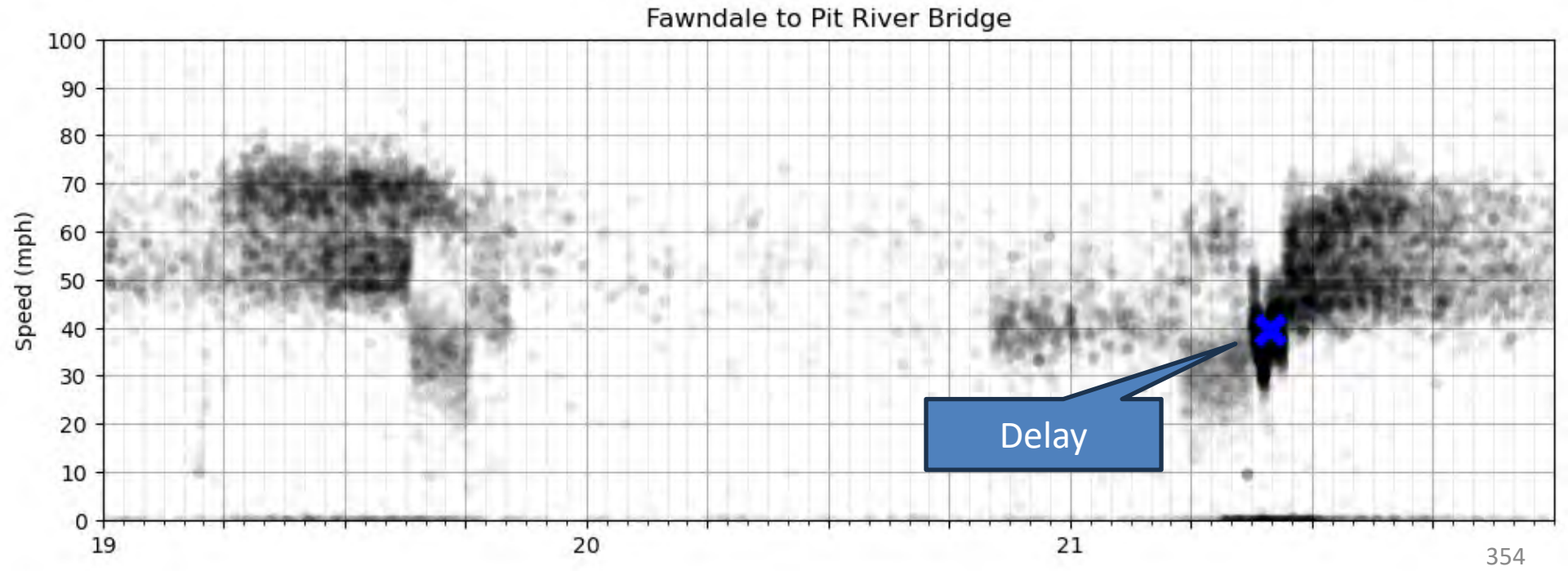
Delay

Delay



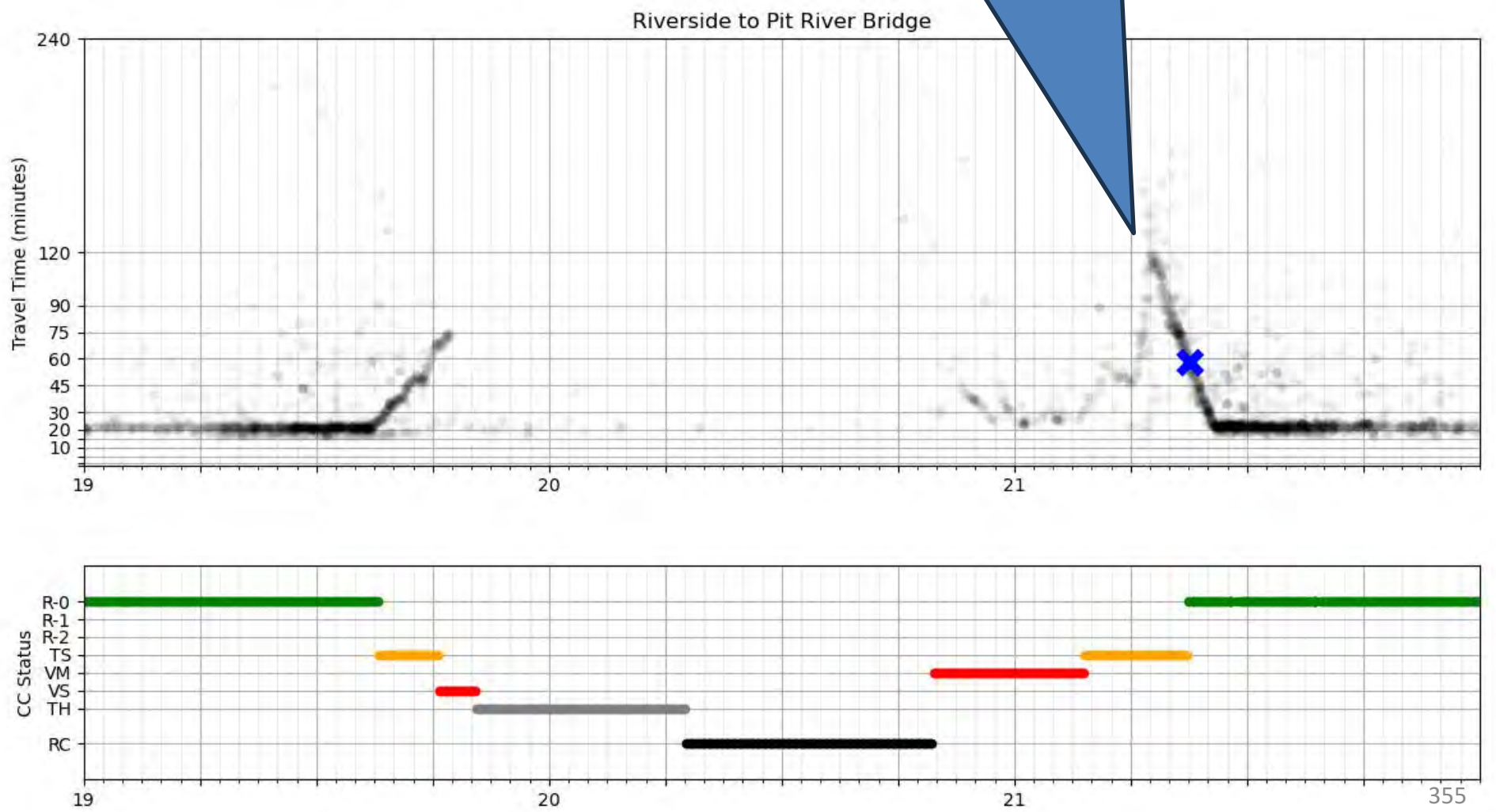
Fawndale
November 21, 2024
09:56:56 AM

Pit River Bridge
November 21, 2024
10:00:08 AM



Track Individual Device : BTLECAPT fa:ba:fb:XX:XX:XX

This device and travel time appear to be real and represent Ground Truth.



Summary: Confirming Ground Truth

It does appear that patterns in the plots of individual device travel times correspond to ground truth.

It is important to isolate devices that traverse the entire corridor, as these correspond to vehicles most impacted by the chain restrictions at Fawndale.

Now we return to attempts to represent speeds and travel times with single summary statistics at given times. In prior work we jumped right into this a faced many challenges. We now have a better foundation to build on.

Part 7: Representing Ground Truth with a Single Aggregate Measure

Represent Ground Truth with a Single Aggregate

For the sake of subsequent comparison and evaluation, it is desirable to represent Ground Truth with a single aggregate measure.

Early efforts to do this were challenging as documented in prior slides.

It is time to revisit this now that we have confidence in where Ground Truth falls relative to individual travel times.

Represent Ground Truth with a Single Aggregate

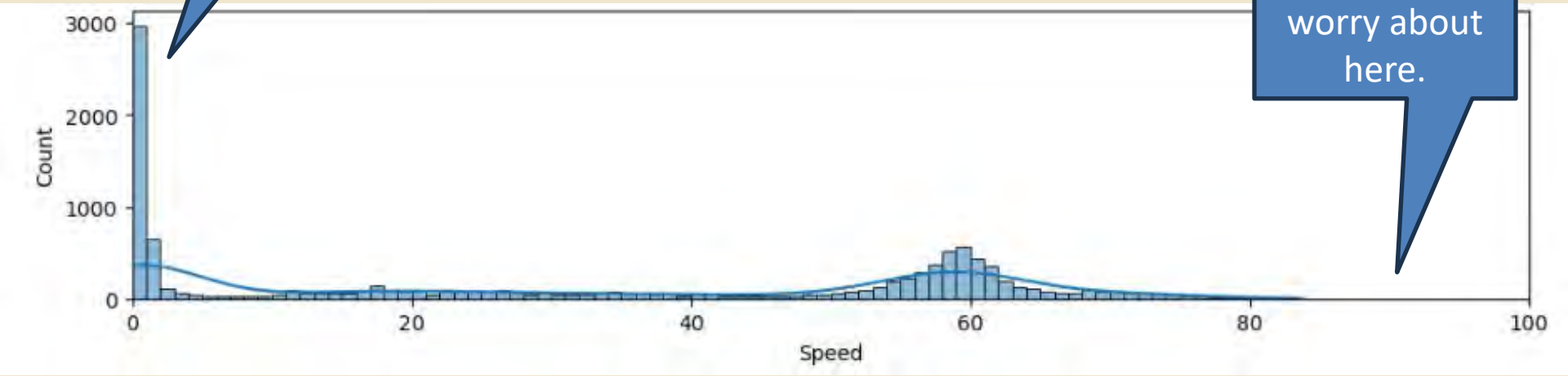
We will try 25th Percentile, Median and 75th Percentile Speeds.

We are doing this after trimming speeds less than 2 mph and greater than 130 mph.

As discussed earlier, there can be a large amount of data with speeds of 2 mph or less. The choice of a threshold here can have a big impact on these percentiles.

Trimming Low and High Speeds

This is a problem.



Not much to worry about here.

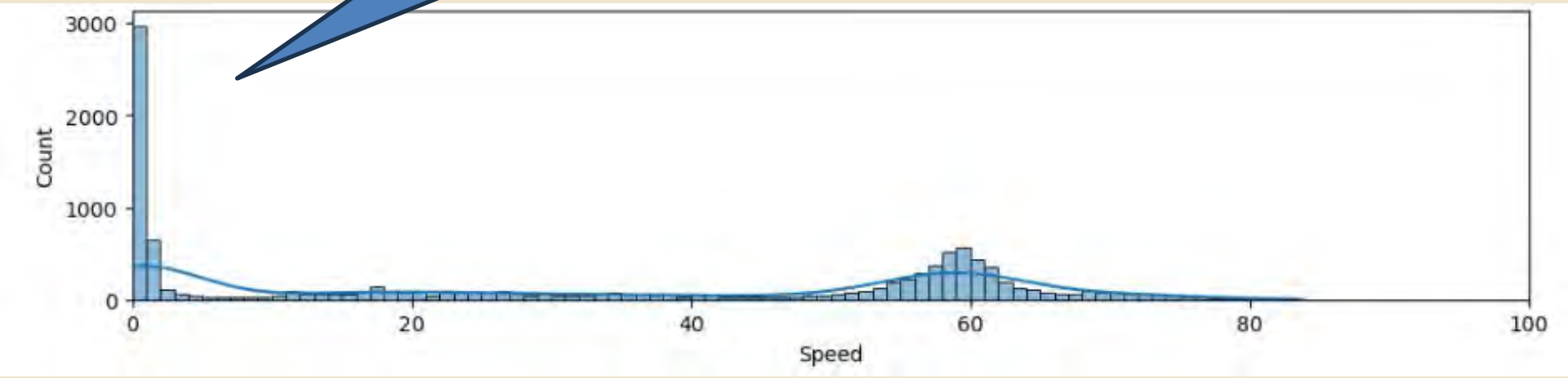
Real speeds can drop to 1 or 2 mph during restrictions.

We don't want to throw away good data. In fact, this may be some of the most important data.

Trimming Low and High Speeds

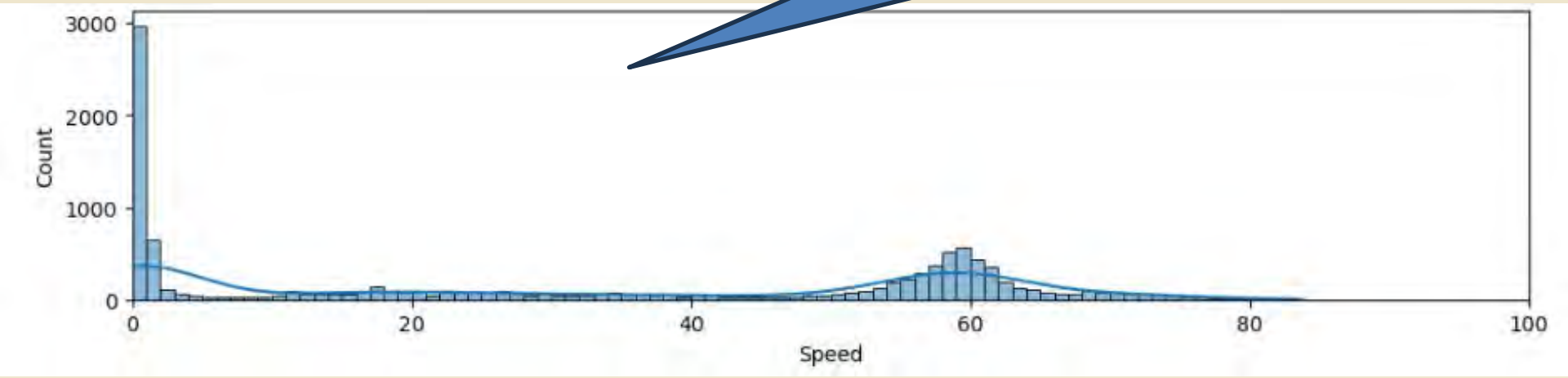
Many these are a consequence of stops along the way (at Costco, or elsewhere).

Some are due to delay from the chain restrictions.



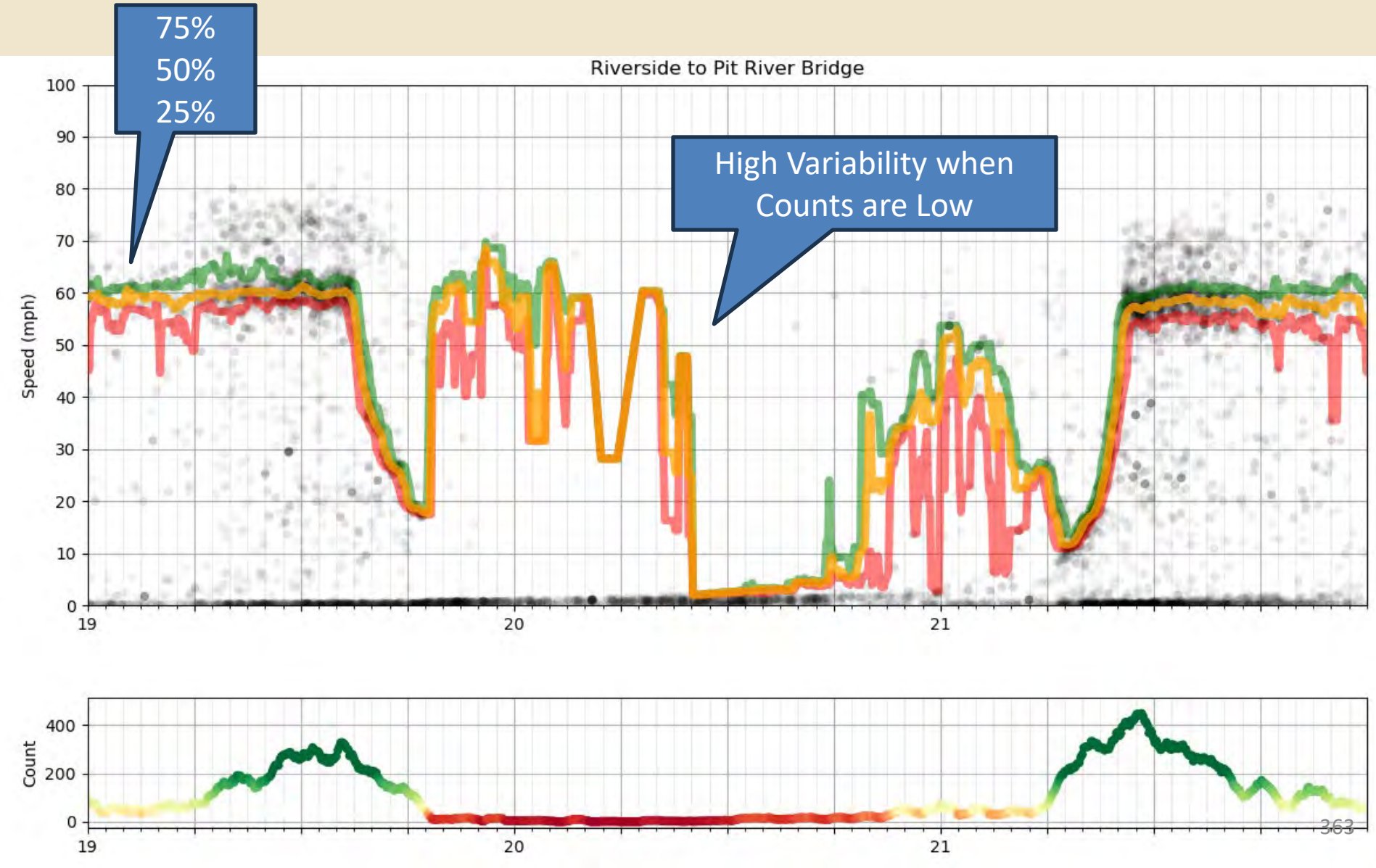
Trimming Low and High Speeds

The choice of a cutoff value can dramatically impact the aggregates.



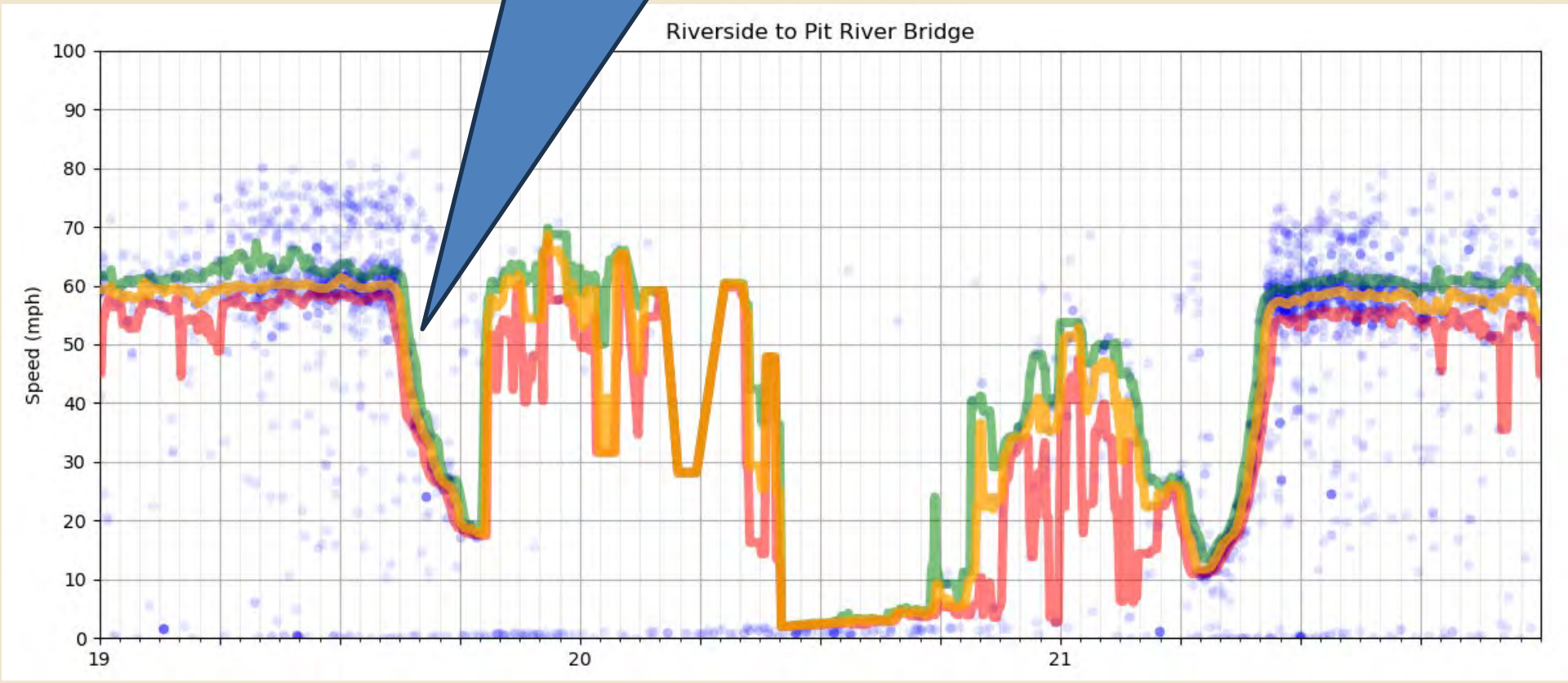
Where is the 25th percentile?

Represent Ground Truth with a Single Aggregate



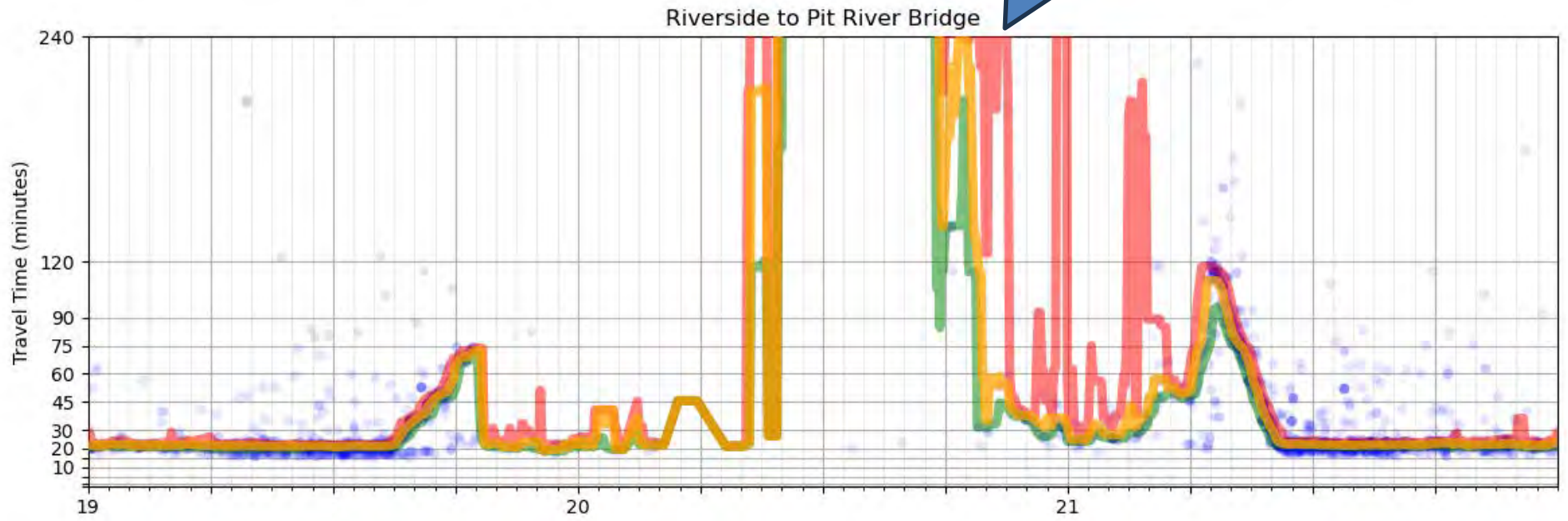
Represent Ground Truth with a Single Aggregate

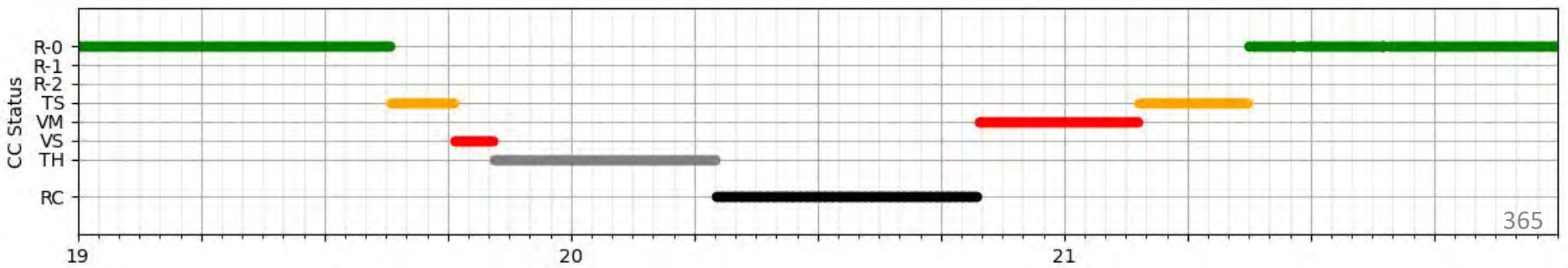
When counts are high, the percentiles track relatively close to the ground truth data.



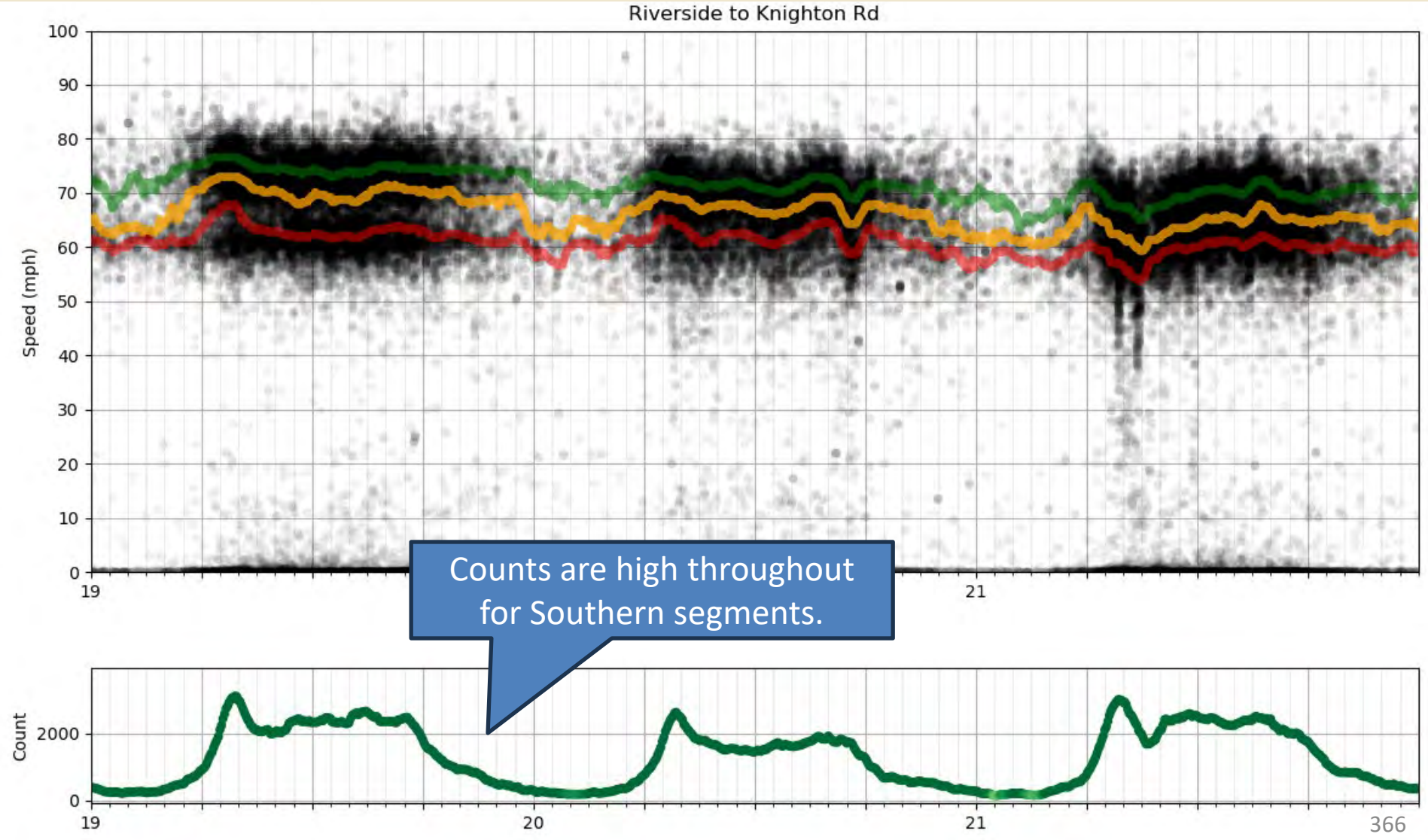
Represent Ground Truth with a Single Aggregate

Travel Times go off the chart when counts are low – not accurate.

