Effect of Signal Control on Bimodal Travel Time Distributions

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VDOT
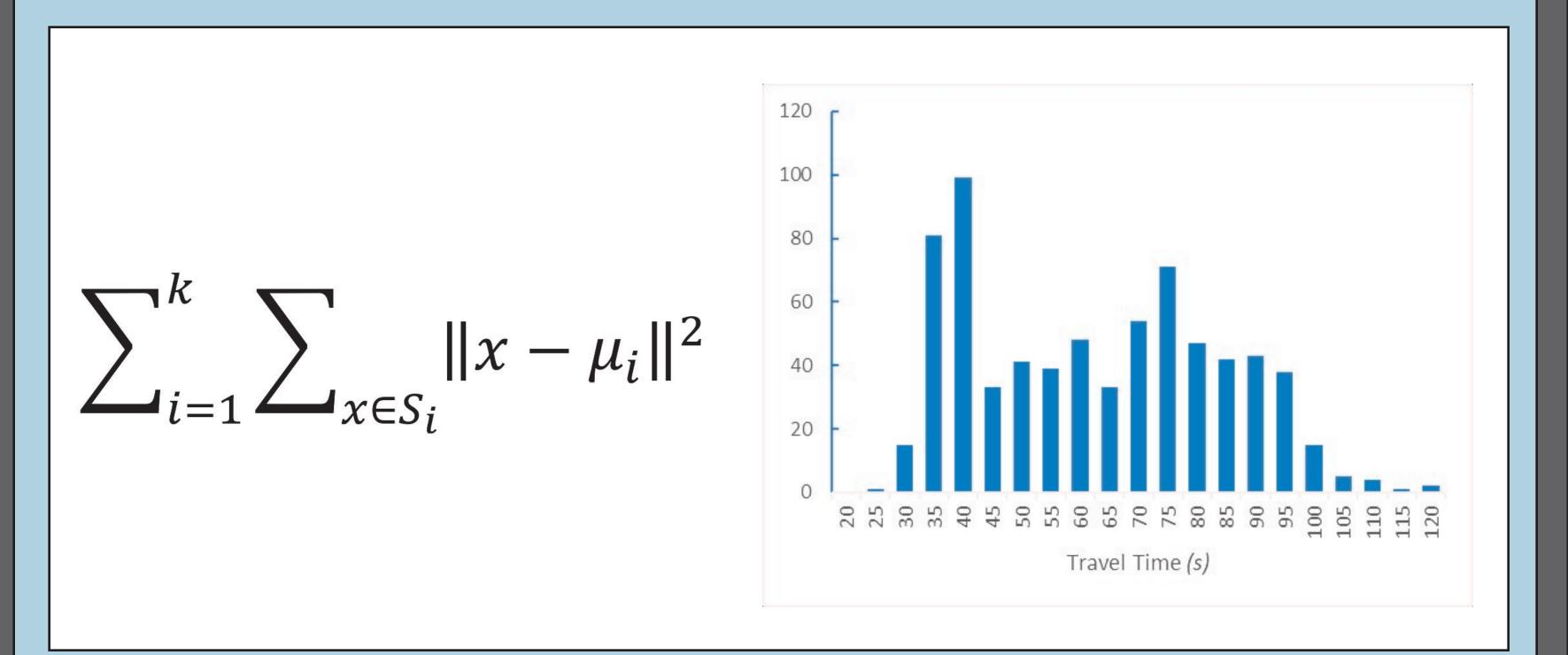Virginia Department of Transportation

INTRODUCTION

- Bluetooth and WiFi sensors can be used to measure individual vehicle travel times along a corridor

- On freeways, travel times creates a unimodal distribution. When measured along signalized intersections and corridors, travel times have been observed to demonstrate **bimodality.**

- Existing literature fits travel time data to bimodal distributions, but does not investigate the way in which signal control may affect the attributes of the distribution.

- Objective of this research is to identify relationships between signal control parameters and the difference in average travel time between two populations in a bimodal distribution.

