Automated, Connected, Electric, Shared, Safe Mobility

THE UNIVERSITY OF ALABAMA® | Alabama Transportation Institute

ACES² MOBILITY

April 28, 2022

Mission

The mission of the Alabama Transportation Institute at The University of Alabama is to **facilitate and reflect world-class leadership in interdisciplinary transportation research that serves the State of Alabama and beyond.**

THE UNIVERSITY OF ALABAMA | Alabama Transportation Institute

ATI Affiliated Centers at UA

ATI partners with a wide variety of research centers at the University of Alabama. Together we can serve the community through a truly interdisciplinary approach.

Alabama Center for Insurance Information and Research
CULVERHOUSE COLLEGE OF BUSINESS

Center for Advanced Public Safety
COLLEGE OF ENGINEERING

Center for Advanced Vehicle Technologies
COLLEGE OF ENGINEERING

Center for Business and Economic Research
CULVERHOUSE COLLEGE OF BUSINESS

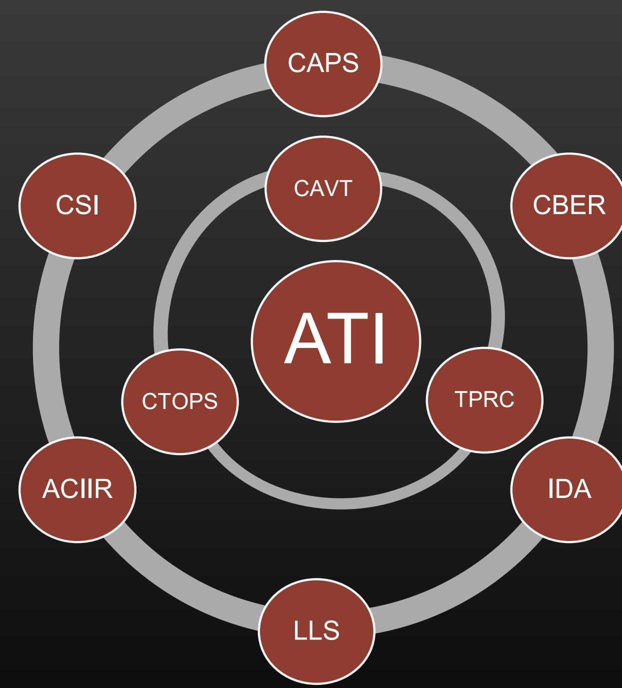
Center for Sustainable Infrastructure
COLLEGE OF ENGINEERING

Center for Transportation Operations, Planning and Safety
COLLEGE OF ENGINEERING

Institute of Data and Analytics
CULVERHOUSE COLLEGE OF BUSINESS

Laboratory for Location Science
COLLEGE OF ARTS AND SCIENCES

Transportation Policy Research Center
RESEARCH & ECONOMIC DEVELOPMENT



THE UNIVERSITY OF ALABAMA | Alabama Transportation Institute

ATI Research Themes

/ RESEARCH THEME ONE /

Digital Transportation

Modern transportation simultaneously generates and relies on enormous amounts of data as the operational requirements to provide accessibility and mobility become increasingly linked to development of smart, connected cities and communities. ATI is embracing the challenge and opportunity of the new data-driven transportation paradigm by cultivating and supporting expertise in the efficient and secure collection, storage, and analysis of transportation-derived data.

/ RESEARCH THEME FOUR /

Electric Vehicles & Fuel Economy

In recognition of the finite supply, security challenges, and environmental consequences associated with fossil fuel consumption, the world is begun preparing for a global shift in how transportation will be powered in the future.

Through rigorous, academic research in partnership with a range of industry and governmental stakeholders, ATI is at the forefront of designing the next generation of electric vehicles and the infrastructure necessary to integrate them into the transportation system.

/ RESEARCH THEME TWO /

Connected Vehicles & Infrastructure

As communications technologies continue to pervade human life and civil society, the physical components of the transportation system will continue to be increasingly connected to each other. ATI is leading research, in the laboratory and in the field, to design and test the latest equipment and protocols that will be necessary to realize the full potential of these new transportation technologies.

/ RESEARCH THEME THREE /

Transportation Safety, Security, & Accessibility

Access to safe and secure transportation is foundational to an economically dynamic and socially inclusive society. ATI fosters an interdisciplinary research portfolio aimed at enhancing quality of life by connecting individuals, communities, and economies via a highly functional transportation system that balances the mandate to provide cost effective, efficient solutions with the needs of the full range of potential system users.

/ RESEARCH THEME FIVE /

Sustainable Transportation Infrastructure

Functional transportation infrastructure is the foundation of vibrant communities and economies. ATI facilitates both basic and applied research into new materials, designs, as well as construction and maintenance techniques to enhance the sustainability and resiliency of surface transportation infrastructure.


ALABAMA MOBILITY AND POWER CENTER
Alabama Power
THE UNIVERSITY OF ALABAMA
Mercedes-Benz
U.S. International, Inc.

OUR MISSION

To fuel innovative research in the field of e-mobility and bring together academia, industry, and government to pursue advancements in electrification and digitization.

TIMELINE

September 2020
Idea Proposed

November 2020
Initial Strategic Plan Developed with a consultant

April 2021
MOU signed with Alabama Power and MBUSI to establish AMP

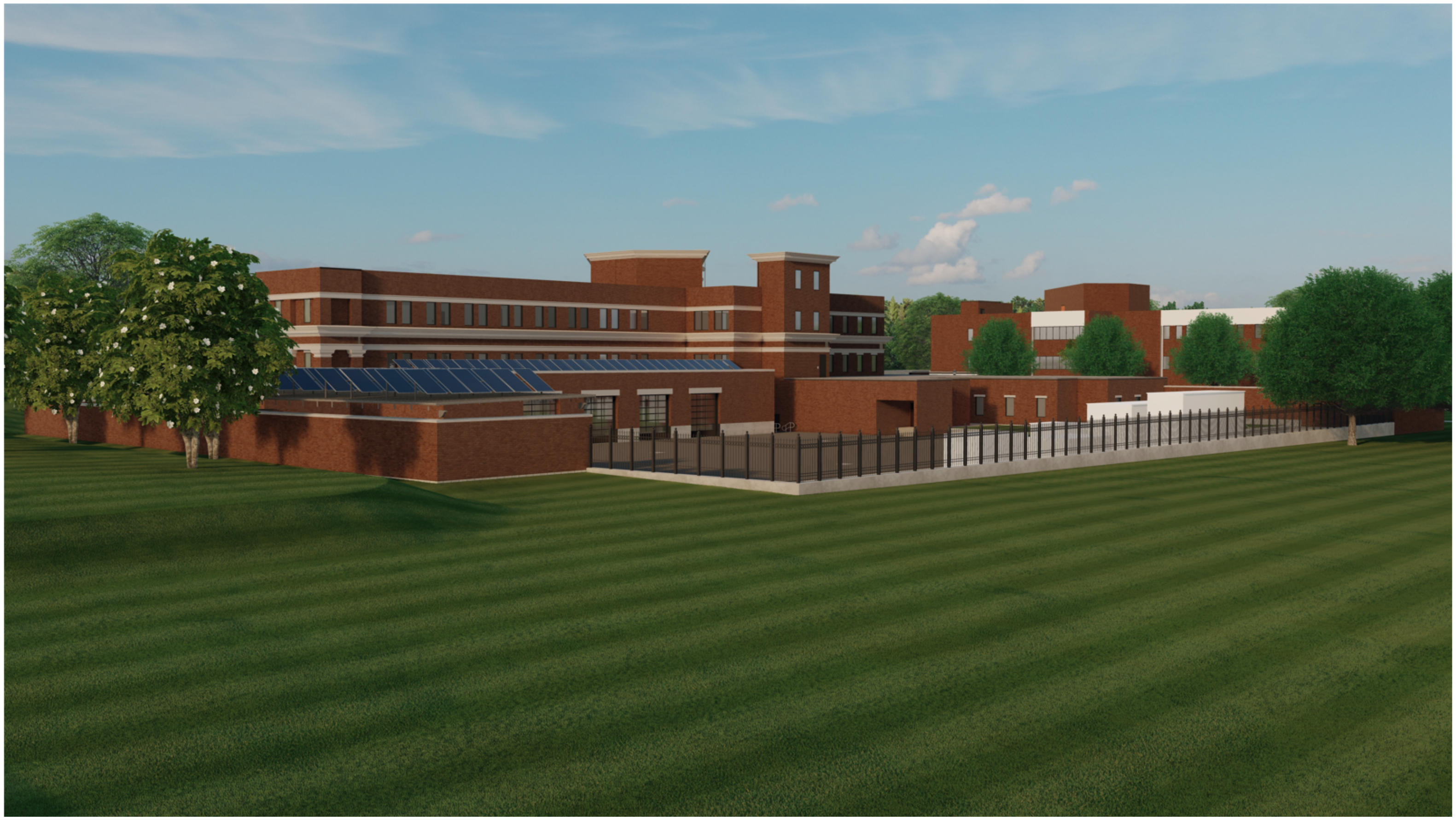
July 2021
State of Alabama awards $16.5M to construct the Smart Communities and Innovation Building

January 2022
Executive Director search initiated

SMART COMMUNITIES AND INNOVATION BUILDING

Looking Southeast
from Kirkbride Lane

SCIB



Looking Northeast
from Randall Way

EXECUTIVE DIRECTOR SEARCH

Implement a vision for electric vehicle research and education including basic cell materials and chemistry, battery pack management, manufacturing, and integration of electric vehicles into the power grid.

Work closely with existing centers affiliated with the Alabama Transportation Institute and external stakeholders to support collaborative proposal development and project management for large team efforts.

Provide effective leadership over the full range of disciplines represented by the AMP Center.

Foster and support high quality research and scholarly activities within the AMP Center by ensuring a stimulating, collegial, and well-managed environment.

MAJOR THEMES

01

Preparing the electric vehicle workforce

02

Driving collaborations between industry and UA

03

Creating innovations in electric vehicle R&D, including battery technology and manufacturing and use

04

Developing effective and sustainable vehicle charge infrastructure

THE UNIVERSITY OF
ALABAMA®

Evaluating Transportation Network Mobility and Enhancing Traffic Signal Operations Performance Using Probe Data and Connected Vehicle Technology

Md Abu Sufian Talukder

Doctoral Dissertation Defense

Alex Hainen

College of Engineering
Civil, Construction and Environmental Engineering

June 11, 2021

Presentation Outline

- **Past Academic Credentials and Projects**
  - Credentials and Experience
  - Coursework
  - Field Works and Projects Involvements
- **Dissertation Discussion**
  - Dissertation Motivation
  - **Paper #1:** Characterizing Transportation Network Mobility [**Published**]
  - **Paper #2:** Trajectory-Based Signal Control [**Published**]
  - **Paper #3:** Connected Freight Signal Priority System[**Published**]
- **Dissertation Conclusions**
  - Novelty and Contribution to Academia and Industry
  - Future Research Directions

Dr. Sufian Talukder, PhD – AECOM 2021

- Completed Masters in Civil Engineering in Summer 2018
- President and Member - ITE Student Chapter at UA
- **Teaching Experience**
  - ***Taught Classes:*** CE 350 – Intro to Transportation Engineering, CE 458 – Traffic Engineering, CE 573 – Statistical Applications
- **Publications and Presentations**

1. [Published] **Talukder, M.**, Lidbe, A., Tedla, E., Hainen, A. and Atkison, T., 2021. Trajectory-Based Signal Control in Mixed Connected Vehicle Environments. *ASCE - Journal of Transportation Engineering Part A: Systems.*
2. [Published] **Talukder, M**., Hainen, A., Remias, S., Bullock, D. 2018. Route Based Mobility Performance Metrics Using Probe Vehicle Travel Times*, Advances in Transportation Studies.*
3. [Published] Islam, N., **Talukder, M**., Hainen, A., Atkison, T., 2019, Characterizing Co-modality in Urban Transit Systems from a Passengers Perspective, *Journal of Public Transport.*
4. [Published] Li, H., Hainen, A, Sturdevant, J., Atkison, T., **Talukder, M.**, *et.al*. 2019 Indiana Traffic Signal Hi Resolution Data Logger Enumerations, *Indiana Department of Transportation and Purdue University, West Lafayette, Indiana*.
5. [Presented] **Talukder, M.** and Hainen, A., 2021. A Digital Twin for Traffic Monitoring and Proactive Incident Management. USDOT ITS PCB T3e Webinar.
6. [Presented] **Talukder, M.**, Lidbe, A., Tedla, E., Hainen, A. and Atkison, T., 2021. Development and Evaluation of a Weighted Delay-Based Signal Control Algorithm for Connected and Non- Connected Vehicles. *Transportation Research Board 100th Annual Meeting*
7. [Presented] Penmetsa, P., **Talukder, M.**, Islam, N., Adanu, E., Li, X., Harbin, K. and Hainen, A., 2021. Analysis of Emergency Incidents Regarding Natural Gas Distribution Pipelines. *Transportation Research Board 100th Annual Meeting.*
8. [Presented] **Talukder, M.**, Hainen, A. and Atkison, T. 2019. Enhanced Traffic Signal Performance Measures. *Gulf Region Intelligent Transportation Society (GRITS)*.
9. [Presented] Zephaniah, S., **Talukder, M.**, Hainen, A. and Jones, S. 2017. A Comprehensive Examination of the Relationship between Crashes and Congestion along Interstate Highways in Alabama. *Road Safety Simulation International Conference*.