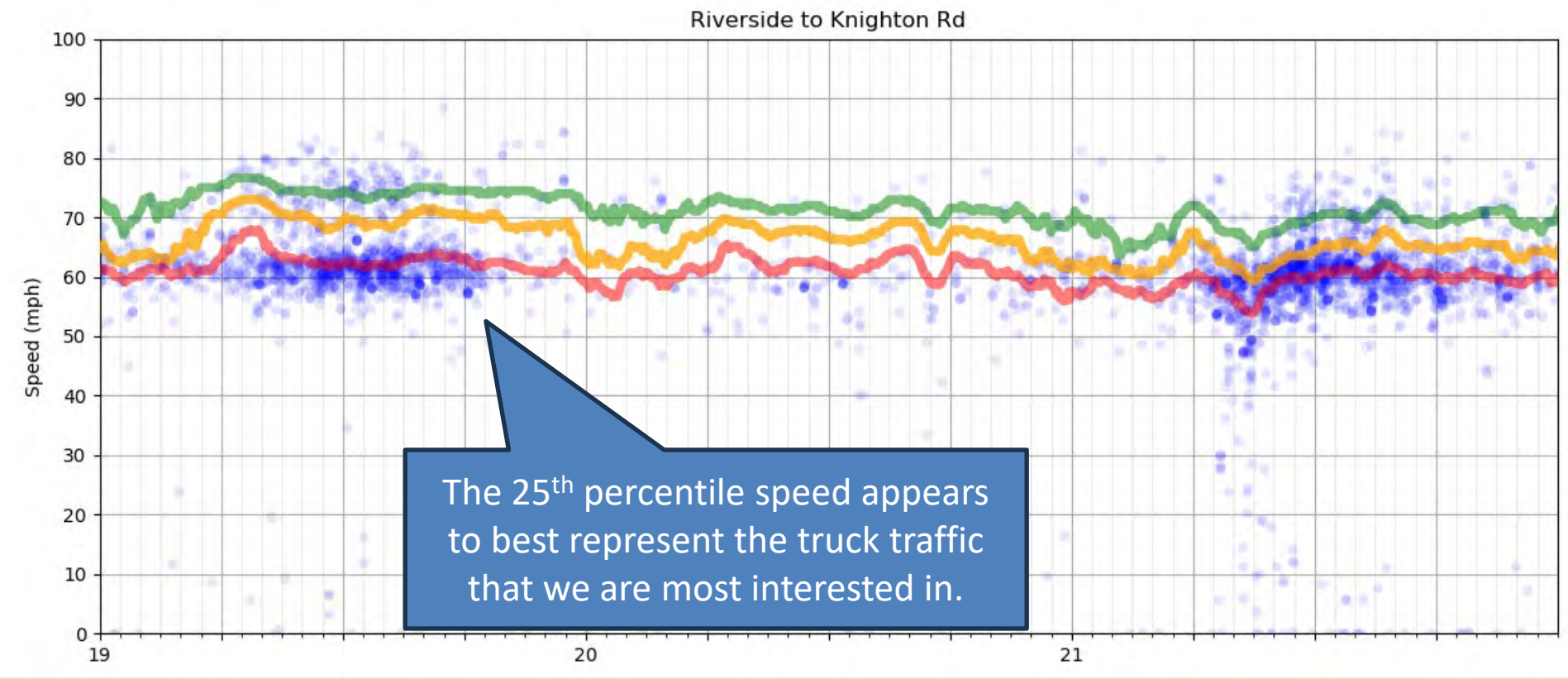




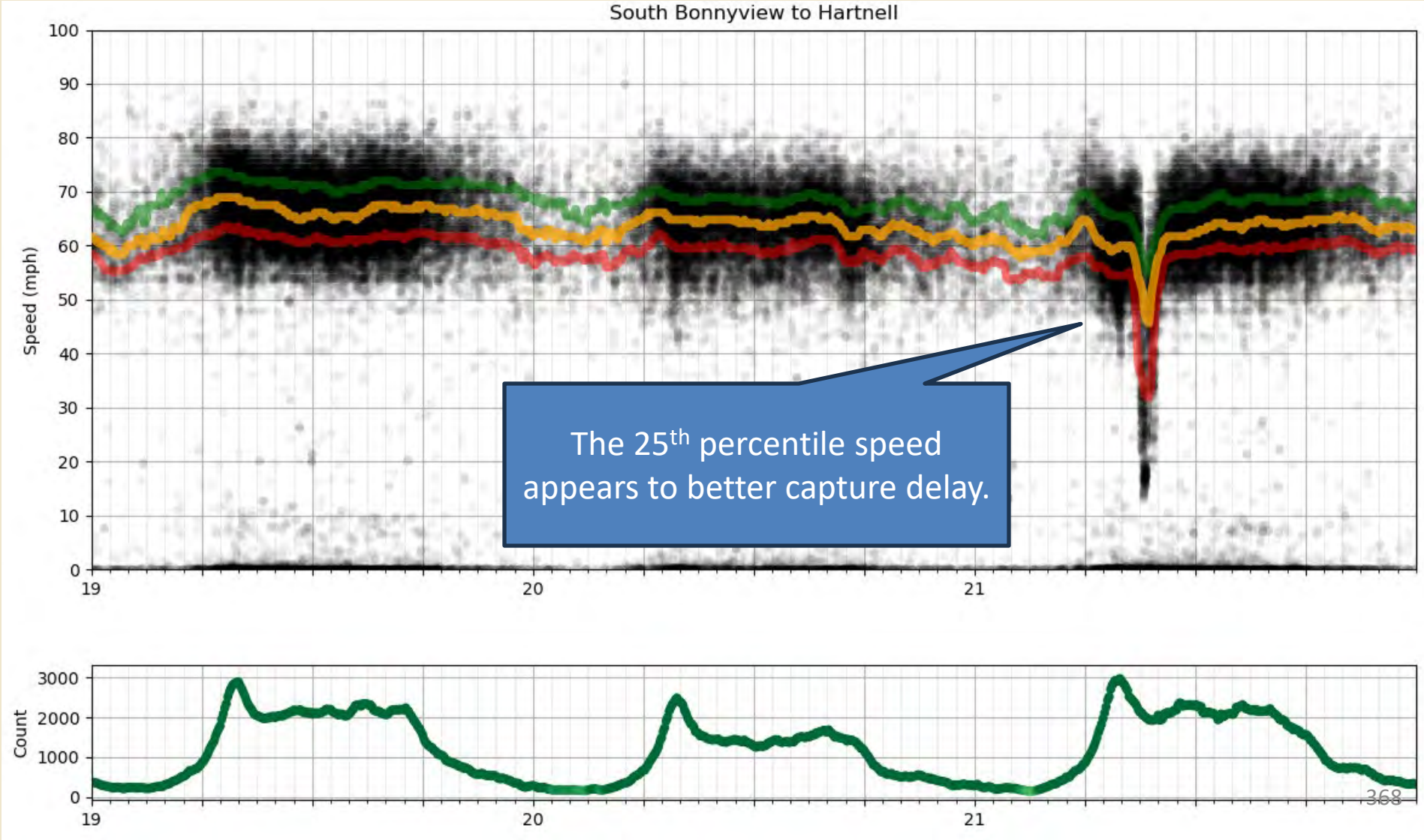
Represent Ground Truth with a Single Aggregate



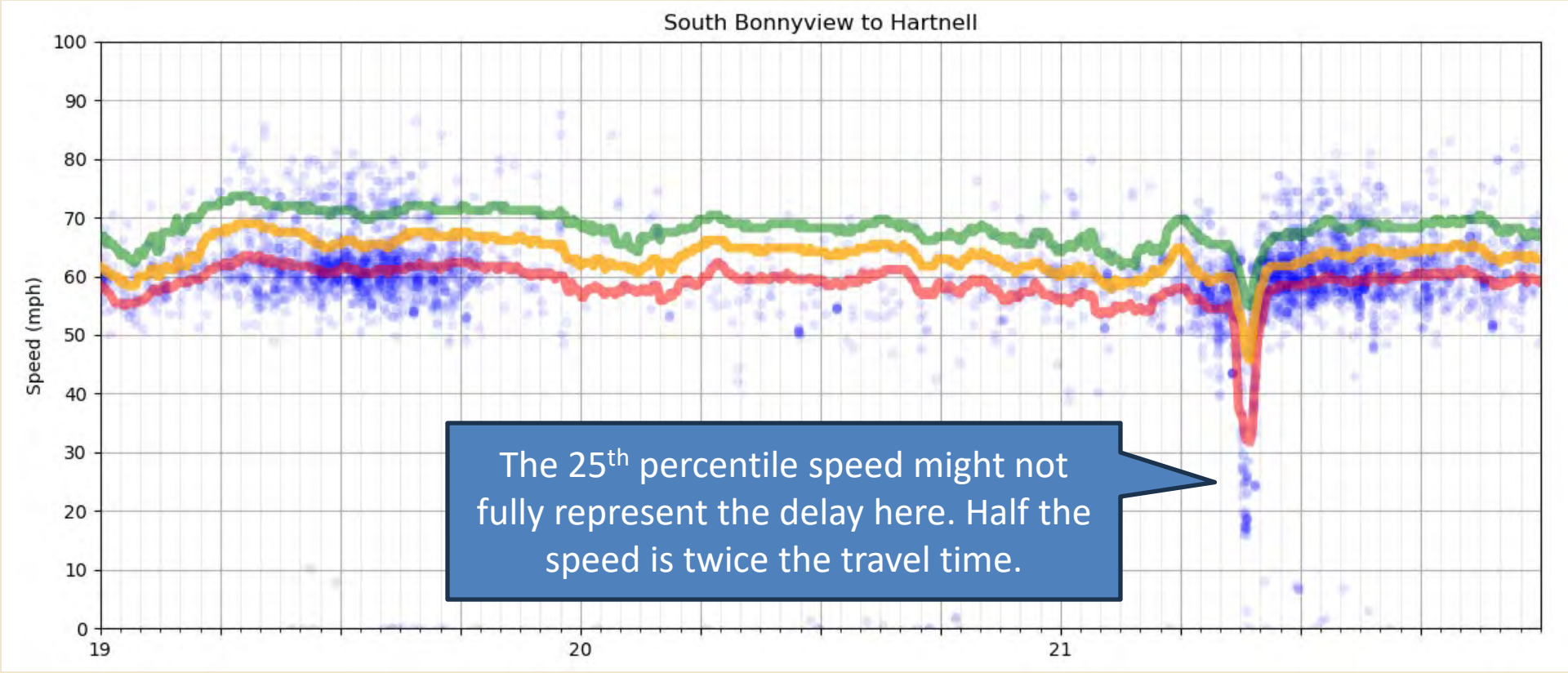
Represent Ground Truth with a Single Aggregate



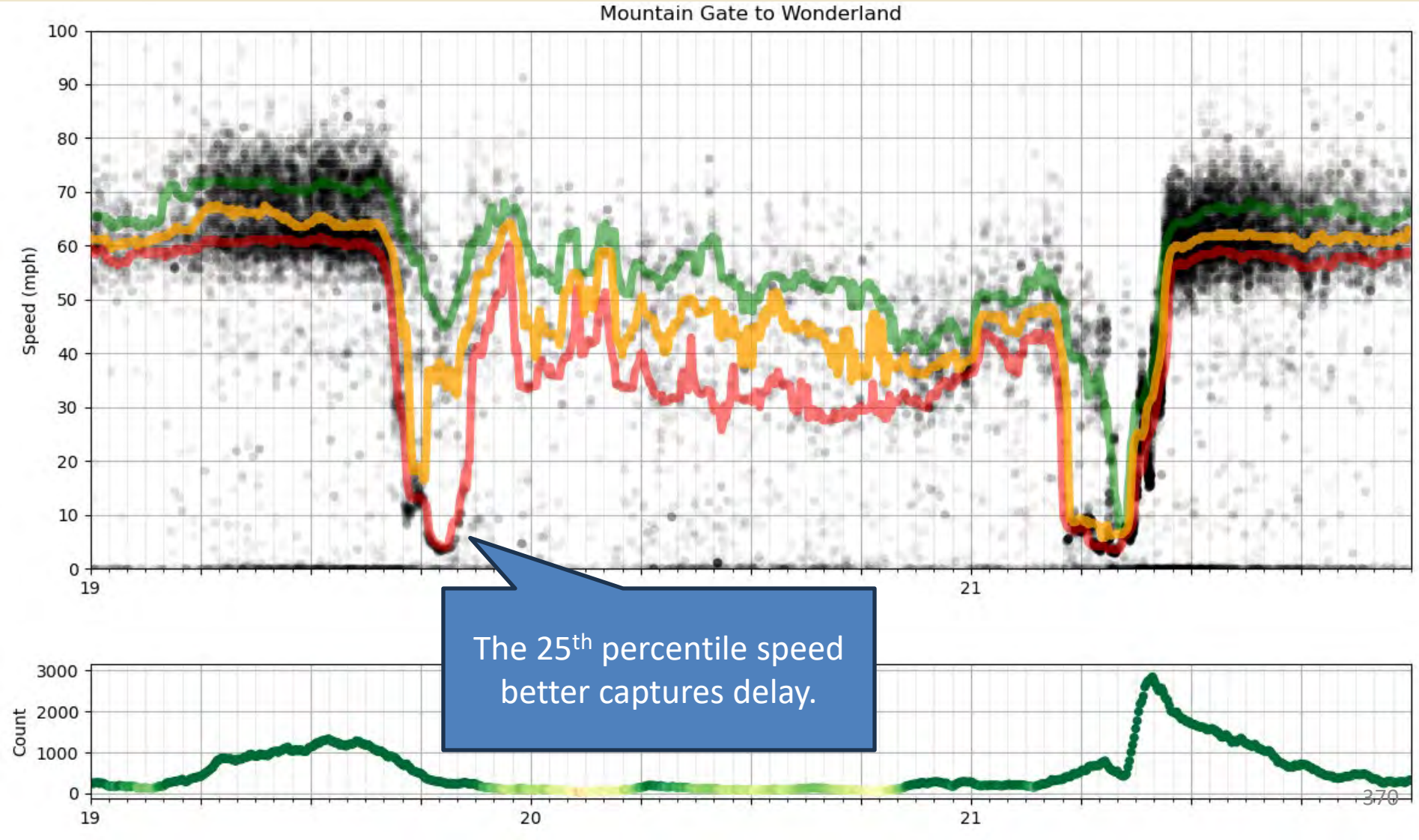
Represent Ground Truth with a Single Aggregate



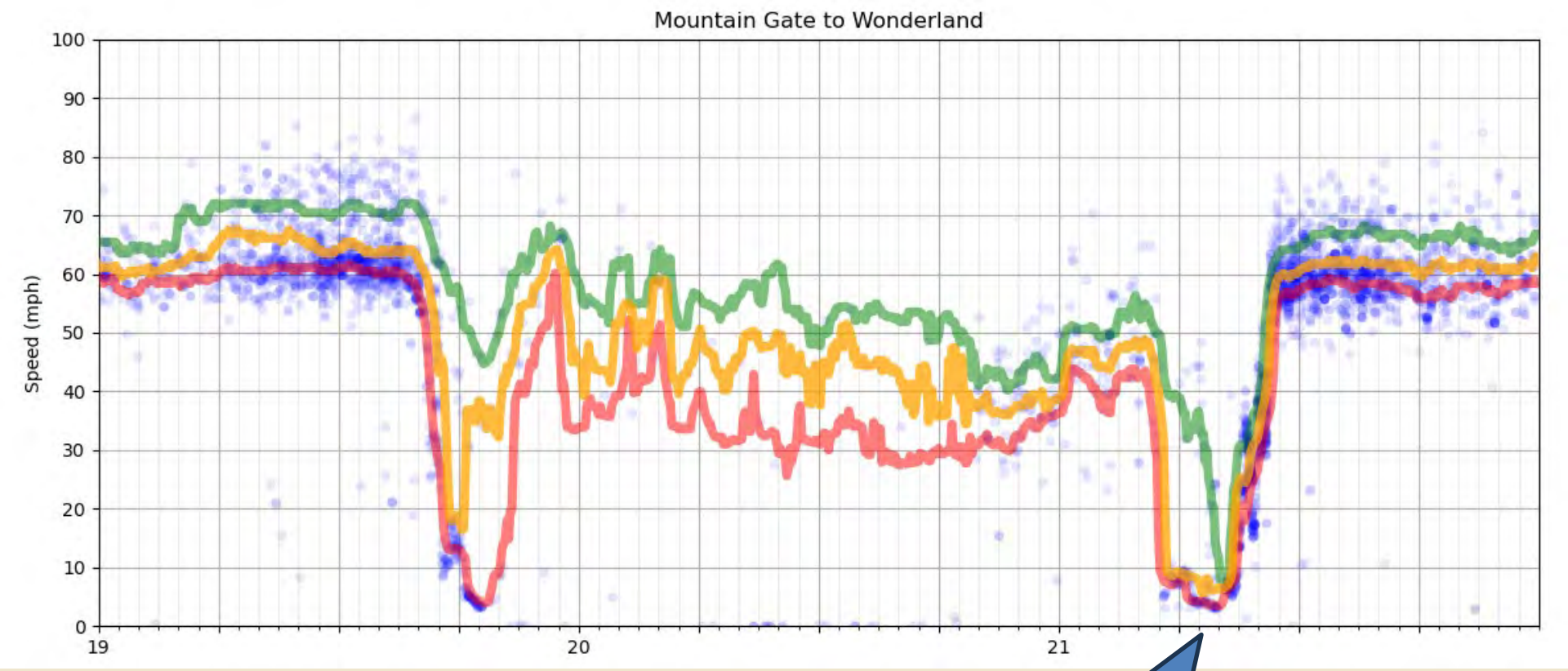
Represent Ground Truth with a Single Aggregate



Represent Ground Truth with a Single Aggregate



Represent Ground Truth with a Single Aggregate



The 25th percentile speed better captures delay.

Represent Ground Truth with a Single Aggregate

The 25th Percentile speed appears to better represent the Ground Truth data we are interested in, but high variability still makes it less than ideal.

This is relative to the cutoff of speeds less than 2 mph. Other cutoff values can change this.

We are experimenting other approaches to address these problems, including the challenge of selecting and using a cutoff for low speeds. We are still working on this, so it is not presented here.

Part 8: Here.com Data

How does 3rd-party data compare?

If 3rd-party paid data accurately reflects ground truth, then it could be used for our application and could make deployment elsewhere easier.

Does it reflect ground truth? How would we know without our sensor data?

How does 3rd-party data compare?

Previously, we were collecting Here.com speed data every 15 minutes. This resolution isn't ideal, but it kept us under the pay threshold. Subsequently we bumped the frequency up to every 5 minutes when forced to use a pay as you go plan.

The 15-minute frequency Here.com data provided us with a basis for comparison now that we have what we consider to be ground truth.

Here Traffic API v7

The HERE Traffic API is a REST API that provides real-time traffic flow and incident information.

…

The HERE Traffic API supports the following use cases:

- *Provides access to real-time traffic flow data in JSON, including information on speed and jam factor for the region(s) defined in each request. The HERE Traffic API can also deliver additional data such as the geometry of the road segments in relation to the flow.*
- *Provides aggregated information about traffic incidents in JSON, including the type and location of each traffic incident, status, start and end time, and other relevant data. This data is useful to dynamically optimize route calculations.*

https://docs.here.com/traffic-api/docs/introduction-to-here-traffic-api-v7

Here Traffic API v7 - Flow

Flow data provides information about how traffic is moving along specific roadways. For each segment of the road network that is covered, flow provides speed values, along with additional information characterizing the traffic conditions.

https://docs.here.com/traffic-api/docs/flow

Here Traffic API v7 – Flow - Speeds

A current flow object contains 3 speed values:

- ***freeFlow*** *- the reference speed (in meters per second) along the roadway when no traffic is present.*
- ***speed*** *- the expected speed (in meters per second) along the roadway; will not exceed the legal speed limit.*
- ***speedUncapped*** *- the expected speed (in meters per second) along the roadway; may exceed the legal speed limit.*

https://docs.here.com/traffic-api/docs/flow

Here Traffic API v7 – Flow - Jam factor

*The **jamFactor** field provides a value for the amount of traffic on the roadway. The value, between 0.0 and 10.0, indicate the expected quality of travel.*

A value of 0.0 indicates that there is no congestion on the roadway. As the value approaches 10.0, it indicates increasing congestion. A value of 10.0 is reserved to represent a blocked roadway (closure).

https://docs.here.com/traffic-api/docs/flow

Here Traffic API v7 – Flow - Traversability

*The **traversability** describes whether the roadway can be driven.*

This parameter can take one of three values:

- ***open** - the roadway is open and can be driven upon.*
- ***closed** - the roadway is closed (blocked) and cannot be driven (jamFactor is 10.0) upon.*
- ***reversibleNotRoutable** - the roadway is reversible but is currently not routable. See below for more information.*

https://docs.here.com/traffic-api/docs/flow

Here Traffic API v7 – Flow - Confidence

*The value of the **confidence** field indicates the proportion of real time data included in the speed calculation. It is a normalized value between 0.0 and 1.0 with the following meaning:*

- *0.7 < **confidence** <= 1.0 indicates real time speeds*
- *0.5 < **confidence** <= 0.7 indicates historical speeds*
- *0.0 < **confidence** <= 0.5 indicates speed limit*

https://docs.here.com/traffic-api/docs/flow

Here Traffic API v7 – Flow - Confidence

This field can be used to identify whether the data for a location is derived from real time probe sources or historical information only. All confidence data 0.71 and above is based on real-time information, where a confidence value of 0.75 or greater indicates high confidence real-time information. A confidence value equal to 0.70 means that the data is derived from historical data only.

https://docs.here.com/traffic-api/docs/flow

Here Traffic API v7 – Location Referencing

Within the HERE Traffic API, location referencing focuses on locations that describe roadways.

…

Traffic Message Channel (TMC) location referencing method uses tables of pre-coded locations. For details refer the specifications ISO 14819-2:2013 and ISO 14819-3:2013.

https://docs.here.com/traffic-api/docs/location-referencing-here-traffic-api-v7-concepts

Here.com Data

There are 14 Northbound Here.com segments overlapping the 11 segments determined by our sensor locations.

The overlap is close but not exact.

It is close enough for us to make comparisons.






Pit River Bridge
Fawndale
Wonderland
Mountain Gate
Pine Grove
I5-SR273
I5-SR299
I5-SR44
Hartnell
South Bonnyview
Knighton
Riverside

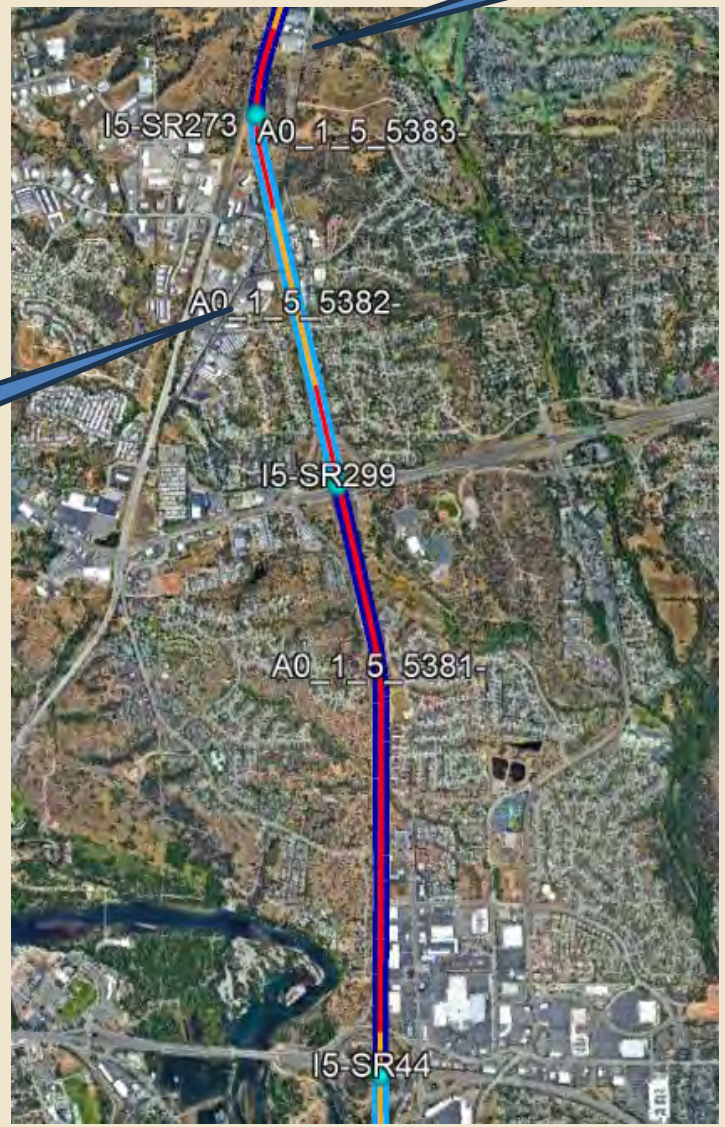



A0_1_5_5390-
A0_1_5_5389-
A0_1_5_5388-
A0_1_5_5387-
A0_1_5_5386-
A0_1_5_5385-
A0_1_5_5384-
A0_1_5_5383-
A0_1_5_5382-
A0_1_5_5381-
A0_1_5_5380-
A0_1_5_5379-
A0_1_5_5378-
A0_1_5_5377-

Here.com Data versus Ground Truth Data

Here: A0_1_5_5383- (CA-273/Exit 681)

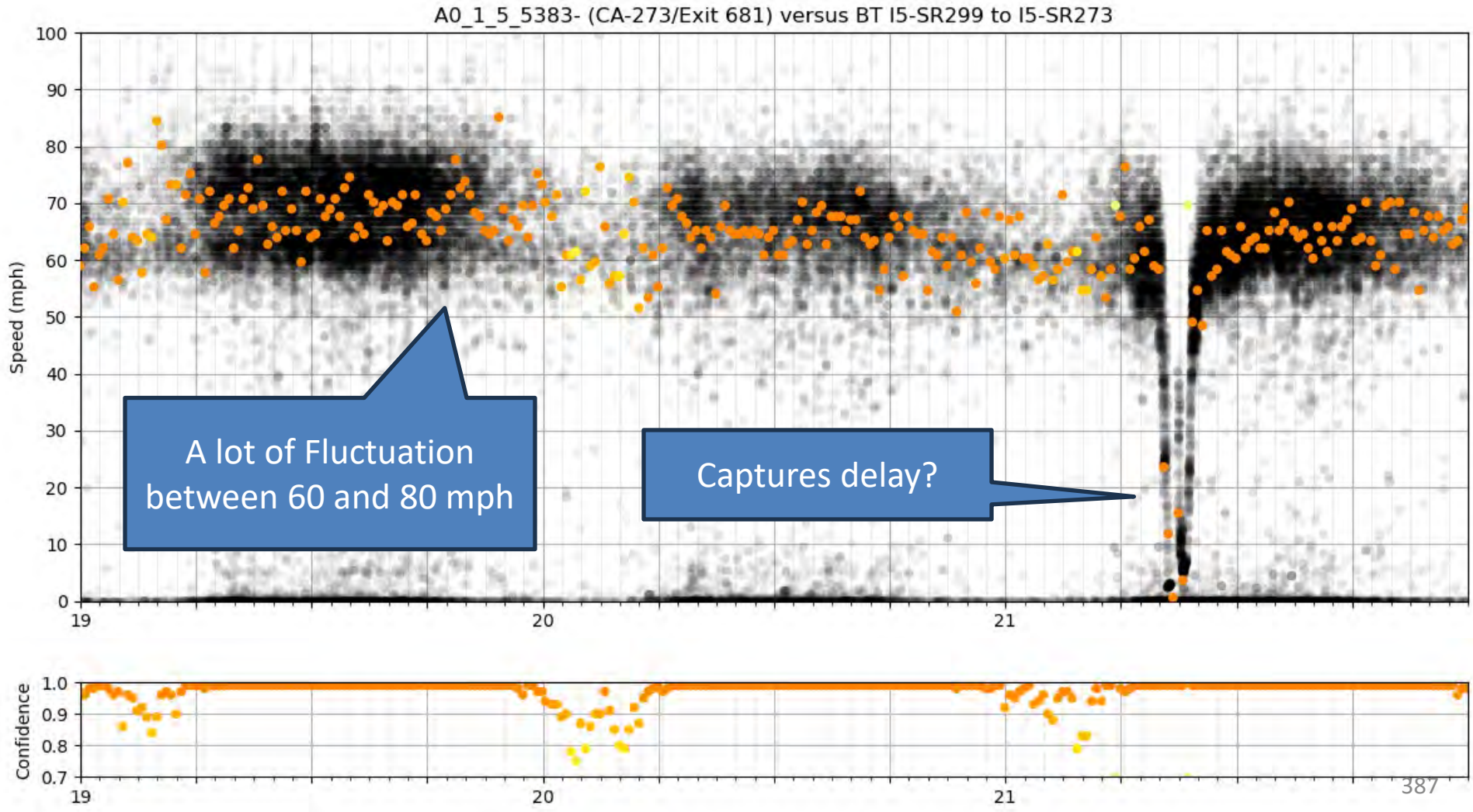
Bluetooth: I5-SR299 to I5-SR273



Here.com Data versus Ground Truth Data

Here: A0_1_5_5383- (CA-273/Exit 681)

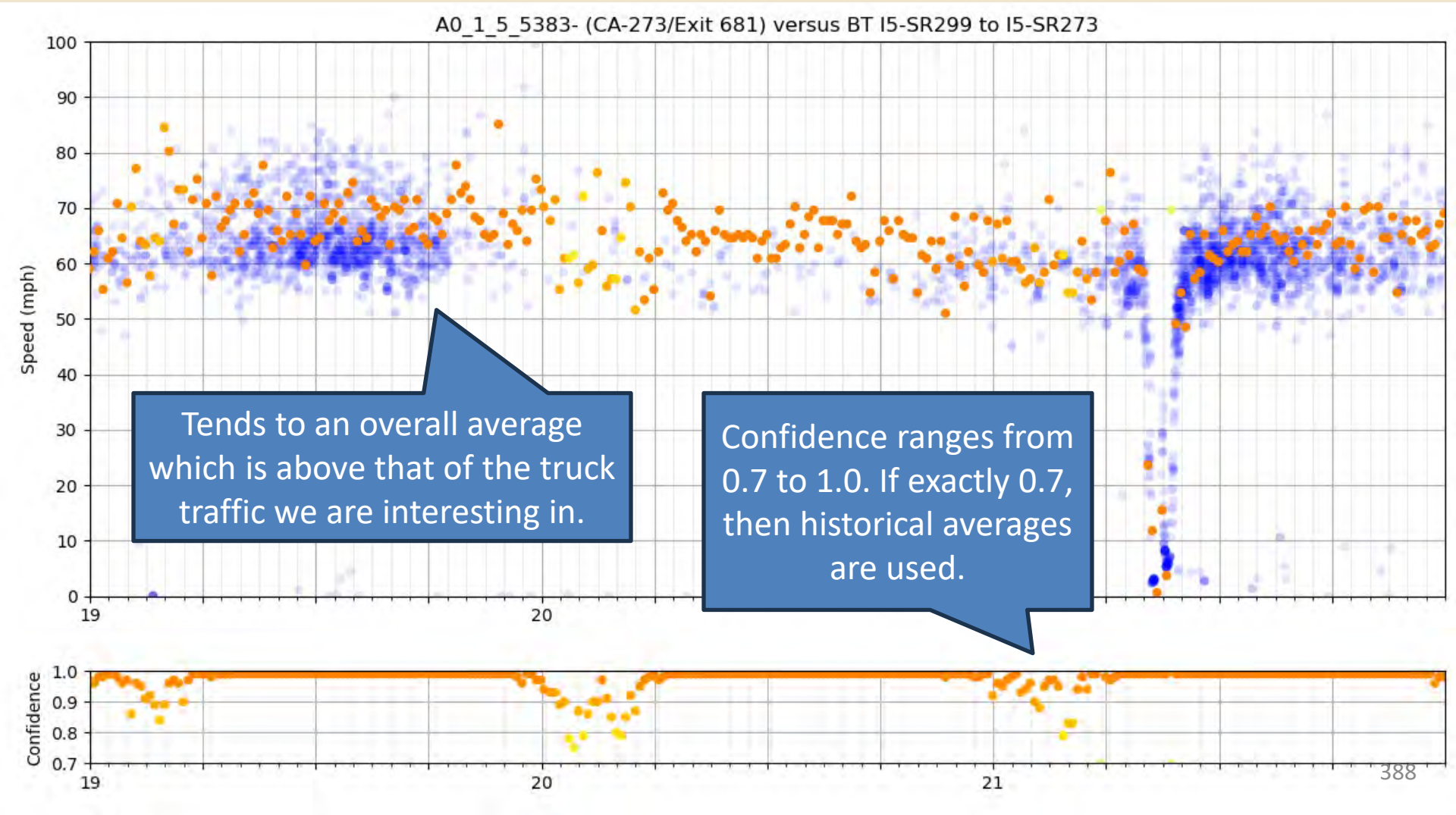
Bluetooth: I5-SR299 to I5-SR273



Here.com Data versus Ground Truth Data

Here: A0_1_5_5383- (CA-273/Exit 681)

Bluetooth: I5-SR299 to I5-SR273



Here.com Data versus Ground Truth Data

Here: A0_1_5_5387- (Old Oregon Trl/Exit 687)

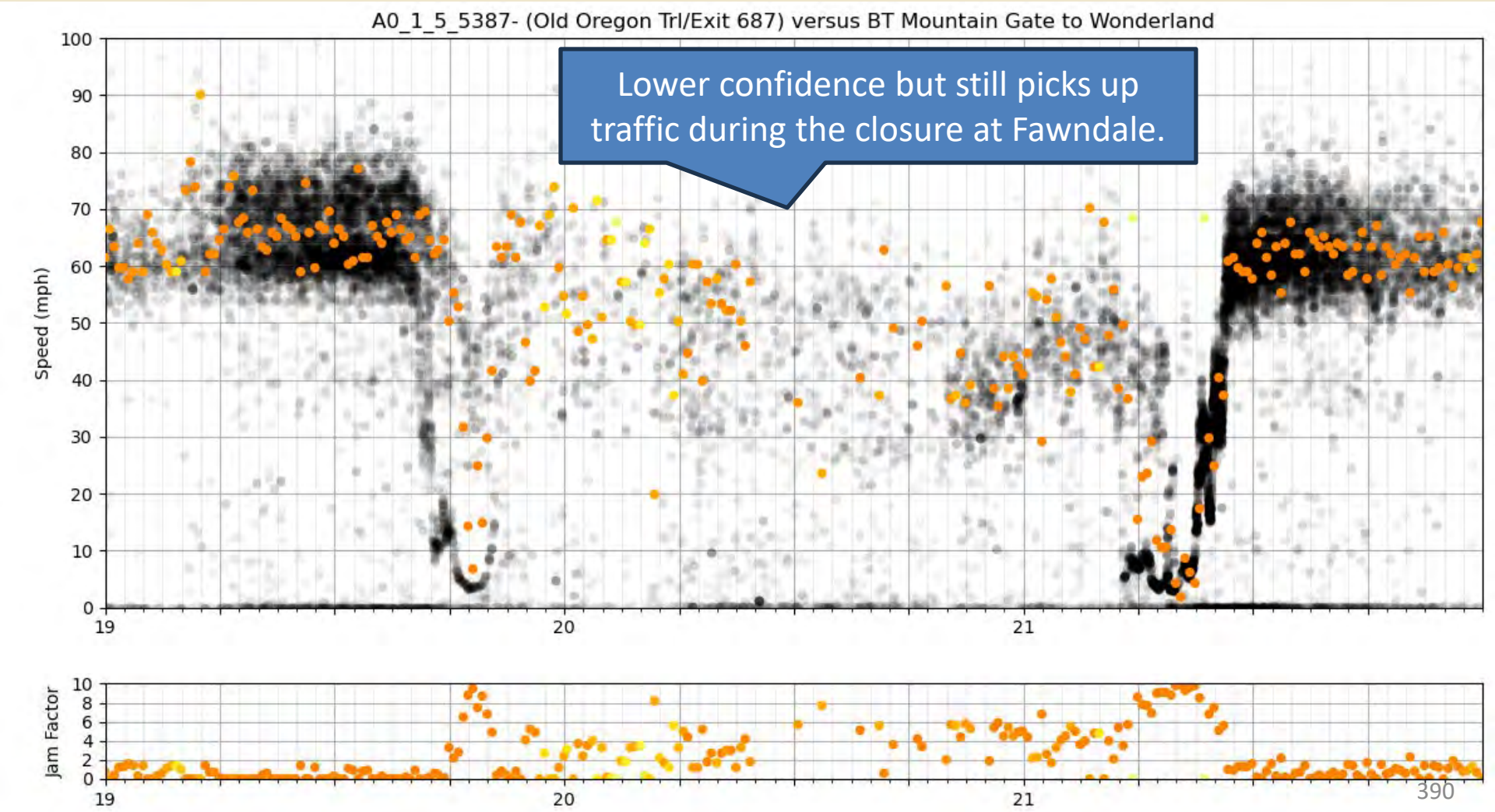
Bluetooth: Mountain Gate to Wonderland



Here.com Data versus Ground Truth Data

Here: A0_1_5_5387- (Old Oregon Trl/Exit 687)