THEORY

- Red phases are the primary source of delay on signalized corridors

- At **isolated intersections** with uniform vehicle arrival:
  - Some vehicles arrive during green and experience no delay
  - Others arrive during red phase at a uniform rate, experience on average half the delay of the entire red phase

- At **coordinated intersections** with platoon vehicle arrival:
  - Most vehicles arrive during green and experience no delay
  - A few vehicles arrive at the end of a green phase, and experience the entire red phase delay.

Population travel time difference =
0.5 x red time + lost time

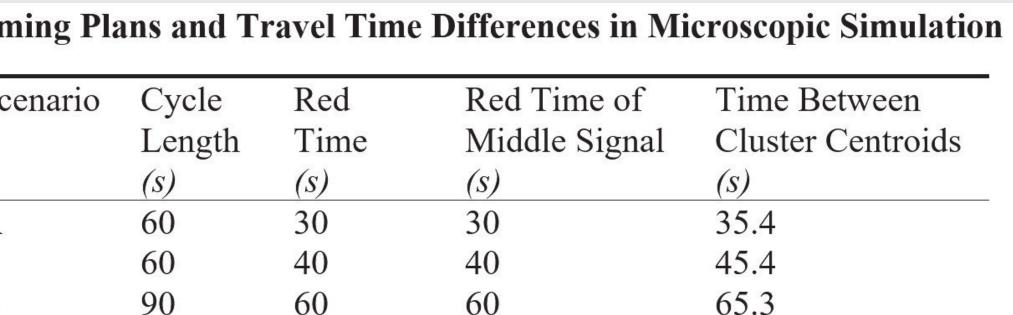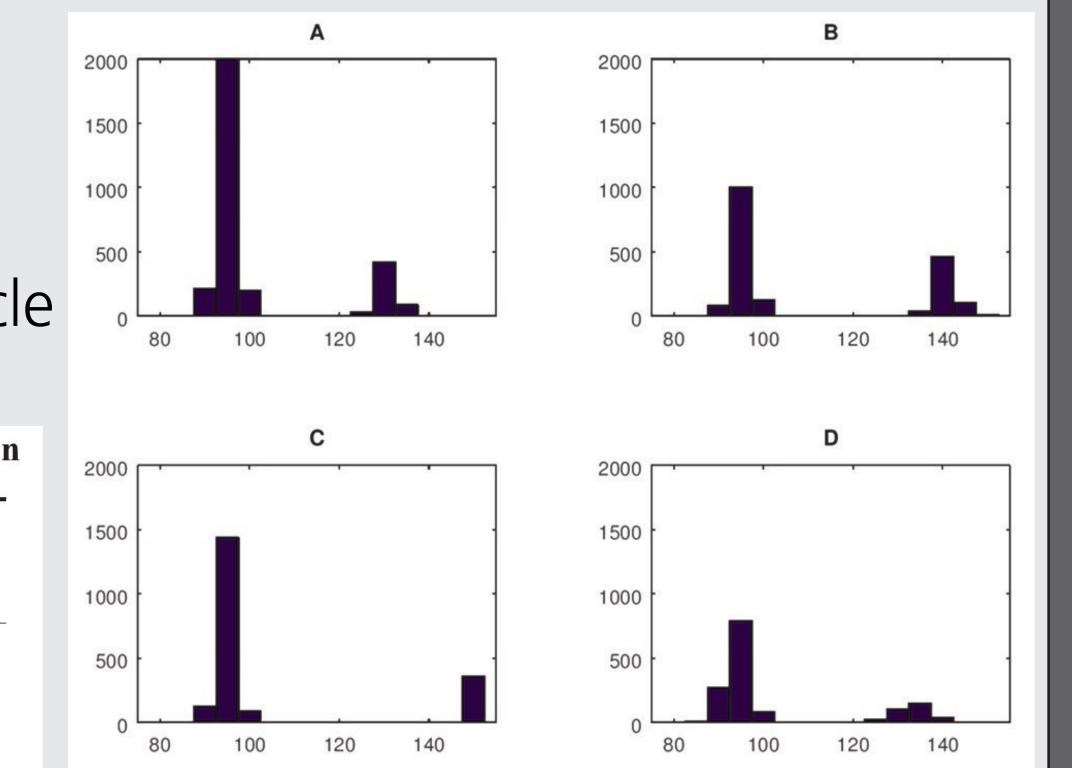Population travel time difference =
red time + lost time

CLUSTERING POPULATIONS

- Used k-means clustering to differentiate different travel time populations.