Analytical and Empirical Evaluation of Freight Priority System in Connected Vehicle Environment

Presented June 2021

Analytical and Empirical Evaluation of Freight Priority System in Connected Vehicle Environment

Md Abu Sufian Talukder[1]; Elsa G. Tedla[2]; Alexander M. Hainen, Ph.D., M.ASCE[3]; and Travis Atkison, Ph.D.[4]

[1]Ph.D. Student, Dept. of Civil, Construction and Environmental Engineering, Univ. of Alabama, P.O. Box 870288, Tuscaloosa, AL 35487-0205 (corresponding author). Email: mtalukder@crimson.ua.edu

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[3]Associate Professor, Dept. of Civil, Construction and Environmental Engineering, Univ. of Alabama, P.O. Box 870288, Tuscaloosa, AL 35487-0205. Email: ahainen@eng.ua.edu

[4]Assistant Professor, Dept. of Computer Science, Univ. of Alabama, P.O. Box 870290, Tuscaloosa, AL 35487-0205. Email: atkison@cs.ua.edu

Introduction

Traffic signal priority is an operational strategy from Intelligent Transportation System (ITS) which has been generally used in the form of Transit Signal Priority (TSP) to improve operation performance of transit vehicles. In recent years, several research efforts and implementations indicate the operational benefit that can be achieved from TSP which notably includes reduced travel time and delays, fewer no of stops, improved schedule adherence, and lower emissions (Muthuswamy, et al., 2007; Ekeila, et al., 2009; Liao & Davis, 2011; Wang, et al., 2013; Yelchuru, et al., 2014; Hu, et al., 2014; Ahn, et al., 2015; Song,

Published April 2022

Check for updates

ASCE

Analytical and Empirical Evaluation of Freight Priority System in Connected Vehicle Environment

Md Abu Sufian Talukder[1]; Elsa G. Tedla[2]; Alexander M. Hainen, Ph.D., M.ASCE[3]; and Travis Atkison, Ph.D.[4]

Abstract: The transit signal priority (TSP) strategy has been widely adopted as a practical approach to improving the efficiency and reliability of transit operations. Over the years, few studies have adopted the concept of TSP to implement freight signal priority (FSP) for improving the safety and operational performances of freight vehicles. Despite the promising outcome in previous studies, several drawbacks, such as inaccurate estimation of a freight's arrival time at a stop bar and inefficient use of priority measures, have prevented their wide applications. This paper aims to develop a FSP system that utilizes emerging connected vehicle technology to overcome the challenges associated with conventional FSP systems. An estimated time of arrival (ETA)-based FSP logic was developed and analytically examined to demonstrate the operational efficiency that can be achieved. The proposed FSP system was implemented in a real-world coordinated signalized corridor for systematical analysis and validation of its field operation. Analysis results showed that the proposed FSP system can effectively address the shortcomings in traditional FSP systems by accurately estimating a freight's arrival time and providing accurate and efficient priority measures. **DOI: 10.1061/JTEPBS.0000673.** *© 2022 American Society of Civil Engineers.*

Author keywords: Freight signal priority (FSP); Signal control; Priority logic; Connected vehicle; Field experiment.

Introduction

Traffic signal priority is an operational strategy from intelligent transportation systems (ITS) and has been generally used in the form of transit signal priority (TSP). In recent years, several research efforts and implementations have indicated the operational benefit achievable from TSP, which notably includes reduced travel time and delays, fewer number of stops, improved schedule adherence, and lower emissions (Muthuswamy et al. 2007; Ekeila et al. 2009; Liao and Davis 2011; Wang et al. 2013; Yelchuru et al. 2014; Hu et al. 2014; Ahn et al. 2015; Song et al. 2016; Lee et al. 2017; Wu and Guler 2018). Similar to TSP, freight signal priority (FSP) can be a feasible solution to improving the safety and operational efficiency of freight vehicles on signalized arterials. However, relatively fewer studies have been performed concerning FSP. The majority of these studies relied on a simulation environment due to the difficulties and costs associated with field deployments.

With the limited freight-detection technology that exists in conventional traffic environments, most research on FSP focuses on using traditional loop detectors to activate priority requests (Sunkari et al. 2000; Plum 2004; Mahmud 2014; Kaisar et al. 2020). One major drawback in a loop-detection system is its inability to accurately predict freight arrival time at an intersection, which could lead to the inefficient use of priority measures. Such challenges associated with a traditional detection system can be addressed by taking advantage of emerging connected vehicle (CV) technology, which establishes rapid two-way communications between freight vehicles and intersection infrastructure. In recent years, a few studies have investigated leveraging CV technology to provide signal priority to freight vehicles (Kari et al. 2014; Ahn et al. 2015; University of Arizona, University of California PATH Program, and Savari Networks and Econolite 2016; Park et al. 2019). Although these early efforts are valuable guidelines for FSP research, they were conducted in a simulated environment and limited to the assumption of 100% vehicle-to-infrastructure (V2I) communication in place. Furthermore, these studies lack comprehensive FSP logic, systematic evaluation, and a framework on how emerging CV data are to be handled by existing traffic signal controllers.

This research attempts to overcome these shortcomings by developing a FSP system that relies on CV-based freight detection strategy for existing signal control equipment. The study developed an estimated time of arrival (ETA)-based priority logic for pilot deployment and uses high-resolution event-based operational traffic data to systematically evaluate the proposed priority system. The study also showed the benefit of such ETA-based freight priority system in the context of previous studies in this area.

Literature Review

TSP is the most conventional form of traffic signal priority strategy, which is generally accomplished by an extending green phase or truncating red phase for the priority movement. In the United States, the first TSP was introduced back in the 1970s (Evans and Skiles 1970). Since then, numerous studies have been conducted to demonstrate the benefits achievable from TSP. However, very limited research has been done regarding FSP. In 2019, the Urban Mobility

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Note. This manuscript was submitted on July 7, 2021; approved on January 7, 2022; published online on April 7, 2022. Discussion period open until September 7, 2022; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Transportation Engineering, Part A: Systems***, © ASCE, ISSN 2473-2907.

Connected Freight Signal Priority System

USDOT List of CAV Applications

V2I Safety
- Red Light Violation Warning
- Curve Speed Warning
- Stop Sign Gap Assist
- Spot Weather Impact Warning
- Reduced Speed/Work Zone Warning
- Pedestrian in Signalized Crosswalk Warning (Transit)

V2V Safety
- Emergency Electronic Brake Lights (EEBL)
- Forward Collision Warning (FCW)
- Intersection Movement Assist (IMA)
- Left Turn Assist (LTA)
- Blind Spot/Lane Change Warning (BSW/LCW)
- Do Not Pass Warning (DNPW)
- Vehicle Turning Right in Front of Bus Warning (Transit)

Agency Data
- Probe-based Pavement Maintenance
- Probe-enabled Traffic Monitoring
- Vehicle Classification-based Traffic Studies
- CV-enabled Turning Movement & Intersection Analysis
- CV-enabled Origin-Destination Studies
- Work Zone Traveler Information

Environment
- Eco-Approach and Departure at Signalized Intersections
- Eco-Traffic Signal Timing
- Eco-Traffic Signal Priority
- Connected Eco-Driving
- Wireless Inductive/Resonance Charging
- Eco-Lanes Management
- Eco-Speed Harmonization
- Eco-Cooperative Adaptive Cruise Control
- Eco-Traveler Information
- Eco-Ramp Metering
- Low Emissions Zone Management
- AFV Charging / Fueling Information
- Eco-Smart Parking
- Dynamic Eco-Routing (light vehicle, transit, freight)
- Eco-ICM Decision Support System

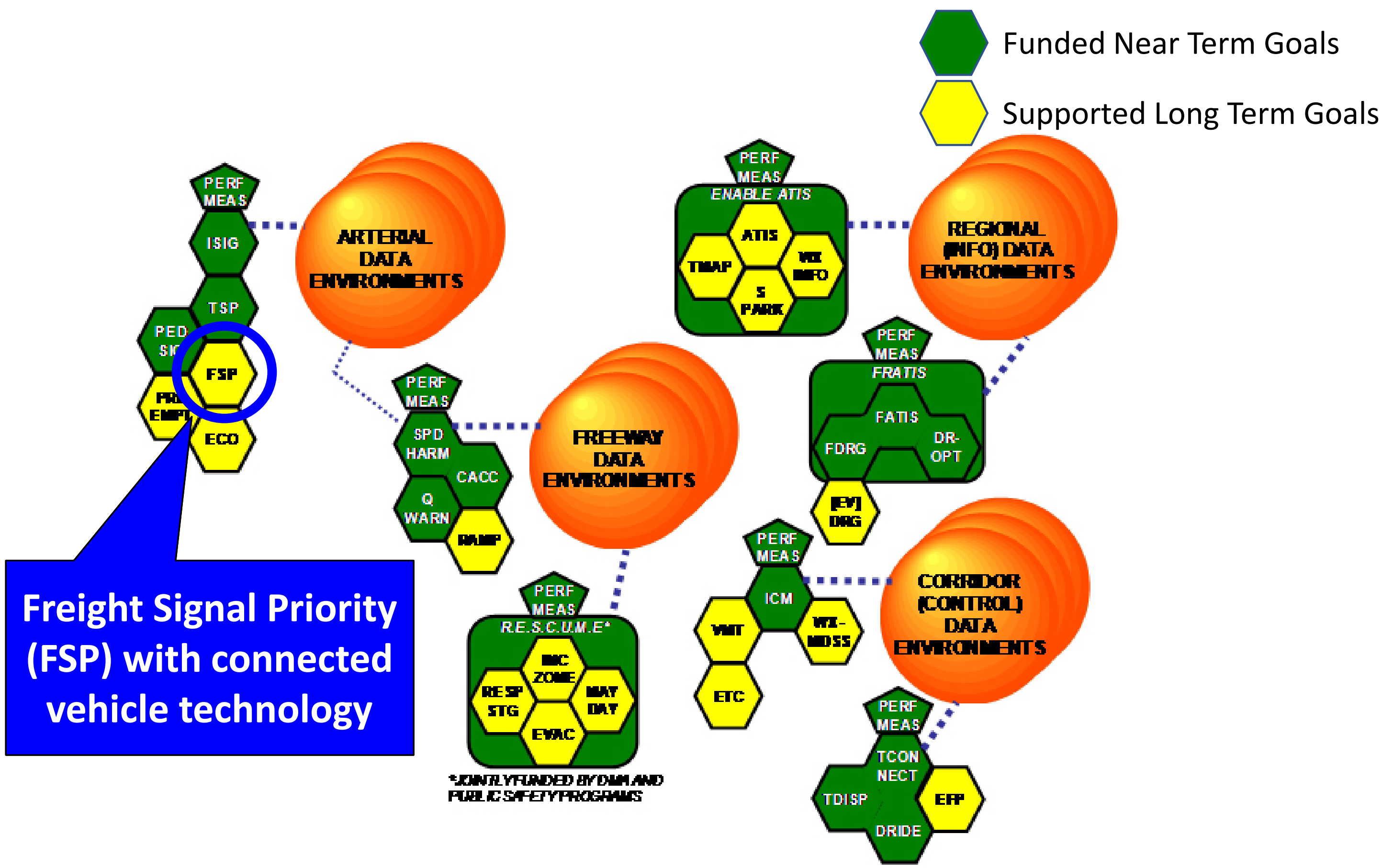
Road Weather
- Motorist Advisories and Warnings (MAW)
- Enhanced MDSS
- Vehicle Data Translator (VDT)
- Weather Response Traffic Information (WxTINFO)

Mobility
- Advanced Traveler Information System
- Intelligent Traffic Signal System (I-SIG)
- Signal Priority (transit, freight)
- Mobile Accessible Pedestrian Signal System (PED-SIG)
- Emergency Vehicle Preemption (PREEMPT)
- Dynamic Speed Harmonization (SPD-HARM)
- Queue Warning (Q-WARN)
- Cooperative Adaptive Cruise Control (CACC)
- Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG)
- Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)
- Emergency Communications and Evacuation (EVAC)
- Connection Protection (T-CONNECT)
- Dynamic Transit Operations (T-DISP)
- Dynamic Ridesharing (D-RIDE)
- Freight-Specific Dynamic Travel Planning and Performance
- Drayage Optimization

Smart Roadside
- Wireless Inspection
- Smart Truck Parking

Connected Freight Signal Priority System

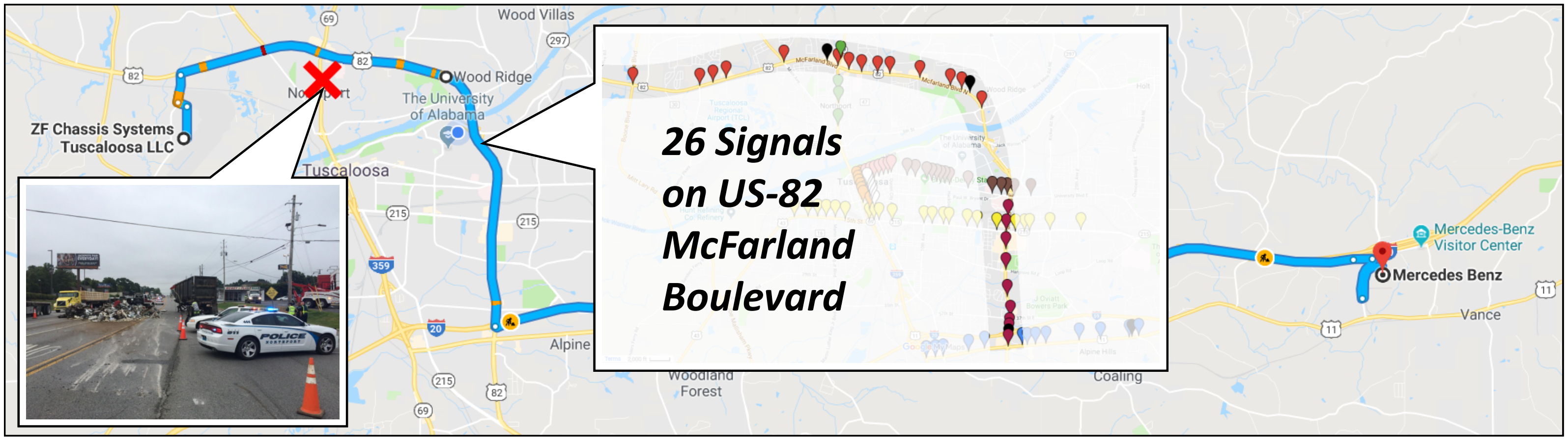
USDOT High-Priority Dynamic Mobility Applications with CV Technology

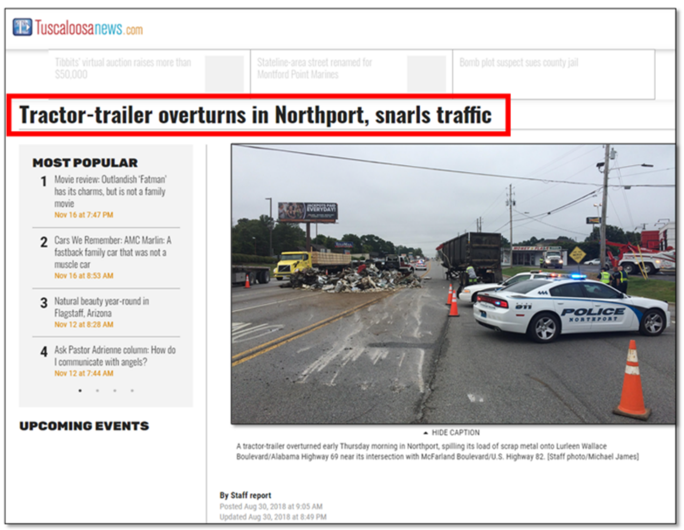


Intelligent Transportation Systems Joint Program Office. "USDOT High-Priority Dynamic Mobility Applications". Research and Innovative Technology Administration, U.S. Department of Transportation.