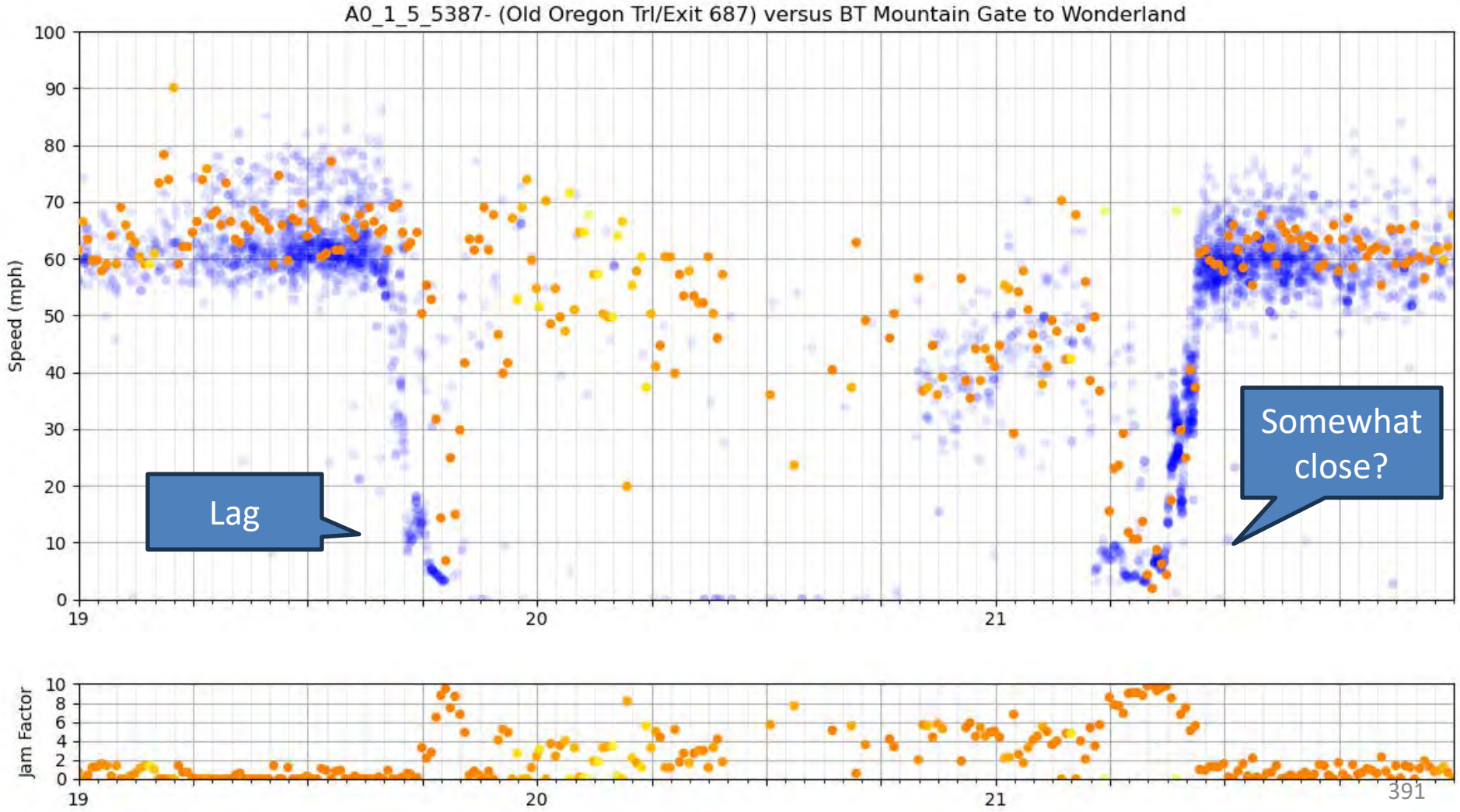
Bluetooth: Mountain Gate to Wonderland



Here.com Data versus Ground Truth Data

Here: A0_1_5_5387- (Old Oregon Trl/Exit 687)

Bluetooth: Mountain Gate to Wonderland

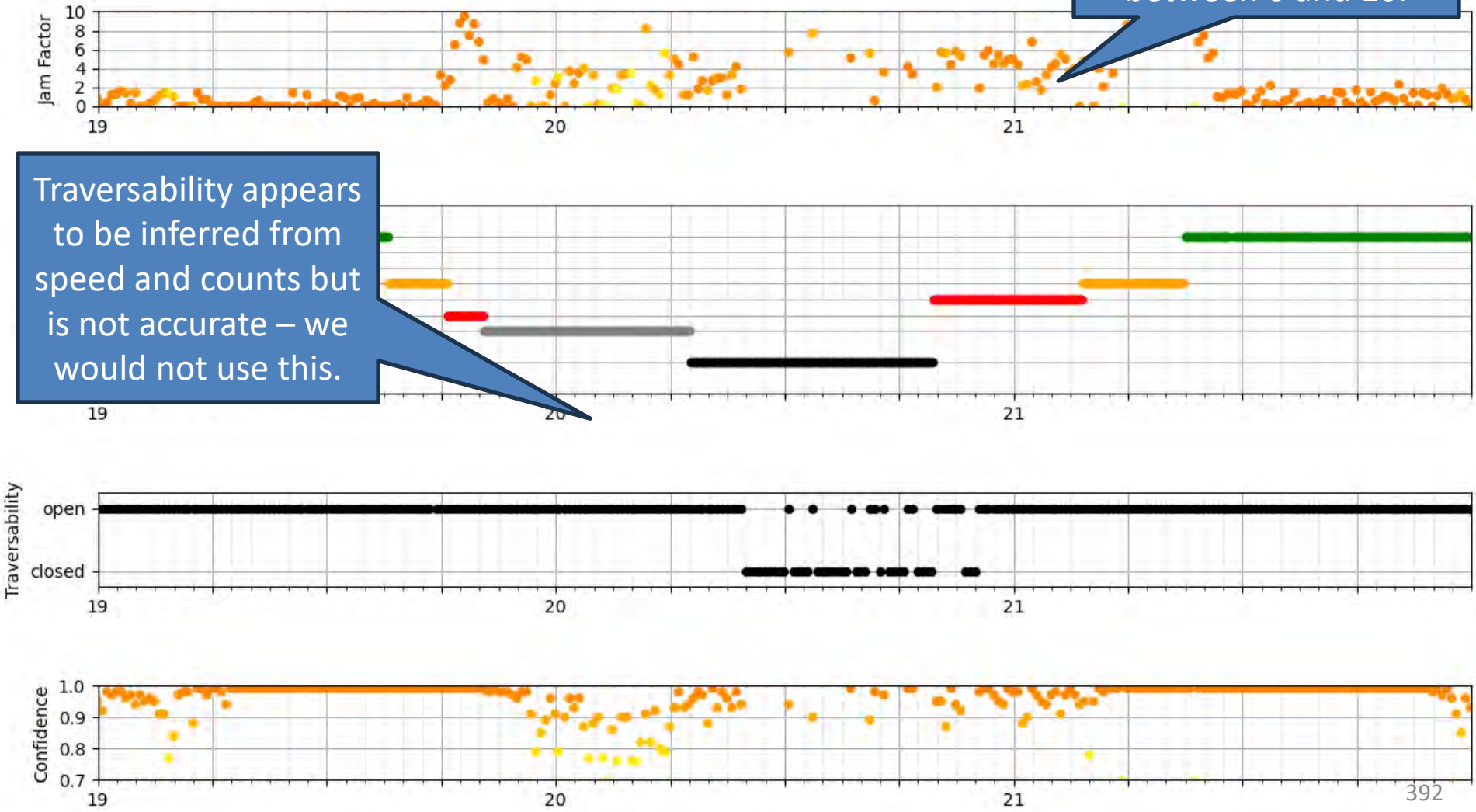


Here.com Data versus Ground Truth Data

Here: A0_1_5_5387- (Old Oregon Trl/Exit 687)
Bluetooth: Mountain Gate to Wonderland

Jam Factor correlates inversely to Speed, placing it on a scale between 0 and 10.

Traversability appears to be inferred from speed and counts but is not accurate – we would not use this.



Here.com Data Summary

There is a lot of fluctuation during normal travel, including times when their confidence is reported as high.

During normal travel, values tend to be higher than the truck traffic we are most interested in. This makes sense for southern sites that are dominated by commuter traffic. We still see a bias to higher speeds in the northern sites.

Lag of up to two hours is apparent during delay.

Confidence is low at night.

Confidence is suspect during delay.

Part 9: Preliminary Algorithm(s)

Preliminary Algorithm(s)

We refer to the following as preliminary algorithms because they are a first attempt, meant for testing with historical data.

They are a first step towards a real-time algorithm that could be deployed and provide the opportunity to fine tune and identify further challenges.

Preliminary Algorithm(s)

Three Preliminary Algorithms:

- Destination-Based, Direct Point to Point Delay Estimation Algorithm using BT Data
- Destination-Based, Cumulative Delay Estimation Algorithm using BT Data
- Here.com Cumulative Delay Estimation Algorithm

Preliminary Algorithm(s)

We also plan to revisit an algorithm that mimics the real time process but did not have time to present that here. The algorithms using historical sensor data should reasonably approximate this.

Destination-Based, Direct Point to Point Delay Estimation Algorithm

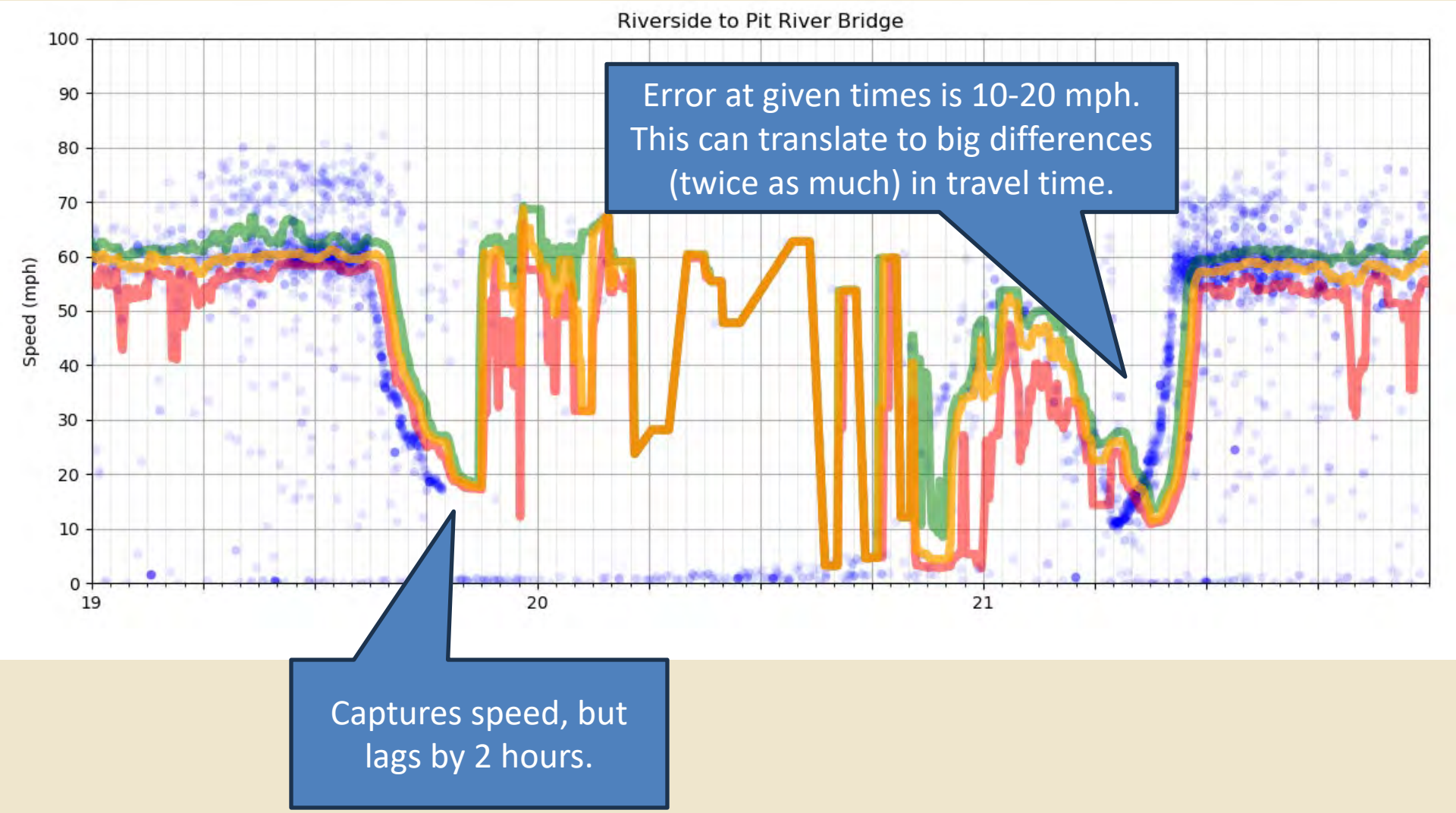
For this algorithm, travel times are computed directly based on arrival at the destination.

The travel time from A to B is determined directly based on arrival at destination B from origin A.

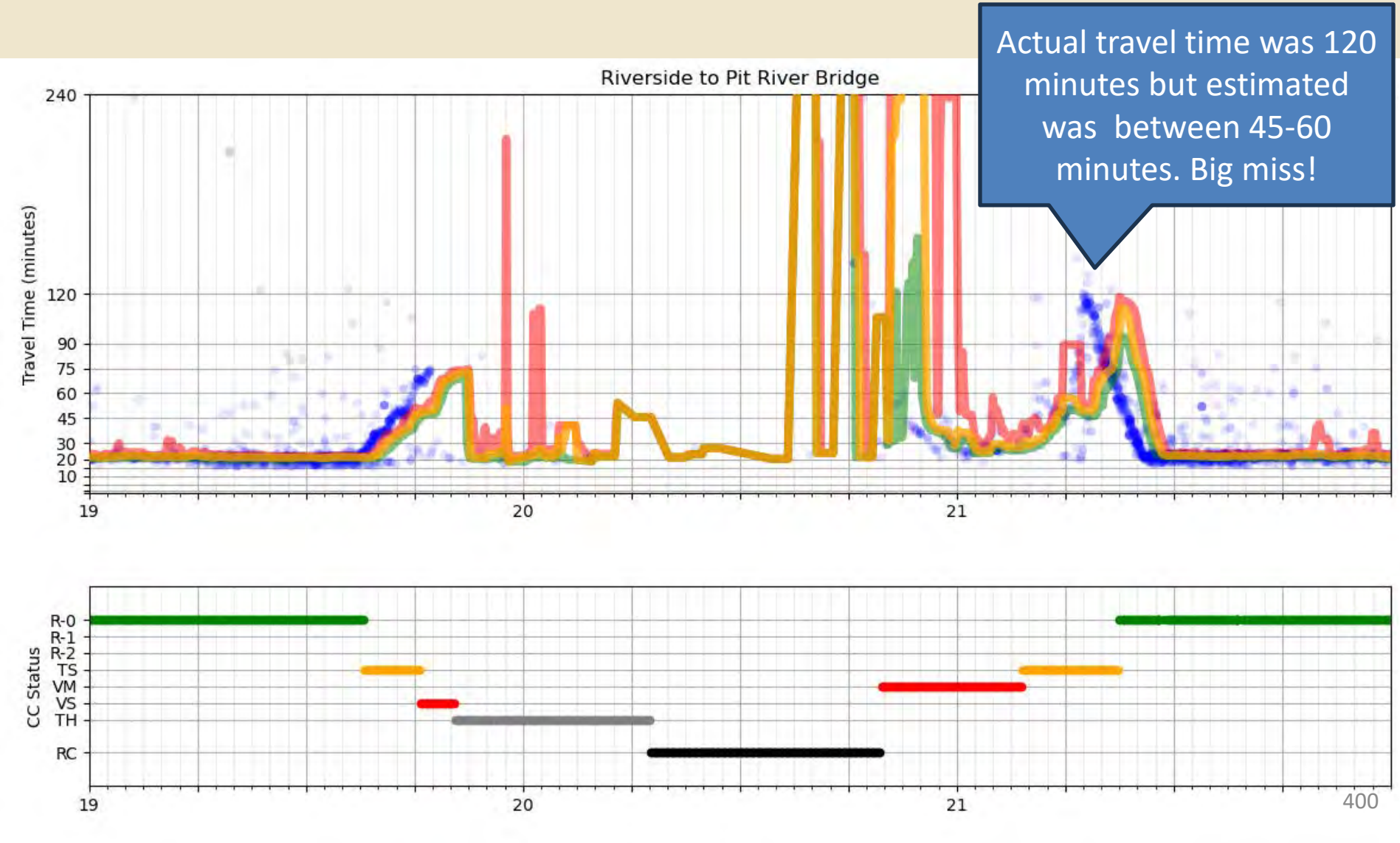
Individual travel times for devices are aggregated based on arrival at destination B within the prior 60 minutes.

The estimate of travel time from A to B is the current measured travel time from A to B.

Destination-Based, Direct Point to Point Delay Estimation Algorithm



Destination-Based, Direct Point to Point Delay Estimation Algorithm



Actual travel time was 120 minutes but estimated was between 45-60 minutes. Big miss!

Destination-Based, Direct Point to Point Delay Estimation Algorithm

Not surprisingly this approach yields travel times that lag behind ground truth.

We don't know the actual travel time from A to B until devices arrive at destination B.

If travel from A to B experiences delay, then arrival at destination B is delayed.

Destination-Based, Cumulative Delay Estimation Algorithm

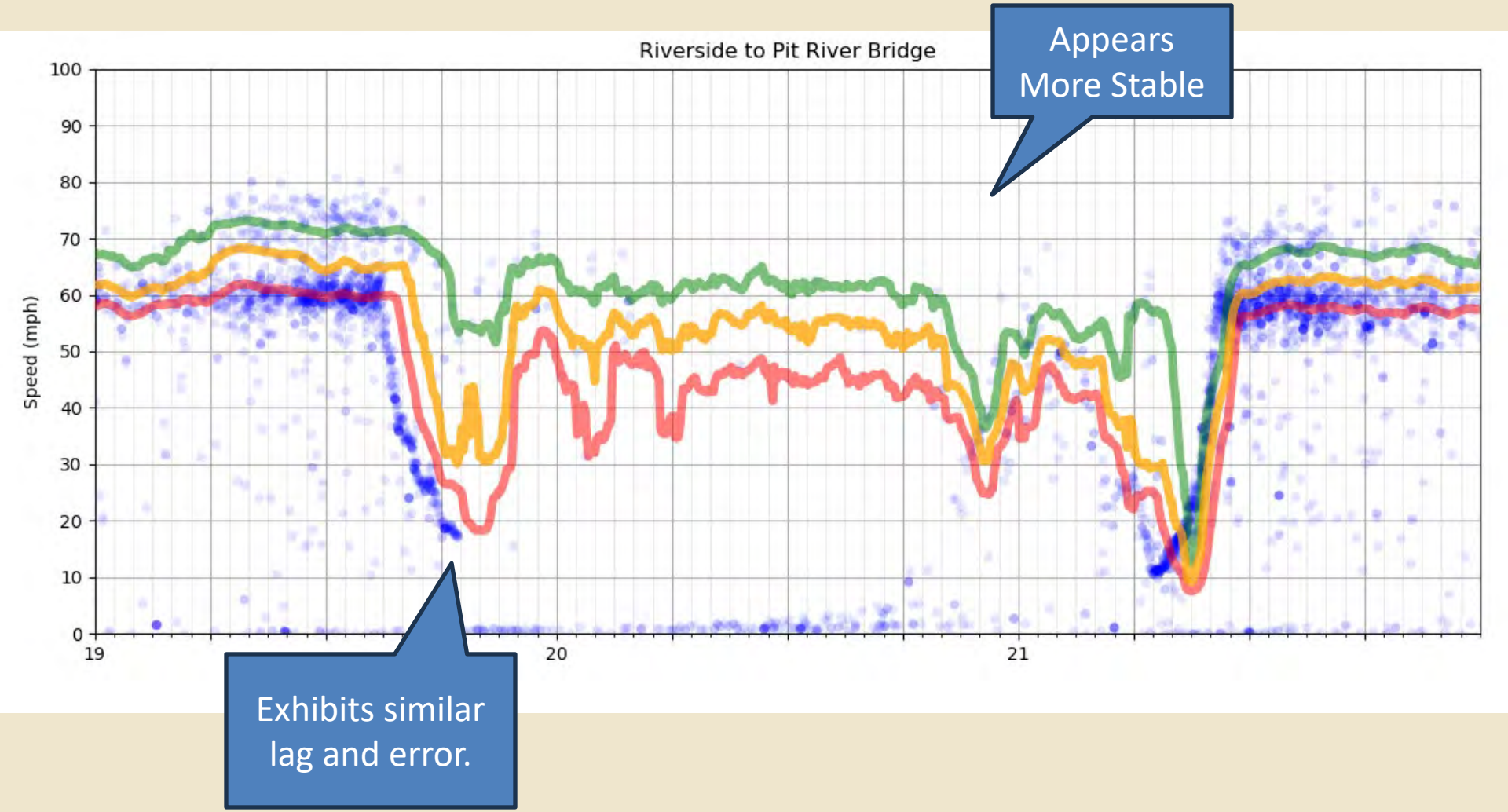
For this algorithm, travel times are computed based on the sum of travel times for the (shorter) segments between the origin and destination.

The travel time from A to B is determined by summing the travel times for the segments between destination B from origin A.

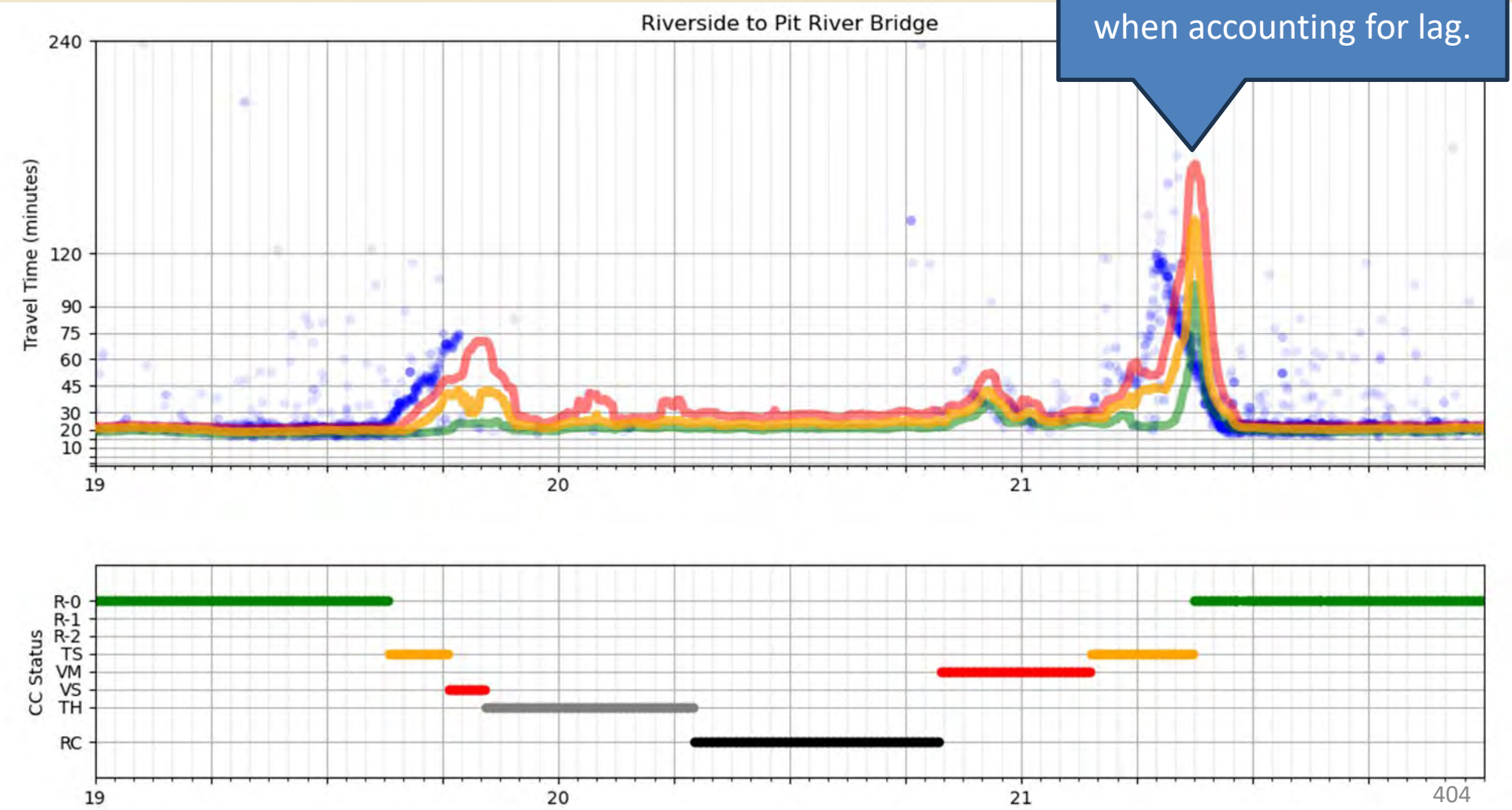
Individual travel times for devices are aggregated based on arrivals within prior 60 minutes.

The estimate of travel time from A to B is the sum of the current measured travel times on all segments from A to B.

Destination-Based, Cumulative Delay Estimation Algorithm



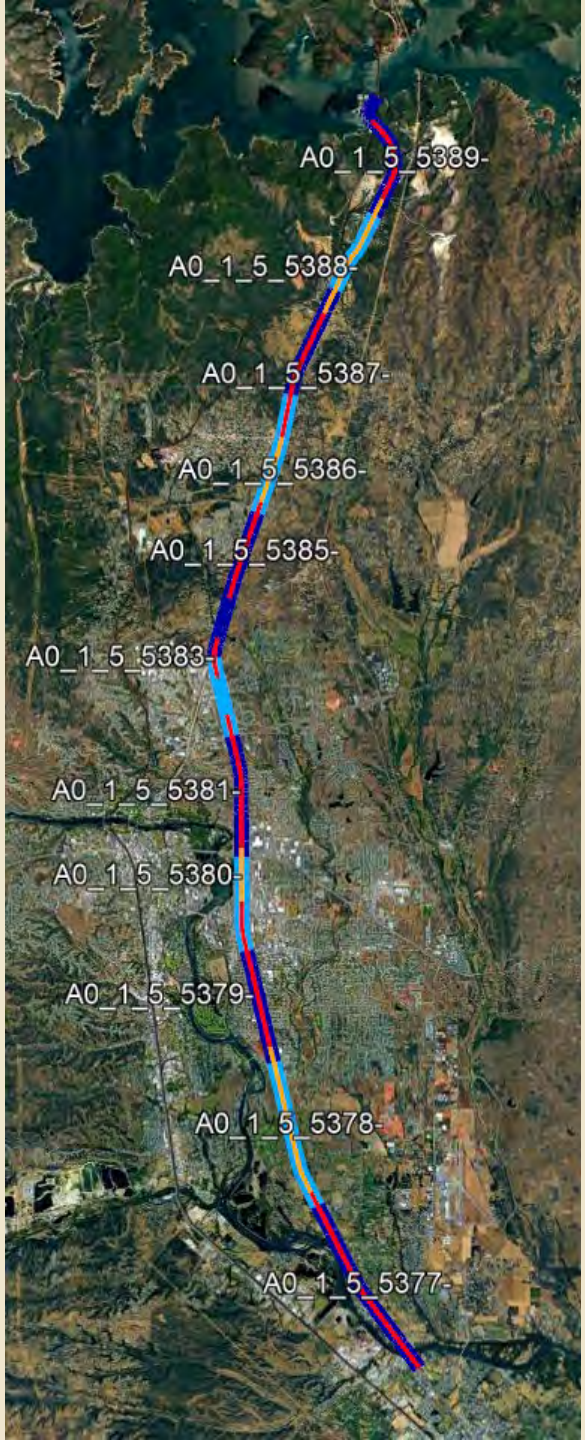
Destination-Based, Cumulative Delay Estimation Algorithm



Here.com Cumulative Delay Estimation Algorithm

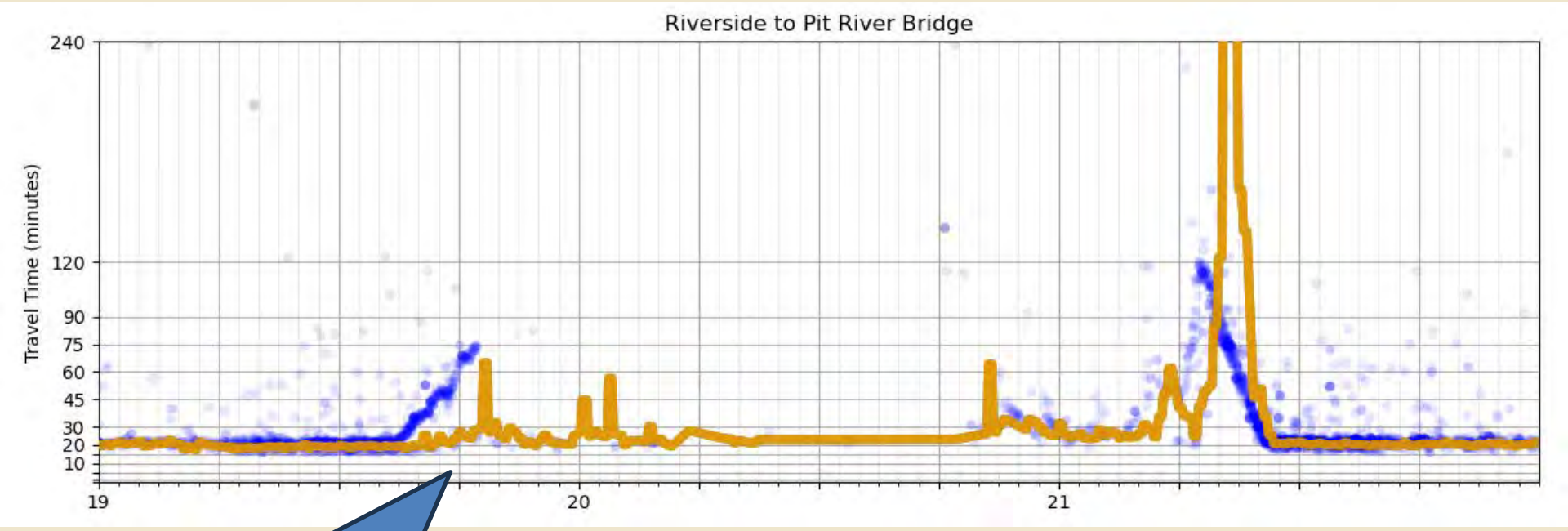
For comparison and a preliminary algorithm, we matched one Here.com segment with each study segment. We tried to pick the best match.

We used Here.com speeds to compute travel times for the study segments. We then added travel times for individual segments to get overall travel times.



Here.com Cumulative Delay Estimation Algorithm

Lags and over-estimates travel time.



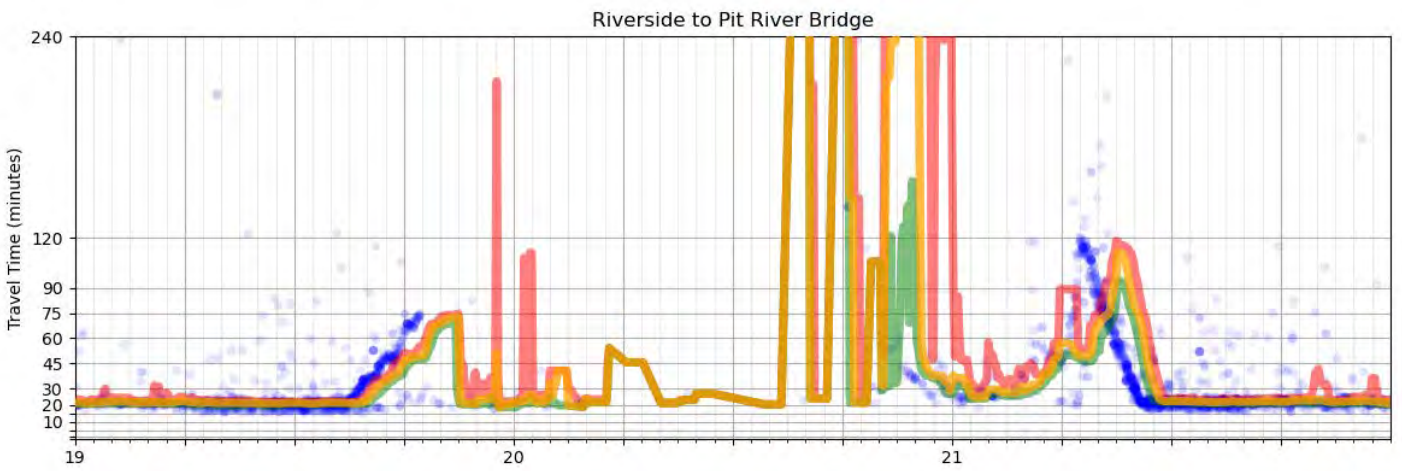
Lags and under-estimates travel time.