- Used visual inspection to establish bimodality.

$$\sum_{i=1}^{k} \sum_{x \in S_i} \| x - \mu_i \|^2$$
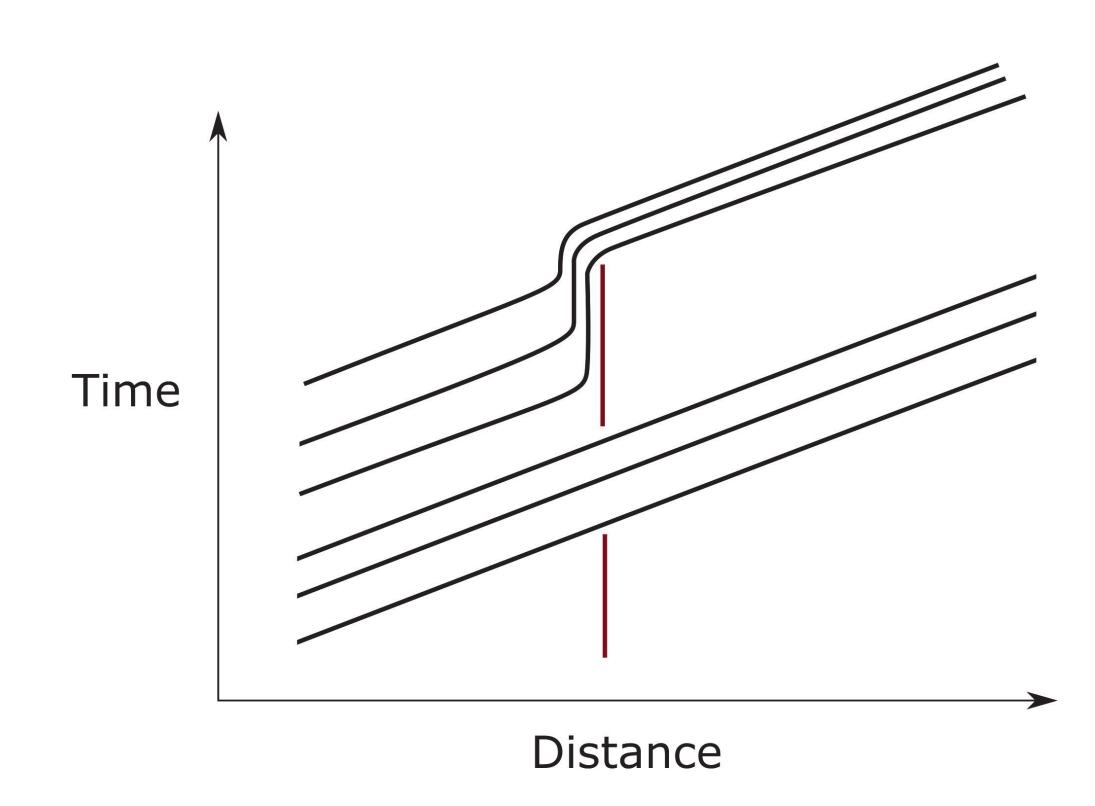

SIMULATION

- Simulated, four-signal one-way corridor in VISSIM

- First signal acts as meter to form platoons, while last three signals coordinated based on design speed.

- Four scenarios of various cycle lengths and red phases tested.