Connected Freight Signal Priority System

Freight Overturned in Northport, Alabama





Tuscaloosanews.com

Tractor-trailer overturns in Northport, snarls traffic

MOST POPULAR

1. Movie review: Outlandish 'Fatman' has its charms, but is not a family movie — Nov 16 at 7:47 PM
2. Cars We Remember: AMC Marlin: A fastback family car that was not a muscle car — Nov 16 at 8:53 AM
3. Natural beauty year-round in Flagstaff, Arizona — Nov 12 at 8:28 AM
4. Ask Pastor Adrienne column: How do I communicate with angels? — Nov 12 at 7:44 AM

UPCOMING EVENTS

A tractor-trailer overturned early Thursday morning in Northport, spilling its load of scrap metal onto Lurleen Wallace Boulevard/Alabama Highway 69 near its intersection with McFarland Boulevard/U.S. Highway 82. [Staff photo/Michael James]

By Staff report
Posted Aug 30, 2018 at 9:05 AM
Updated Aug 30, 2018 at 8:49 PM

Connected Freight Signal Priority System

First Traffic Signal Priority Application in 1970

- **Location**: Los Angeles, CA
- **Detection Technique:** Handheld two-position manual switch for driver
- **Objective:** Reduce overall person delay
- **Results:** 70-76% Reduction in bus passenger delay.

Improving Public Transit through Bus Preemption of Traffic Signals

HENRY K. EVANS AND GERALD W. SKILES

Mr. Evans is a Senior Vice-President of Wilbur Smith and Associates. He received a B.S. in Engineering from the California Institute of Technology and was awarded a fellowship at the Yale University Bureau of Highway Traffic. A registered Professional Engineer, he is a member of the Institute of Traffic Engineers, American Society of Civil Engineers, and the American Marketing Association, and author of many publications on transportation.*

Mr. Skiles is Traffic Planning Engineer for the Department of Traffic of the City of Los Angeles, where he is responsible for the Department's planning, design, and research activities. Before joining the city agency in 1956, Mr. Skiles was Assistant District Traffic Engineer for the California Division of Highways in the Los Angeles District. He received a B.S. degree in Electrical Engineering from the University of Washington, and an M.S. in Engineering from University of California (Los Angeles). He is a member of the Institute of Traffic Engineers and a registered Professional Engineer in California.

INCREASING attention is being given across the country to the advantages of providing improved balance in urban transportation systems. Plans and programs are going forward to supplement the private auto with rail rapid transit in the large cities and with better bus systems, both for local and rapid transit service, in smaller areas. These efforts are being made with the knowledge that getting people out of their autos and into public transit vehicles will require a more competitive service. Comfort, convenience, dependability, and attractive surroundings are important, as well as travel time. Generally speaking, it takes twice as long to travel from portal to portal by bus compared to the auto, although rail rapid transit usually does a better job of matching private vehicle travel time.

* We deeply regret to announce that we have learned of Mr. Evans' death on September 9th, 1970. Over a number of years, Mr. Evans was a valued contributor to TRAFFIC QUARTERLY, having been the author or co-author of four articles. One in particular, "Parking Study Applications," which appeared in 1963, is still frequently requested as an important reference in the study of parking and trip generation.

531

Evans, H., and Skiles, G. (1970). "Improving public transit through bus preemption of traffic signals". Traffic Quarterly, 24(4), pp: 531–543.

Connected Freight Signal Priority System

Previous Literature - Conventional Loop Detection for Freight Priority

Year	Location	Priority Vehicle Type	Detection Technique	Objective	Results
2000	*Sunkari, S. R., H. Charara, and T. Urbanik. (2000). "Reducing Truck Stops at High-Speed Isolated Traffic Signals". TTI Report No. FHWA/TX-01/1439-8. Texas Department of Transportation, Austin*				
	Sullivan City, Texas	Freight	Loop Detector	Reduce Freight stops	5,000 fewer freight stops
2014	*Mahmud, M. (2014). "Evaluation of Truck Signal Priority at N Columbia Blvd and Martin Luther King Jr. Blvd Intersection". Civil and Environmental Engineering Master's Project Reports. Portland State University, Portland, OR*				
	Portland, OR	Freight	Loop Detector	Reduce freight delay and no of stop(s)	13%-20% delay reduction and 9%-16% stop reduction
2020	*Kaisar, E. I., Hadi, M., Ardalan, T., and Iqbal, M. S. (2020). "Evaluation of Freight and Transit Signal Priority Strategies in Multi-Modal Corridor for Improving Transit Service Reliability and Efficiency". Contract No BDV27-977-14. Florida Department of Transportation (FDOT), Tallahassee, Florida*				
	Broward County, FL	Freight	Loop Detector	Reduce freight travel time and delay	22% reduction in travel time and 29% delay reduction

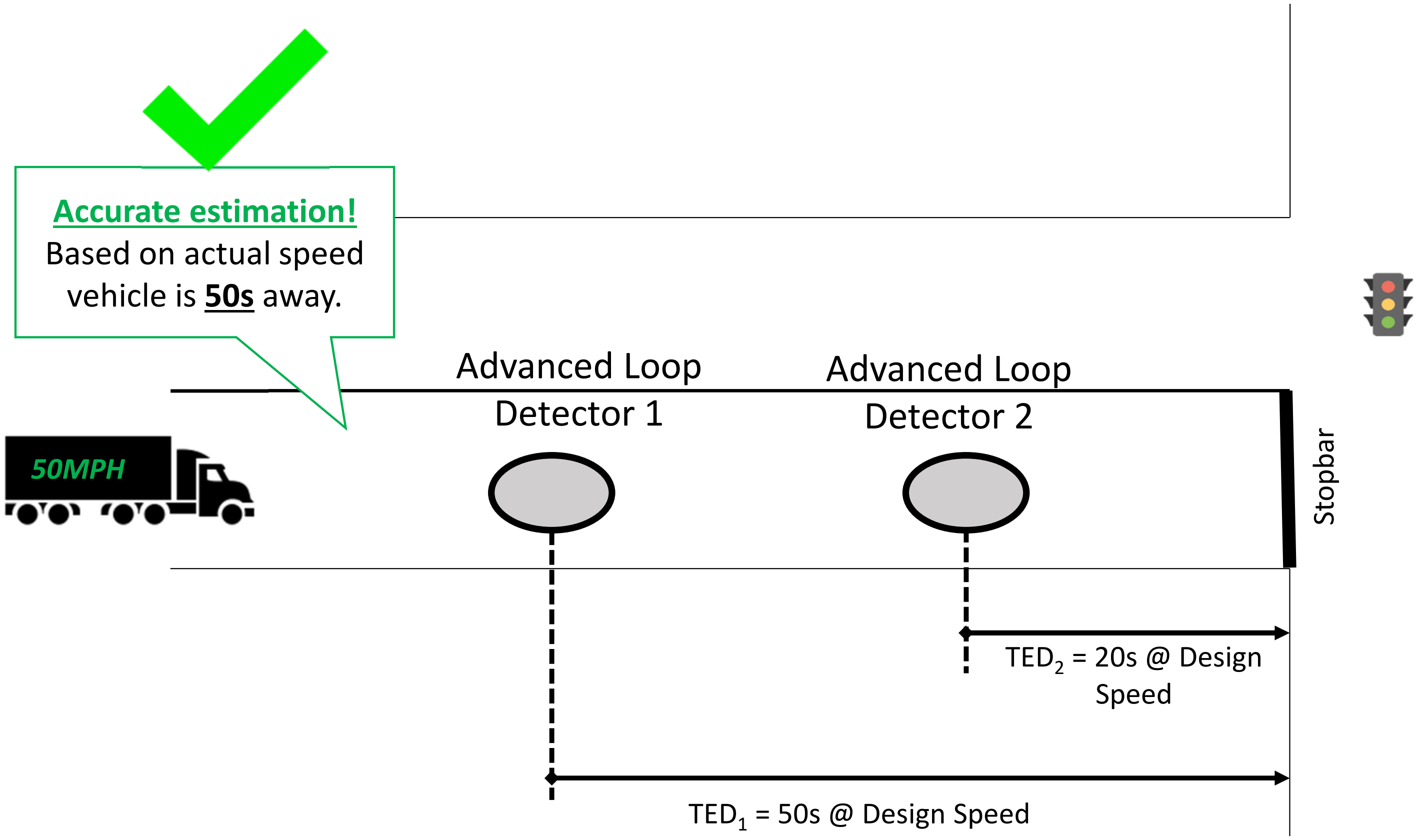
Connected Freight Signal Priority System

Study Objectives

- Developing a **signal priority system** to facilitate freight movement by leveraging CV technology to **improve** upon traditional priority systems.
- Establish an **ETA-based FSP logic** and analytically identify **shortcoming** related to traditional priority system.
- Conducting **field deployment** and performing systematic analysis for **validating** field operation of the proposed FSP system.

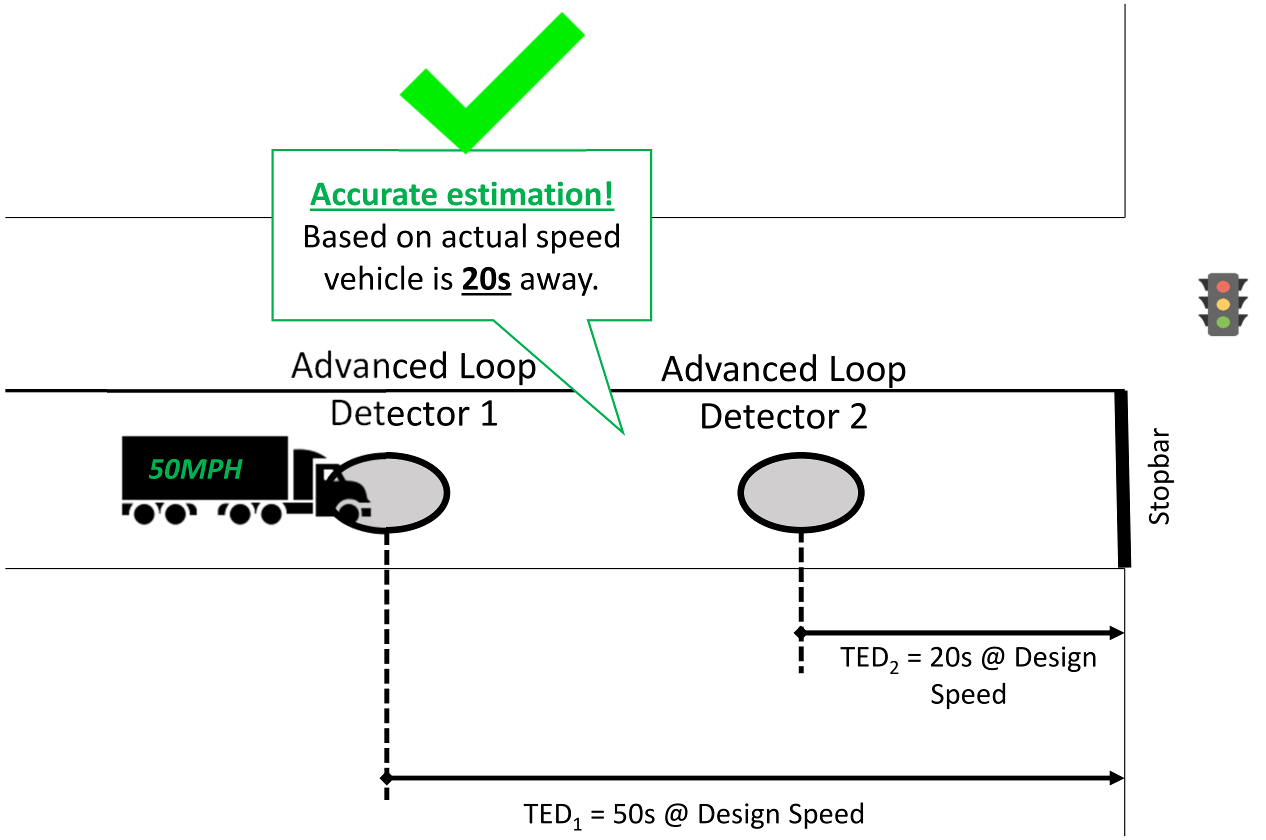
Connected Freight Signal Priority System

Traditional Loop Detection Issues



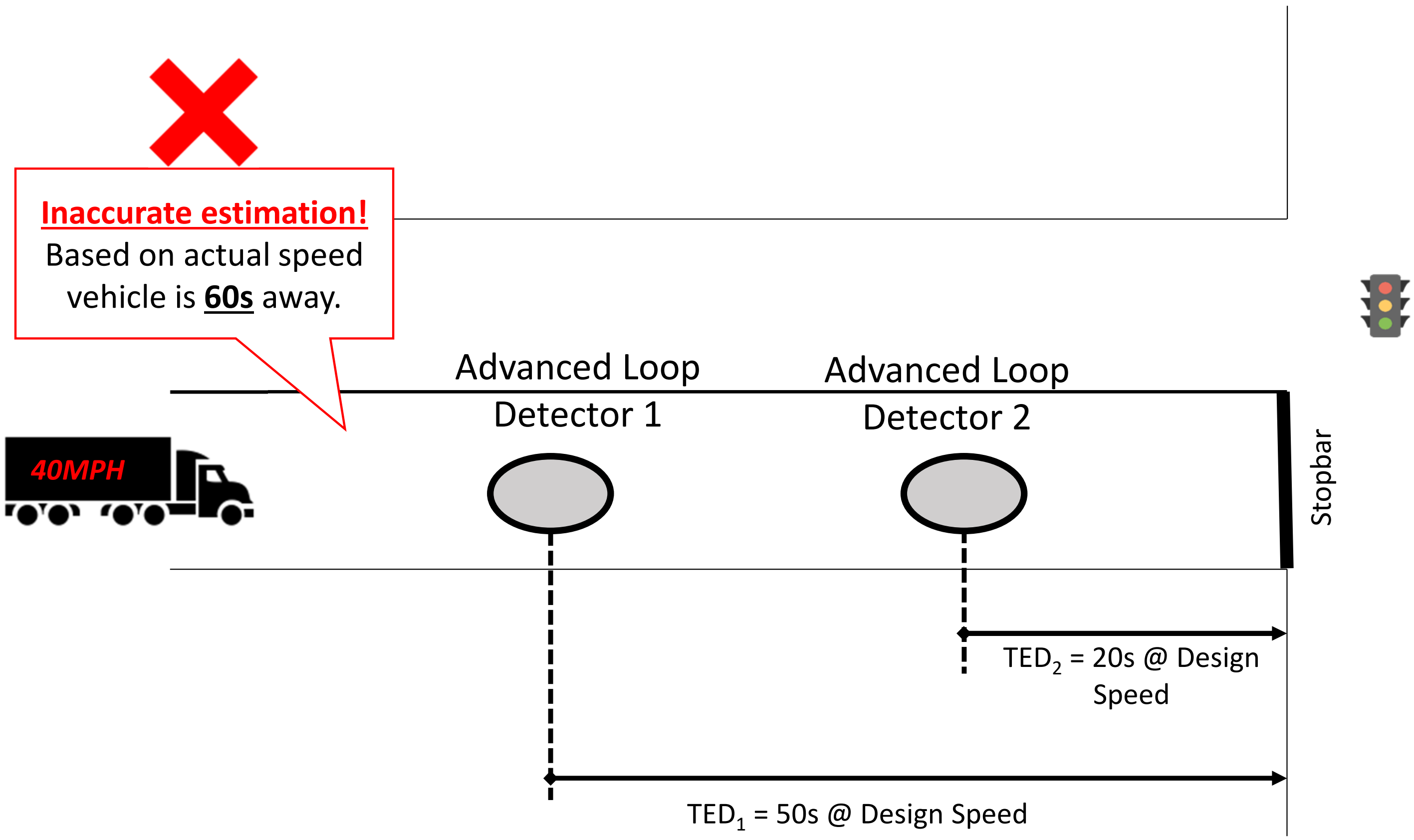
Connected Freight Signal Priority System