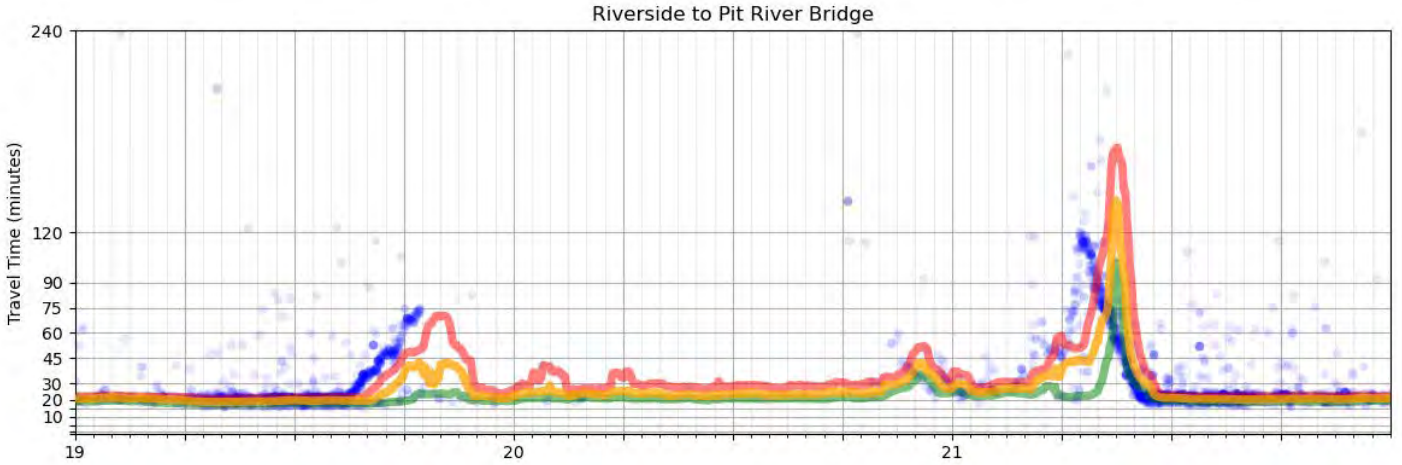
Algorithm Comparison

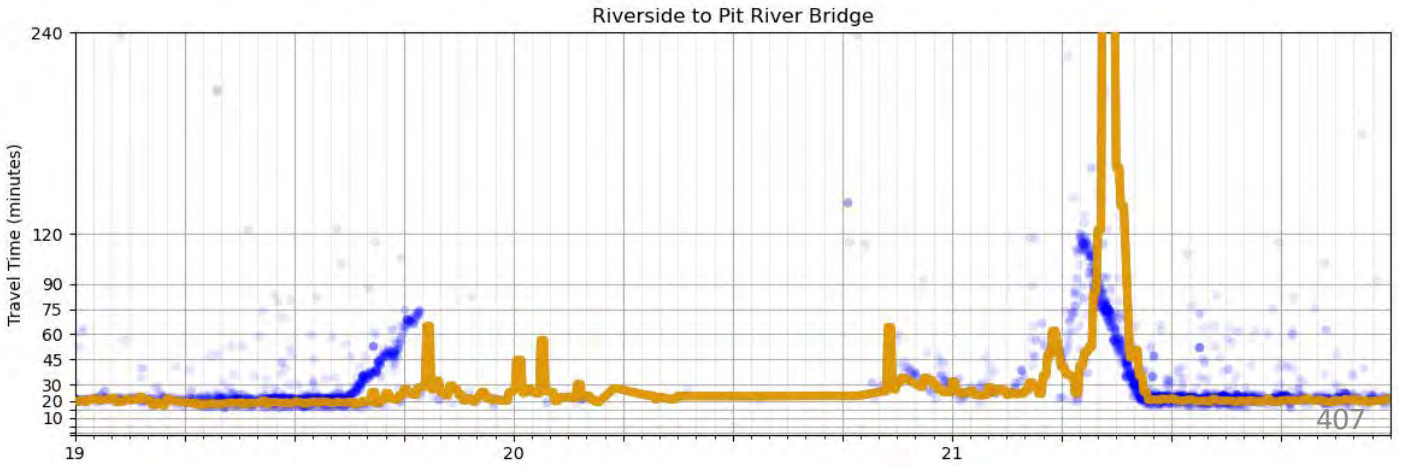
BT Direct

BT Cumulative

Here.com Cumulative







Preliminary Algorithm Summary

None of the preliminary algorithms are perfect – they not ready for deployment.

Lag is an issue with all of them.

The BT Cumulative approach appears to be the best of the three, but more work needs to be done, particularly to address lag.

Finer resolution on the Here.com data might help.

This comparison is for one event, and that event was used for "tuning". We need to look at a separate event for testing.

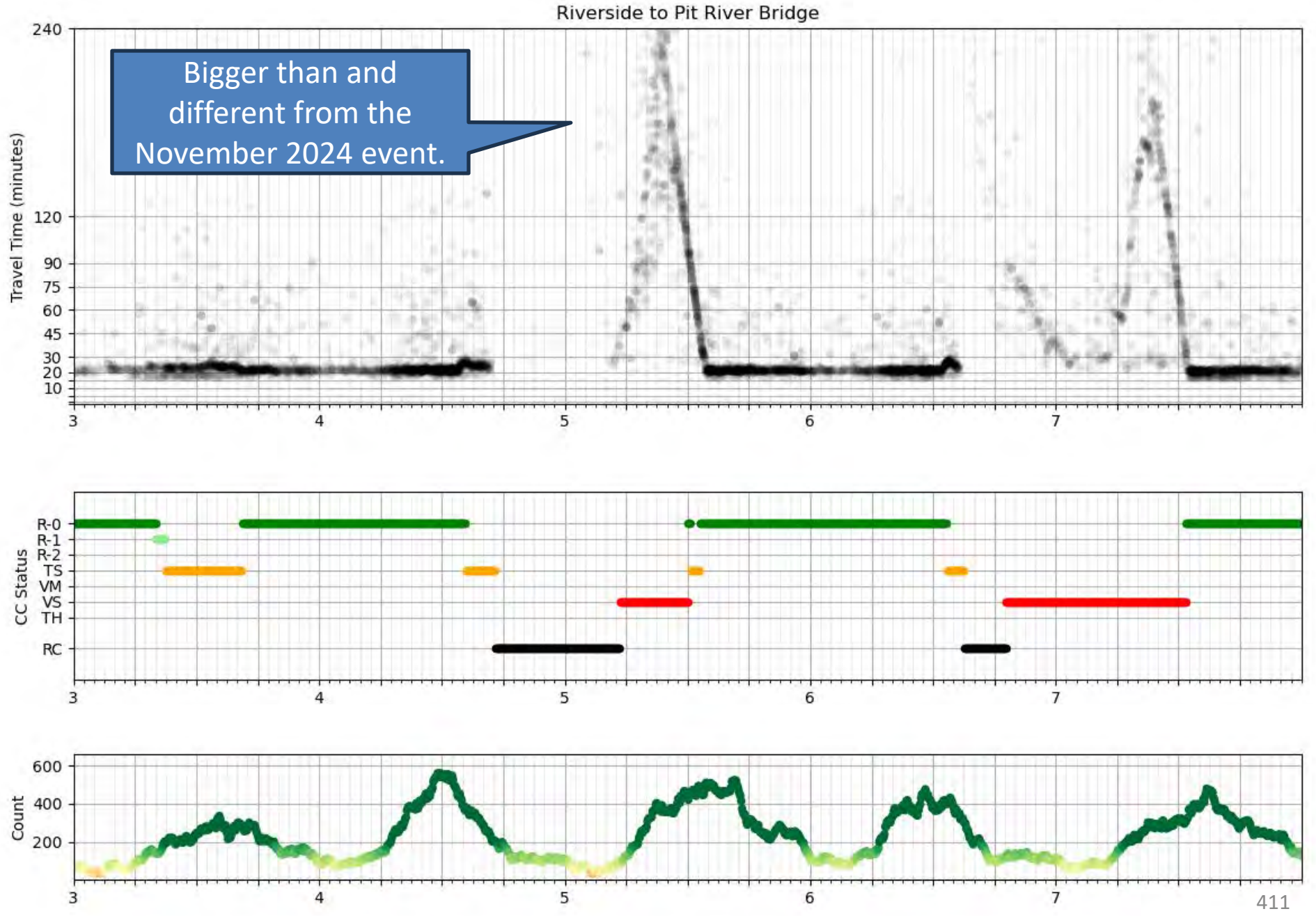
Part 10: Testing

Testing Against February 2025 Events

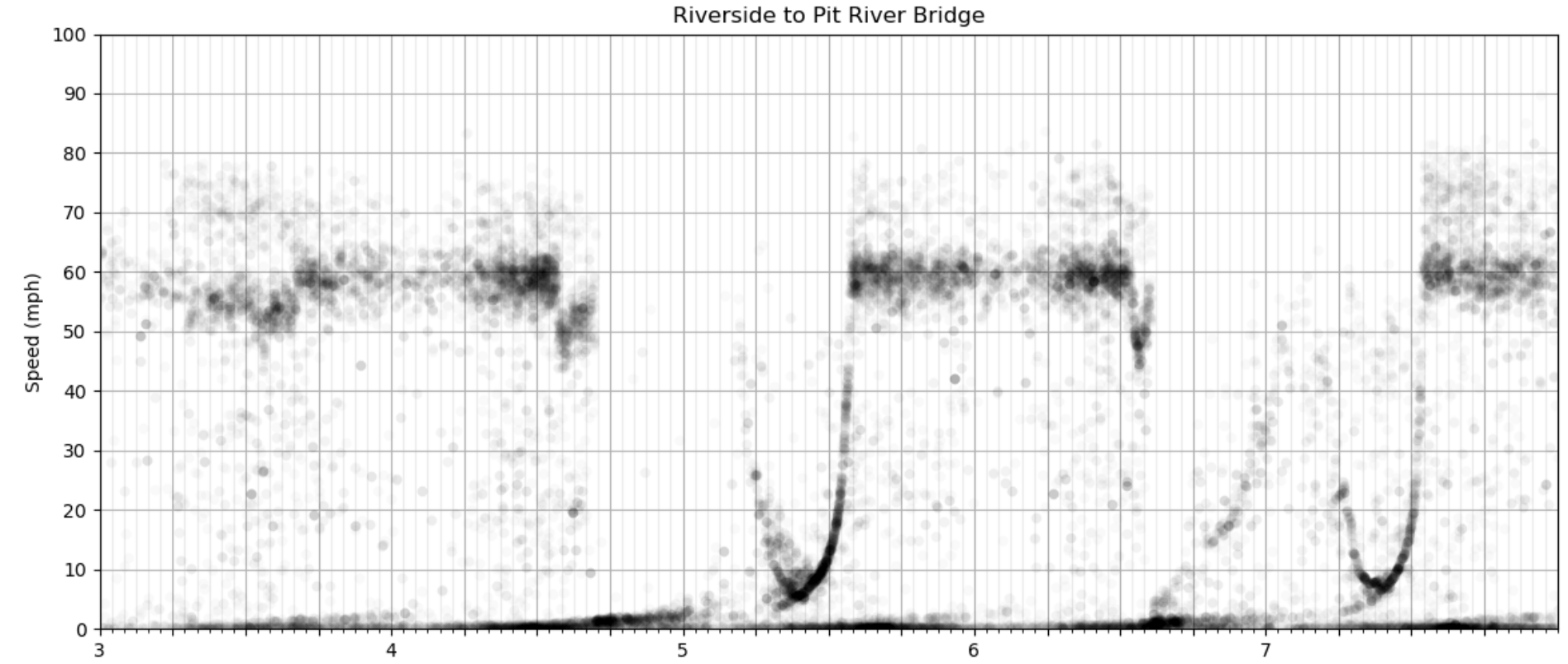
We tested our conclusions from November 2024 against February 2025 events. We held out the February data for this purpose.

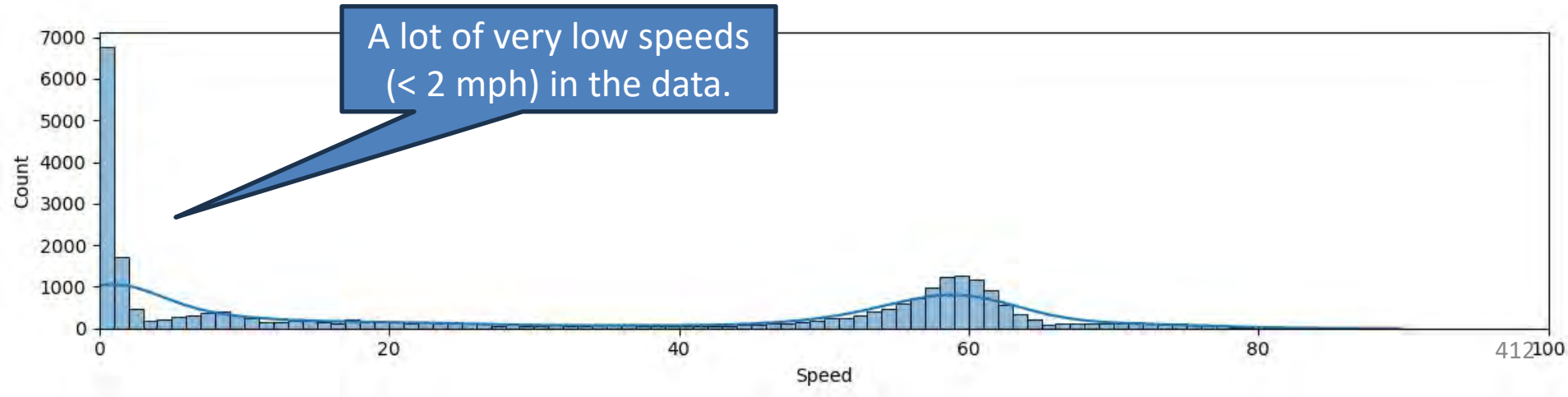
Multiple chain restrictions were in place between February 3rd and February 8th, 2025, including two closures. This provides an opportunity for testing.

February 2025 Events



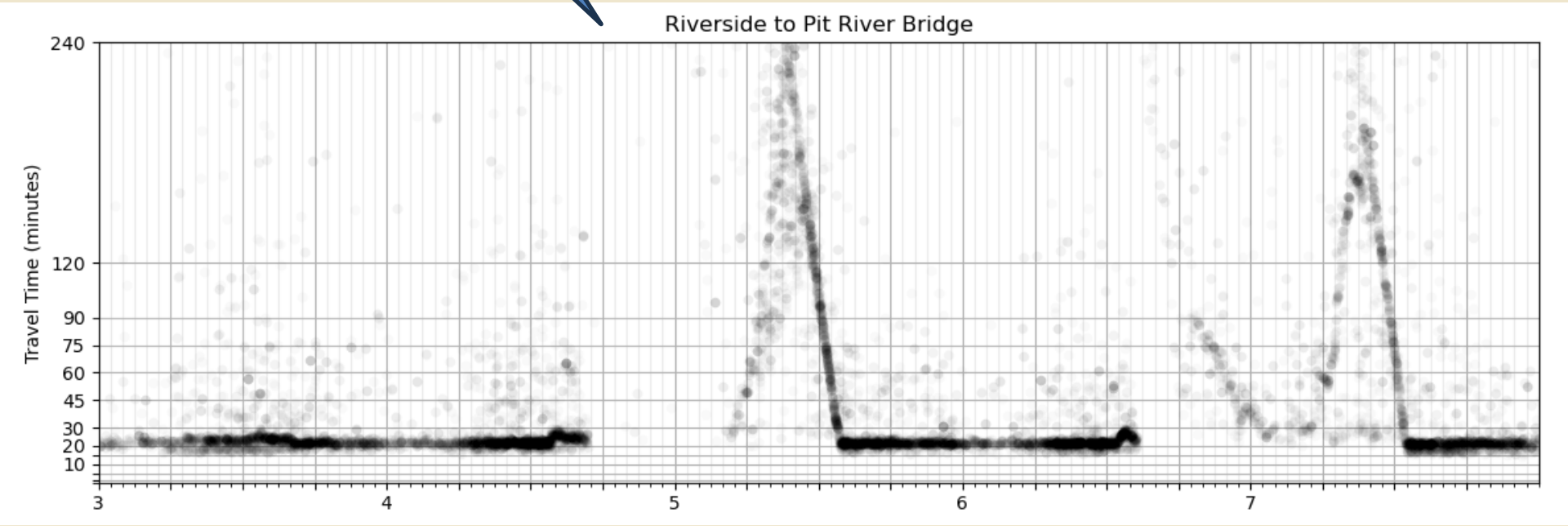
February 2025 Events





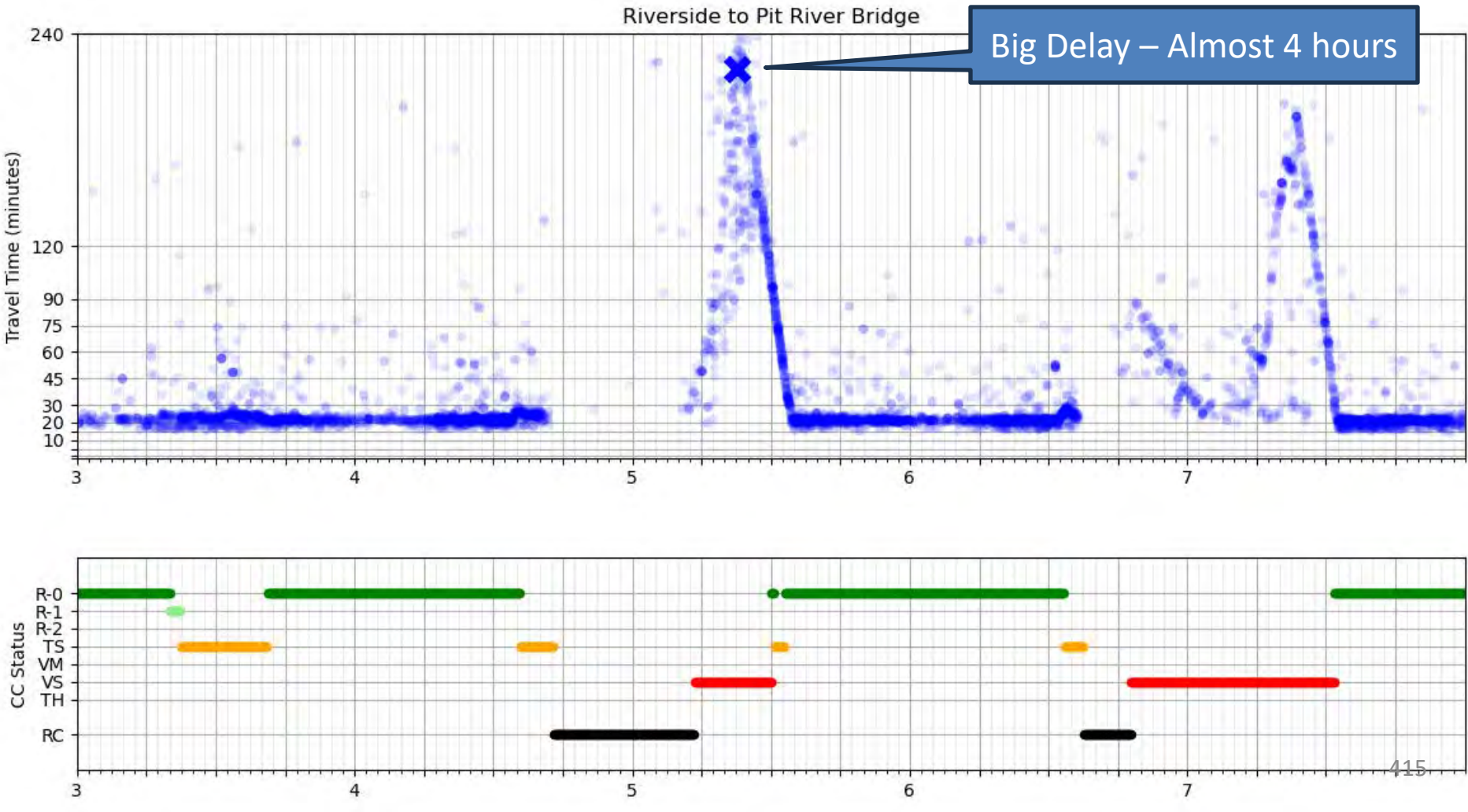
February 2025 Events

Is it real?



Track a Device : BTLECAPT 2c:41:a1:XX:XX:XX

Track Individual Device : BTLECAPT 2c:41:a1:XX:XX:XX



Track Individual Device : BTLECAPT 2c:41:a1:XX:XX:XX

Date	Time	Site	Speed	Travel Time
February 05, 2025	09:04:36 AM	Riverside	57 mph	3 min 9 sec
February 05, 2025	09:07:45 AM	Knighton Rd	58 mph	2 min 30 sec
February 05, 2025	09:10:15 AM	South Bonnyview	54 mph	2 min 0 sec
February 05, 2025	09:12:15 AM	Hartnell	59 mph	1 min 32 sec
February 05, 2025	09:13:47 AM	I5-SR44	54 mph	2 min 7 sec
February 05, 2025	09:15:54 AM	I5-SR299	57 mph	1 min 22 sec
February 05, 2025	09:17:16 AM	I5-SR273	56 mph	2 min 33 sec
February 05, 2025	09:19:49 AM	Pine Grove	**1 mph**	**101 min 25 sec**
February 05, 2025	11:01:14 AM	Mountain Gate	**2 mph**	**66 min 55 sec**
February 05, 2025	12:08:09 PM	Wonderland	**2 mph**	**31 min 44 sec**
February 05, 2025	12:39:53 PM	Fawndale	26 mph	4 min 51 sec
February 05, 2025	12:44:44 PM	Pit River Bridge	**TOTAL**	**220 min 8 sec**

1 mph and 2 mph

Big Delay between Pine Grove and Fawndale

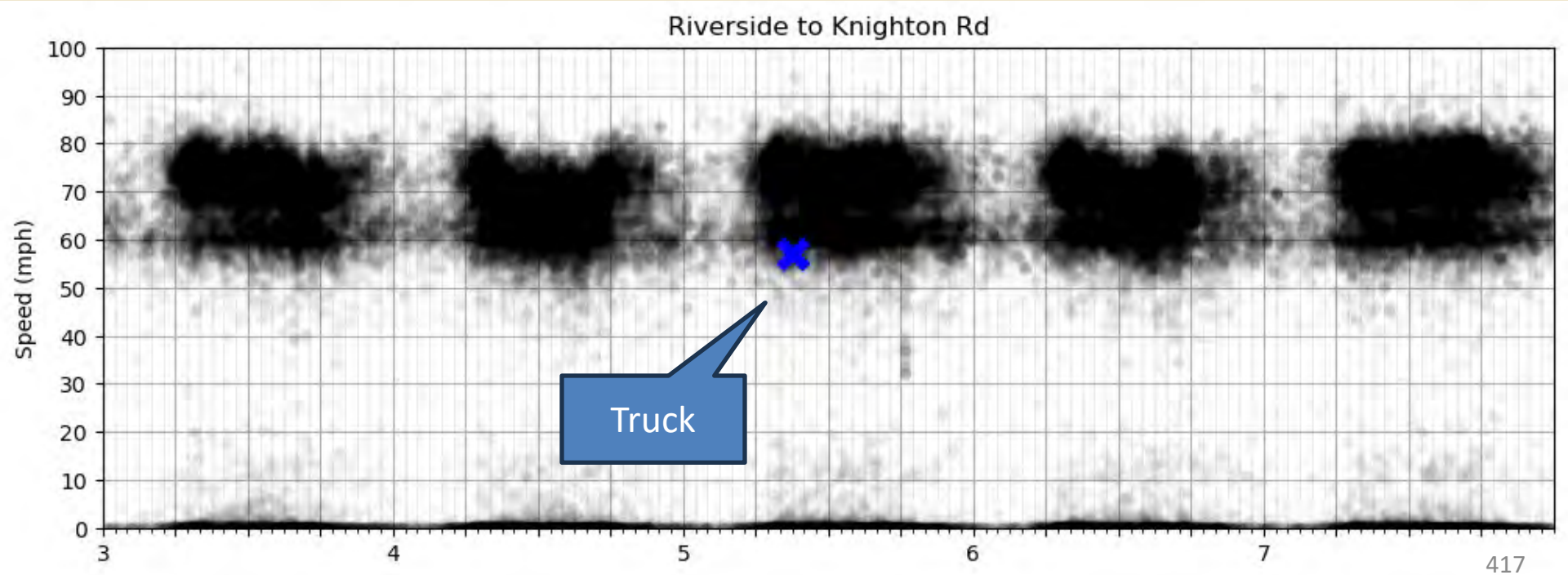


Riverside to Knighton Rd
Speed: 57 mph
Travel Time: 3 min 9 sec



Riverside
February 05, 2025
09:04:36 AM

Knighton Rd
February 05, 2025
09:07:45 AM



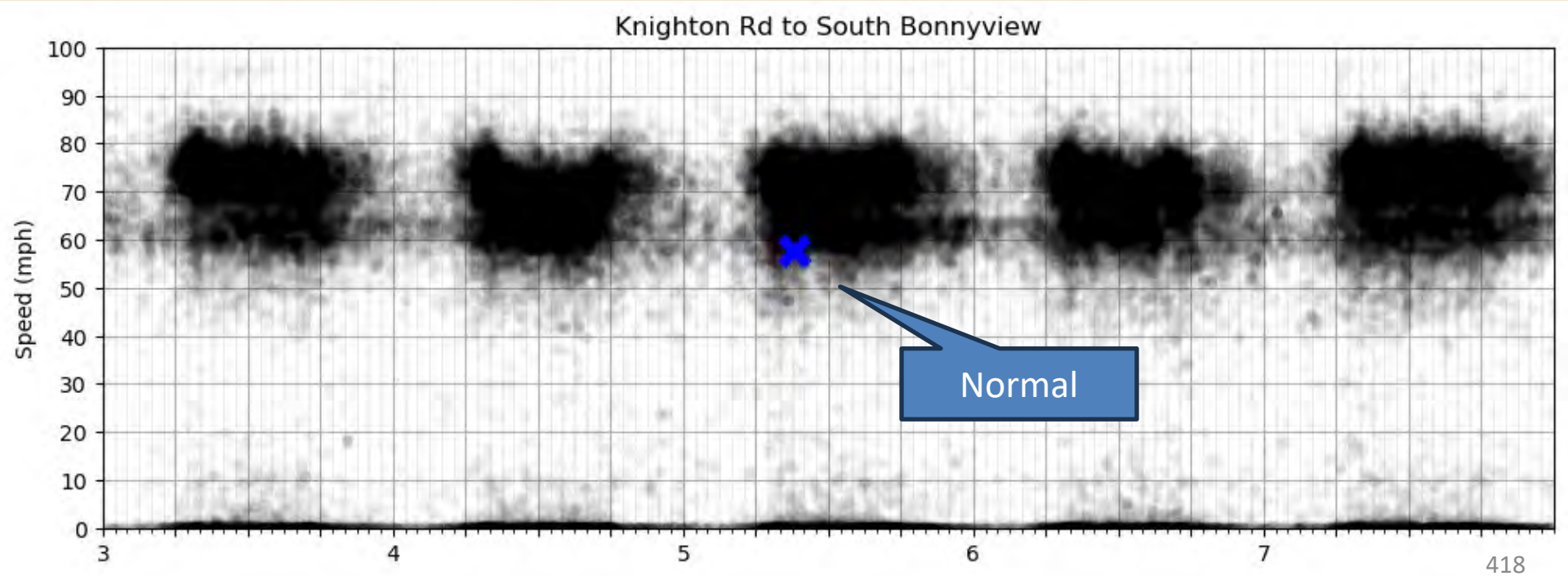


Knighton Rd to South Bonnyview
Speed: 58 mph
Travel Time: 2 min 30 sec



Knighton Rd
February 05, 2025
09:07:45 AM

South Bonnyview
February 05, 2025
09:10:15 AM



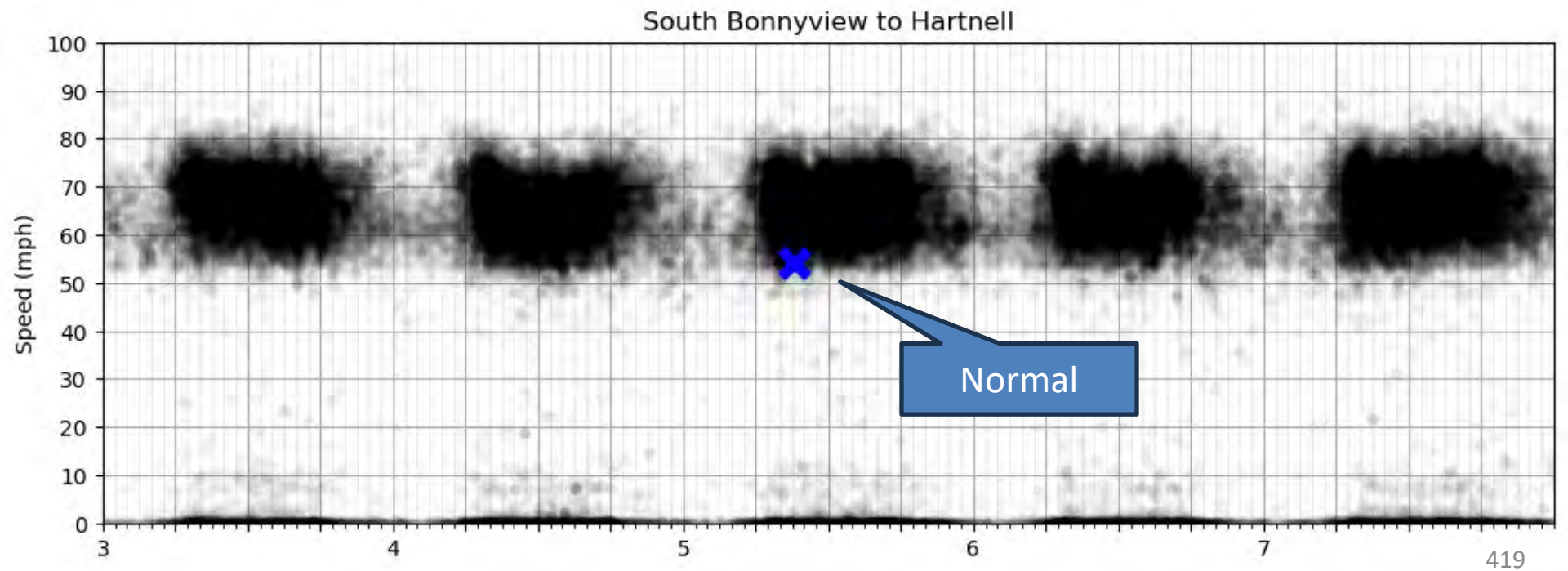
South Bonnyview to Hartnell
Speed: 54 mph
Travel Time: 2 min 0 sec