- Differences in travel times between two populations were equivalent to the longest red time plus approximately five seconds for vehicle acceleration
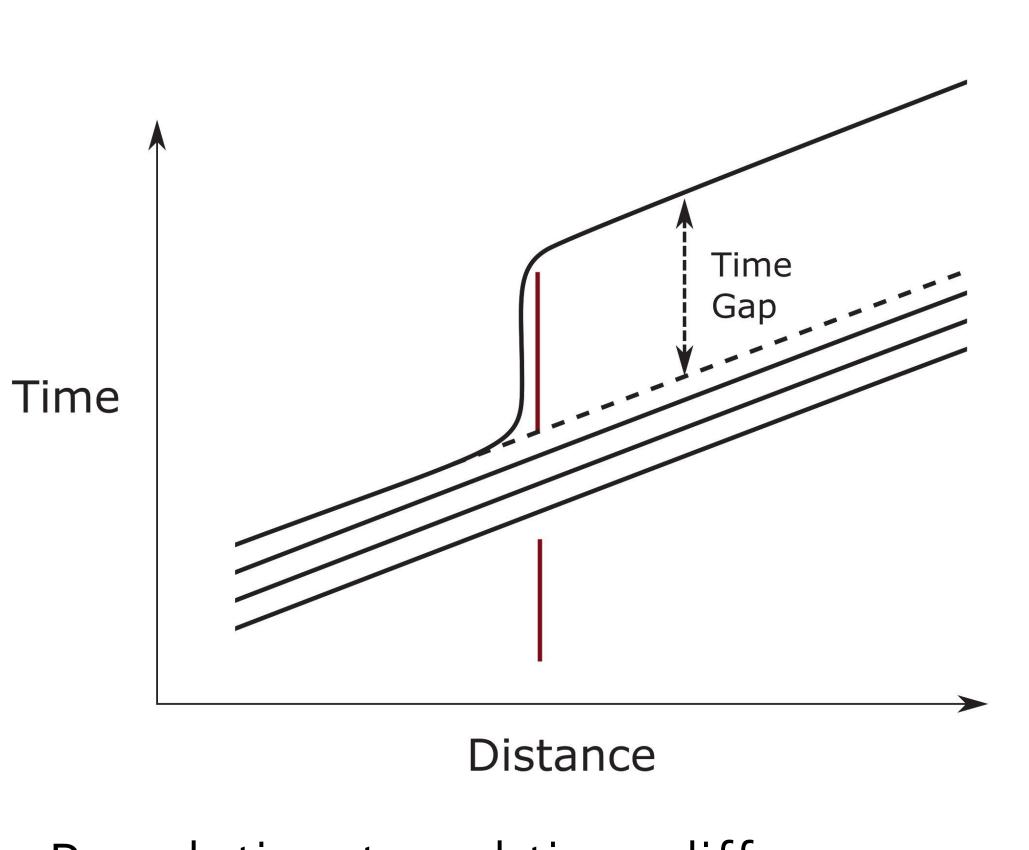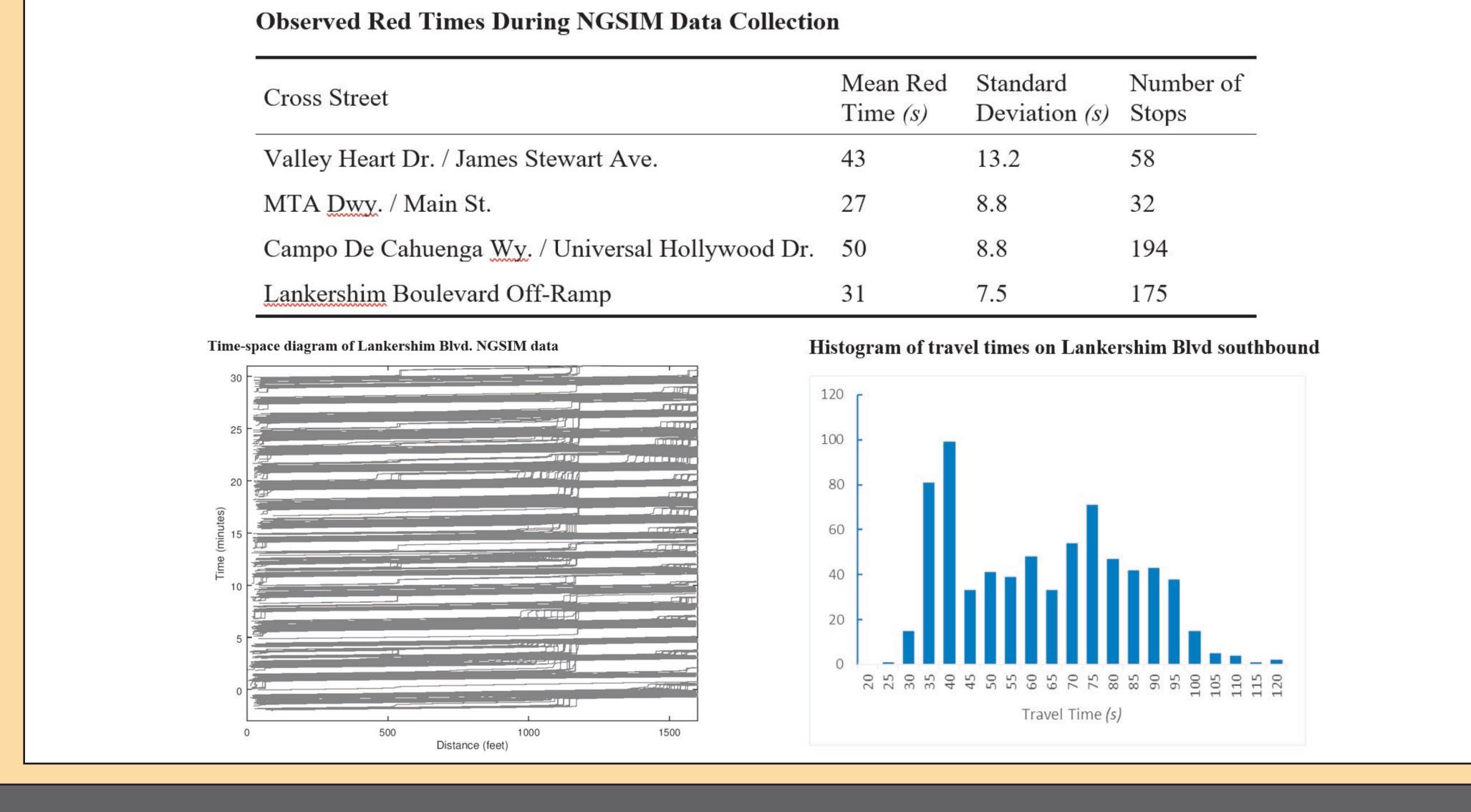
Timing Plans and Travel Time Differences in Microscopic Simulation