Traditional Loop Detection Issues



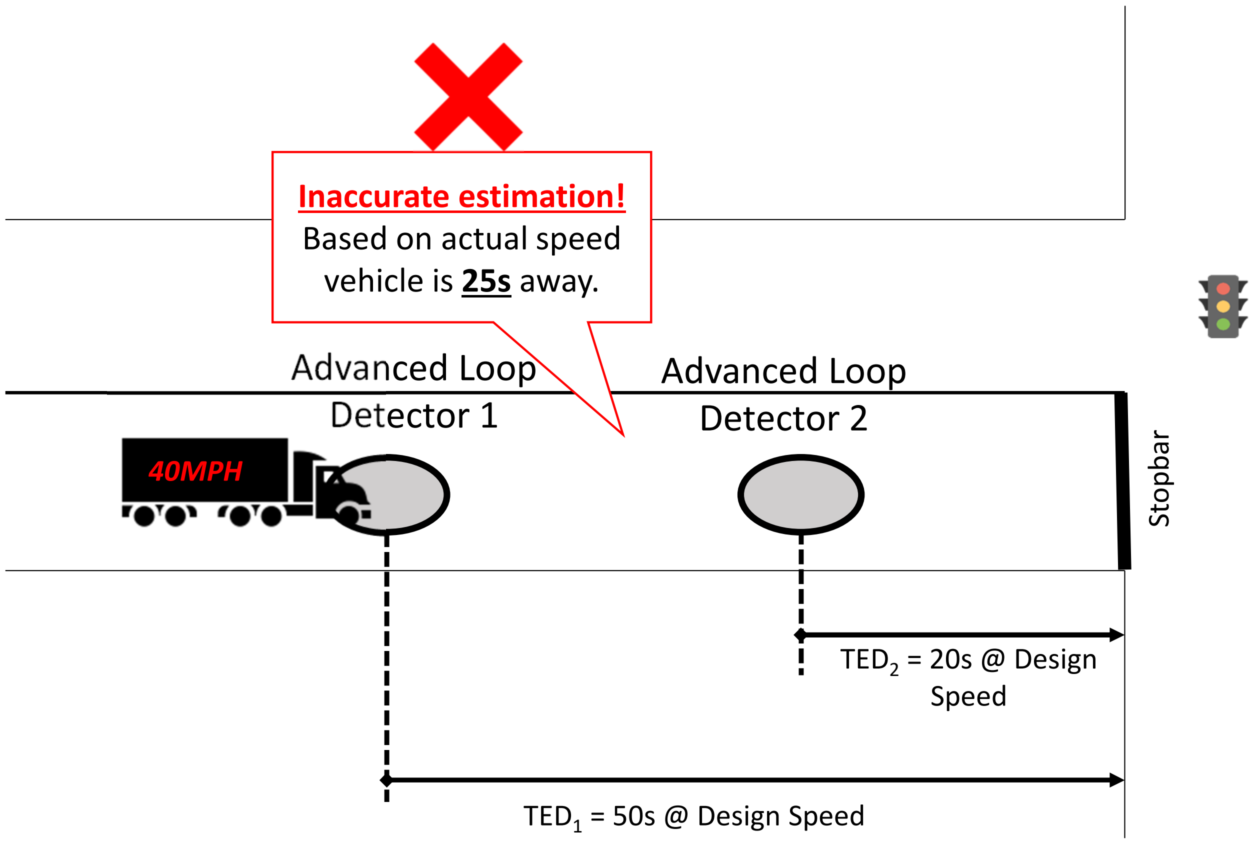
Connected Freight Signal Priority System

Traditional Loop Detection Issues



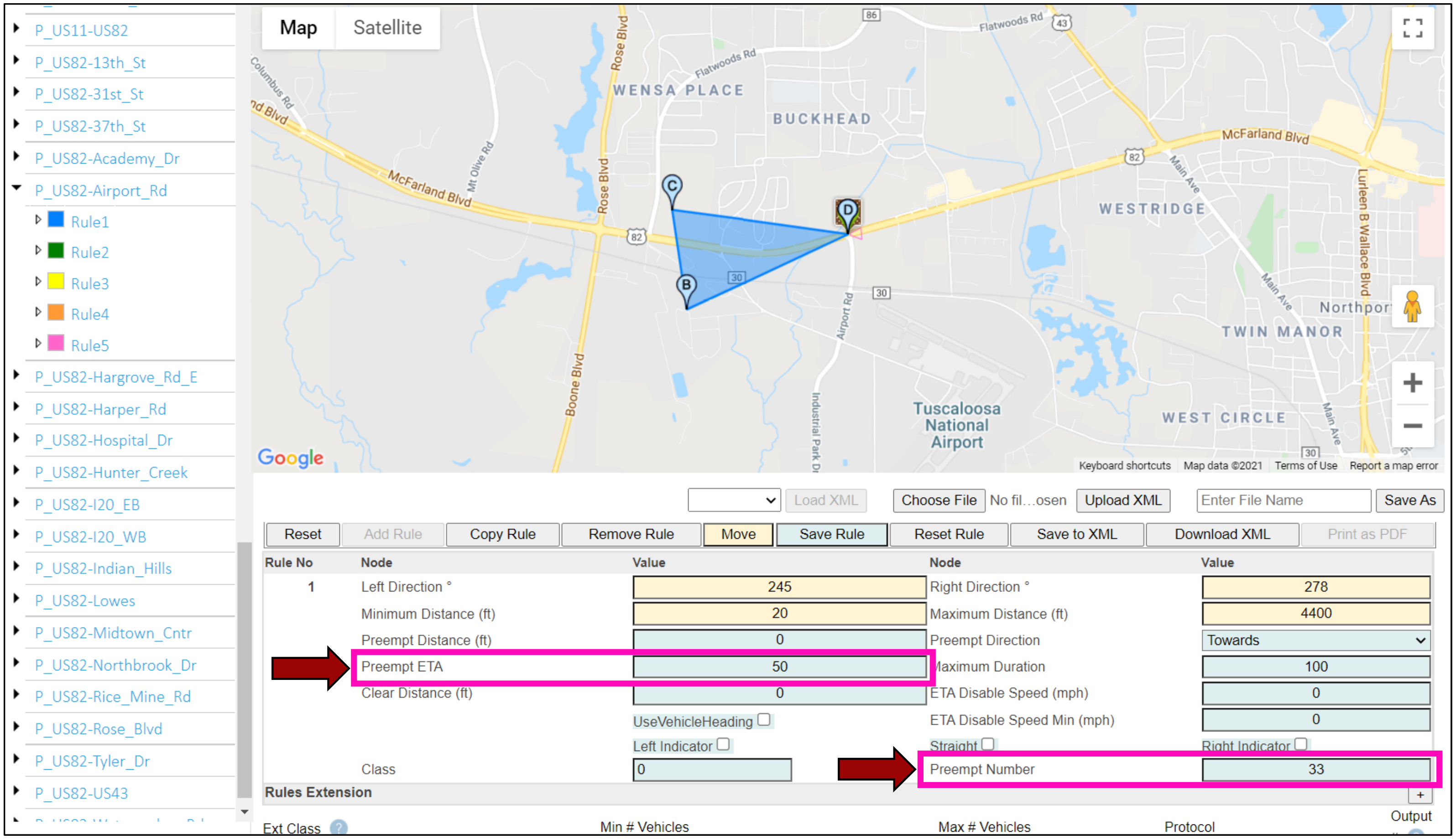
Connected Freight Signal Priority System

Traditional Loop Detection Issues



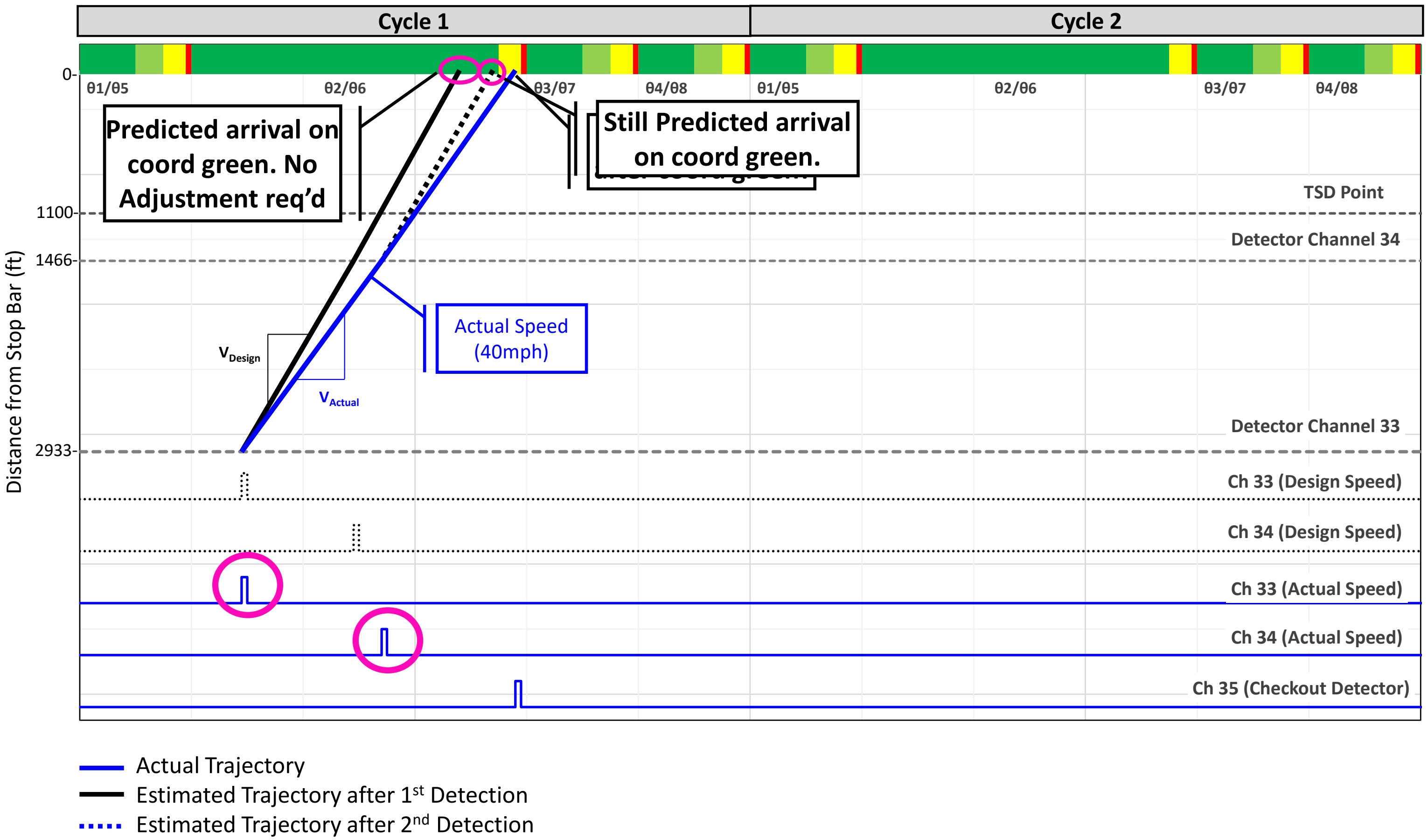
Connected Freight Signal Priority System

ETA Priority System – LOTS of settings and configurations



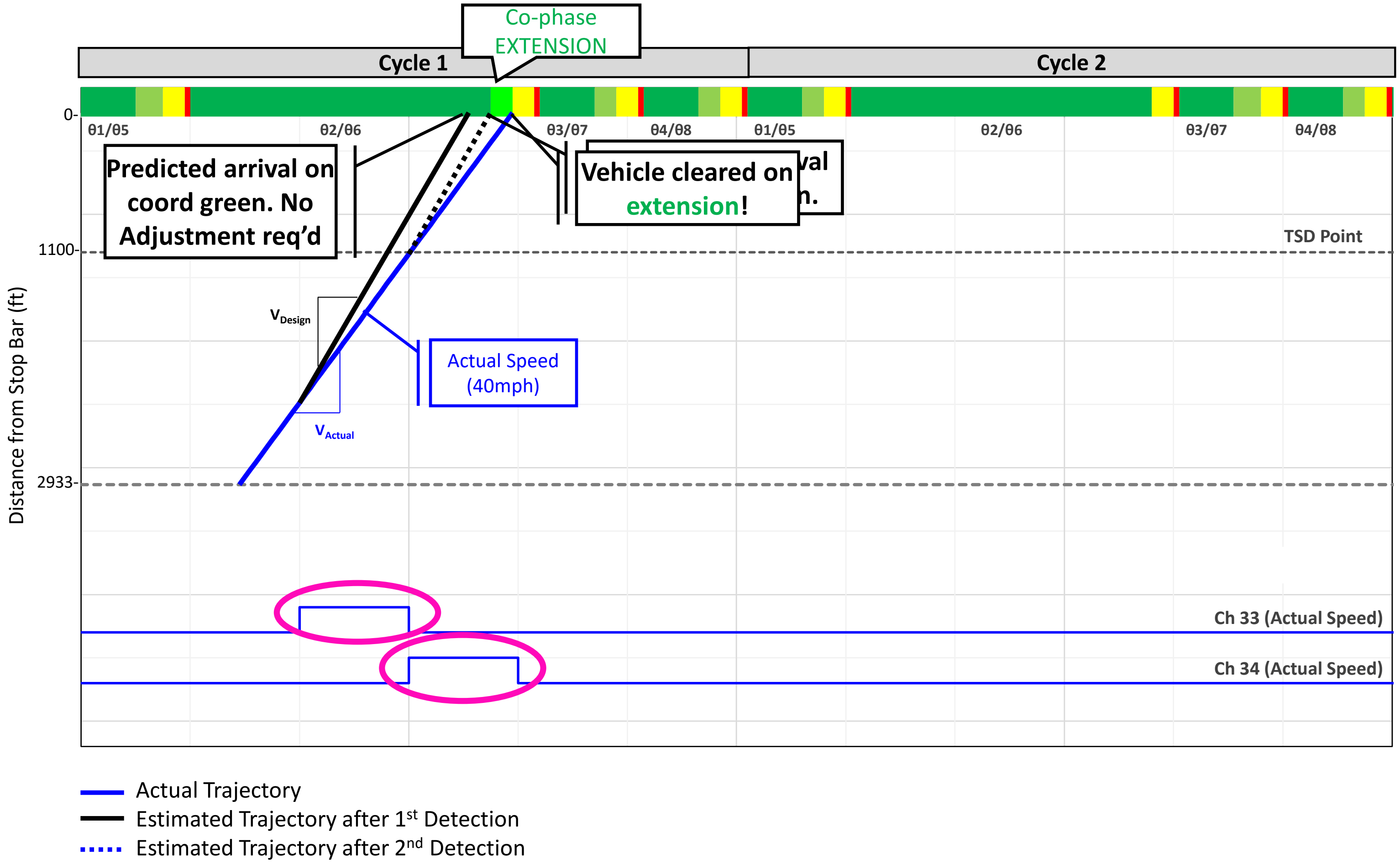
Connected Freight Signal Priority System

Loop Detection – Inaccurate Priority Measure!