South Bonnyview
February 05, 2025
09:10:15 AM



Hartnell
February 05, 2025
09:12:15 AM



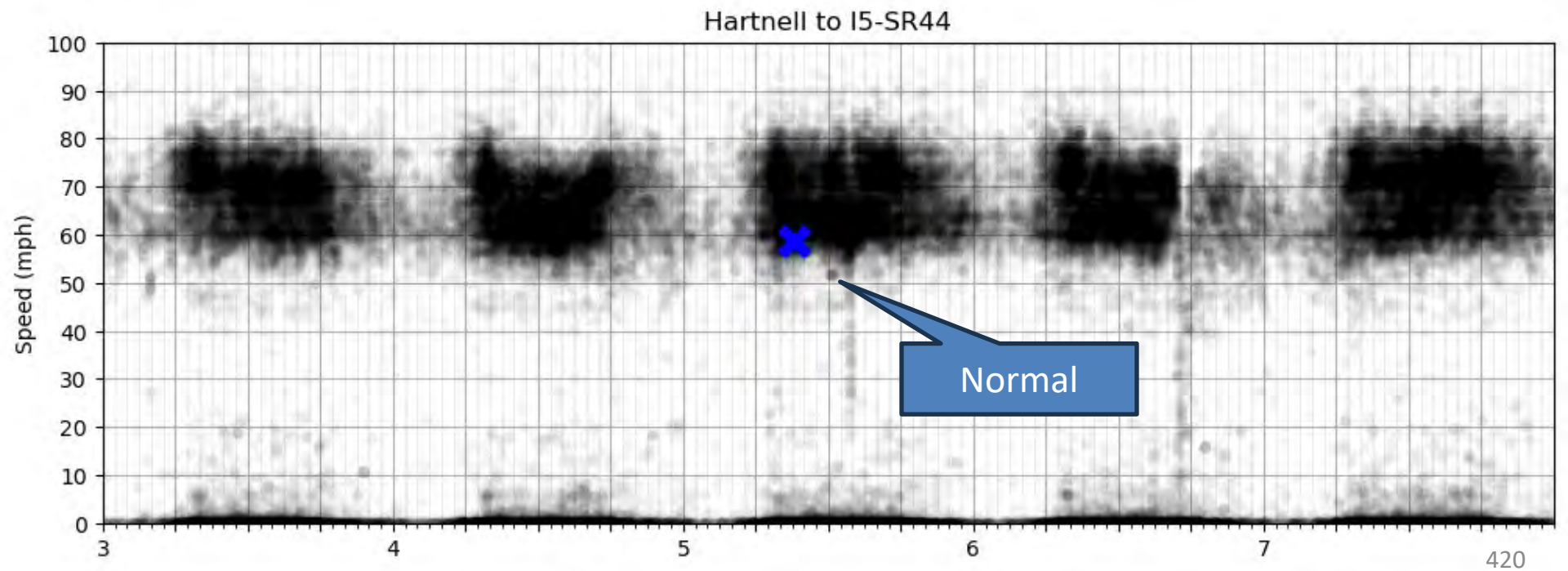


Hartnell to I5-SR44
Speed: 59 mph
Travel Time: 1 min 32 sec



Hartnell
February 05, 2025
09:12:15 AM

I5-SR44
February 05, 2025
09:13:47 AM



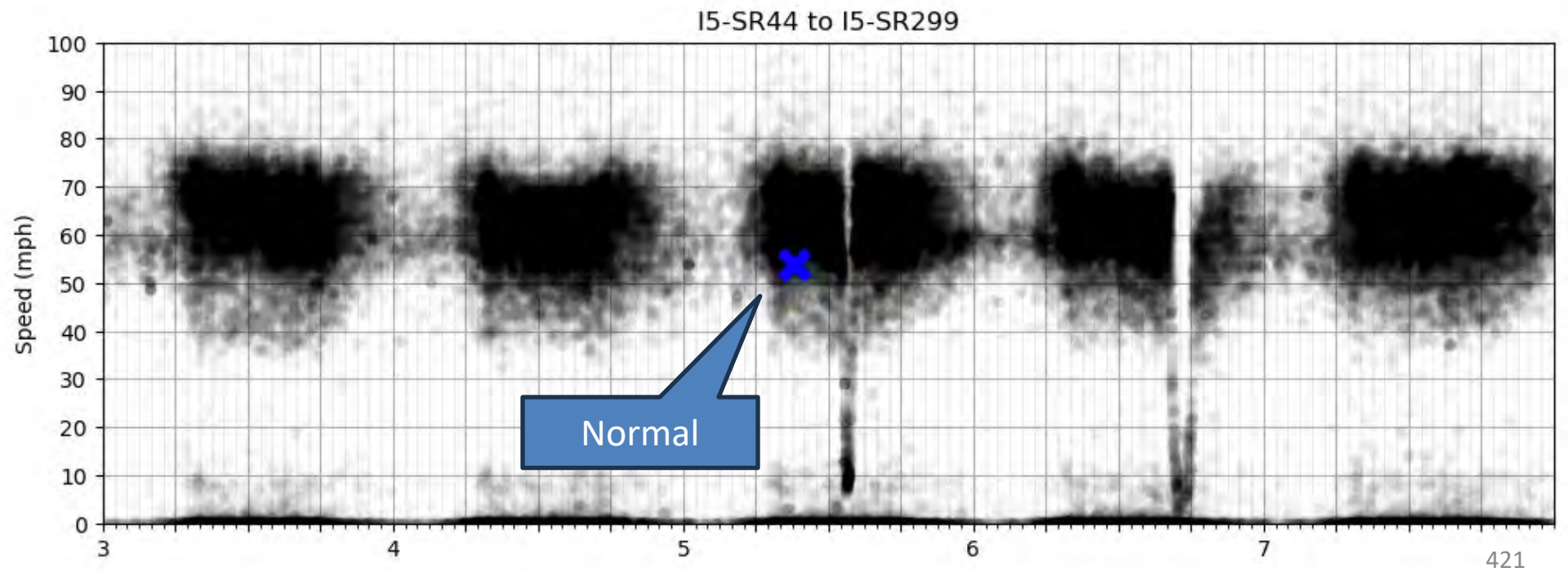


I5-SR44 to I5-SR299
Speed: 54 mph
Travel Time: 2 min 7 sec



I5-SR44
February 05, 2025
09:13:47 AM

I5-SR299
February 05, 2025
09:15:54 AM



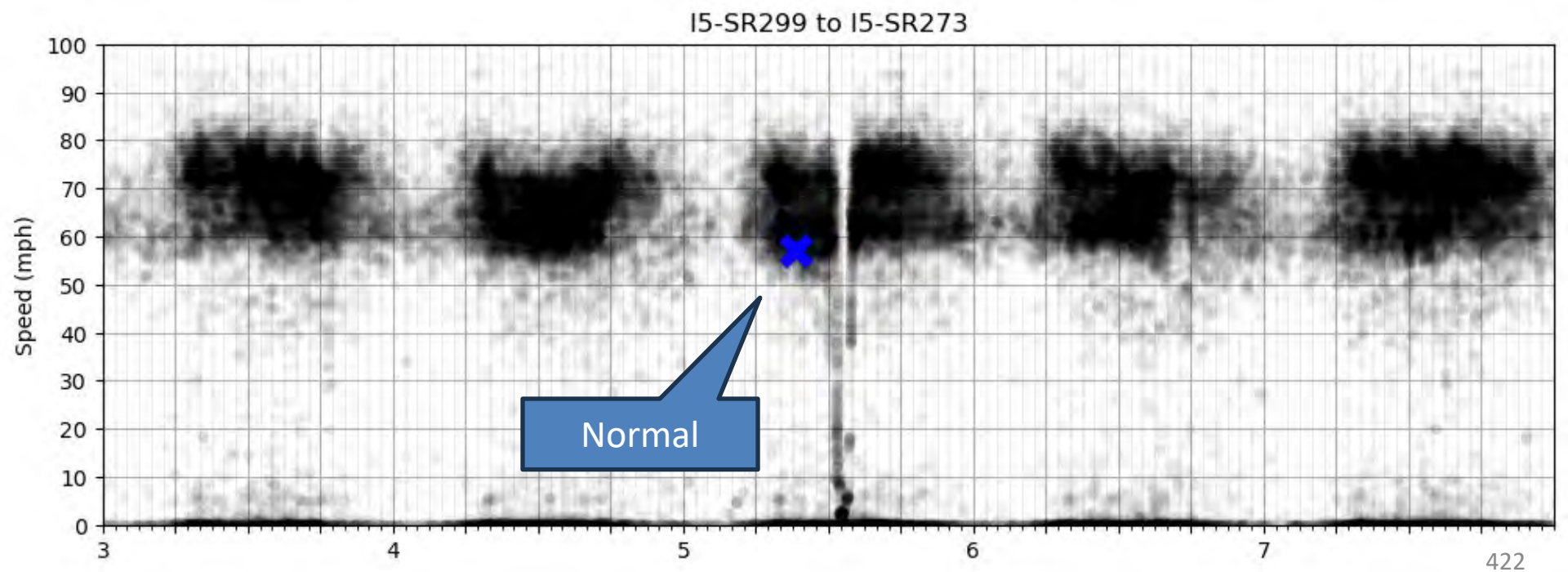
I5-SR299 to I5-SR273
Speed: 57 mph
Travel Time: 1 min 22 sec





I5-SR299
February 05, 2025
09:15:54 AM

I5-SR273
February 05, 2025
09:17:16 AM





I5-SR273 to Pine Grove
Speed: 56 mph
Travel Time: 2 min 33 sec

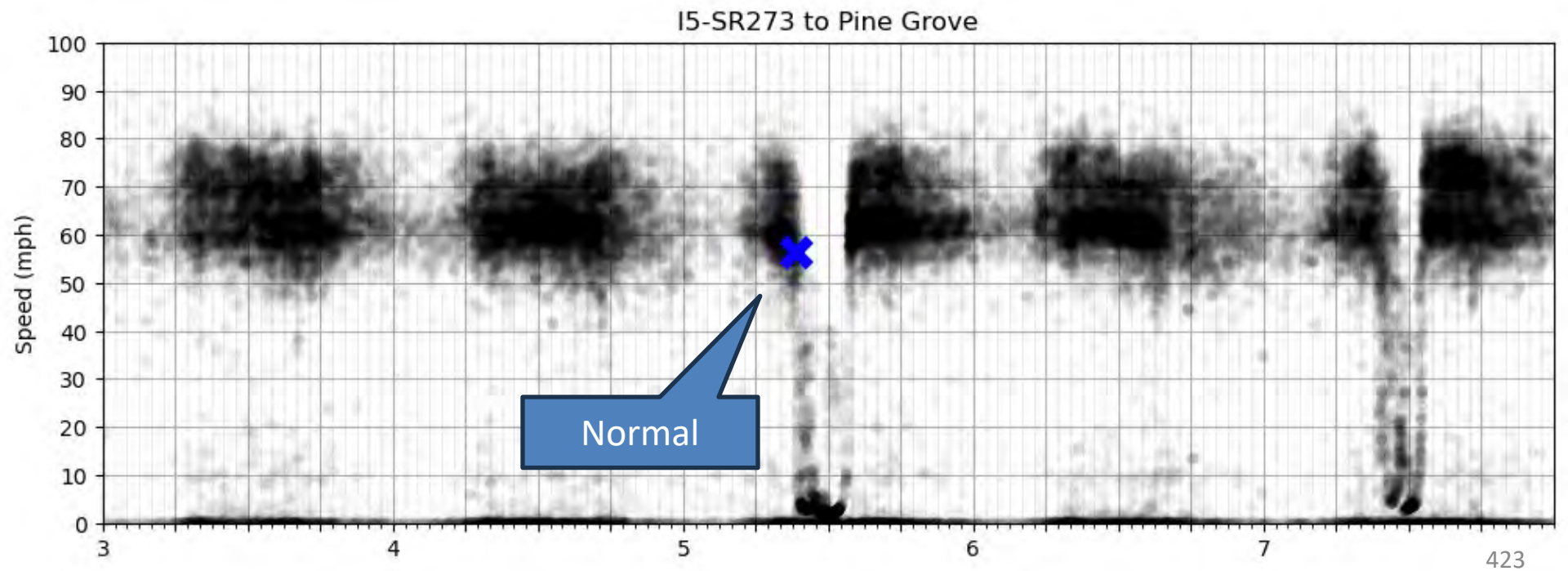
Normal to the end of the queue

Normal



I5-SR273
February 05, 2025
09:17:16 AM

Pine Grove
February 05, 2025
09:19:49 AM





Pine Grove to Mountain Gate
Speed: 1 mph
Travel Time: 101 min 25 sec

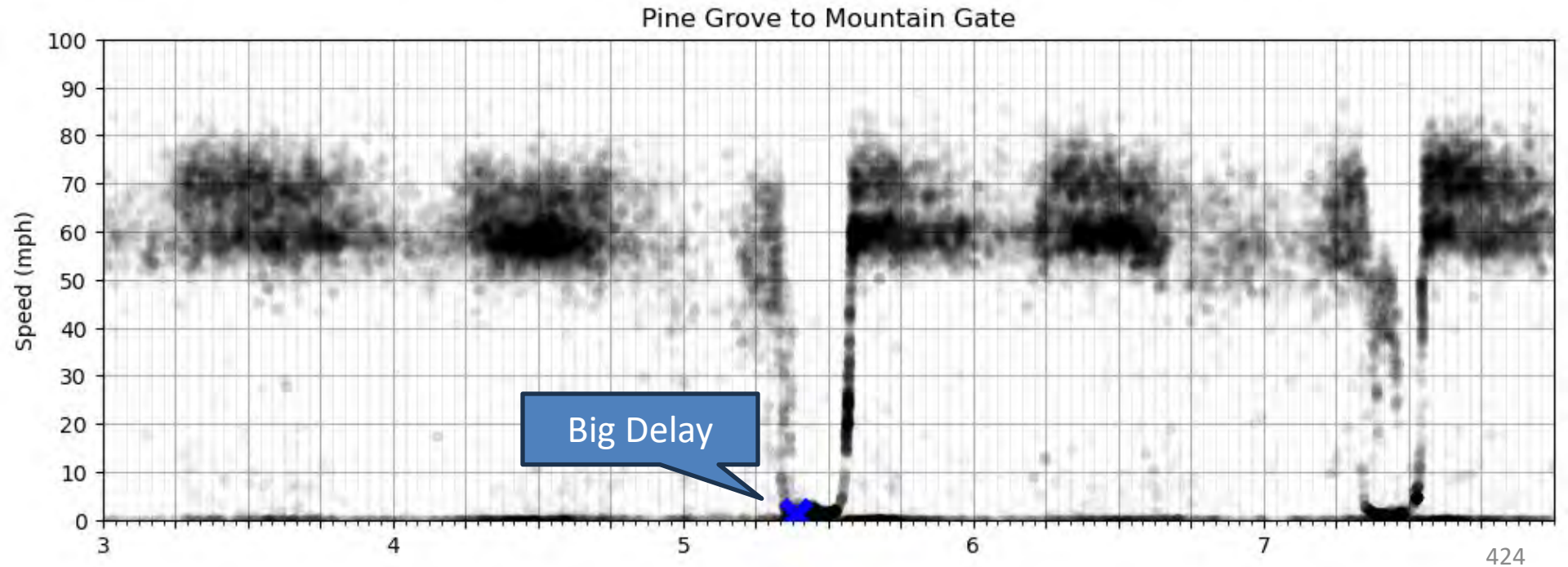
Normal to the end of the queue

Big Delay



Pine Grove
February 05, 2025
09:19:49 AM

Mountain Gate
February 05, 2025
11:01:14 AM





Mountain Gate to Wonderland
Speed: 2 mph
Travel Time: 66 min 55 sec

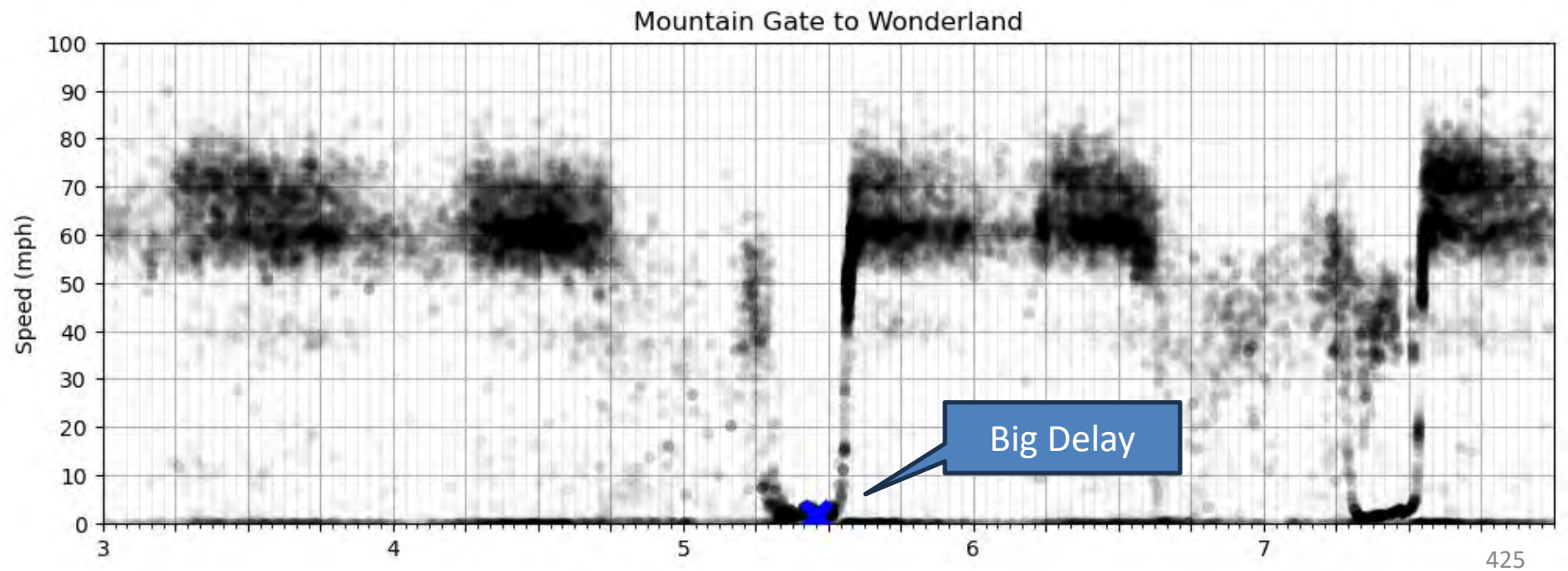
Big Delay

Big Delay



Mountain Gate
February 05, 2025
11:01:14 AM

Wonderland
February 05, 2025
12:08:09 PM

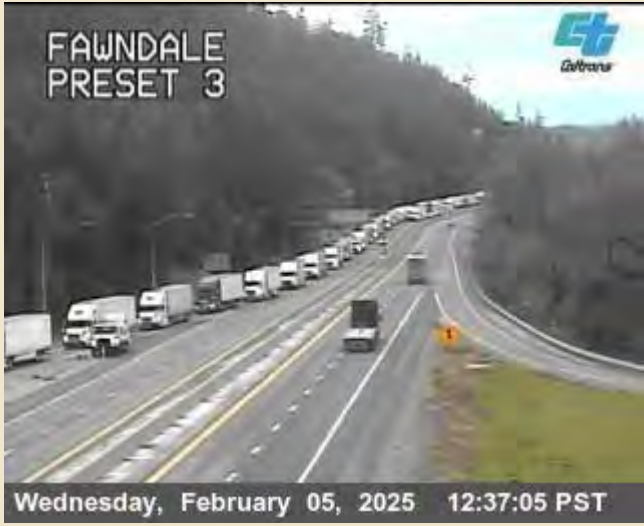




Wonderland to Fawndale
Speed: 2 mph
Travel Time: 31 min 44 sec

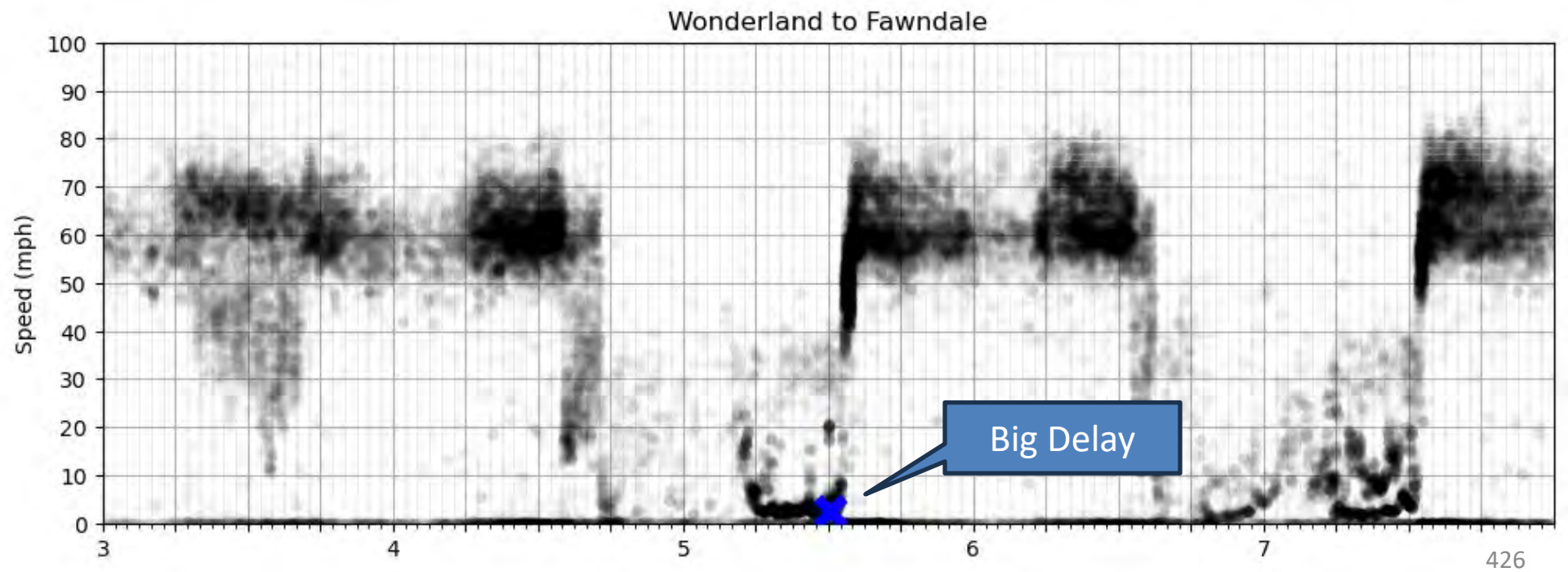
Big Delay

Big Delay



Wonderland
February 05, 2025
12:08:09 PM

Fawndale
February 05, 2025
12:39:53 PM





Fawndale to Pit River Bridge
Speed: 26 mph
Travel Time: 4 min 51 sec

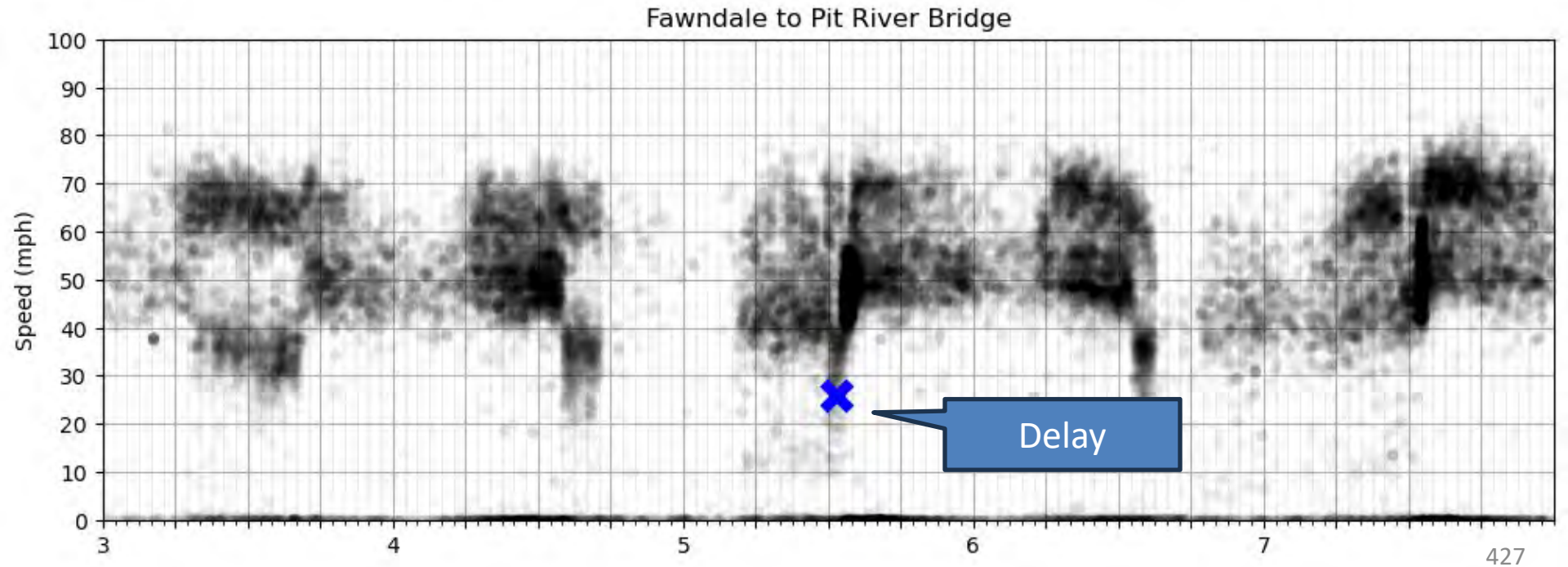
Big Delay

Normal



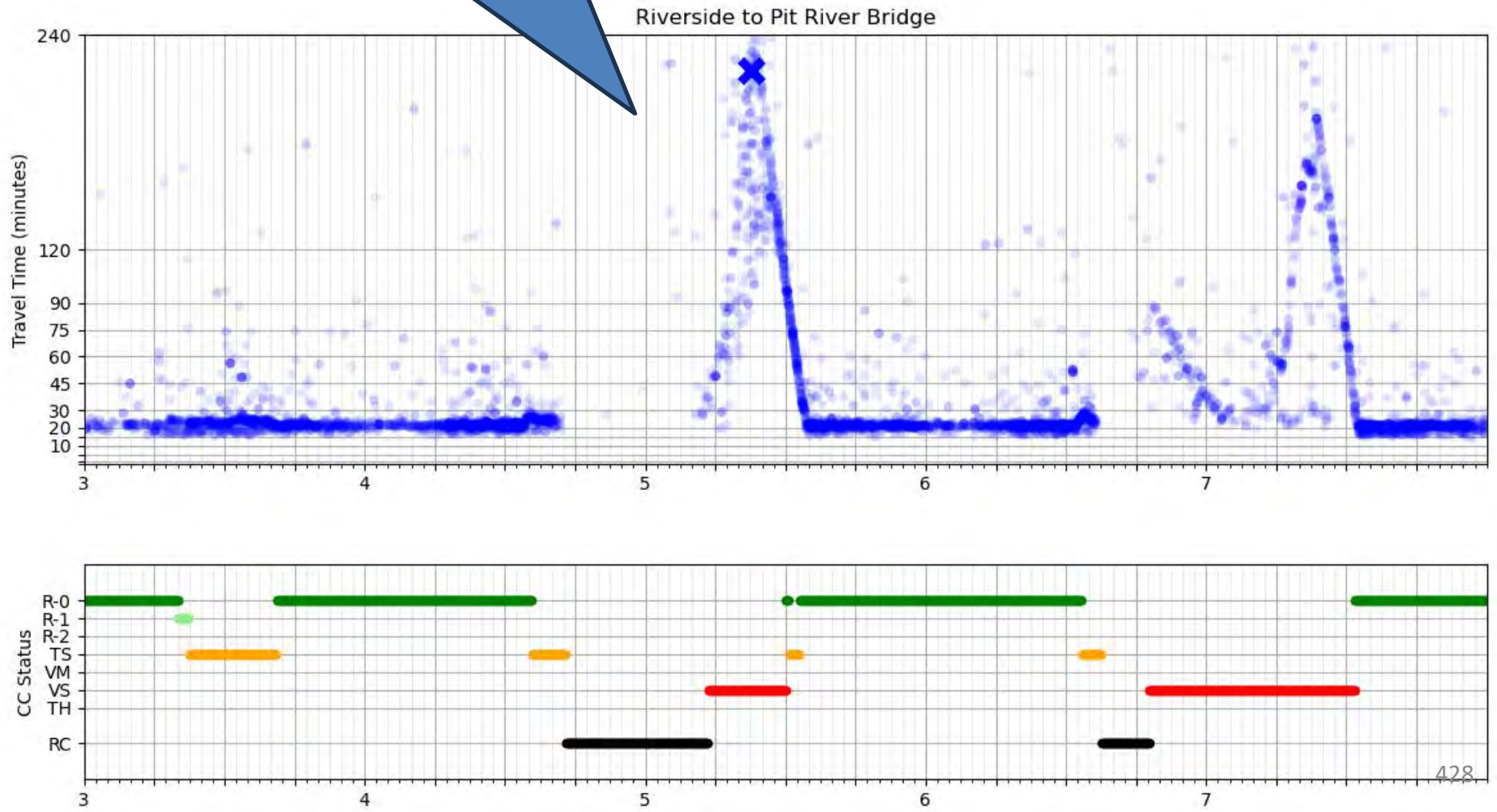
Fawndale
February 05, 2025
12:39:53 PM

Pit River Bridge
February 05, 2025
12:44:44 PM



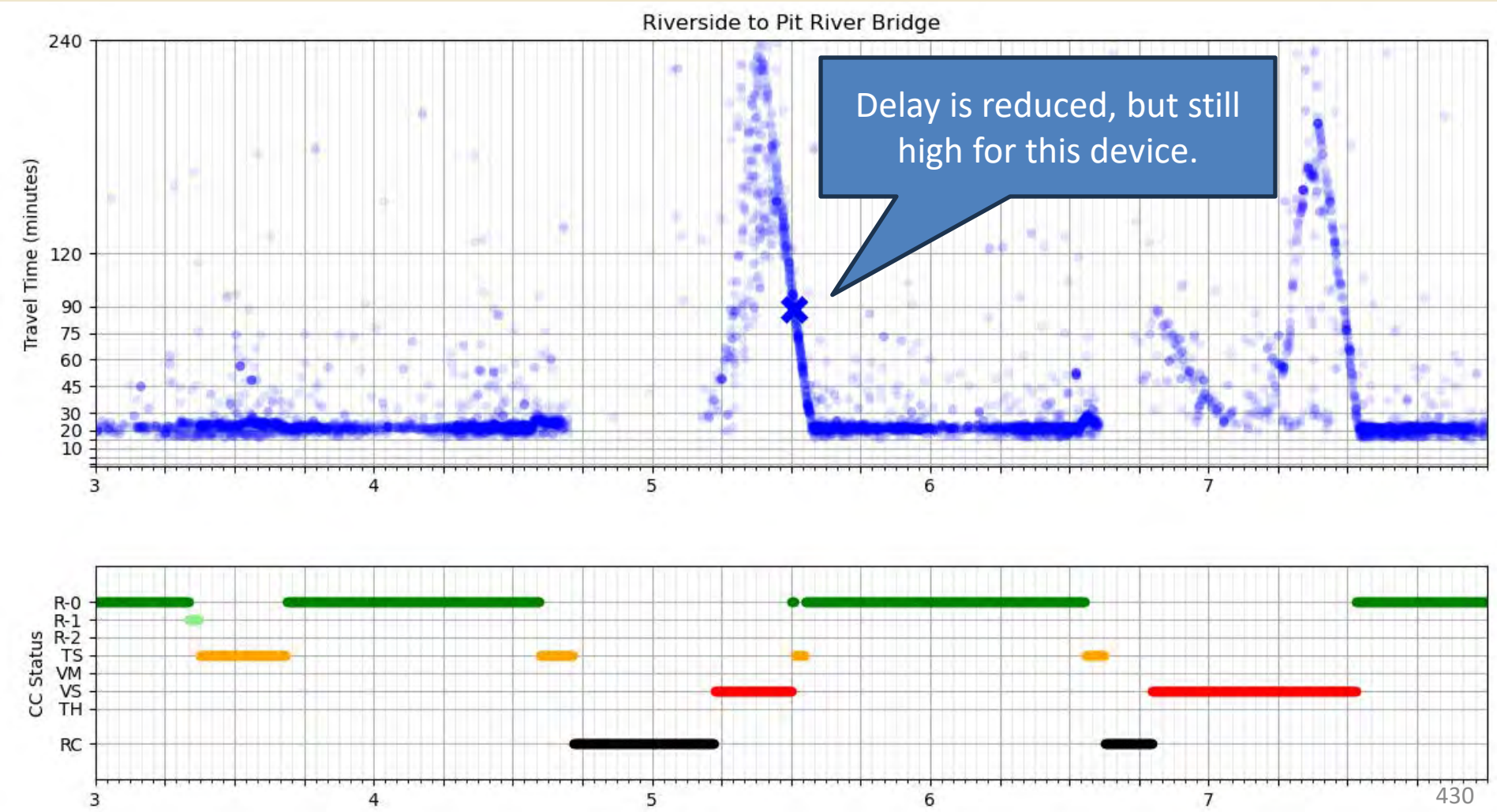
Track Individual Device : BTLECAPT 2c:41:a1:XX:XX:XX

This device and travel time appear to be real and represent Ground Truth.



