TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): **Indiana Department of Transportation**

INSTRUCTIONS:

Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Program Project # *TPF-5(377)*	Transportation Pooled Fund Program - Report Period: **Quarter 1 (January 1 – March 31)** Quarter 2 (April 1 – June 30) Quarter 3 (July 1 – September 30) Quarter 4 (October 1 – December 31)
Project Title: Enhanced Traffic Signal Performance Measures	

Name of Project Manager(s): **James R. Sturdevant**	**Phone Number:** **(317) 691-9091**	**E-Mail** jsturdevant@indot.in.gov
Lead Agency Project ID: **TPF 5(377)**	**Other Project ID (i.e., contract #):**	**Project Start Date:** July 1, 2018
Original Project End Date: June 30, 2021	**Current Project End Date:** June 30, 2022	**Number of Extensions:** 1

Project schedule status:

On schedule X On revised schedule   ☐ Ahead of schedule   ☐ Behind schedule

Overall Project Statistics:

Total Project Budget	Total Cost to Date for Project	Percentage of Work Completed to Date
$933,000	$832,035.89	90%

Quarterly Project Statistics:

Total Project Expenses and Percentage This Quarter	Total Amount of Funds Expended This Quarter	Total Percentage of Time Used to Date
	$37,243.61	92%

Project Description

Background
The Pooled Fund Project TPF-5(258) led by Indiana and with participation from FHWA, California, Georgia, Minnesota, Mississippi, New Hampshire, Pennsylvania, Texas, Utah, Wisconsin, and City of Chicago produced the following technical reports:

- o Performance Measures for Traffic Signal Systems: An Outcome-Oriented Approach.
  http://dx.doi.org/10.5703/1288284315333 [1]
- o Integrating Traffic Signal Performance Measures into Agency Business Processes.
  http://dx.doi.org/10.5703/1288284316063 [2]

The following states have made commitments totally $750,000 for TPF-5(377): Enhanced Traffic Signal Performance Measures: Georgia, Minnesota, Texas, Utah, Wisconsin, North Carolina, Pennsylvania, Ohio. Indiana has committed $275,000 via SPR-4205 Connected Vehicle Corridor Deployment and Performance Measures for Assessment. In addition, College Station, TX, has committed $3,000 to join the PFS as a local agency partner.

Project Objectives

The project will address the following initiatives that complement and expand on the past work the multi-state team has done in the area of traffic signal performance measures:

1. **Traffic Signal Data Logger Update**: Update the data logger specification to provide secure file transfer, incorporate new enumerations that have emerged, and logging new connected vehicle messages.
2. **Probe Data**: Current probe data tools are focused on freeway data. There is a need to build upon the work of Indiana and Pennsylvania DOTs to develop methodologies and tools for using high resolution vehicle trajectory data to compute traffic signal performance measures.

Progress per Quarter (includes meetings, work plan status, contract status, significant progress, etc.):

July 1 – September 30, 2018
- o Conducted telecom for participating states on May 2, 2018, and reached concurrence on the project objectives, task list and timeline.
- o INDOT issued a purchase order for $30,000 to Purdue University to establish the project. Additional funds will be transferred to Purdue as funds are received by INDOT from participating states.
- o Participating states approved tasks for University of Alabama for work on the traffic signal data logger update. A sub-contract proposal was submitted by University of Alabama to Purdue University for those tasks.

October 1 - December 31, 2018
- o Additional funds were received by partner states and INDOT issued a purchase order to increase the project budget by $170,000.
- o Established a subcontract to University of Alabama for work on the traffic signal data logger.
- o A project kick-off telecom is scheduled for January 23, 2019.
- o A face-to-face meeting is scheduled on the Purdue University campus for March 27-28, 2019.

With regards to the scope of work, the following tasks have been accomplished by University of Alabama:
(#1) Identify a set of current issues – This list is based on the issues identified by UDOT and Kittelson.
- o **Pedestrian call** – issues with event codes 45 and 90 and how they were reported for multiple ped button actuations (source: Jamie Mackey, UDOT)
- o **Coordination** – Event code 150 and 151 are handled differently for the local zero and transition (source: Jamie Mackey, UDOT)
- o **Phase gap out** – Event code 10 and event code 9 are being reported differently between controllers. The definition of phase gap out may be interpreted multiple ways. (source: Kittelson)

The manufacturers were asked about this, but no additional issues were identified.

The following University of Alabama tasks are underway:
- o **(#3) Characterize the current issues** – YouTube videos and write-ups are being generated for the Econolite, Intelight, and Siemens controllers.
  - o Siemens M50
    - ▪ **Data**: https://youtu.be/nEESZ0V9bmw
    - ▪ **Ped**: ***FLASH***
  - o Intelight X3
    - ▪ **Data**: https://youtu.be/Cm8JM0kSBtU
    - ▪ **Ped**: https://youtu.be/a0cJpPLLr_4
  - o Econolite Cobalt
    - ▪ **Data**: https://youtu.be/MKD3ulsM9Qs
    - ▪ **Ped**: https://youtu.be/X5rXC7SKzxE
- o **(#4) Develop and define a new XML specification** – The computer science team is working on this specification. Many details such as the header information, filename, and other key data have been examined.