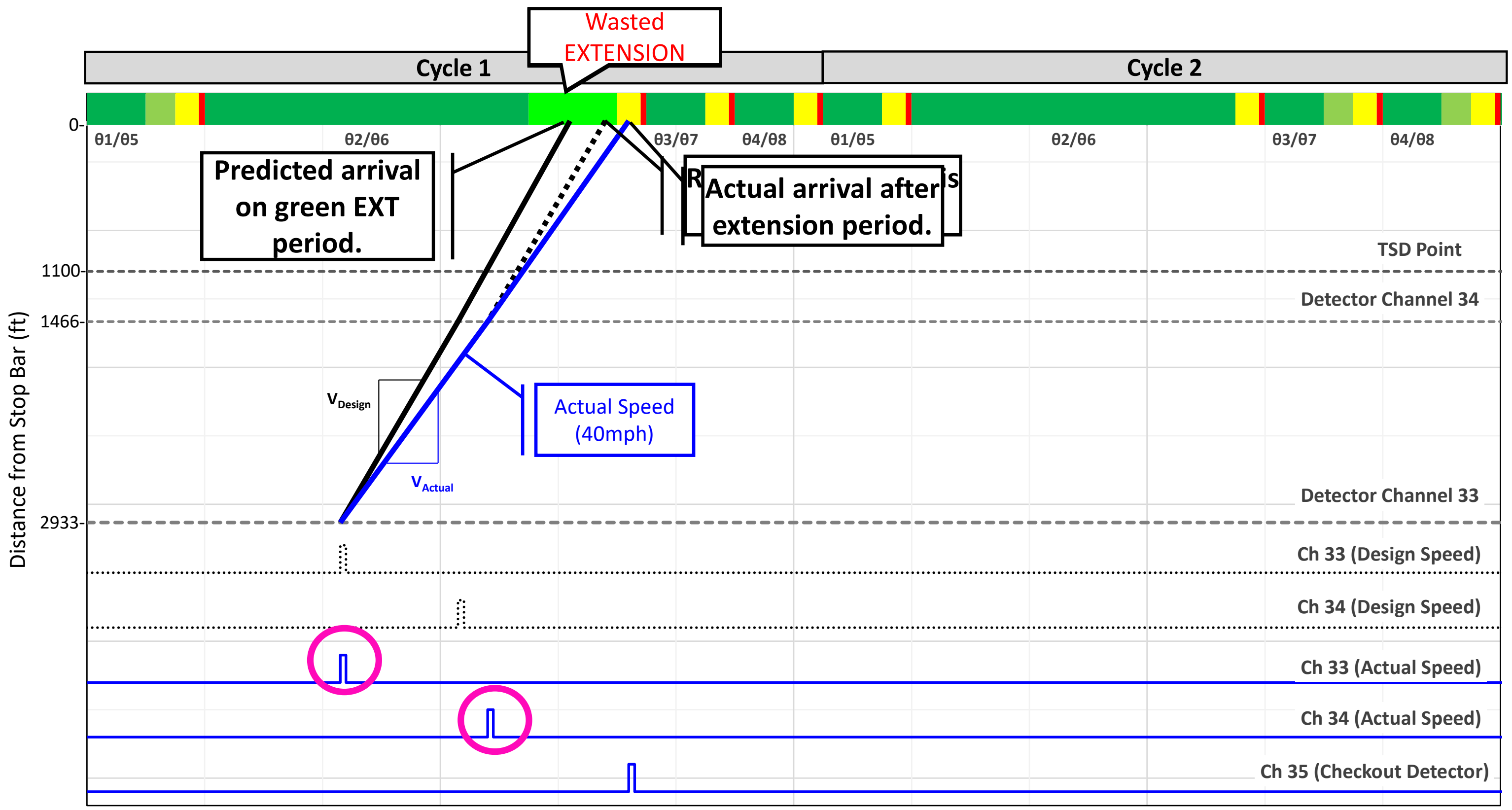
Connected Freight Signal Priority System

ETA-Based Detection– Accurate Priority Measure – Co-Phase Extension



Connected Freight Signal Priority System

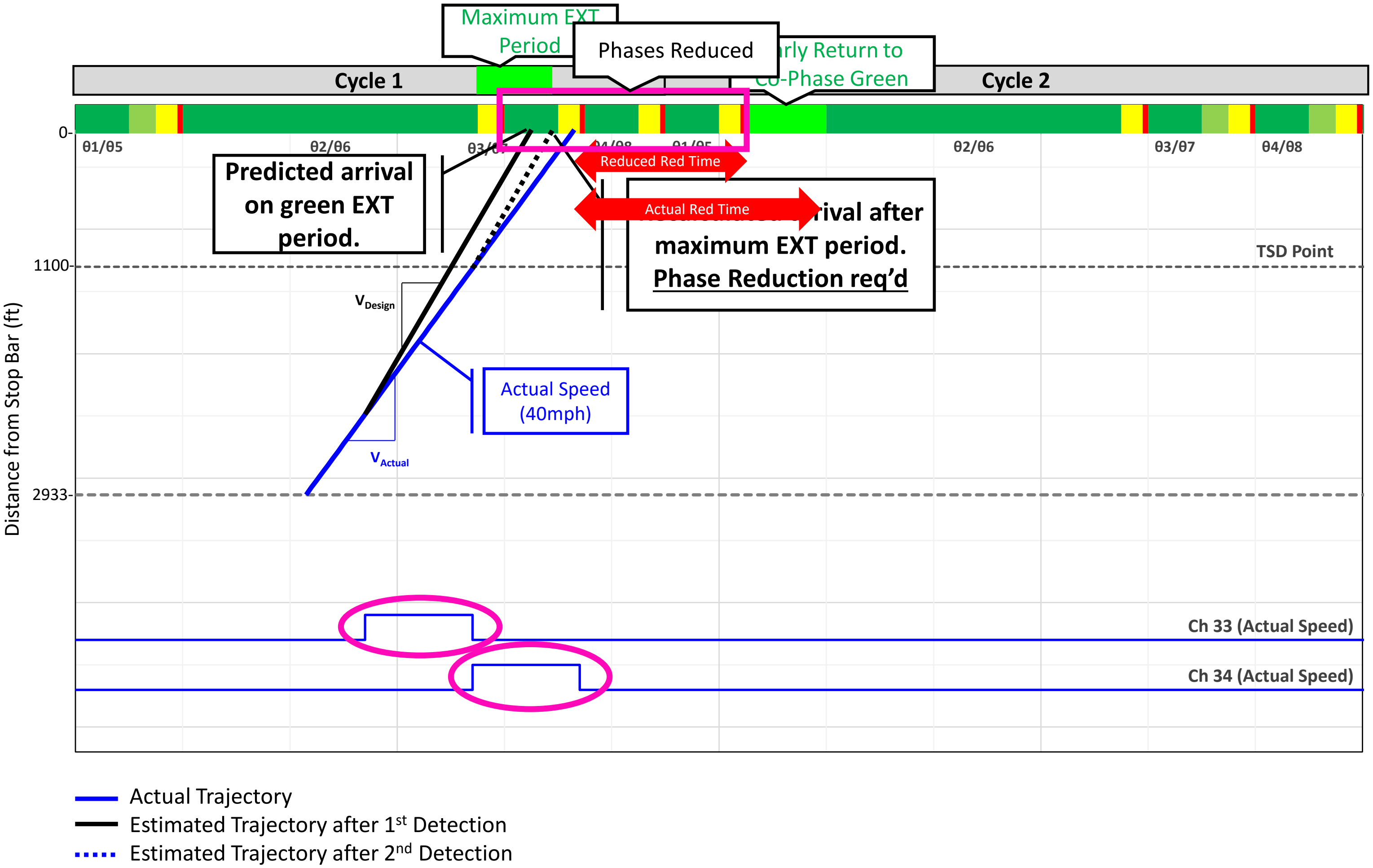
Loop Detection – Inaccurate Priority Measure!



- Actual Trajectory
- Estimated Trajectory after 1st Detection
- Estimated Trajectory after 2nd Detection

Connected Freight Signal Priority System

ETA-Based Detection– Accurate Priority Measure – Co-Phase Early Green

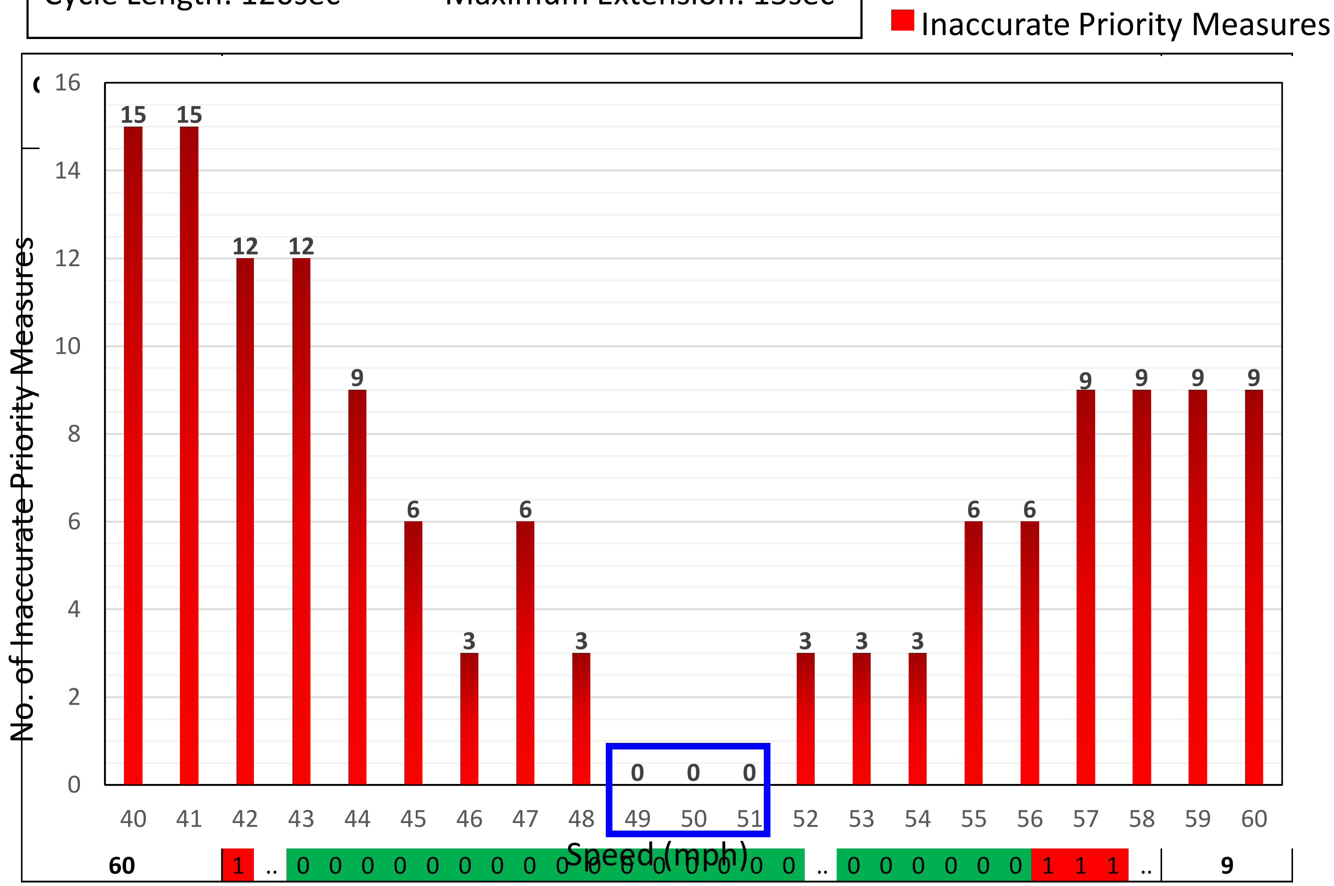


Connected Freight Signal Priority System

Analytical Testing

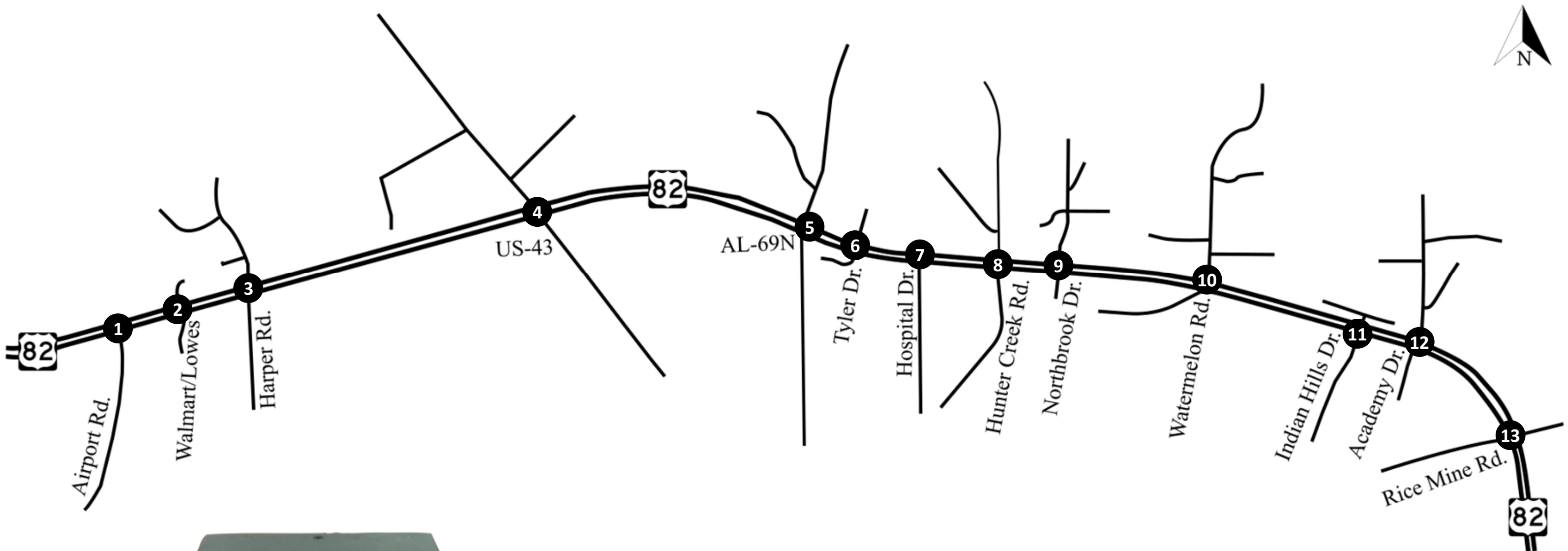
Design Speed: 50MPH
Cycle Length: 120sec
Offset: 10sec
Maximum Extension: 15sec