Track another Device : BTLECAPT 00:25:ca:XX:XX:XX

Track Individual Device : BTLECAPT 00:25:ca:XX:XX:XX



Track Individual Device : BTLECAPT 00:25:ca:XX:XX:XX

Date	Time	Site	Speed	Travel Time
February 05, 2025	12:16:17 PM	Riverside	60 mph	3 min 0 sec
February 05, 2025	12:19:17 PM	Knighton Rd	60 mph	2 min 23 sec
February 05, 2025	12:21:40 PM	South Bonnyview	61 mph	1 min 47 sec
February 05, 2025	12:23:27 PM	Hartnell	63 mph	1 min 26 sec
February 05, 2025	12:24:53 PM	I5-SR44	56 mph	2 min 3 sec
February 05, 2025	12:26:56 PM	I5-SR299	54 mph	1 min 27 sec
February 05, 2025	12:28:23 PM	I5-SR273	**2 mph**	**66 min 7 sec**
February 05, 2025	01:34:30 PM	Pine Grove	26 mph	4 min 27 sec
February 05, 2025	01:38:57 PM	Mountain Gate	47 mph	2 min 17 sec
February 05, 2025	01:41:14 PM	Wonderland	59 mph	1 min 19 sec
February 05, 2025	01:42:33 PM	Fawndale	52 mph	2 min 25 sec
February 05, 2025	01:44:58 PM	Pit River Bridge	**TOTAL**	**88 min 41 sec**

The Delay is between I5-SR273 and Pine Grove

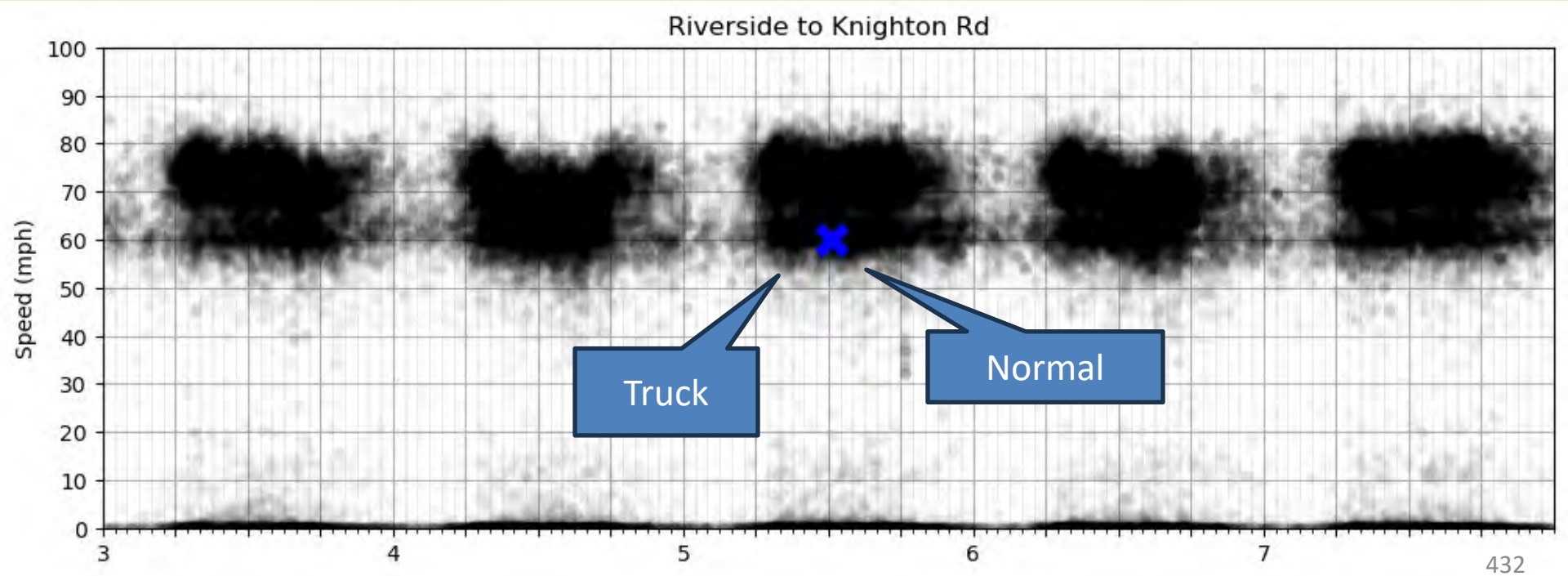


Riverside to Knighton Rd
Speed: 60 mph
Travel Time: 3 min 0 sec



Riverside
February 05, 2025
12:16:17 PM

Knighton Rd
February 05, 2025
12:19:17 PM



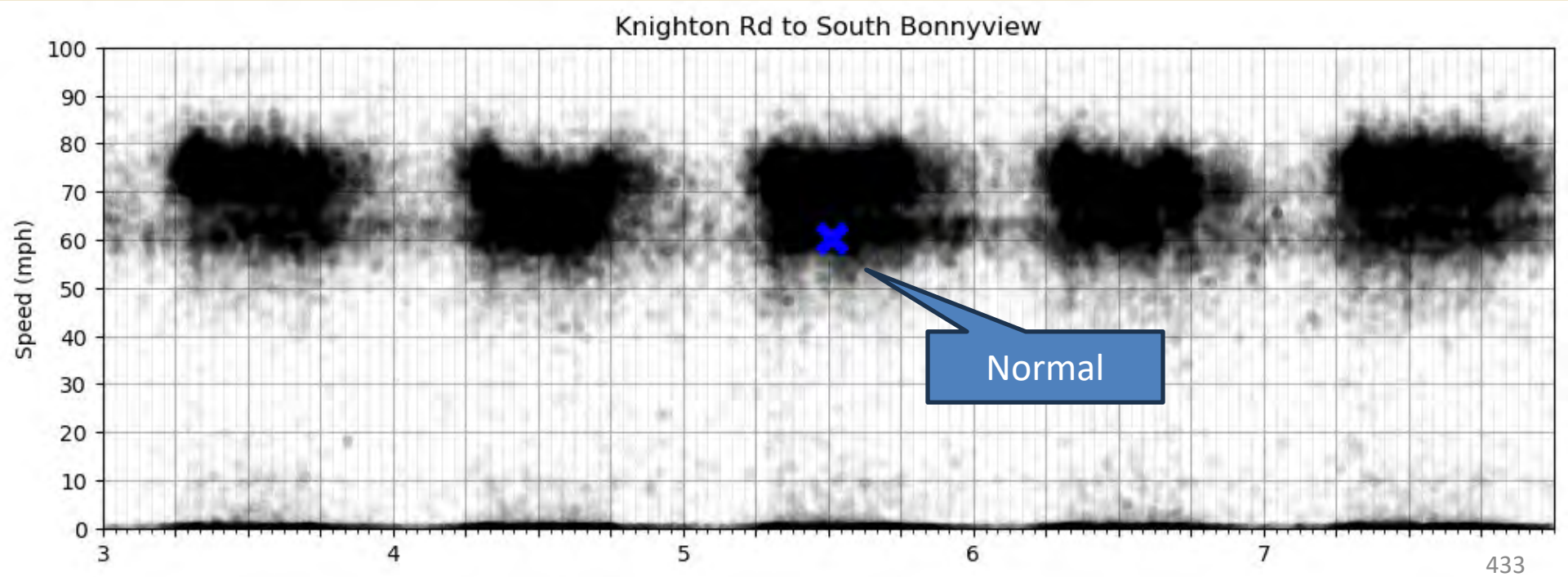


Knighton Rd to South Bonnyview
Speed: 60 mph
Travel Time: 2 min 23 sec



Knighton Rd
February 05, 2025
12:19:17 PM

South Bonnyview
February 05, 2025
12:21:40 PM



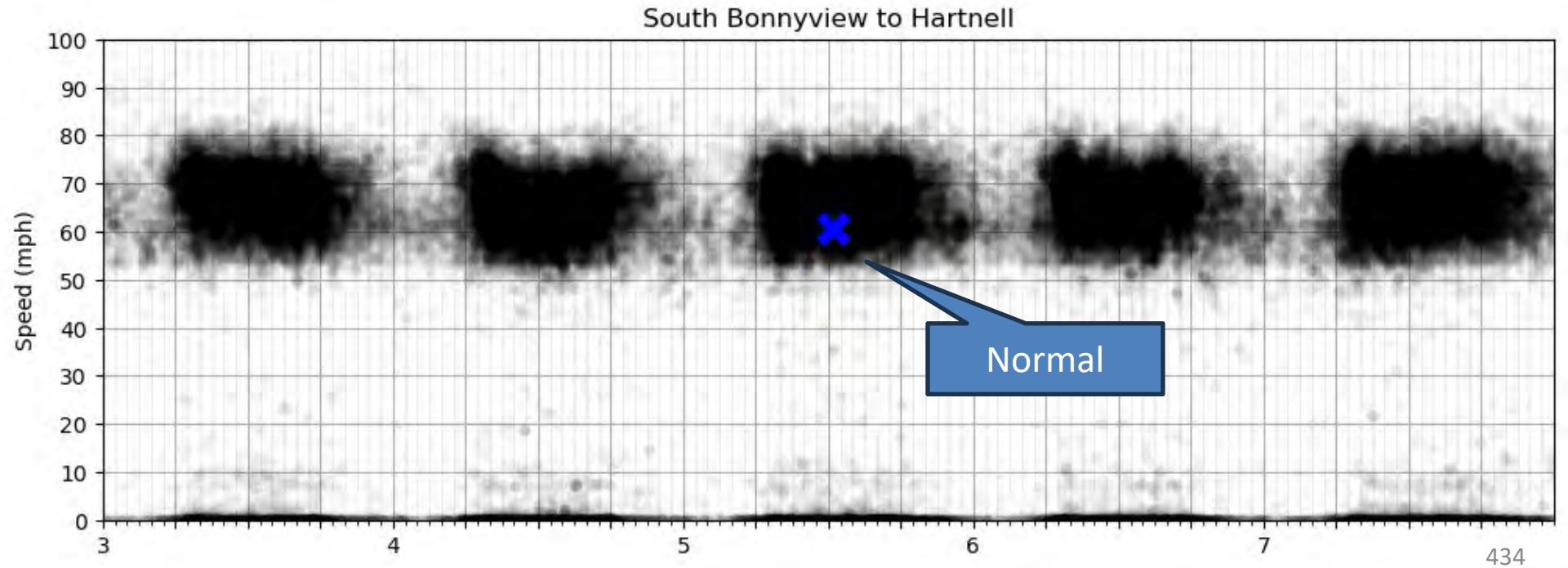


South Bonnyview to Hartnell
Speed: 61 mph
Travel Time: 1 min 47 sec



South Bonnyview
February 05, 2025
12:21:40 PM

Hartnell
February 05, 2025
12:23:27 PM



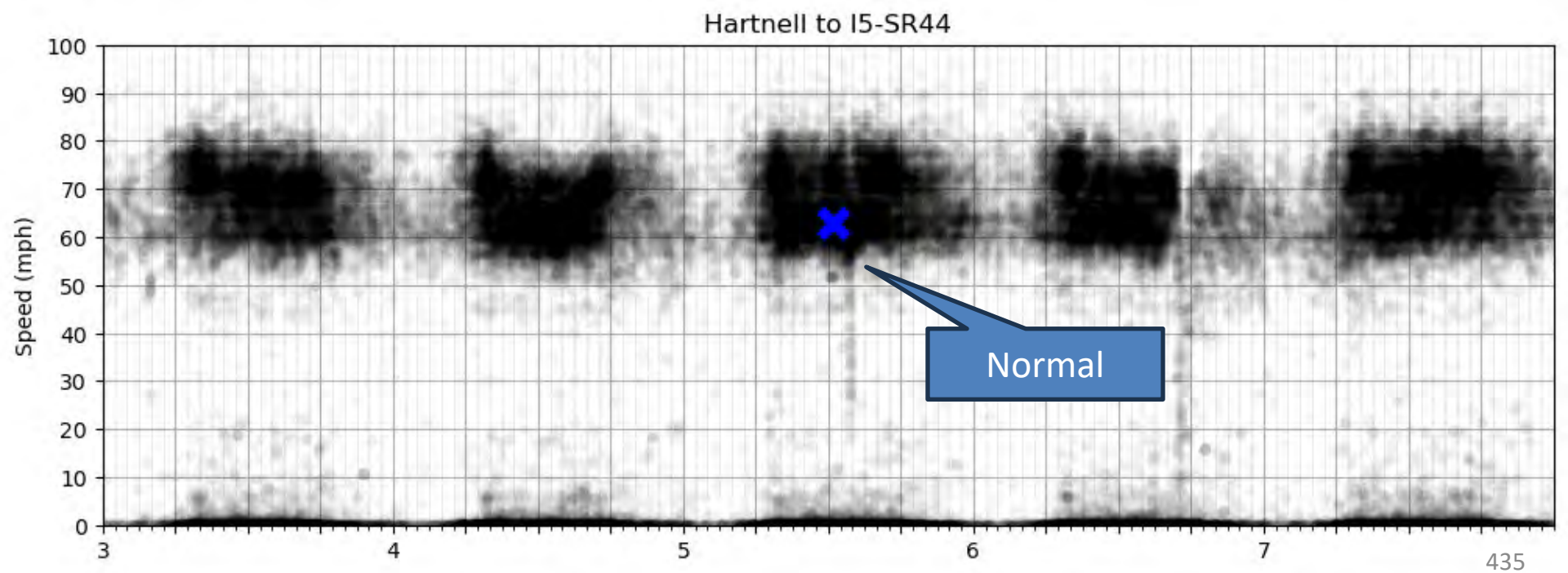


Hartnell to I5-SR44
Speed: 63 mph
Travel Time: 1 min 26 sec



Hartnell
February 05, 2025
12:23:27 PM

I5-SR44
February 05, 2025
12:24:53 PM



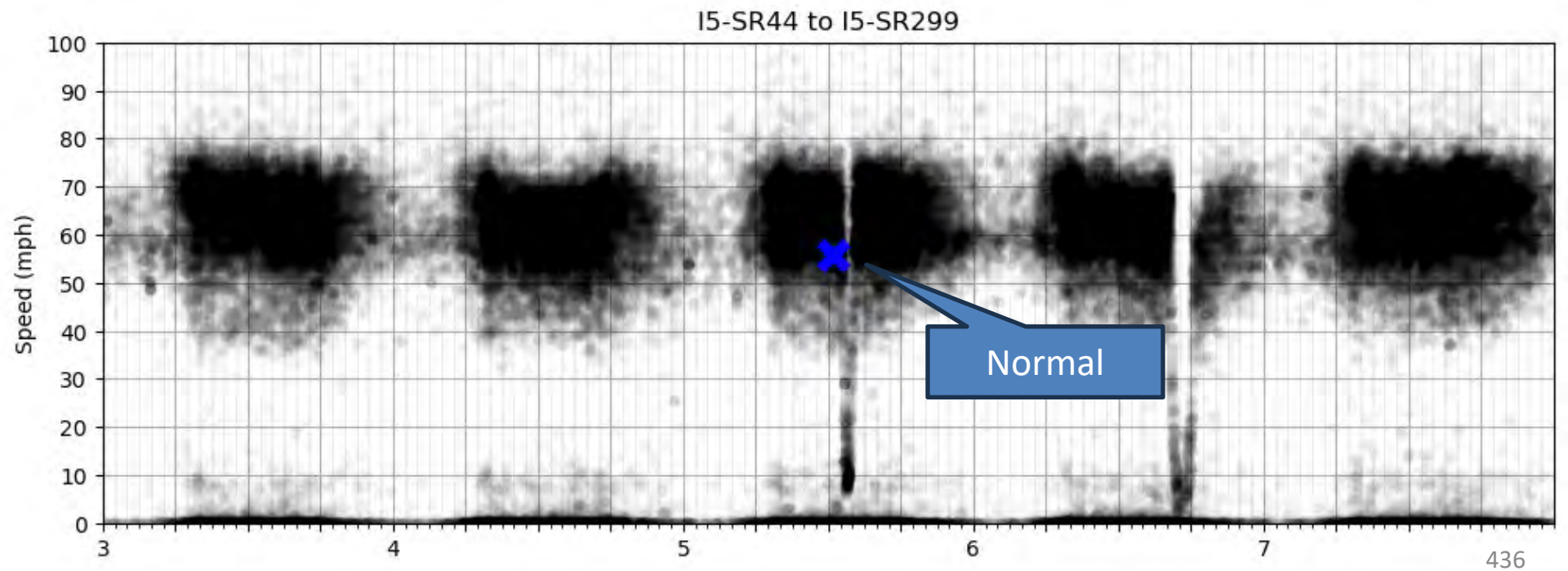


I5-SR44 to I5-SR299
Speed: 56 mph
Travel Time: 2 min 3 sec



I5-SR44
February 05, 2025
12:24:53 PM

I5-SR299
February 05, 2025
12:26:56 PM



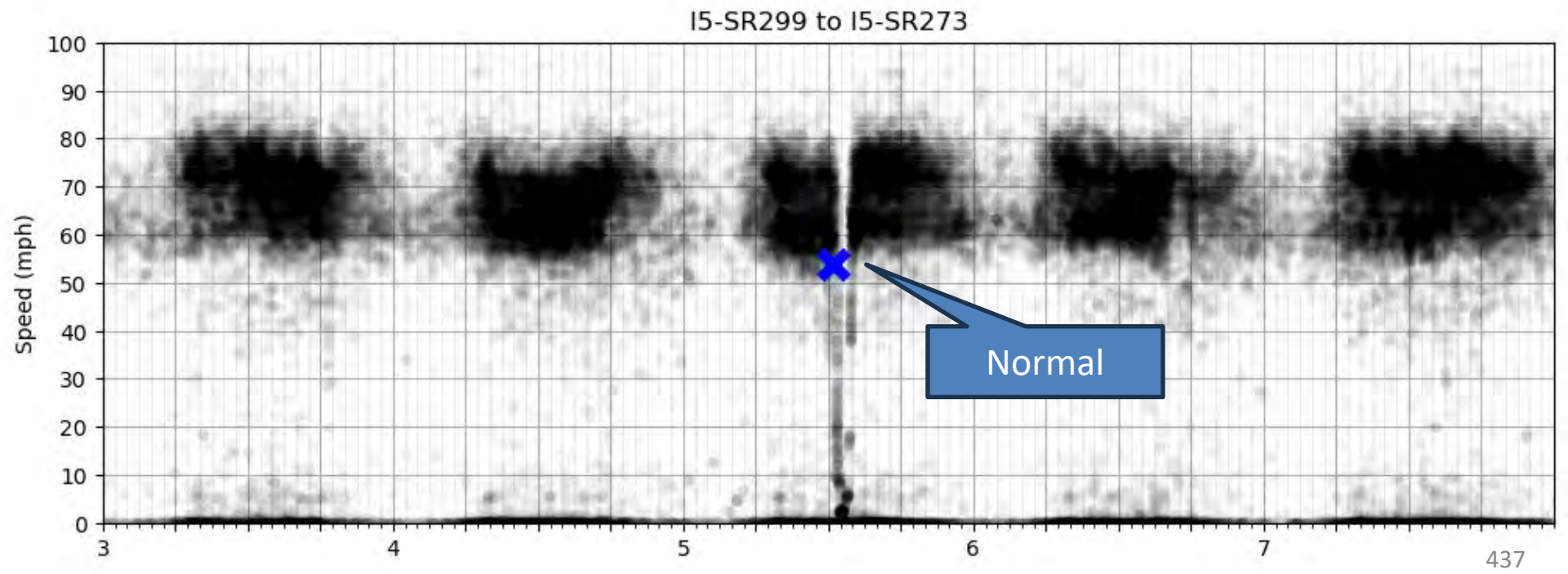
I5-SR299 to I5-SR273
Speed: 54 mph
Travel Time: 1 min 27 sec





I5-SR299
February 05, 2025
12:26:56 PM

I5-SR273
February 05, 2025
12:28:23 PM





I5-SR273 to Pine Grove
Speed: 2 mph
Travel Time: 66 min 7 sec

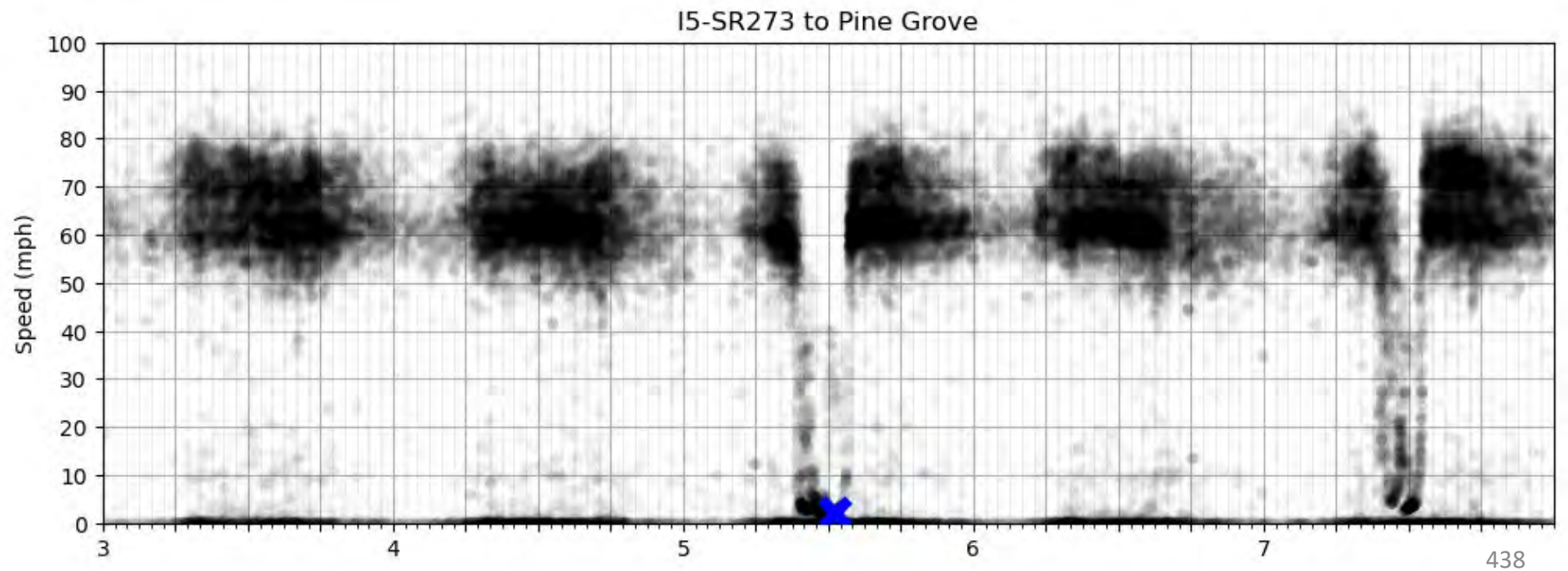
Big Delay

Big Delay



I5-SR273
February 05, 2025
12:28:23 PM

Pine Grove
February 05, 2025
01:34:30 PM





Pine Grove to Mountain Gate
Speed: 26 mph
Travel Time: 4 min 27 sec

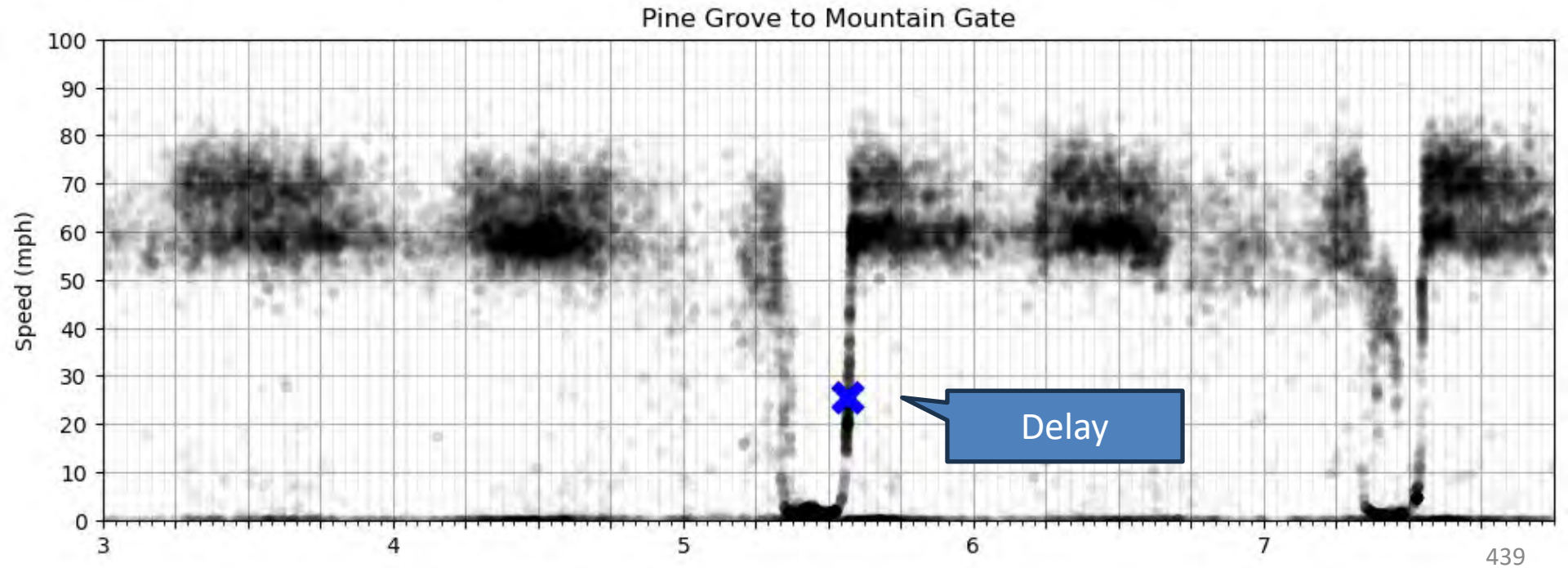
Big Delay

Delay



Pine Grove
February 05, 2025
01:34:30 PM

Mountain Gate
February 05, 2025
01:38:57 PM





Mountain Gate to Wonderland
Speed: 47 mph
Travel Time: 2 min 17 sec

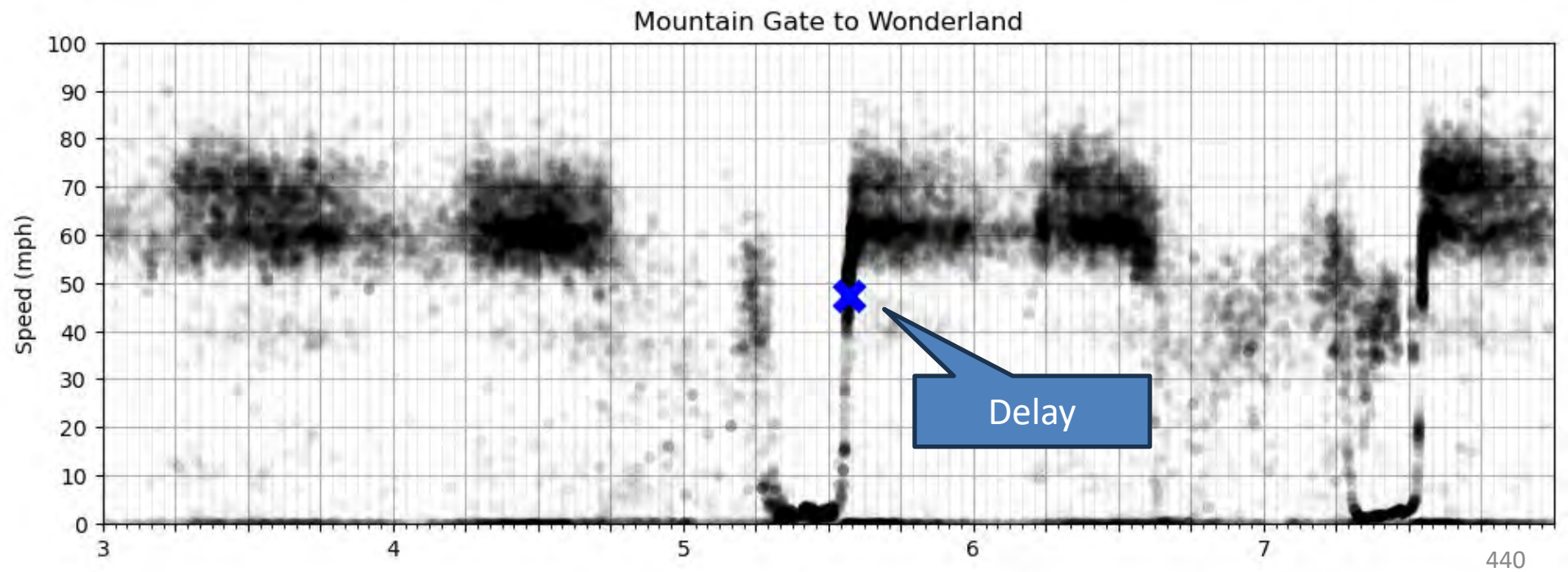
Delay

Delay



Mountain Gate
February 05, 2025
01:38:57 PM

Wonderland
February 05, 2025
01:41:14 PM





Wonderland to Fawndale
Speed: 59 mph
Travel Time: 1 min 19 sec

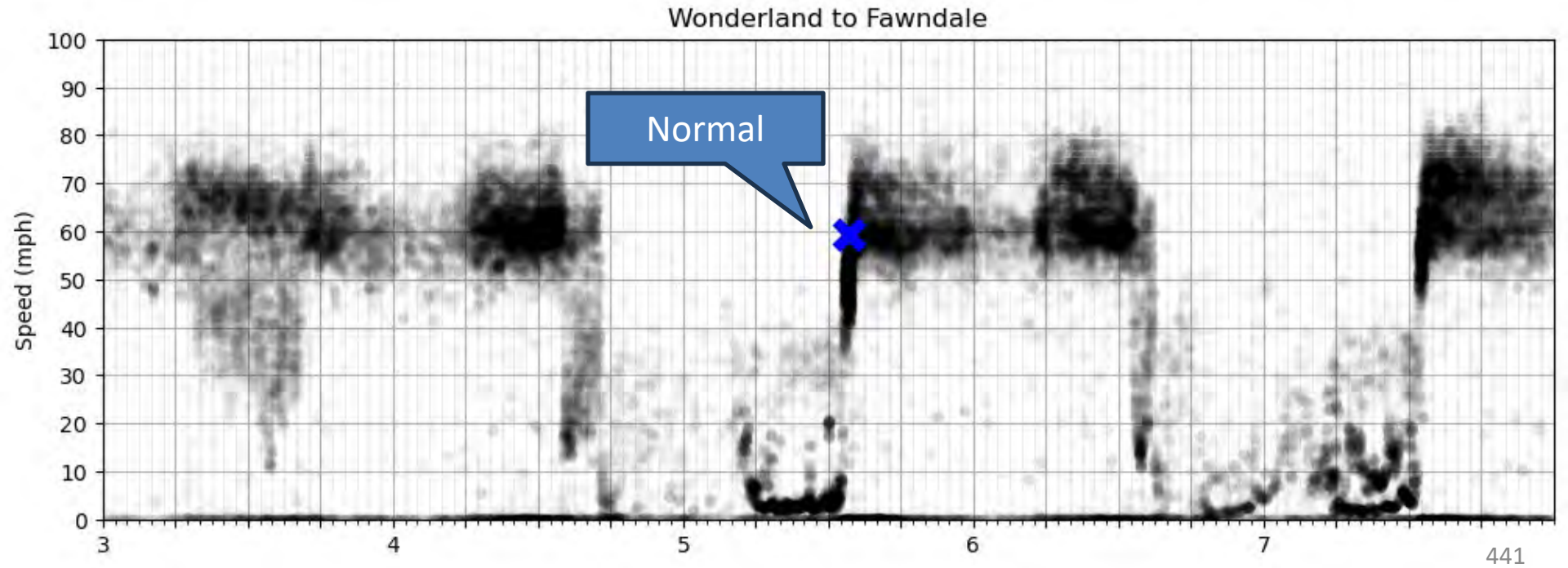
Normal?

Normal?



Wonderland
February 05, 2025
01:41:14 PM

Fawndale
February 05, 2025
01:42:33 PM





Wonderland to Fawndale
Speed: 59 mph
Travel Time: 1 min 19 sec

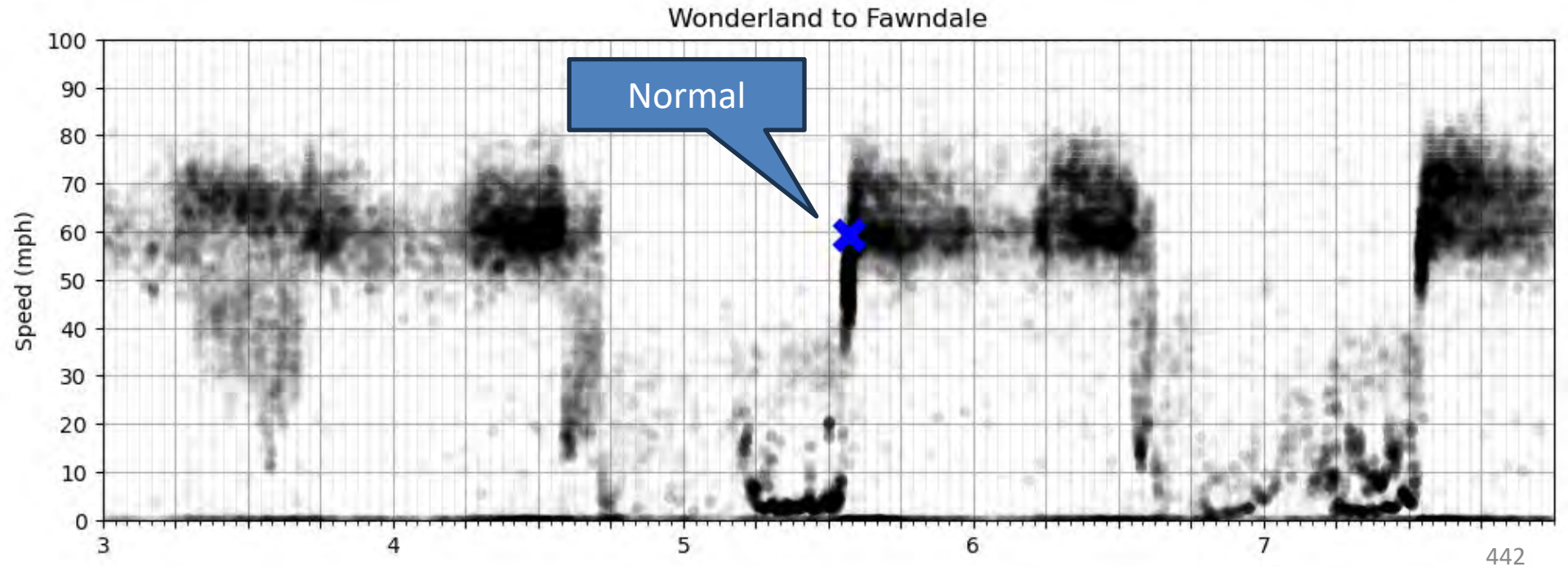
Normal

Normal?