Scenario	Cycle Length (s)	Red Time (s)	Red Time of Middle Signal (s)	Time Between Cluster Centroids (s)
A	60	30	30	35.4
B	60	40	40	45.4
C	90	60	60	65.3
D	60	30	40	39.5

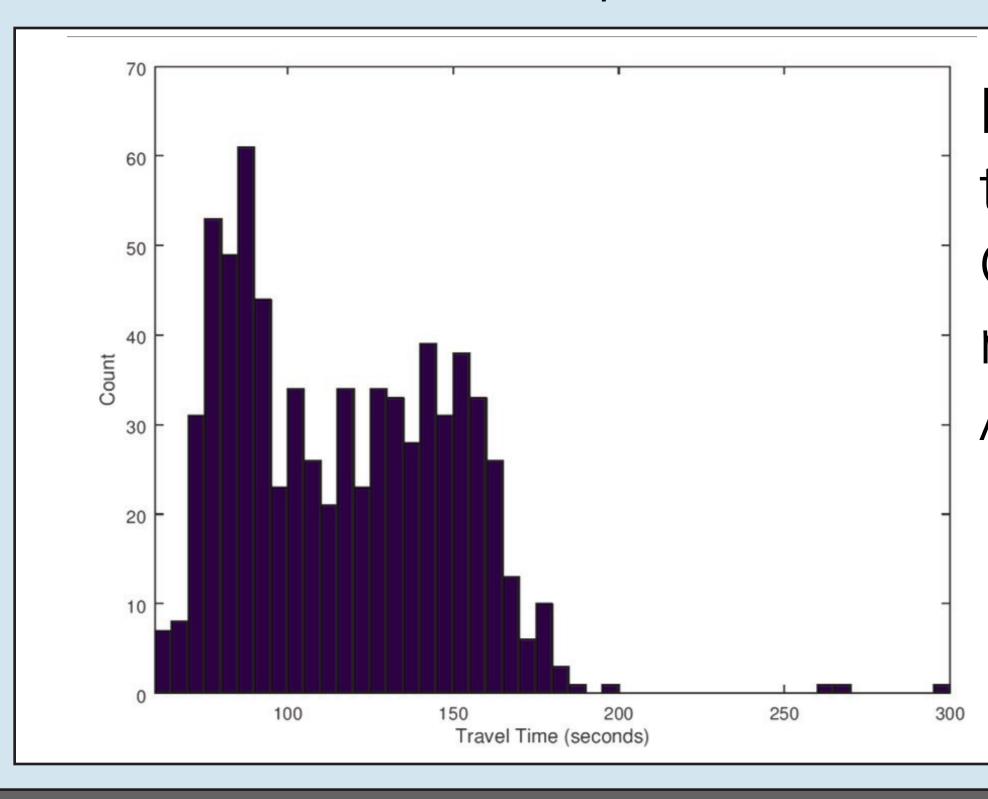Histograms of simulated travel times *(seconds)*

EMPIRICAL VEHICLE TRAJECTORY DATA

- Data from NGSIM video-collected vehicle trajectories on the Lankershim Blvd. coordinated, signalized corridor were analyzed.

- Found **35 second difference in average travel time**, which seemed driven by the high number of stops at the Lankershim Blvd. Off-Ramp intersection's **31 second red time**.

Observed Red Times During NGSIM Data Collection

Cross Street	Mean Red Time (s)	Standard Deviation (s)	Number of Stops
Valley Heart Dr. / James Stewart Ave.	43	13.2	58
MTA Dwy. / Main St.	27	8.8	32
Campo De Cahuenga Wy. / Universal Hollywood Dr.	50	8.8	194
Lankershim Boulevard Off-Ramp	31	7.5	175

Time-space diagram of Lankershim Blvd. NGSIM data

Histogram of travel times on Lankershim Blvd southbound

BLUETOOTH REIDENTIFICATION DATA

- Bluetooth sensors were placed along a four-signal, 1 mile (1.6 km) segment of US-29, a high-volume arterial in Charlottesville, Virginia.

- Data was collected continuously from October 19-27, 2016, focusing on AM peak direction.

- Only signal timing plans available, not actual phase times. Max gap outs were assumed.

- Faster population traveled at 45 mi/hr speed limit, **suggesting they did not encounter red phases.**

- Slower population traveled **57 seconds slower**, 9 seconds longer than the average **maximum red time of 49 seconds**. Supports theory that travel time difference is related to red time plus vehicle acceleration time.

Histogram of travel times for US-20 in Charlottesville northbound during AM peak period.

Maximum Red Times for US-29 SB, AM Peak Period

Cross Street	Maximum Red Time (s)
Hydraulic Road	65
Seminole Court	48
Greenbrier Drive	54
Lenox Avenue	25
Average	48

CONCLUSIONS

- Travel times on signalized corridors have been shown to be bimodal. This is the first effort to investigate the effect of signal control on bimodal characteristics.

- Simulation and field data support three theories:
  1. Fast populations on short segments are not experiencing signal delay.
  2. Slow populations on coordinated segments are slower by an entire red phase plus time for acceleration and deceleration.
  3. Slow populations on non-coordinated segments are slower by half the red phase plus time for acceleration and deceleration.

- Deviations may suggest signal timing issues. Unimodal distributions may indicate over capacity. An unusual time difference between fast and slow populations may indicate a specific signal that is acting as a bottleneck.