Total Cases: **2,520**
Loop Detection Accuracy: **2,382 (95%)**
ETA-based Detection Accuracy: **2,500 (100%)**



Connected Freight Signal Priority System

Field Deployment

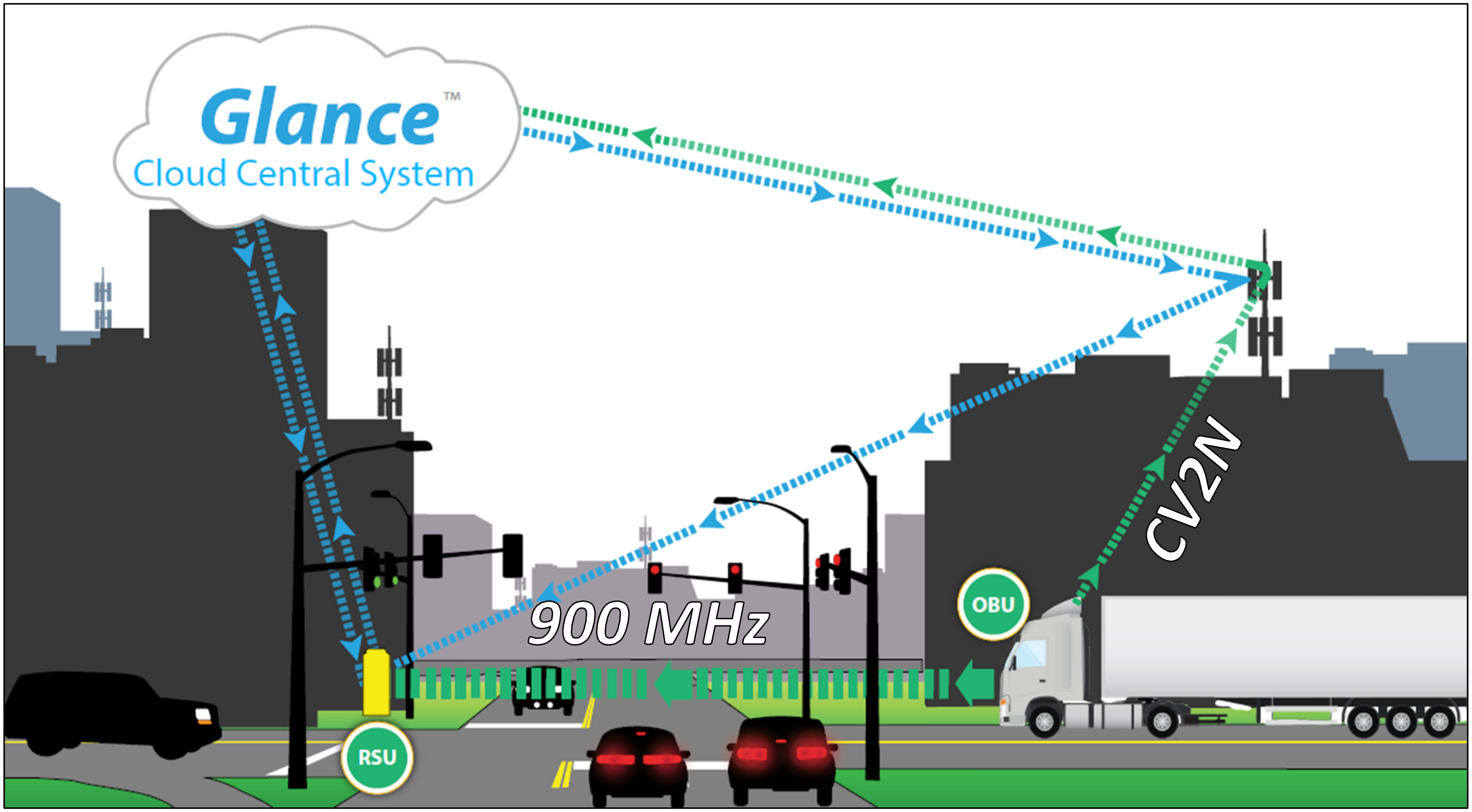


AI-500-065 OBU Unit

AI-500-085 RSU Unit

Connected Freight Signal Priority System

Field Deployment – System Architecture



Connected Freight Signal Priority System

Field Deployment – Corridor Monitoring

Airport Rd.

```
PRIORITY00 PAT021 SEQ01 PH.1PR.1UN.1SY.1
PHASE......1...2...3...4...5...6...7...8
CPHZ*10    01150   0 350 1501000   0   0
USED*10    03343   0   0   02343   0   0
IMPC*10    0   0   0   0   0   0   0   0
PRED*10    0   0   0   0   0   0   0   0
PEXT*10    0   0   0   0   0   0   0   0
PPHZ*10    0   0   0   0   0   0   0   0
COORD TIMERS       SEQ: 01
SYSTEM      021      PRM/INH/BEG/PLN
  CYC   OFF   RING.....1....2....3....4
  150    30  SETING  115  100    .    .
  132    30  ACTIVE   97   97    .    .
    0     0  ADJUST    0    0    .    .
  SYNC:  47   PHSE   2-1  6-1
  CORR: SW    PERM   2-H  6>H
```

Walmart/Lowes

```
PRIORITY00 PAT021 SEQ01 PH.1PR.1UN.1SY.1
PHASE......1...2...3...4...5...6...7...8
CPHZ*10  150 900 150 300 150 900 150 300
USED*10    0 243   0   0   0 750   0   0
IMPC*10    0   0   0   0   0   0   0   0
PRED*10    0   0   0   0   0   0   0   0
PEXT*10    0   0   0   0   0   0   0   0
PPHZ*10    0   0   0   0   0   0   0   0
COORD TIMERS       SEQ: 01
SYSTEM      021      PRM/INH/BEG/PLN
  CYC   OFF   RING.....1....2....3....4
  150    45  SETING   90   90    .    .
  147    45  ACTIVE   87   87    .    .
    0     0  ADJUST    0    0    .    .
  SYNC:  47   PHSE   2-1  6-1
  CORR: SW    PERM   2-H  6-H
```

Harper Rd.

```
PRIORITY00 PAT021 SEQ01 PH.1PR.1UN.1SY.1
PHASE......1...2...3...4...5...6...7...8
CPHZ*10  150 800 250 300 150 800 250 300
USED*10  112   0   0   0 112   0   0   0
IMPC*10    0   0   0   0   0   0   0   0
PRED*10    0   0   0   0   0   0   0   0
PEXT*10    0   0   0   0   0   0   0   0
PPHZ*10    0   0   0   0   0   0   0   0
COORD TIMERS       SEQ: 01
SYSTEM      021      PRM/INH/BEG/PLN
  CYC   OFF   RING.....1....2....3....4
  150    55  SETING   15   15    .    .
    6    55  ACTIVE    6    6    .    .
    0     0  ADJUST    0    0    .    .
  SYNC:  48   PHSE   1-0  5-0
  CORR: SW    PERM   1>   5>
```

US–43/Main Ave.

```
PART PRI06 PAT021 SEQ02 PH.1PR.1UN.1SY.1
PHASE......1...2...3...4...5...6...7...8
CPHZ*10  200 500 400 400 200 500 400 400
USED*10  307 175   0   0   0 482   0   0
IMPC*10  107-342   0   0   0  25   0   0
PRED*10    0   0 -14 -14  -8   0 -14 -14
PEXT*10    0   0   0   0   0 380   0   0
PPHZ*10    0   0   0   0   0   0   0   0
COORD TIMERS       SEQ: 02
SYSTEM      021   P> PRM/INH/BEG/CYC
  CYC   OFF   RING.....1....2....3....4
  150     0  SETING   50   50    .    .
  102     0  ACTIVE   22    4    .    .
    0     0  ADJUST    0    0    .    .
  SYNC:  48   PHSE   2-1  6-1
  CORR: SW    PERM   2-H  5-P
```

AL–69N

```
PRIORITY00 PAT021 SEQ02 PH.1PR.1UN.1SY.1
PHASE......1...2...3...4...5...6...7...8
CPHZ*10  200 600 400 300 250 550   0   0
USED*10    0   0 253   0   0   0   0   0
IMPC*10    0   0   0   0   0   0   0   0
PRED*10    0   0   0   0   0   0   0   0
PEXT*10    0   0   0   0   0   0   0   0
PPHZ*10    0   0   0   0   0   0   0   0
COORD TIMERS       SEQ: 02
SYSTEM      021      PRM/INH/BEG/CYC
  CYC   OFF   RING.....1....2....3....4
  150    65  SETING   40    .    .    .
   17    65  ACTIVE   17    .    .    .
    0     0  ADJUST    0    .    .    .
  SYNC:  47   PHSE   3-0
  CORR: SW    PERM   3-
```

Tyler Dr.

```
PRIORITY00 PAT021 SEQ01 PH.1PR.1UN.1SY.1
PHASE......1...2...3...4...5...6...7...8
CPHZ*10  300 850 200 150 250 900   0 350
USED*10    0  95   0   0   0 283   0   0
IMPC*10    0   0   0   0   0   0   0   0
PRED*10    0   0   0   0   0   0   0   0
PEXT*10    0   0   0   0   0   0   0   0
PPHZ*10    0   0   0   0   0   0   0   0
COORD TIMERS       SEQ: 01
SYSTEM      021      PRM/INH/BEG/PLN
  CYC   OFF   RING.....1....2....3....4
  150    45  SETING   30   90    .    .
  146    45  ACTIVE    1   86    .    .
    0     0  ADJUST    0    0    .    .
  SYNC:  48   PHSE   1-0  6-1
  CORR: SW    PERM   2-   6-H
```

Hospital Rd.

```
PRIORITY00 PAT021 SEQ01 PH.1PR.1UN.1SY.1
PHASE......1...2...3...4...5...6...7...8
CPHZ*10  2501000   0 250   01250   0   0
USED*10   76   0   0   0   0  76   0   0
IMPC*10    0   0   0   0   0   0   0   0
PRED*10    0   0   0   0   0   0   0   0
PEXT*10    0   0   0   0   0   0   0   0
PPHZ*10    0   0   0   0   0   0   0   0
COORD TIMERS       SEQ: 01
SYSTEM      021      PRM/INH/BEG/PLN
  CYC   OFF   RING.....1....2....3....4
  150    42  SETING   25  125    .    .
  143    42  ACTIVE   18  118    .    .
    0     0  ADJUST    0    0    .    .
  SYNC:  48   PHSE   1-0  6-1
  CORR: SW    PERM   1-V  6-H
```

Hunter Creek Rd.

```
PRIORITY00 PAT021 SEQ03 PH.1PR.1UN.1SY.1
PHASE......1...2...3...4...5...6...7...8
CPHZ*10  1501000 200 150 1501000 200 150
USED*10    0 156   0   0   0  66   0   0
IMPC*10    0   0   0   0   0   0   0   0
PRED*10    0   0   0   0   0   0   0   0
PEXT*10    0   0   0   0   0   0   0   0
PPHZ*10    0   0   0   0   0   0   0   0
COORD TIMERS       SEQ: 03
SYSTEM      021      PRM/INH/BEG/PLN
  CYC   OFF   RING.....1....2....3....4
  150    50  SETING   15   15    .    .
    2    50  ACTIVE    2    2    .    .
    0     0  ADJUST    0    0    .    .
  SYNC:  47   PHSE   4-0  8-0
  CORR: SW    PERM   4-   8-
```

Northbrook Dr.

```
PRIORITY00 PAT021 SEQ01 PH.1PR.1UN.1SY.1
PHASE......1...2...3...4...5...6...7...8
CPHZ*10  1501100   0 250 1501100   0 250
USED*10    01078   0   0   01078   0   0
IMPC*10    0   0   0   0   0   0   0   0
PRED*10    0   0   0   0   0   0   0   0
PEXT*10    0   0   0   0   0   0   0   0
PPHZ*10    0   0   0   0   0   0   0   0
COORD TIMERS       SEQ: 01
SYSTEM      021      PRM/INH/BEG/PLN
  CYC   OFF   RING.....1....2....3....4
  150   120  SETING  110  110    .    .
   71   120  ACTIVE   31   31    .    .
    0     0  ADJUST    0    0    .    .
  SYNC:  48   PHSE   2-1  6-1
  CORR: SW    PERM   2-H  6-H
```

Watermelon Rd.

```
PRIORITY00 PAT021 SEQ03 PH.1PR.1UN.1SY.1
PHASE......1...2...3...4...5...6...7...8
CPHZ*10  370 660 250 220 260 770 220 250
USED*10   74   0   0   0   0 527   0   0
IMPC*10    0   0   0   0   0   0   0   0
PRED*10    0   0   0   0   0   0   0   0
PEXT*10    0   0   0   0   0   0   0   0
PPHZ*10    0   0   0   0   0   0   0   0
COORD TIMERS       SEQ: 03
SYSTEM      021      PRM/INH/BEG/PLN
  CYC   OFF   RING.....1....2....3....4
  150   125  SETING   37   77    .    .
   76   125  ACTIVE   29   29    .    .
    0     0  ADJUST    0    0    .    .
  SYNC:  48   PHSE   1-0  6-1
  CORR: SW    PERM   1-V  6-H
```