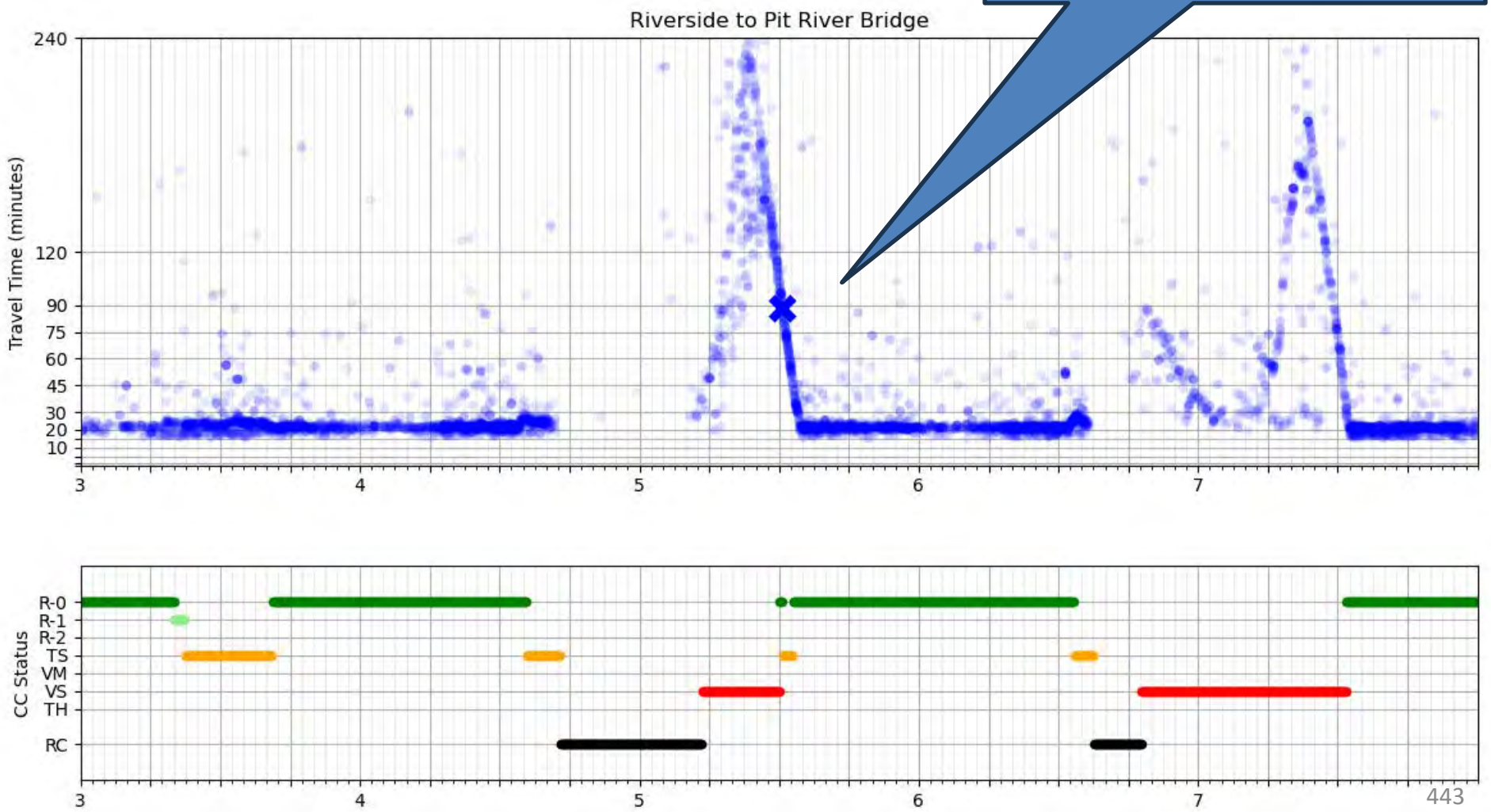
Fawndale
February 05, 2025
01:42:33 PM

Pit River Bridge
February 05, 2025
01:44:58 PM



Track Individual Device : BTLECAPT 00:25:ca:XX:XX:XX

This device and travel time appear to be real and represent Ground Truth.



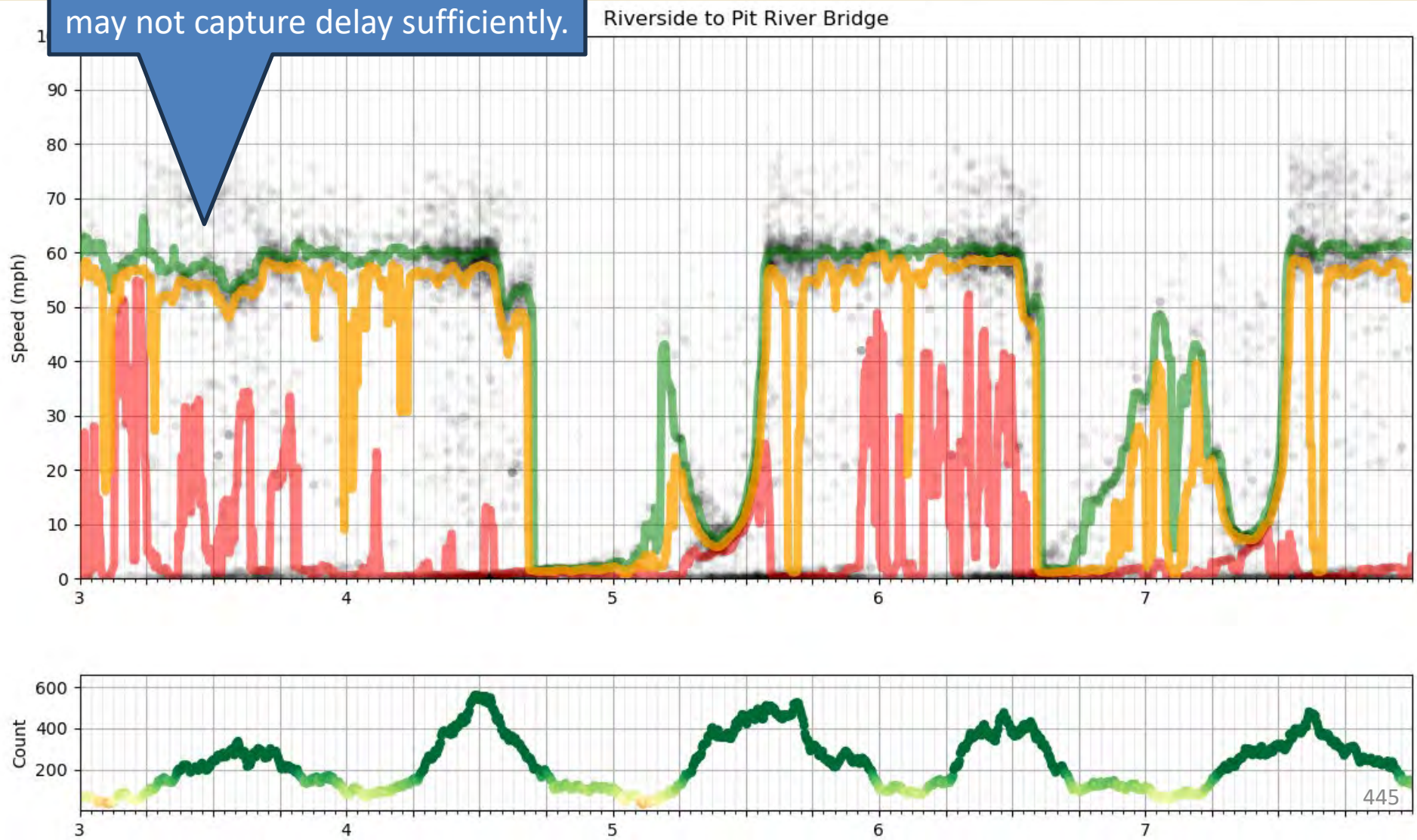
Single Origin-Based Aggregate

Examine the 25th Percentile, Median and 75th Percentile Speeds.

Single Origin-Based Aggregate

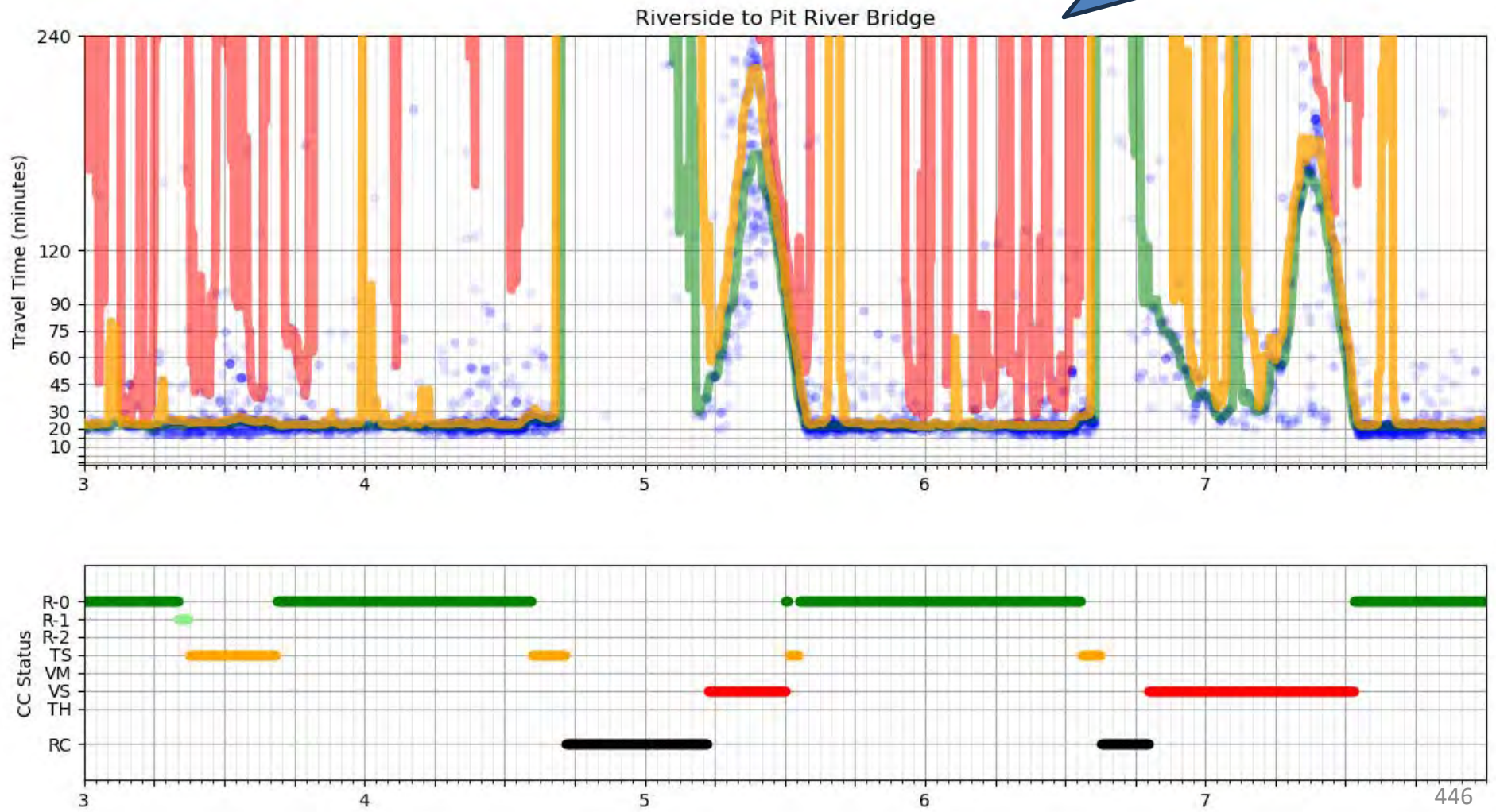
High variability in 25th percentile and median. The 75th percentile may not capture delay sufficiently.

Those low speeds are having a big impact on the statistics.



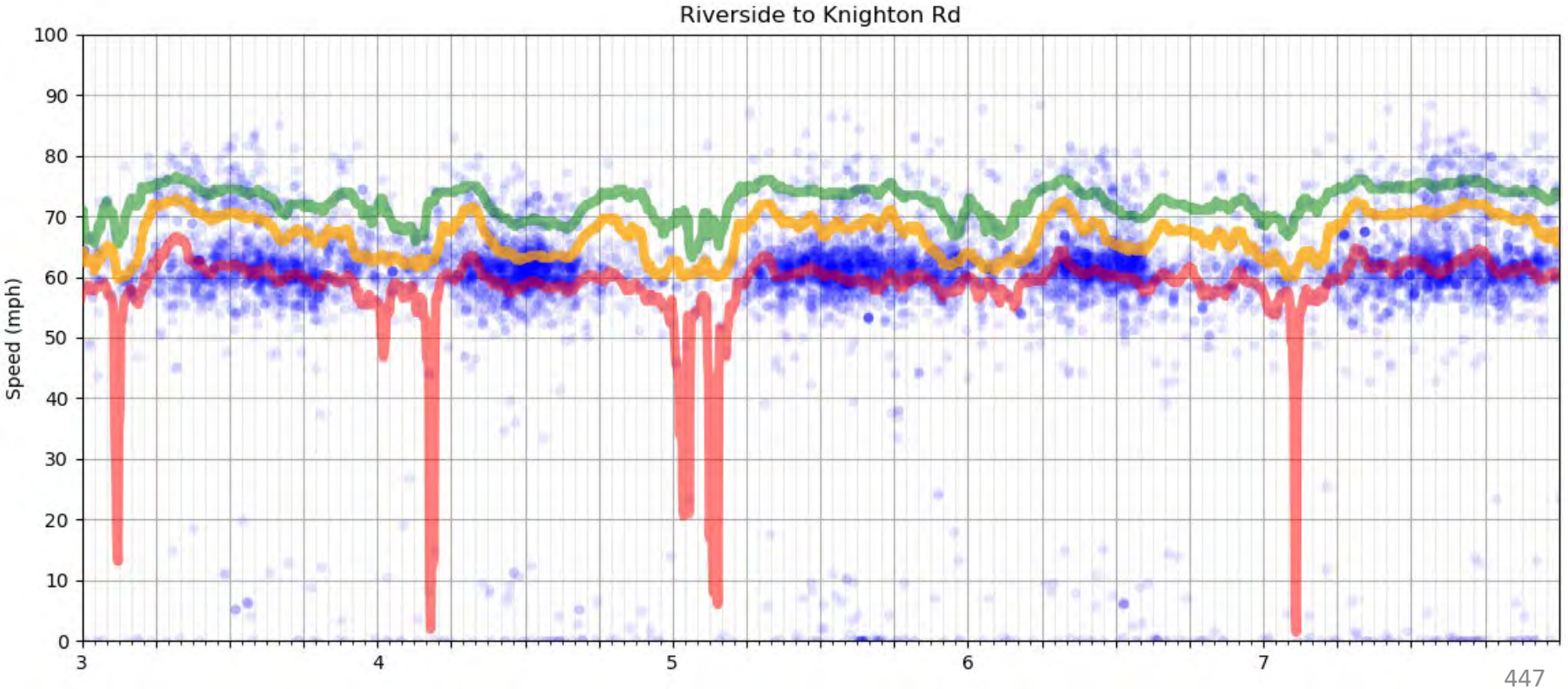
Single Origin-Based Aggregate

Wild fluctuations in aggregate travel times.



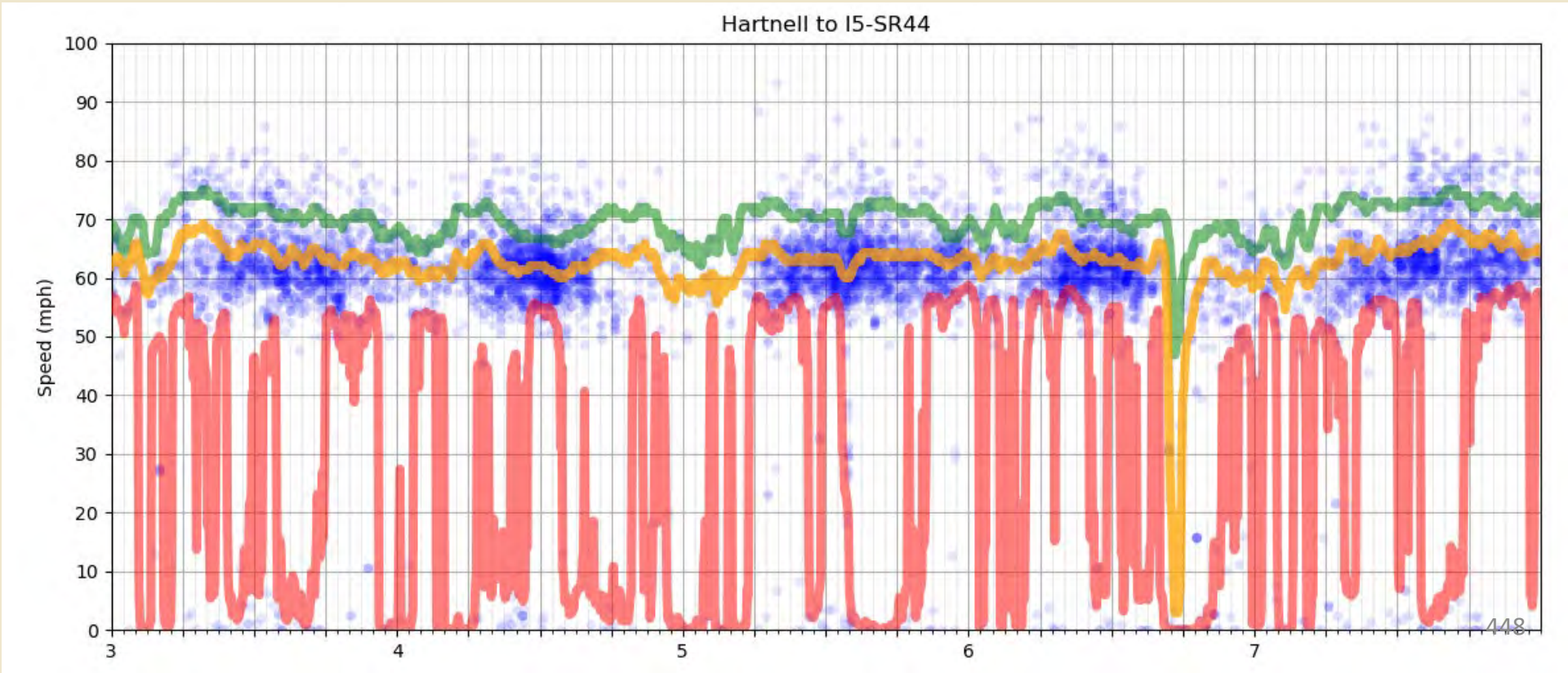
Single Origin-Based Aggregate

Median is too high for this segment, and the 25th percentile shows too much fluctuation.



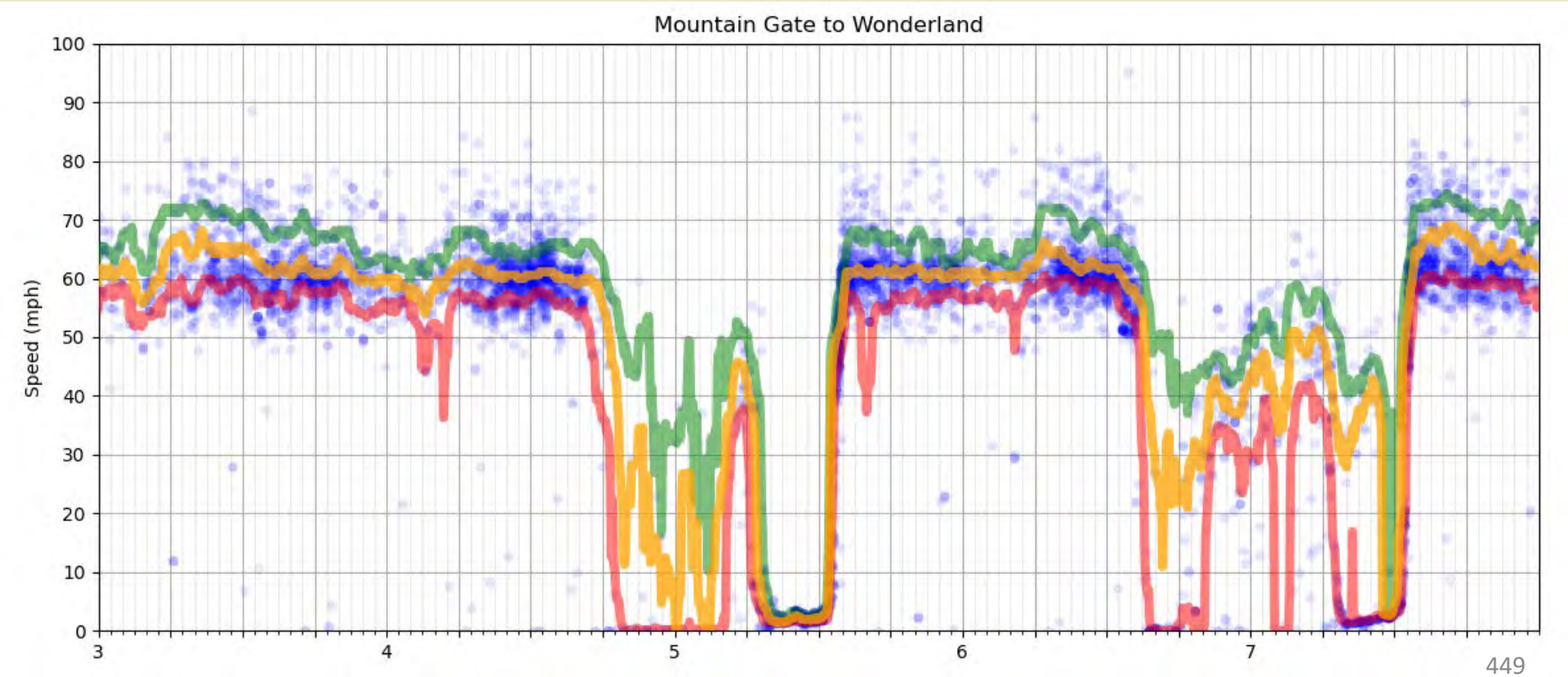
Single Origin-Based Aggregate

Median is too high for this segment, and the 25th percentile shows way too much fluctuation.

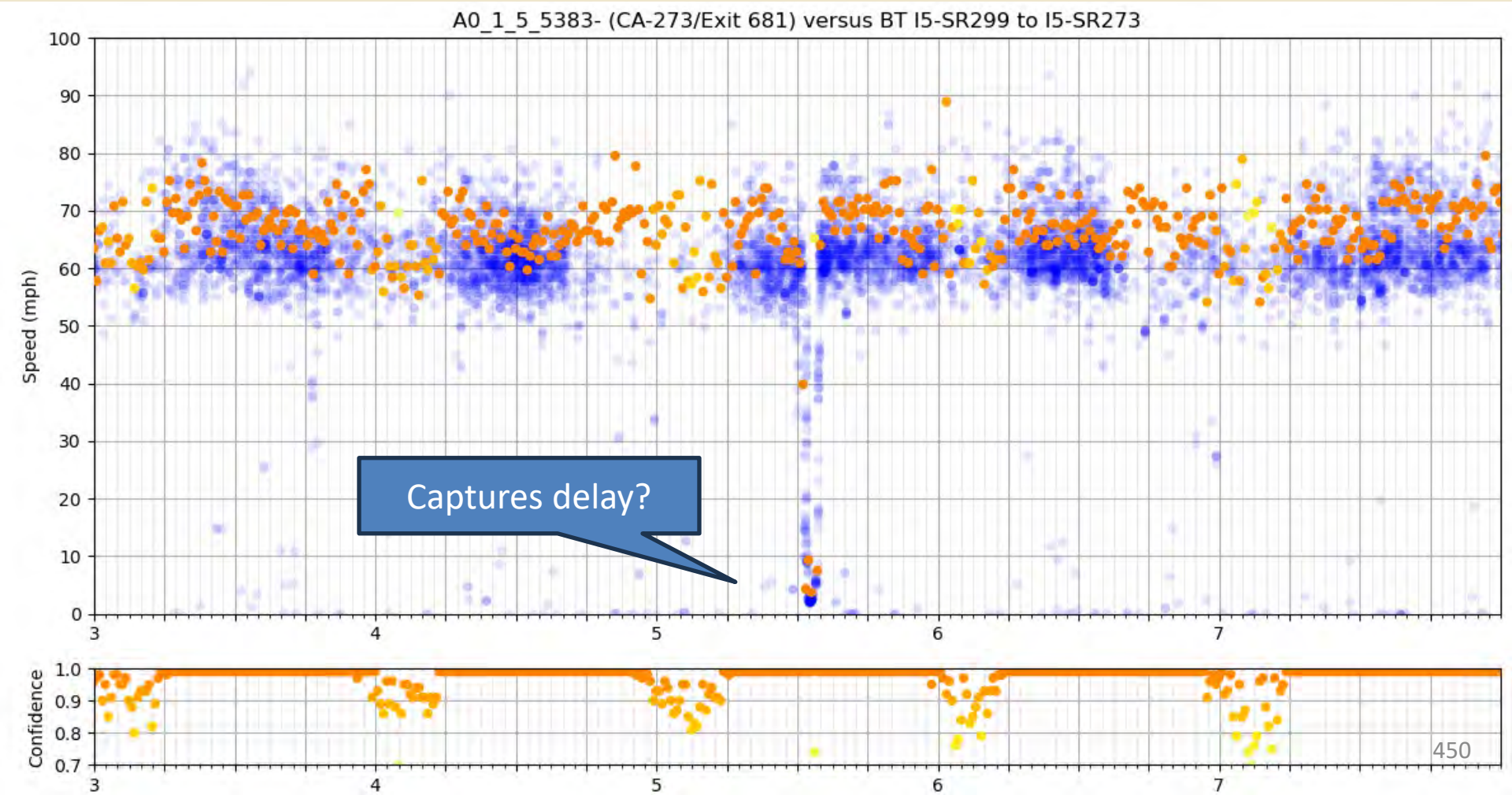


Single Origin-Based Aggregate

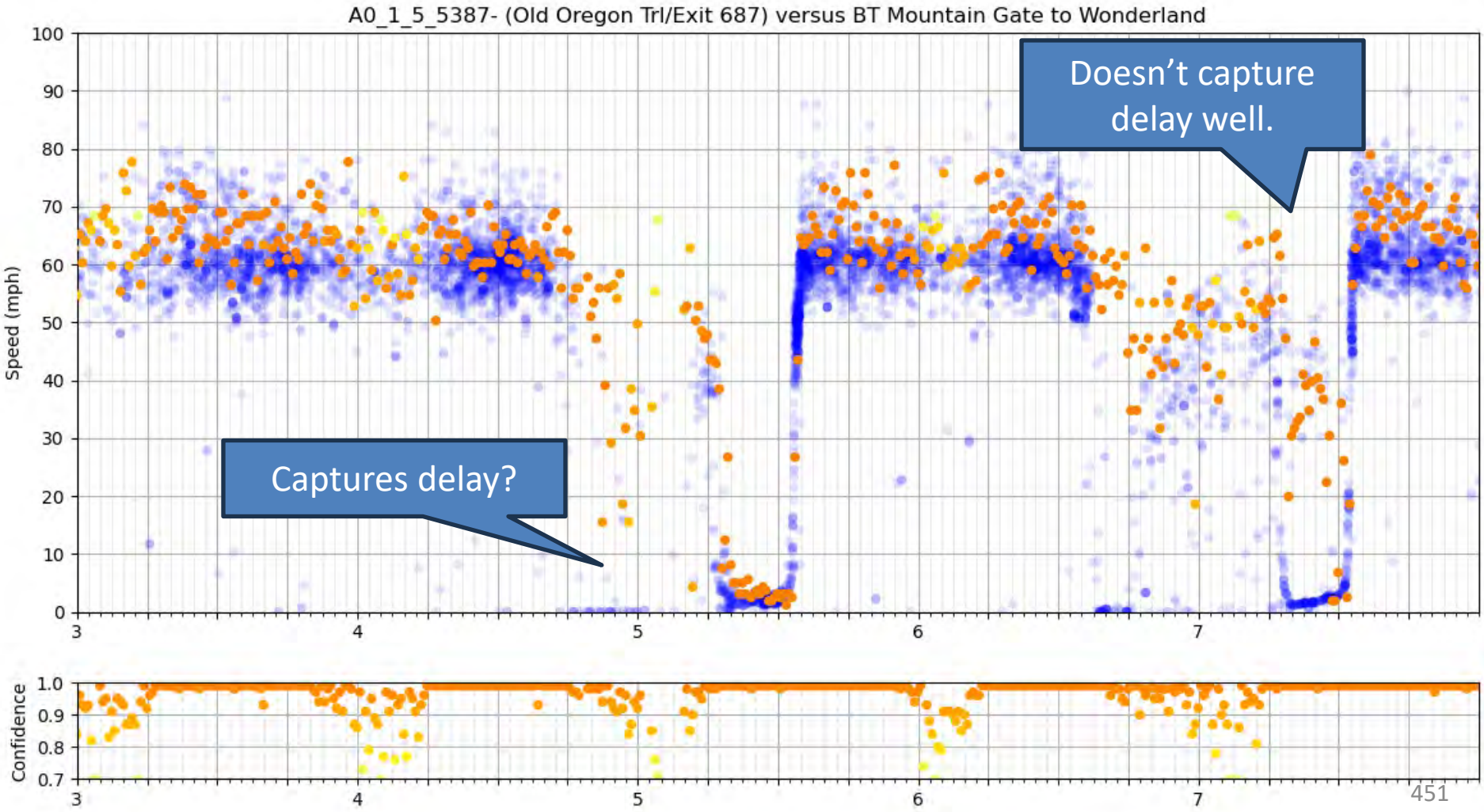
Things look a bit better for this segment.



Here.com Data

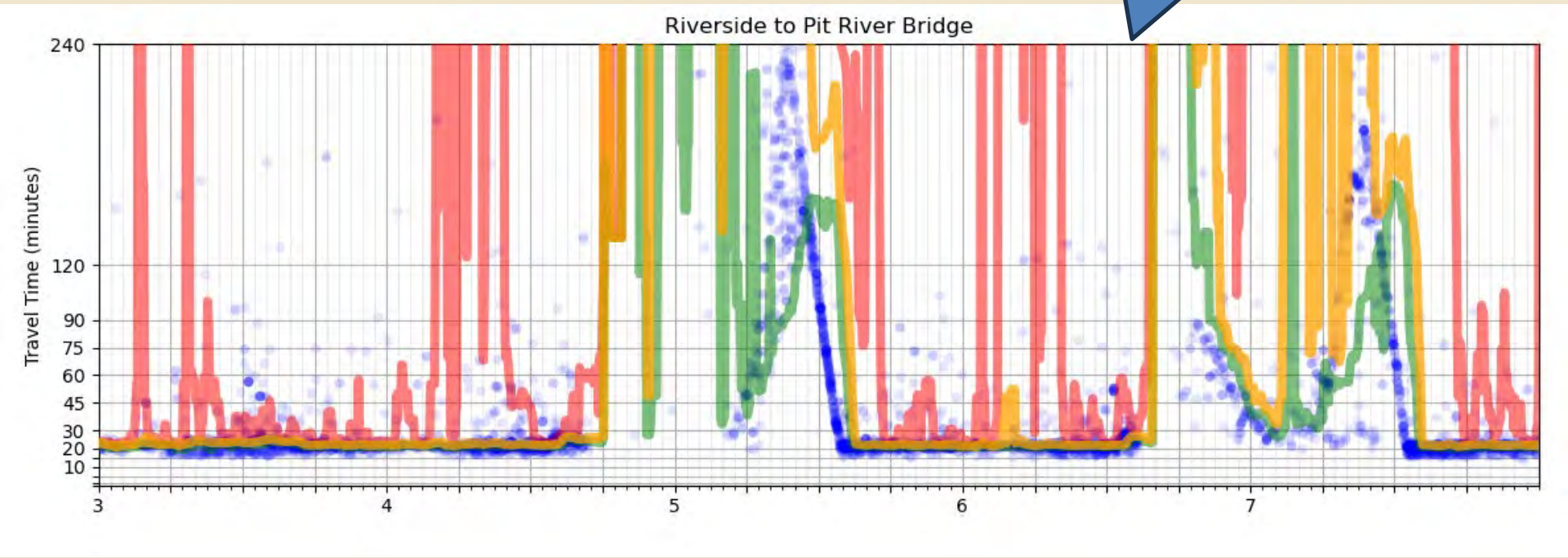


Here.com Data



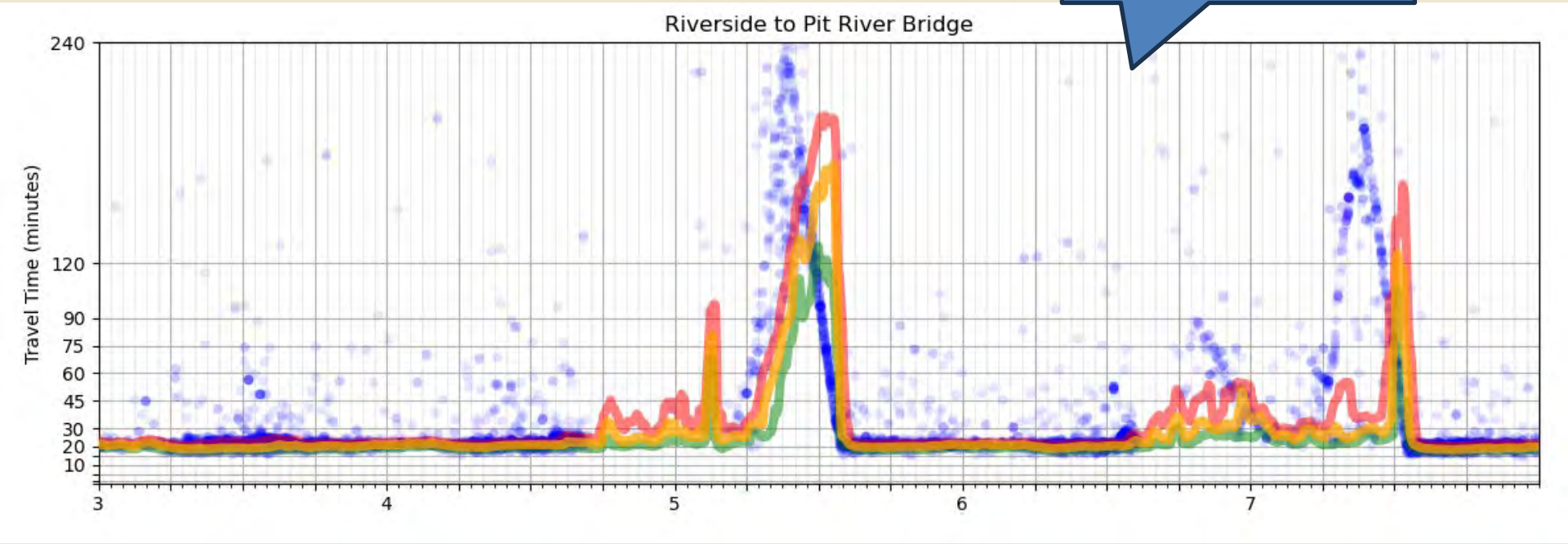
Destination-Based, Direct Point to Point Delay Estimation Algorithm

Apparent lag and wild fluctuation.