Indian Hills Dr.

```
PRIORITY00 PAT021 SEQ01 PH.1PR.1UN.1SY.1
PHASE......1...2...3...4...5...6...7...8
CPHZ*10  1501200   0 150 1501200   0 150
USED*10    0 233   0   0   0 233   0   0
IMPC*10    0   0   0   0   0   0   0   0
PRED*10    0   0   0   0   0   0   0   0
PEXT*10    0   0   0   0   0   0   0   0
PPHZ*10    0   0   0   0   0   0   0   0
COORD TIMERS       SEQ: 01
SYSTEM      021      PRM/INH/BEG/PLN
  CYC   OFF   RING.....1....2....3....4
  150    40  SETING  120  120    .    .
  141    40  ACTIVE  111  111    .    .
    0     0  ADJUST    0    0    .    .
  SYNC:  48   PHSE   2-1  6-1
  CORR: SW    PERM   2-H  6-H
```

Academy Dr.

```
PRIORITY00 PAT021 SEQ01 PH.1PR.1UN.1SY.1
PHASE......1...2...3...4...5...6...7...8
CPHZ*10  200 800   0 500 200 800 300 200
USED*10    0  84   0   0  84   0   0   0
IMPC*10    0   0   0   0   0   0   0   0
PRED*10    0   0   0   0   0   0   0   0
PEXT*10    0   0   0   0   0   0   0   0
PPHZ*10    0   0   0   0   0   0   0   0
COORD TIMERS       SEQ: 01
SYSTEM      021      YLD/INH/BEG/CYC
  CYC   OFF   RING.....1....2....3....4
  150    60  SETING   20   20    .    .
   11    60  ACTIVE   11   11    .    .
    0     0  ADJUST    0    0    .    .
  SYNC:  48   PHSE   1-0  5-0
  CORR: SW    PERM   1-   5-
```

Rice Mine Rd.

```
PRIORITY00 PAT021 SEQ01 PH.1PR.1UN.1SY.1
PHASE......1...2...3...4...5...6...7...8
CPHZ*10    01200   0 300   01200   0 300
USED*10    02626   0   0   02626   0   0
IMPC*10    0   0   0   0   0   0   0   0
PRED*10    0   0   0   0   0   0   0   0
PEXT*10    0   0   0   0   0   0   0   0
PPHZ*10    0   0   0   0   0   0   0   0
COORD TIMERS       SEQ: 01
SYSTEM      021      PRM/INH/BEG/PLN
  CYC   OFF   RING.....1....2....3....4
  150    95  SETING  120  120    .    .
   46    95  ACTIVE   16   16    .    .
    0     0  ADJUST    0    0    .    .
  SYNC:  48   PHSE   2-1  6-1
  CORR: SW    PERM   2-H  6-H
```

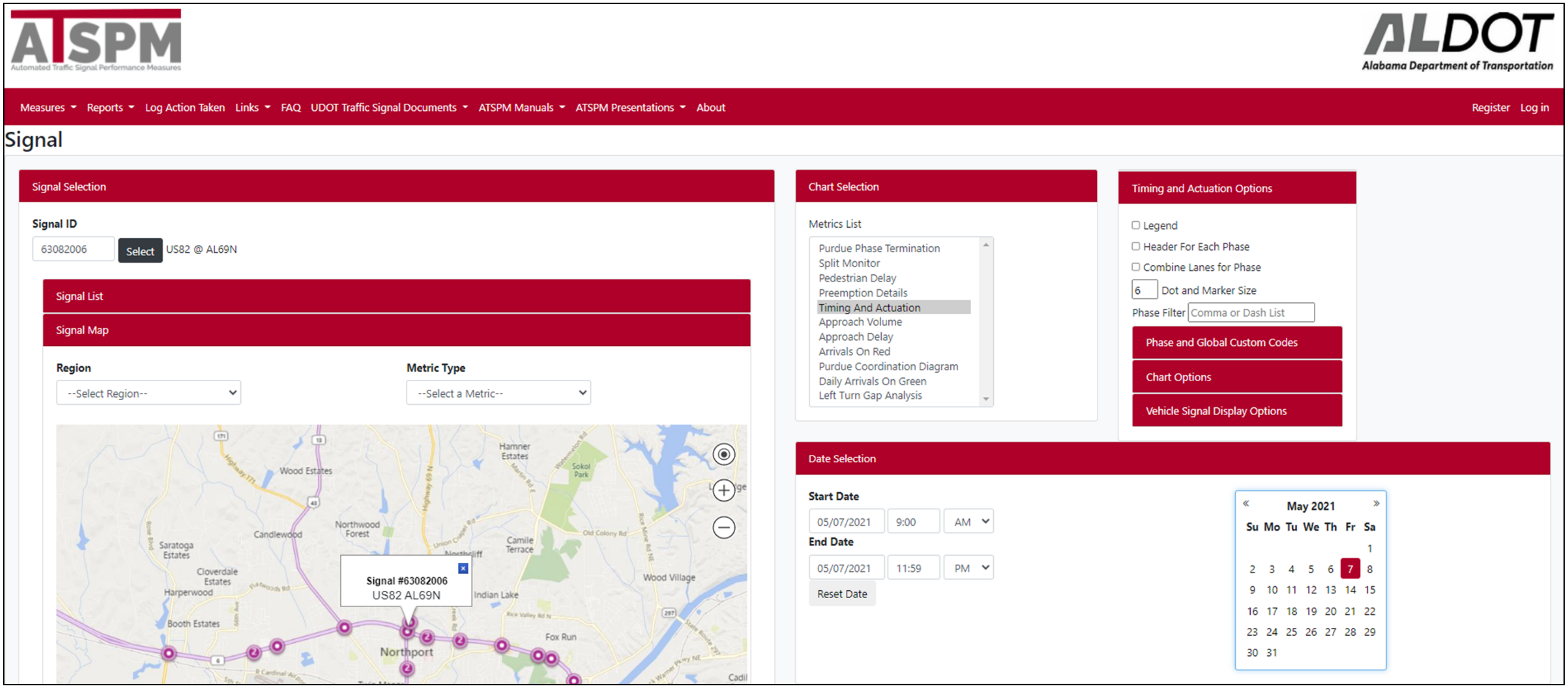
Connected Freight Signal Priority System

Field Deployment – Glance Priority Data

Device Local		Intersection	Time	Headg	ETA	Distance	Speed	Greens	Greens	Comms	Rule	Preempt	
Date	Time		Secs	(Deg)	Secs	(FT)	(mph)	1	2	Cell/Radio		Active	Status
May-07-2021	9:56:02 AM	P_US82-Harper_Rd (5817)	0	254	40	3097	52	-2---6--		Cell	2	34	Prior Confirm
	9:56:05 AM		3	254	37	2867	52	-2---6--		Both	99	99	Prior Confirm
	9:56:13 AM		11	254	30	2326	52	-2---6--		Both	3	35	Prior Confirm
	9:56:22 AM		20	253	20	1575	53	-2---6--		Both	4	36	Prior Confirm
	9:56:45 AM		43	85	255	112	49	-2---6--		Both	5	37	OK
	9:56:48 AM		46	78	255	315	46	-2---6--		Both	5	None	OK
May-07-2021	9:57:12 AM	P_US82-US43 (5816)	0	254	49	3780	52	--3----8		Cell	1	33	OK
	9:57:24 AM		12	254	40	2966	50	--3----8		Both	2	34	OK
	9:57:31 AM		19	254	35	2467	47			Cell	99	99	OK
	9:57:36 AM		24	254	31	2064	45	1----6--		Both	99	99	Prior Confirm
	9:57:51 AM		39	253	19	1155	40	1----6--		Both	4	36	Prior Confirm
	9:58:02 AM		50	252	30	692	16	-----6--		Both	99	99	Prior Confirm
	9:58:08 AM		56	252	38	604	11	-2---6--		Both	99	99	Prior Confirm
	9:58:23 AM		71	105	255	98	39	-2------		Both	5	37	OK
	9:58:28 AM		76	78	255	404	43	-2--5---		Both	5	37	OK
	9:58:33 AM		81	76	255	528	44	-2--5---		Both	5	None	OK
May-07-2021	9:58:48 AM	P_69N-US82 (3401)	0	25	49	3189	43	1----6--		Cell	1	33	Prior Confirm
	9:58:56 AM		8	28	42	2697	43	-----6--		Cell	1	33	Prior Confirm
	9:59:01 AM		13	29	40	2451	42	-2---6--		Cell	99	99	Prior Confirm
	9:59:09 AM		21	31	30	1900	42	-2---6--		Cell	3	35	Prior Confirm
	9:59:19 AM		31	34	20	1286	42	-2---6--		Cell	4	36	Prior Confirm
	9:59:34 AM		46	34	5	351	41	-2------		Cell	99	99	Prior Confirm
	9:59:40 AM		52	134	255	75	43	-2--5---		Cell	5	37	OK
	9:59:44 AM		56	118	255	318	42	-2--5---		Cell	5	37	OK
	9:59:50 AM		62	115	255	499	42	-2--5---		Cell	5	None	OK
May-07-2021	9:59:05 AM	P_US82-Tyler_Dr (5815)	0	32	49	3140	43	-2---6--		Both	1	33	Prior Confirm
	9:59:15 AM		10	34	40	2530	42	-2---6--		Both	2	34	Prior Confirm

Connected Freight Signal Priority System

Field Deployment – ATSPM Hi-Resolution Traffic Events Data



Connected Freight Signal Priority System

Field Deployment – ATSPM Hi-Resolution Traffic Events Data

Signal ID	Timestamp	Event Code	Event Parameter	Event Description
63082009	5/7/2021 10:00:14	82	4	Phase 4 Detector On
63082009	5/7/2021 10:00:14	81	4	Phase 4 Detector Off
63082009	5/7/2021 10:00:15	9	1	Phase 1 End Yellow Clearance
63082009	5/7/2021 10:00:15	10	1	Phase 1 Begin Red Clearance
63082009	5/7/2021 10:00:15	82	2	Phase 2 Detector On
63082009	5/7/2021 10:00:15	81	2	Phase 2 Detector Off
63082009	5/7/2021 10:00:15	82	33	Priority Detector 33 On
63082009	5/7/2021 10:00:14	9	3	Phase 3 End Yellow Clearance
63082009	5/7/2021 10:00:14	10	7	Phase 7 Begin Red Clearance
63082009	5/7/2021 10:00:14	81	3	Phase 3 Detector Off
63082009	5/7/2021 10:00:14	82	7	Phase 7 Detector On
63082009	5/7/2021 10:00:15	9	1	Phase 1 End Yellow Clearance
63082009	5/7/2021 10:00:15	10	6	Phase 6 Begin Red Clearance
63082009	5/7/2021 10:00:15	81	1	Phase 1 Detector Off
63082009	5/7/2021 10:00:15	82	6	Phase 6 Detector On

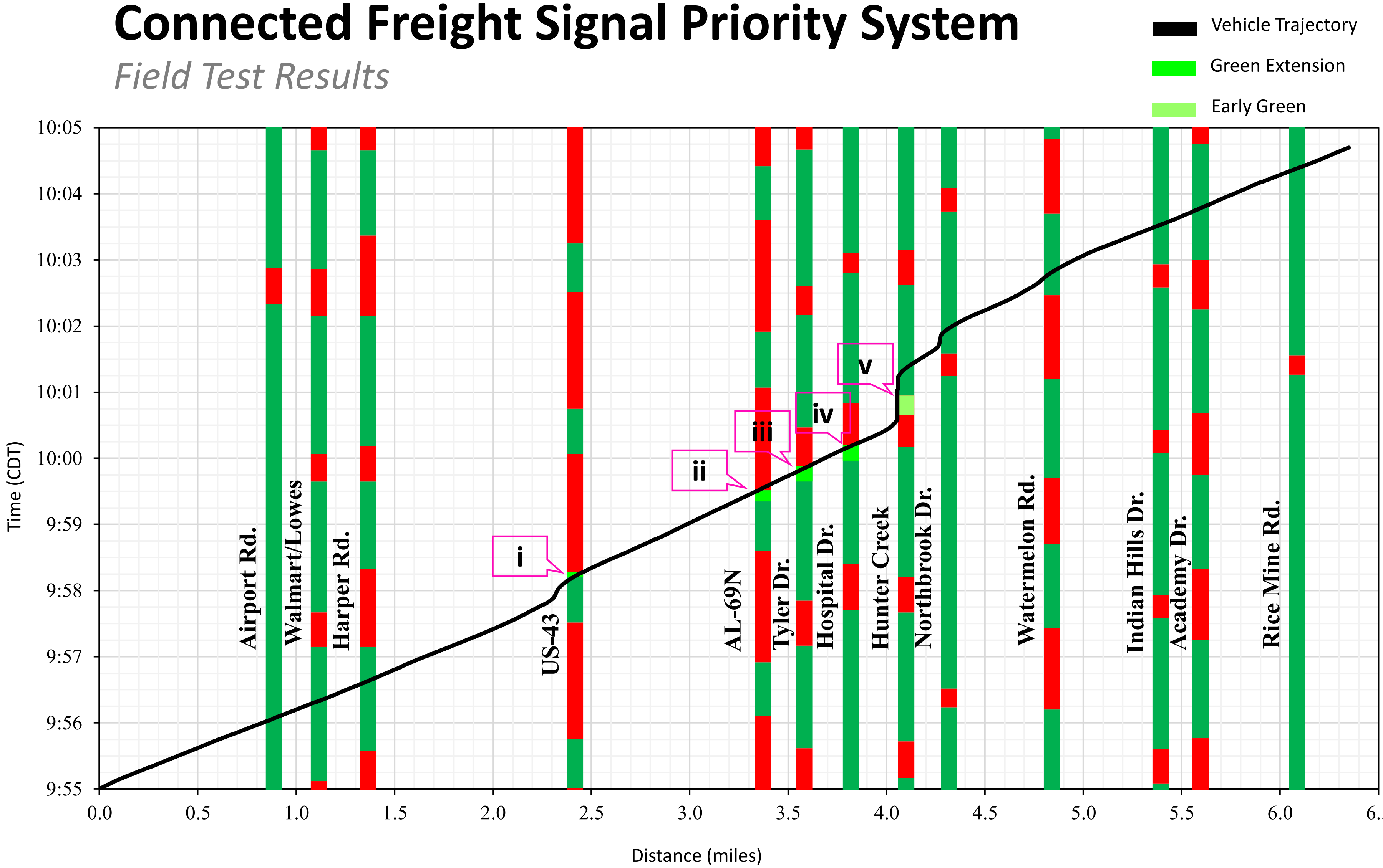
Connected Freight Signal Priority System