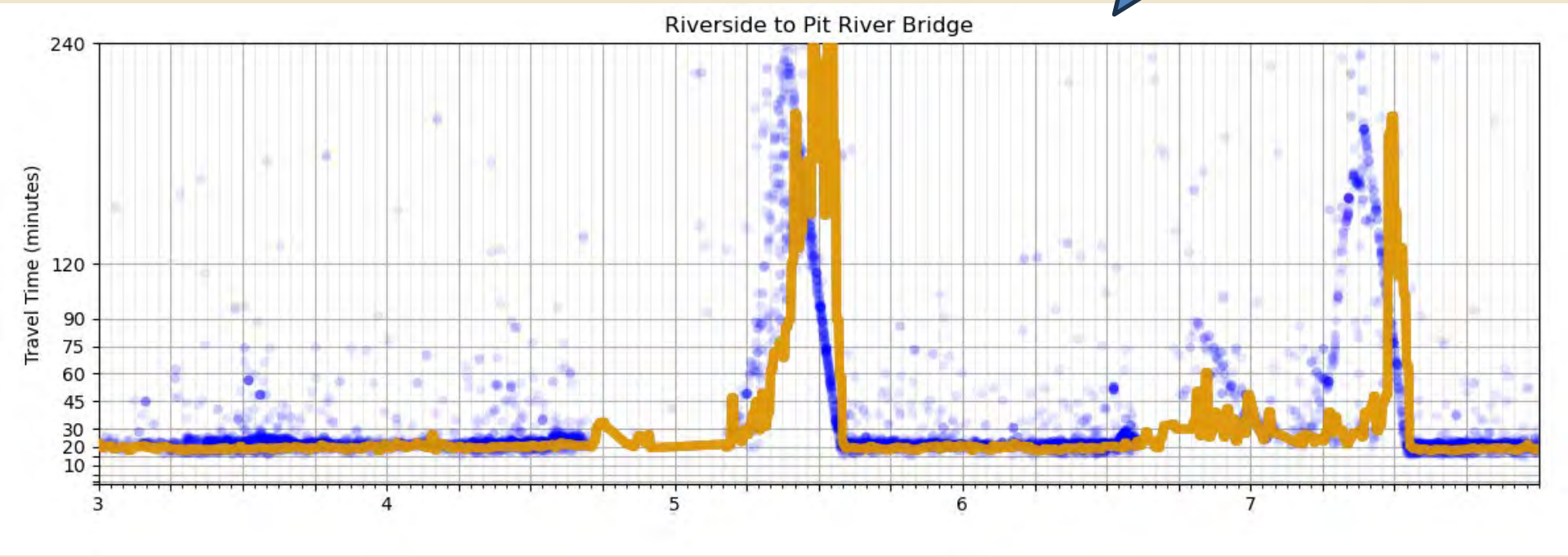
Destination-Based, Cumulative Delay Estimation Algorithm

Apparent lag but more stable.



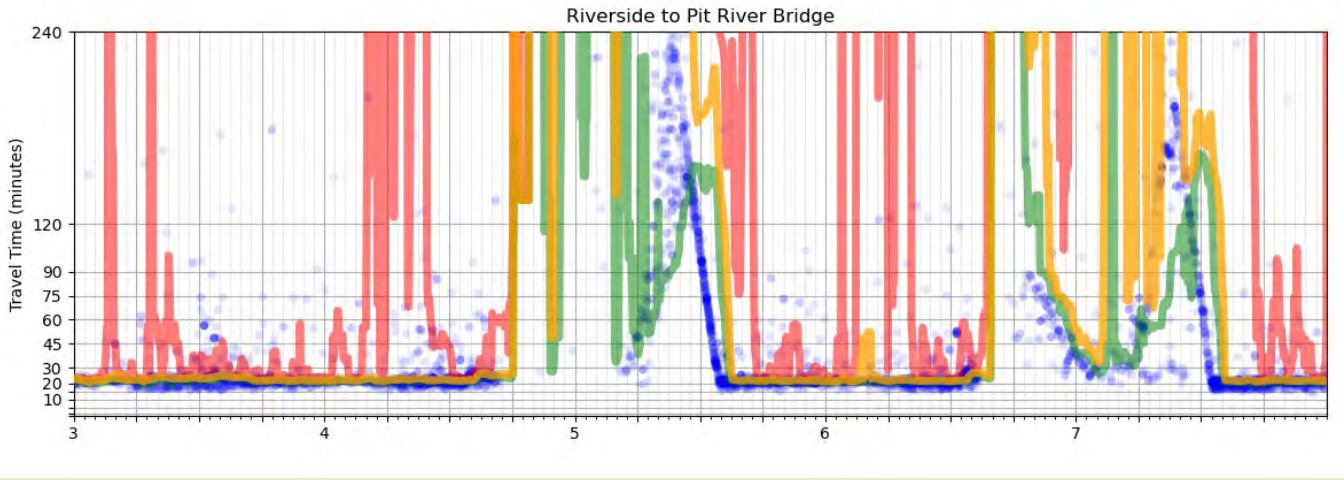
Here.com Cumulative Delay Estimation Algorithm

Comparable to BT Cumulative approach?

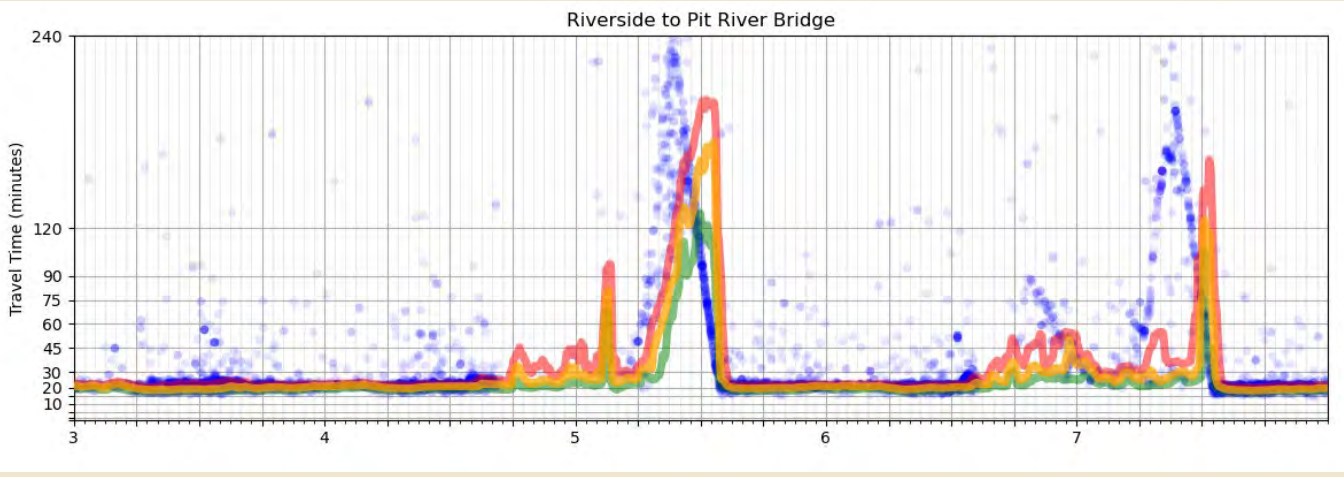


Comparison

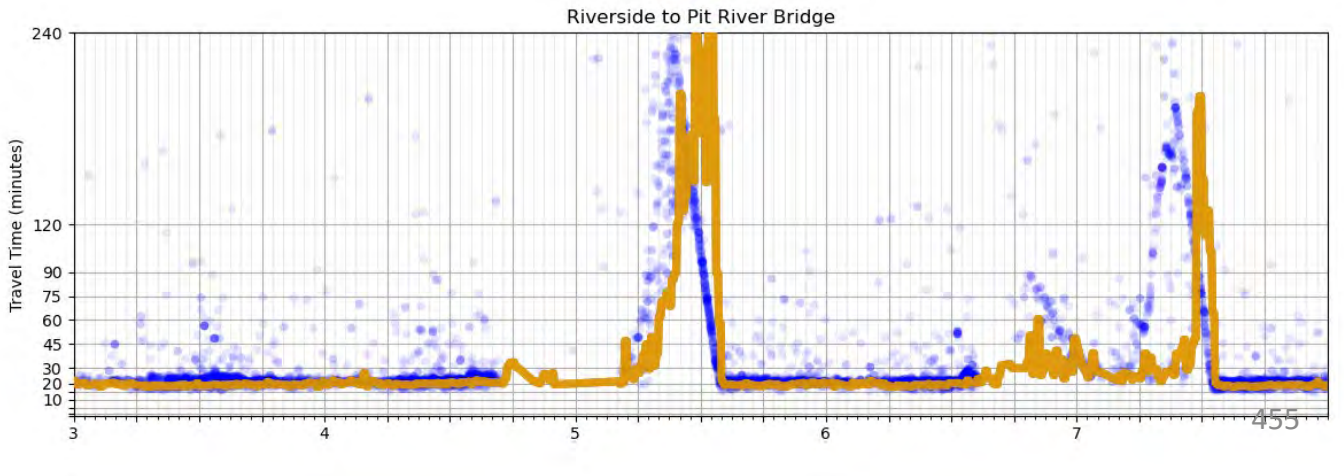
BT Direct



BT Cumulative



Here.com Cumulative



February 2025 Event Testing Summary

The BT Cumulative approach is again the best of the three, although the Here.com Cumulative approach appears to be comparable. More work needs to be done, particularly to address lag.

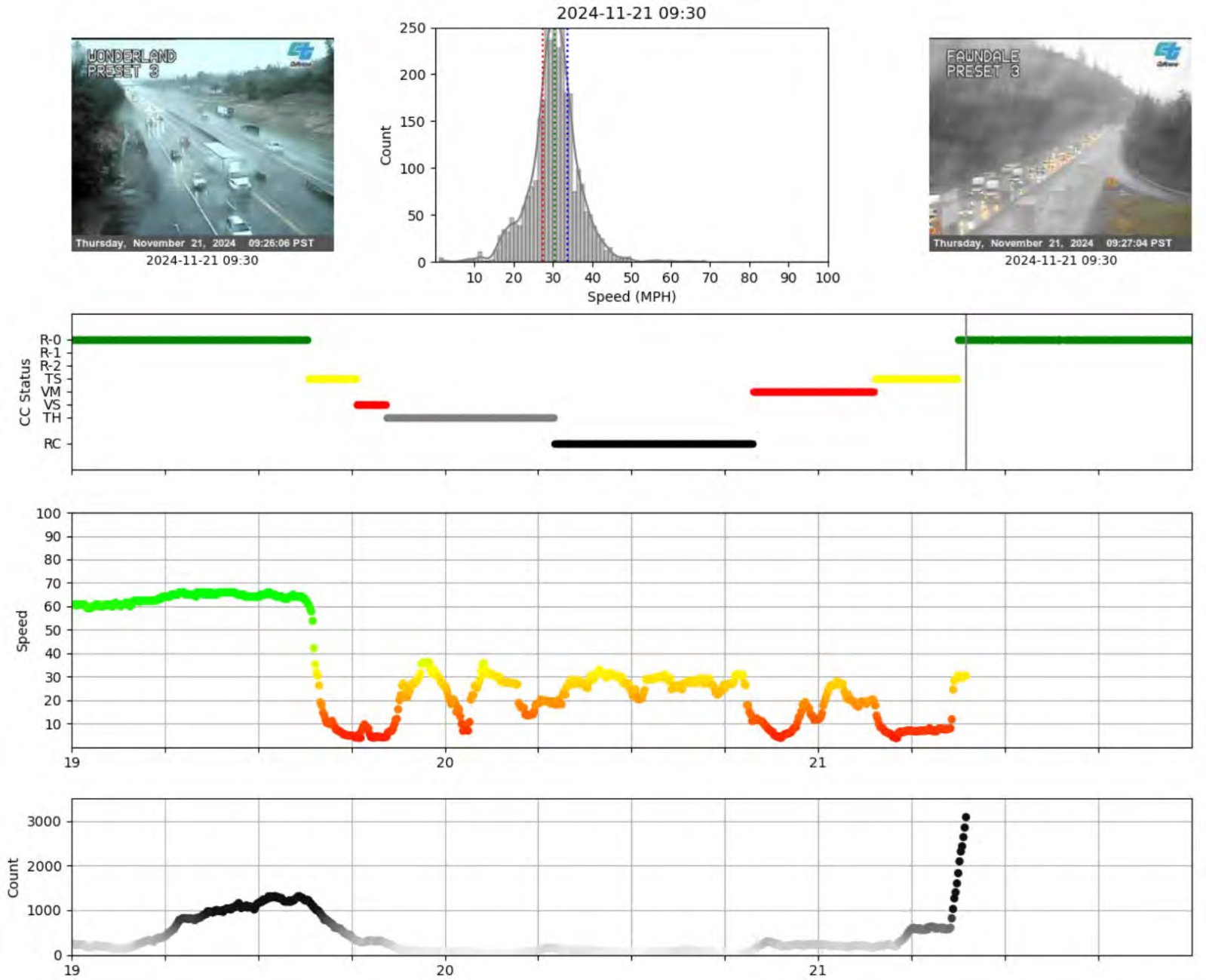
The aggregate measures show wild fluctuation and require more tuning to be usable.

Percentiles and fixed cutoffs do not appear to be sufficiently robust to work across all segments and different events. One size does not fit all. For this data a more aggressive cutoff may be needed or a different approach altogether.

More work needs to be done to address these issues.

Part 11: Related Side Project(s)

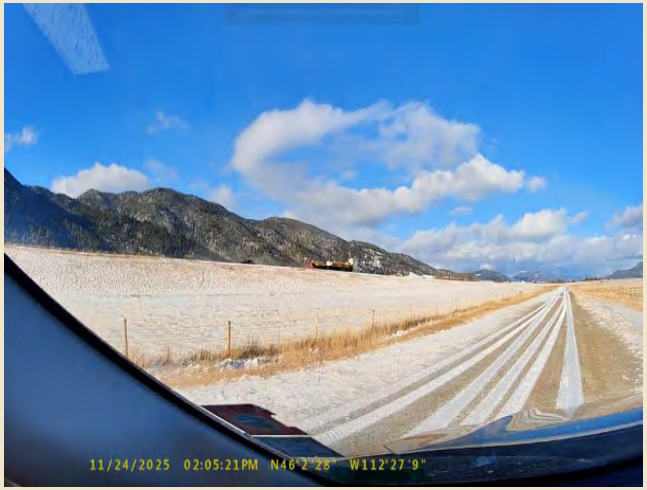
Animation


WONDERLAND
PRESET 3
Thursday, November 21, 2024 09:26:06 PST
2024-11-21 09:30
2024-11-21 09:30
Count
Speed (MPH)
FAUNDALE
PRESET 3
Thursday, November 21, 2024 09:27:04 PST
2024-11-21 09:30
CC Status
R-0
R-1
R-2
TS
VM
VS
TH
RC
Speed
Count

Data Collection in Elk Park, MT

Students:

- Avrey Coombe
- Parker Weber
- Dylan Williams
- (plus, Michael Galarus)





November 2025, March 2026

Data Collection in Elk Park, MT

Two field tests:

- November 24, 2025
- March 2, 2026

These experiments were conducted on I-15 in the Elk Park area north of Butte.

The team developed simple software to log BTLE timestamps and signals.

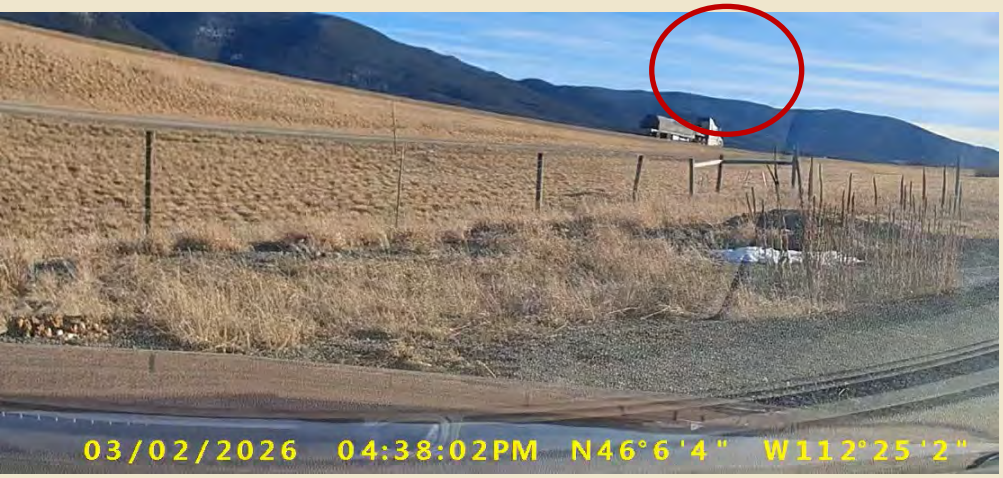
There were two monitored scanner sites on safe pull outs. Each scanner site had a Bluetooth scanner to record BTLE mac addresses and a dashcam to record video.





Data Collection in Elk Park, MT

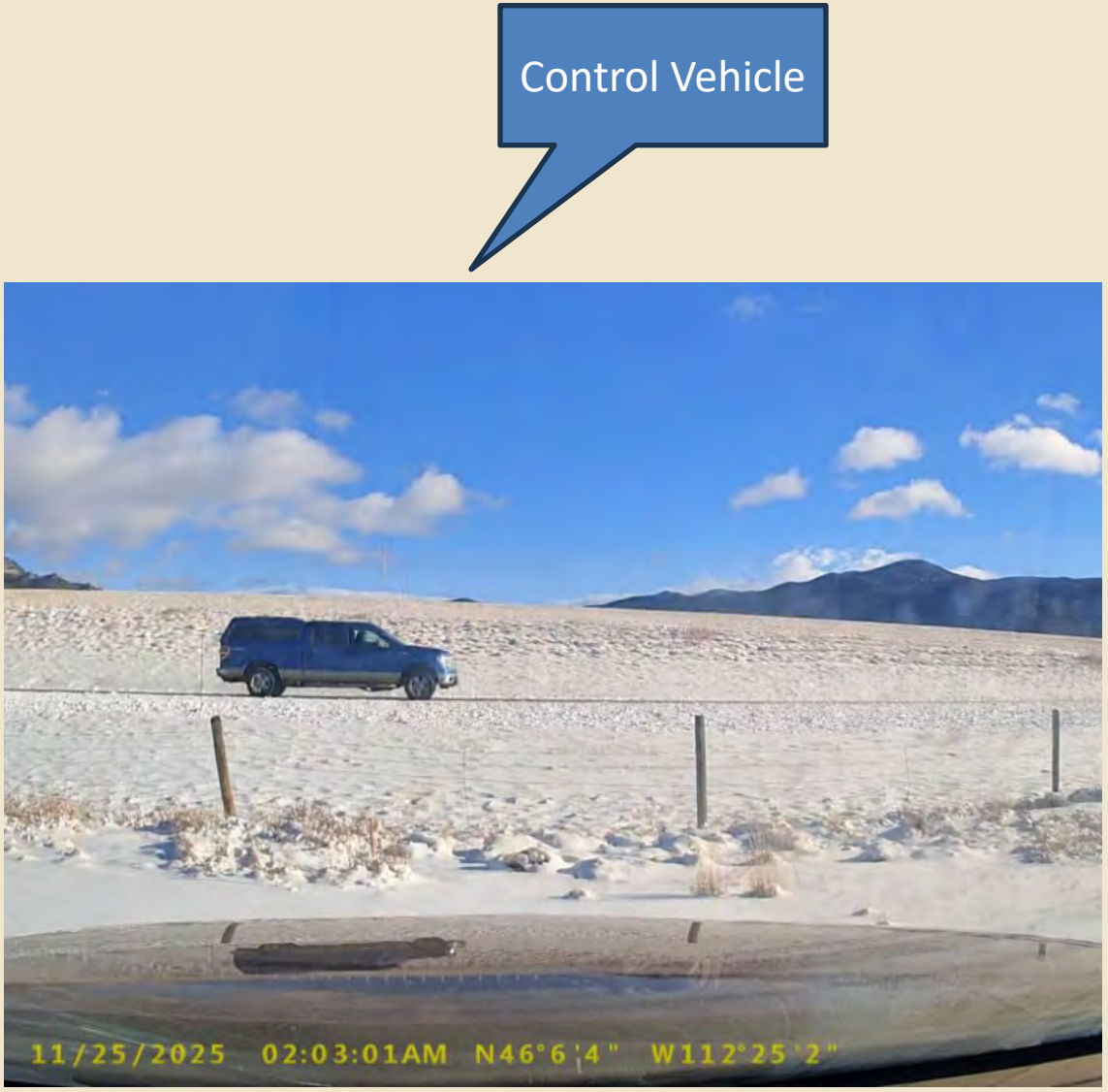
The estimated travel time between our two scanner sites was 3-5 minutes. The paired data between sites matched these estimates. This confirms that our scanners are working. The field tests also revealed some interesting BTLE behavior. Signals are sent out in triplets; the scanners consistently pick up two of these signals.





Data Collection in Elk Park, MT

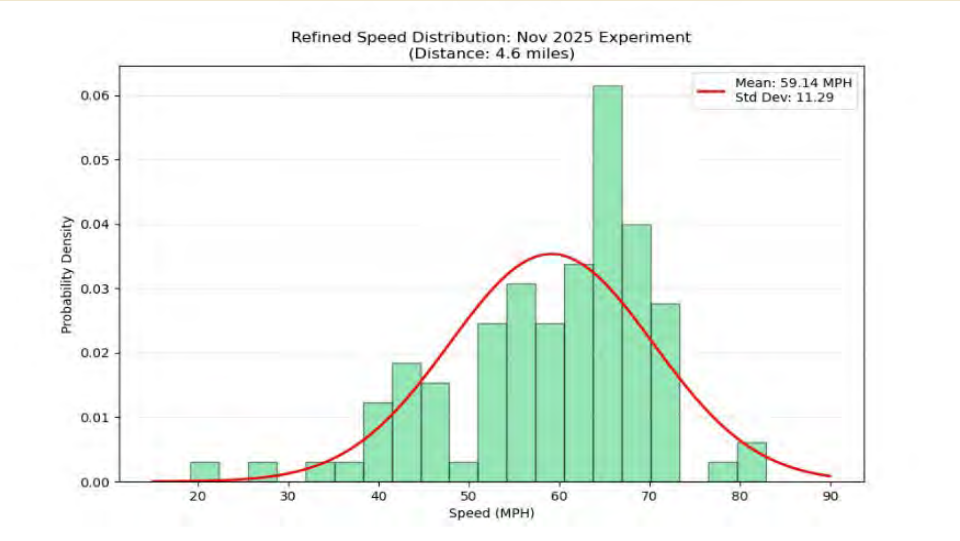
MAC Address	RSSI	Time
XX:XX:XX:XX:XX:06	-102	2:22:11 PM
XX:XX:XX:XX:XX:06	-100	2:22:11 PM
XX:XX:XX:XX:XX:06	-100	2:22:11 PM
XX:XX:XX:XX:XX:06	-100	2:22:11 PM
XX:XX:XX:XX:XX:06	-102	2:22:11 PM
XX:XX:XX:XX:XX:06	-102	2:22:11 PM
XX:XX:XX:XX:XX:06	-96	2:22:13 PM
XX:XX:XX:XX:XX:06	-98	2:22:13 PM
XX:XX:XX:XX:XX:06	-100	2:22:13 PM
XX:XX:XX:XX:XX:06	-100	2:22:13 PM
XX:XX:XX:XX:XX:06	-96	2:22:13 PM
XX:XX:XX:XX:XX:06	-96	2:22:13 PM
XX:XX:XX:XX:XX:06	-100	2:22:13 PM
XX:XX:XX:XX:XX:06	-100	2:22:13 PM
XX:XX:XX:XX:XX:99	-100	2:22:14 PM
XX:XX:XX:XX:XX:06	-100	2:22:18 PM

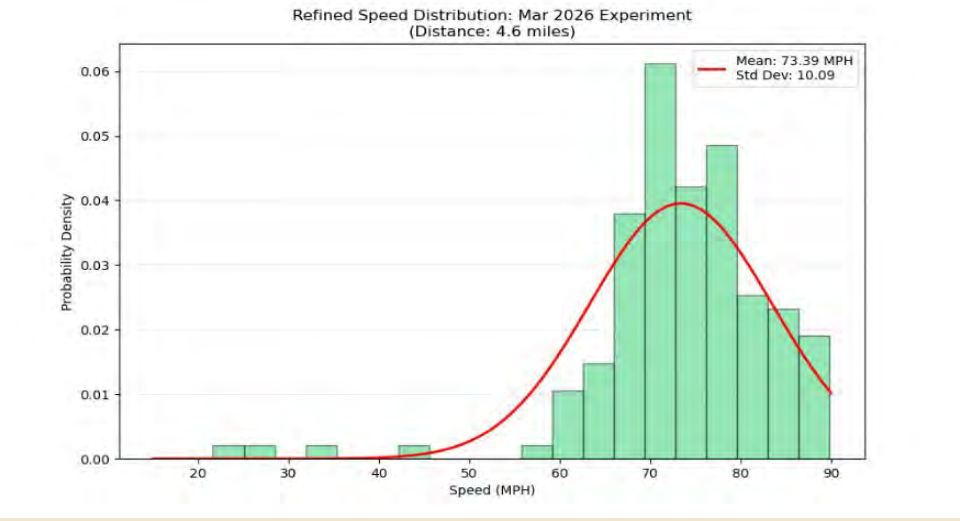


Data Collection in Elk Park, MT

Key Observations:

- Matches provided a substantial spread of data
- Average speed is what you would expect
- Noticeably slower speeds in the November experiment, which is likely due to inclement weather conditions
- Data collected is accurate enough to be used for roadside speed monitoring





Techxpo 2026
(Montana Tech Student Research Exposition)

Bluetooth Sensing and Logging to Estimate Vehicle Speeds on Rural Highways - Software Development and Field Evaluation

MONTANA TECHNOLOGICAL UNIVERSITY

Team Members: Avrey Coombe, Parker Weber, Dylan Williams, Dr. Douglas Galarus(Advisor) Computer Science Department, Montana Technological University

Background

The California Department of Transportation (Caltrans) is actively using Bluetooth and Wi-Fi signal scanning to monitor traffic and calculate travel times on I-5 North of Redding. This project is a part of a larger project conducted by Dr. Galarus and other peers, "Chain-up Delay Tracking and Estimation", which tries to predict delays caused by inclement weather, improving road safety as well as an individual's ability to plan for traffic.

The goal of this project is to replicate and explore the data gathered by Caltrans' industrial grade scanners with commercial grade equipment looking specifically at BTLE to explore the behaviors and form of the data gathered from distinct kinds of devices.





Methods

Throughout this project we did two field tests one Nov 24, 2025, the second March 2, 2026.

These experiments were conducted on I-15 centered around the Elk Park area. There were two monitored scanner sights on safe pull outs. Each scanner sight had a Bluetooth scanner to record mac addresses, and a dashcam to record video.

Scanner 1 - exit 138 , Scanner 2 - exit 134

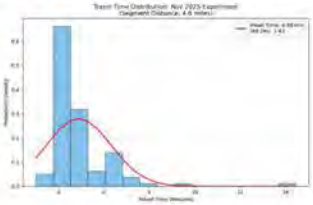
Mac Address Structure: 00:00:00:00:00:00
OUI NIC
OUI is an ID for the Bluetooth adapter NIC is device specific

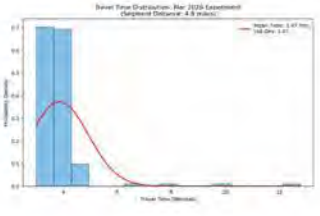


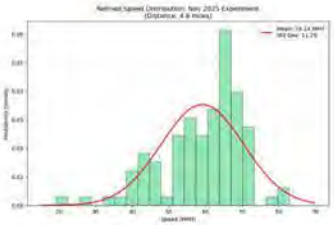


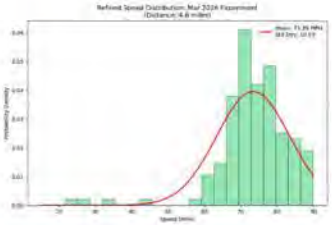
Results

The data retrieved confirmed what we see in the Caltrans data. The estimated travel time between our two scanner sights was 3-5 minutes. The paired data between sites matched these estimates. This confirms that our scanners are working. The field tests also revealed some interesting BTLE behavior. Signals are sent out in triplets; the scanners consistently pick up two of these signals.









MAC Address	RSSI	Time
XX:XX:XX:XX:XX:06	-102	2:22:11 PM
XX:XX:XX:XX:XX:06	-100	2:22:11 PM
XX:XX:XX:XX:XX:06	-100	2:22:11 PM
XX:XX:XX:XX:XX:06	-100	2:22:11 PM
XX:XX:XX:XX:XX:06	-102	2:22:11 PM
XX:XX:XX:XX:XX:06	-102	2:22:11 PM
XX:XX:XX:XX:XX:06	-96	2:22:13 PM
XX:XX:XX:XX:XX:06	-98	2:22:13 PM
XX:XX:XX:XX:XX:06	-100	2:22:13 PM
XX:XX:XX:XX:XX:06	-100	2:22:13 PM
XX:XX:XX:XX:XX:06	-96	2:22:13 PM
XX:XX:XX:XX:XX:06	-96	2:22:13 PM
XX:XX:XX:XX:XX:06	-100	2:22:13 PM
XX:XX:XX:XX:XX:06	-100	2:22:13 PM
XX:XX:XX:XX:XX:99	-100	2:22:14 PM
XX:XX:XX:XX:XX:06	-100	2:22:18 PM
XX:XX:XX:XX:XX:06	-100	2:22:18 PM
XX:XX:XX:XX:XX:B2	-98	2:22:46 PM
XX:XX:XX:XX:XX:B3	-98	2:22:46 PM
XX:XX:XX:XX:XX:B4	-98	2:22:47 PM
XX:XX:XX:XX:XX:B5	-98	2:22:47 PM
XX:XX:XX:XX:XX:B6	-102	2:22:47 PM
XX:XX:XX:XX:XX:B7	-102	2:22:47 PM
XX:XX:XX:XX:XX:B8	-102	2:22:49 PM



Next Steps

If this project continues next steps could include creating a stationary fully enclosed deployable scanner, as well as creating a faraday cage to study specific devices signals more in depth.



Privacy Concerns

Collecting MAC addresses of devices raises significant privacy and security concerns. Although the public signals devices actively broadcast may seem innocent, they are often used without their owners' knowledge to track behavior. Many commercial entities use this information to monitor human activity. This data can be used to track movement and patterns, sometimes even tracking a specific individual's behavior.

In our research, we found that some devices attempt to mitigate this risk by changing their address every few minutes. Older and less secure devices, such as headphones, unfortunately do not change their MAC addresses.

Acknowledgements

Thank you to Dr. Douglas Galarus for providing us with this project and his continued support throughout the project. Thank you to the Montana Technological University for our permitted use of resources for our field tests.

Part 12: Conclusions and Next Steps

Why deploy and use Bluetooth Sensors?

Good for the “research” side of this project.

Bluetooth sensors that we control provide unbiased ground-truth and situational awareness.

We have full control over the data – no reliance on a single vendor, no proprietary methods or secret sauce.

Why not to deploy and use Bluetooth Sensors?

We may determine that 3rd-party paid data is sufficient for the chain-up delay application. We will continue use the Bluetooth data to evaluate this.

If 3rd-party paid data proves sufficient, it will open the door to further applications and greater coverage without deployment of additional sensors and infrastructure. This would be a positive outcome, enabling corridor-wide applications such as winter travel time estimation.

Data Wrangling for the Bluetooth data is non-trivial.

Background

Is it too late? Is Bluetooth detection now out of vogue? Useful?

Cons from A. Chavez's 2019 WSF Presentation 2019

1. Low Rural nenetration – **Expect this to be less of an issue along the I-5 corridor**
2. HW Failure – **Of the 12 sensor, 0 HW failure in 2.5-years**
3. Snowpack – **We can live with this as we have other elements in snow country**
4. Rural power – **Use existing ITS nodes, all nodes have a BBS**
5. Few cabinets – **Use existing ITS nodes**
6. Duplicate MAC Addresses – **So far not an issue**
7. 2.4 GHz Interference – **So far, not an issue**
8. Erratic Travel Times – **N/A**

Conclusions

The Bluetooth sensor data appears to capture important information characterizing chain control events at Fawndale including travel time, stopped traffic, and length of the impacted area.

We are still confident that this data can be used to develop a real-time delay estimation algorithm.

Further work will need to be done to address challenges including lag.

Next Steps

Continue to refine and tune the data.

Further develop and test algorithm(s). – there was not much to look at for 2025-26 Bad Weather Season

Bluetooth data compared to other 3rd party paid data (Inrix?) Can we get this from Caltrans?

Big Picture WSRTC Goal – Integrate the outcome of this effort into a corridor-based winter travel time estimation system.

For Further Information Contact:

Jeremiah Pearce, P.E.
Chief, Office of ITS Engineering and Support
Caltrans, District 2
1657 Riverside Drive
Redding, CA 96001
(530) 225-3320
(530) 225-3255 (fax)

jeremiah.pearce@dot.ca.gov
https://dot.ca.gov/caltrans-near-me/district-2

Douglas Galarus, PhD
Associate Professor
Department of Computer Science
Montana Tech
Museum 202
1300 West Park Street
Butte, MT 59701
(406) 496-4858

dgalarus@mtech.edu
https://cs.mtech.edu/