Field Deployment – Test Drives

Date	04/27/2021				04/29/2021				05/03/2021		05/06/2021						05/07/2021	
Intersection	Drive 1	Comms	Drive 2	Comms	Drive 3	Comms	Drive 4	Comms	Drive 5	Comms	Drive 6	Comms	Drive 7	Comms	Drive 8	Comms	Drive 9	Comms
Airport Rd.	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio	ERTG	Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio
Walmart/Lowes	GB	Cell & Radio	ERTG	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio
Harper Rd.	GB	Cell & Radio	GB	Cell & Radio	ERTG	Cell & Radio	GB	Cell & Radio	GB	Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio
US-43	ERTG	Cell & Radio	ERTG	Cell & Radio	ERTG	Cell & Radio	GB	Cell & Radio	ERTG	Radio	ERTG	Cell & Radio	ERTG	Cell & Radio	ERTG	Cell & Radio	EXT	Cell & Radio
AL-69N	GB	Cell	GB	Cell	GB	No Comms	GB	No Comms	GB	Cell	ERTG	Cell	GB	Cell	GB	Cell	EXT	Cell
Tyler Dr.	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio	EXT	Cell & Radio
Hospital Dr.	ERTG	Radio	GB	Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio	EXT	Cell & Radio
Hunter Creek Rd.	ERTG	Radio	ERTG	Radio	ERTG	Cell & Radio	EXT	Cell & Radio	ERTG	Radio	GB	Cell & Radio	ERTG	Cell & Radio	ERTG	Cell & Radio	ERTG	Cell & Radio
Northbrook Dr.	ERTG	Radio	GB	Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio	GB	Cell & Radio
Watermelon Rd.	GB	No Comms	Stop	No Comms	GB	Cell	EXT	Cell	Stop	No Comms	GB	Cell	GB	Cell	ERTG	Cell	GB	Cell
Indian Hills Dr.	GB	No Comms	GB	No Comms	GB	Cell	GB	Cell	GB	No Comms	GB	Cell	GB	Cell	GB	Cell	GB	Cell
Academy Dr.	GB	No Comms	GB	No Comms	GB	Cell	GB	Cell	GB	No Comms	GB	Cell	GB	Cell	GB	Cell	GB	Cell
Rice Mine Rd.	GB	No Comms	GB	No Comms	GB	Cell	GB	Cell	GB	No Comms	GB	Cell	GB	Cell	GB	Cell	GB	Cell
Travel Time (minutes)	14.44	✕	12.55	✕	10.08	✕	8.53	✕	11.28	✕	9.48	✓	9.32	✓	10.15	✓	9.70	✓

Connected Freight Signal Priority System

Field Test Results



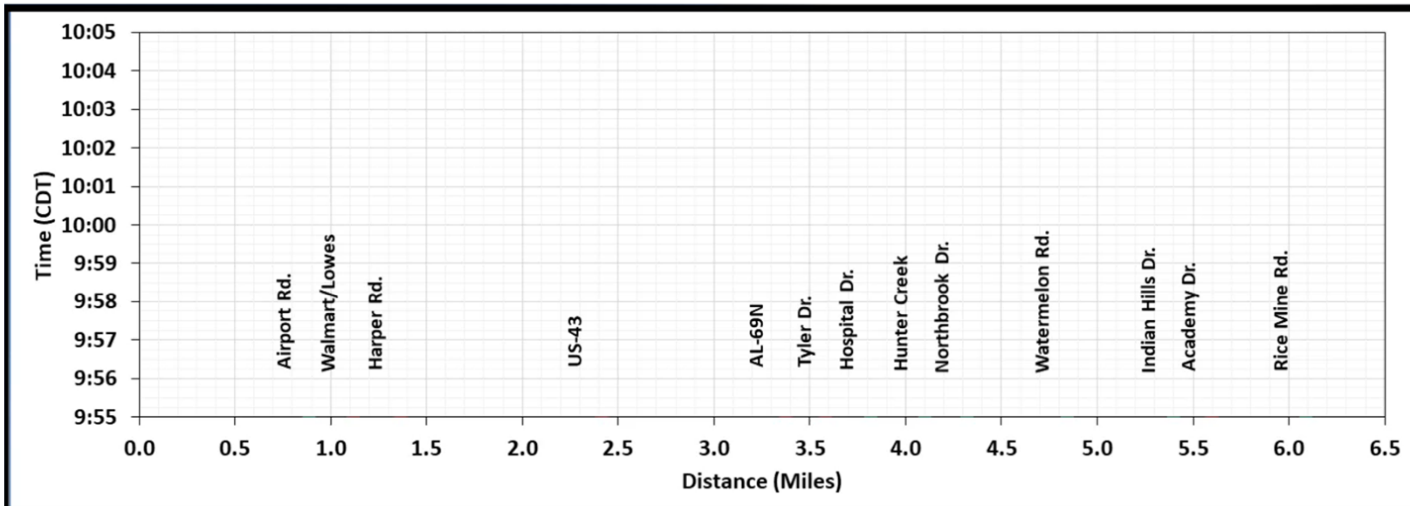
Connected Freight Signal Priority System

Field Test Results

Intersection	Detection	Detection Parameters				Active Phases	Decision Parameters			Possible Outcomes			Detection Outcome	Expected Decision	Field Decision
		D_i	DS_i	dmc_i	dlc_i		$\widehat{T_{SB}}$	CS_{NORM}	CS_{MAX}	$COORD_i$	EXT_i	$ERTG_i$			
US-43	Detection 1	9:57:07 AM	35827	127	136	Phase 3 & 8	36	44	82	1	0	0	COORD	EXT	EXT
	Detection 2	9:57:18 AM	35838	138	147	Phase 3 & 8	37			1	0	0	COORD		
	Detection 3	9:57:32 AM	35852	2	11	Phase 1 & 6	41			1	0	0	COORD		
	Detection 4	9:57:46 AM	35866	16	25	Phase 1 & 6	45			0	1	0	EXT		
AL-69N	Detection 1	9:58:46 AM	35926	76	10	Phase 1 & 6	60	49	67	0	1	0	EXT	EXT	EXT
	Detection 2	9:58:59 AM	35939	89	23	Phase 2 & 6	63			0	1	0	EXT		
	Detection 3	9:59:08 AM	35948	98	32	Phase 2 & 6	62			0	1	0	EXT		
	Detection 4	9:59:18 AM	35958	108	42	Phase 2 & 6	62			0	1	0	EXT		
Tyler Dr.	Detection 1	9:59:04 AM	35944	94	48	Phase 2 & 6	98	84	102	0	1	0	EXT	EXT	EXT
	Detection 2	9:59:14 AM	35954	104	58	Phase 2 & 6	98			0	1	0	EXT		
	Detection 3	9:59:25 AM	35965	115	69	Phase 2 & 6	99			0	1	0	EXT		
	Detection 4	9:59:36 AM	35976	126	80	Phase 2 & 6	100			0	1	0	EXT		
Hospital Dr.	Detection 1	9:59:25 AM	35965	115	61	Phase 2 & 6	111	95	125	0	1	0	EXT	EXT	EXT
	Detection 2	9:59:37 AM	35977	127	73	Phase 2 & 6	113			0	1	0	EXT		
	Detection 3	9:59:46 AM	35986	136	82	Phase 2 & 6	112			0	1	0	EXT		
	Detection 4	9:59:54 AM	35994	144	90	Phase 2 & 6	110			0	1	0	EXT		
Hunter Creek	Detection 1	9:59:49 AM	35989	139	73	Phase 2 & 6	123	94	107	0	0	1	ERTG	ERTG	ERTG
	Detection 2	10:00:03 AM	36003	3	87	Phase 1 & 6	127			0	0	1	ERTG		
	Detection 3	10:00:08 AM	36008	8	92	Phase 1 & 6	122			0	0	1	ERTG		
	Detection 4	10:00:15 AM	36015	15	99	Phase 3 & 7	119			0	0	1	ERTG		

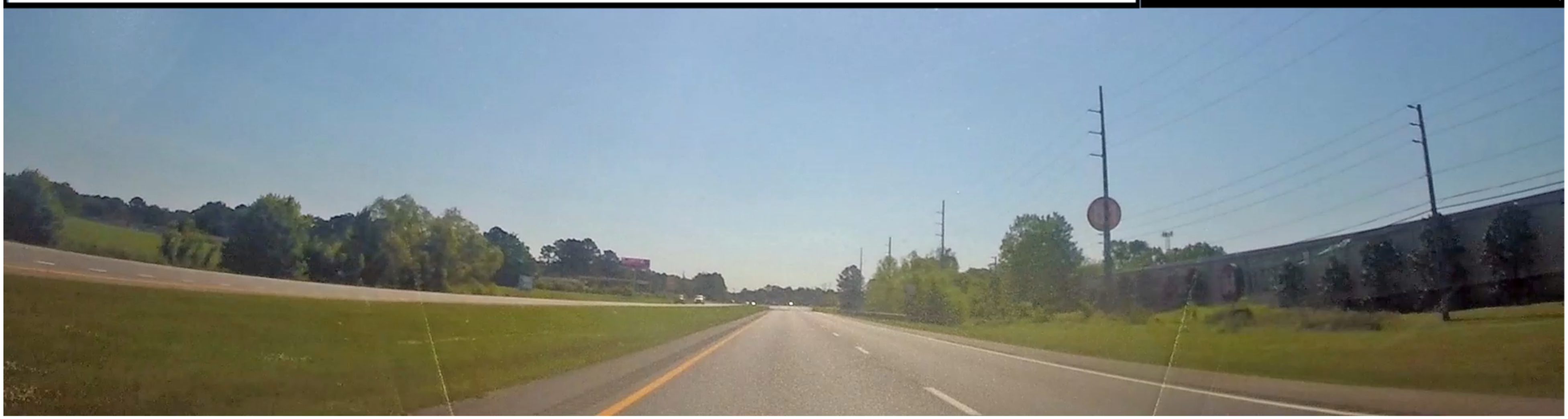
Connected Freight Signal Priority System (ERTG)

Connected Freight Signal Priority   U.S. Route 82 EB   Talukder, Hainen, Tedla, Atkison   **Friday, 05/07/2021 09:55:00**



Airport Rd.

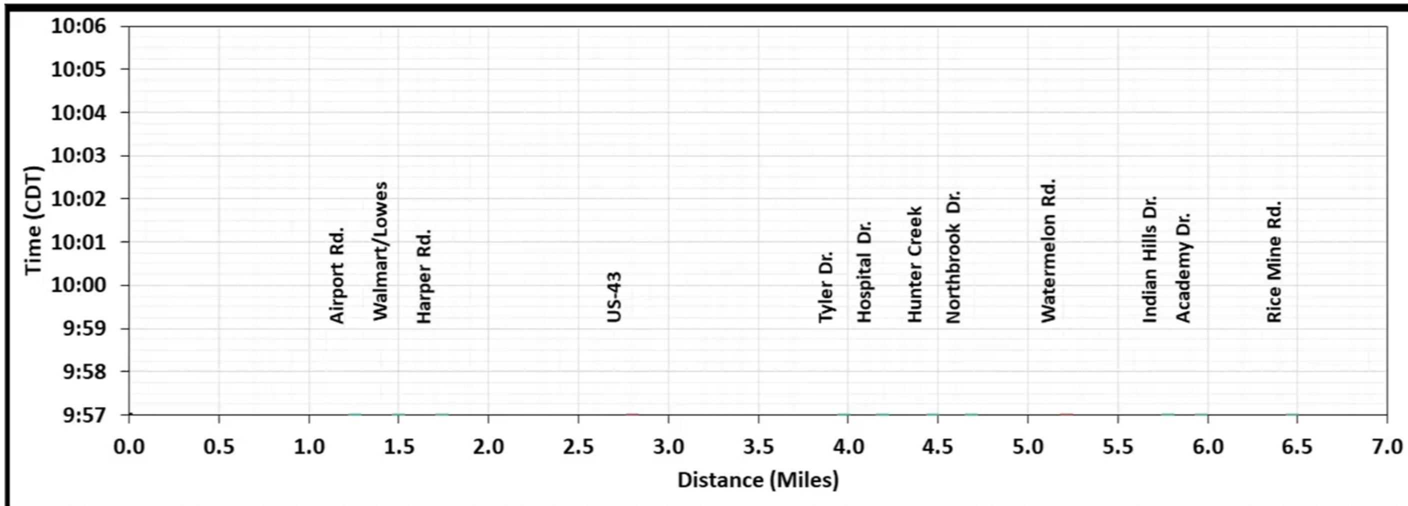
```
PRIORITY00 PAT021 SEQ01 PH.1PR.1UN.1SY.1
PHASE......1...2...3...4...5...6...7...8
CPHZ*10    01150   0 350 1501000   0   0
USED*10    01375   0   0   01375   0   0
IMPC*10    0   0   0   0   0   0   0   0
PRED*10    0   0   0   0   0   0   0   0
PEXT*10    0   0   0   0   0   0   0   0
PPHZ*10    0   0   0   0   0   0   0   0
COORD TIMERS          SEQ: 01
SYSTEM       021        PRM/INH/BEG/PLN
  CYC   OFF   RING.....1....2....3....4
  150    30  SETING   35    .    .    .
   29    30  ACTIVE   29    .    .    .
    0     0  ADJUST    0    .    .    .
  SYNC:   0   PHSE   4-0
  CORR: SW    PERM   4-V
```



Connected Freight Signal Priority System 5X (Best Run)

Connected Freight Signal Priority U.S. Route 82 EB Talukder, Hainen, Tedla, Atkison **Thursday, 04/29/2021 09:57:01**

THE UNIVERSITY OF ALABAMA



Airport Rd.

```
PRIORITY00 PAT021 SEQ01 PH.1PR.1UN.1SY.1
PHASE......1...2...3...4...5...6...7...8
CPHZ*10     01150    0 350 1501000   0   0
USED*10     0 999    0   0    0 999   0   0
IMPC*10     0   0    0   0    0   0   0   0
PRED*10     0   0    0   0    0   0   0   0
PEXT*10     0   0    0   0    0   0   0   0
PPHZ*10     0   0    0   0    0   0   0   0
COORD TIMERS          SEQ: 01
SYSTEM       021      PRM/INH/BEG/PLN
  CYC    OFF    RING.....1....2....3....4
  150     30   SETING   115   100    .    .
   59     30   ACTIVE    24    24    .    .
    0      0   ADJUST     0     0    .    .
  SYNC: 120    PHSE     2-1   6-1
  CORR: SW     PERM     2-H   6-H
```

Connected Freight Signal Priority System

Study Conclusions

- ETA-based FSP system can **overcome** the shortcomings and **enhance** operational efficiency of traditional freight priority system.
- Analytical testing revealed that the proposed FSP system can **accurately** estimate freight's arrival time at the stop bar and can provide accurate and **efficient** priority measure.
- Field deployment results confirmed the **accuracy** and **consistency** of the proposed priority system.

Research During COVID