January 1 – March 31, 2019
The pooled fund study face-to-face two day meeting was held at Purdue University on March 27-28, 2019. The meeting was attended by representatives from FHWA, state DOT's (California, Utah, Minnesota, Wisconsin, Georgia, Pennsylvania, Ohio, North Carolina, Indiana), City of College Station, private sector (McCain, Iteris, Econolite, Siemens, Miovision, Intelight, TTS, Ford).
- o Each participating agency provided an overview of their signal infrastructure, including updates on central system initiatives, communication architecture, detection and signal controllers. They also shared various challenges and s stories using SPM's. Finally, they wrapped up with related innovations for signal management, especially the prepa for connected vehicle deployments
- o Dr. Alex Hainen from University of Alabama shared his updates on potential ambiguities in the current data logger specifications. He highlighted the inconsistency on "phase gap-outs" across three signal controllers and proposed relevant solutions. His team also stressed on the importance of secure file transfer protocol (SFTP) to combat cyber security threats. His team will reach out to all participating agencies and vendors to gather other potential inconsistencies and concerns before publishing the draft version of the recommendations in the next 3-6 months.

- o Private sector participants provided a brief overview of the topics-of-interest for the vendor panel discussion to follow the next day. The vendor moderated panel on day 2 discussed the enumerations activities, challenges and future opportunities. Representatives from the auto industry (Audi/Ford) discussed interests of automotive industry in traffic signal performance measures

Figure 1: Photography of panel meeting on March 28, 2019 in West Lafayette, IN.

April 1 – June 30, 2019
- o Professor Alex Hainen and the University of Alabama team met with traffic signal vendors to review enumerations and develop recommendations for revisions and additions.
- o A webinar for participants was held on June 25. Alex Hainen provided an overview of the process to obtain feedback and engage with signal vendors. This process resulted in recommendations for 24 new enumerations and revision of 3 existing enumerations.
- o Following discussion of the recommendations, the revised Indiana Traffic Signal Hi Resolution Data Logger Enume document was distributed to the panel for review.

July 1 – September 30, 2019
- o Panel feedback was collected from the previous webinar. Five states replied with suggestions for a total of 27 new considerations.
- o All new enumerations and comments were incorporated into the published draft. A total of 49 new enumerations were added to the original 2012 set, along with 9 modifications to existing definitions.
- o A webinar was held on September 9 for the panel to discuss the published enhanced enumerations document.
- o Feedback from vendors is new controllers will begin deploying these new enumerations in 2020
- o Exploratory hard braking event data has been obtained to assess feasibility of developing dilemma zone performance measures
- o Developed white paper describing performance measure calculations for Populating SAE J2735 Message Confidence Values for Traffic Signal Transitions along a Signalized Corridor (see results)

October 1 – December 31, 2019
- o A webinar was held on December 9, 2019, with member participation from 11 states, Purdue University, and University of Alabama
- o Alex Hainen reported on the Traffic Signal Data Logger update:
  - o Most vendors plan to implement the new enumerations in Q1 of 2020.
  - o Alabama team is developing a white paper on how to partially automate the exercising & testing of the new enumerations.
  - o Full automation will require close collaboration with vendors to get access to their MIB, but a reasonable level of automation will likely be possible without full MIB access.
- o Darcy Bullock noted that data sharing is a significant concern for automotive manufacturers and takes considerable time to navigate. He provided updates on enhanced probe data activities with auto manufacturers

- o General Motors
  - Negotiating an agreement to get statewide trajectory and hard braking event data for July & August 2019 and January 2020.
  - Travel time distributions are straightforward and will improve fidelity of before/after travel time analysis because they will use trajectory data instead of average segment speed.
  - Team has begun preliminary fusion with Green distributions with enhanced probe data that provides hard braking events.
  - To provide a scalable path, the team is evaluating using cloud services to facilitate processing of the large data sets.
- o Ford Motor Company
  - Two Purdue employee vehicles now reporting into Ford's Big Data Drive.
  - Team met with Ford colleagues in Ft. Wayne on November 20 to receive training on a loaner F150 that can provide enhanced probe data for research purposes to validate use cases.

January 1 – March 31, 2020
- o Alex Hainen/University of Alabama update on Traffic Signal Data Logger automation activities:
  - o The updated enumerations posted at https://docs.lib.purdue.edu/jtrpdata/4/ has been downloaded over 160 times. Vendors have been engaging with Alex to interpretation. We expect to post an updated document in the next month or two with some minor changes and clarifications.
- o Darcy Bullock/Purdue University update on enhanced probe data activities with auto manufacturers:
  - o General Motors
    - GM/Wejo agreement for data was signed and statewide trajectory and hard braking event data for July 2019, August 2019, and January 2020 was received.
    - Research team is processing the data sets and developing analysis tools to fuse GM data with signal data.
  - o Ford Motor Company
    - Data for two Purdue employee vehicles for September/October 2019 has been received from Ford's Big Data Drive. Additional data is expected in the next quarter.
  - o Trajectory Data Analysis
    - Research team has developed algorithms for identifying split failures from high fidelity trajectory data. These algorithms are vendor neutral. A manuscript is being prepared that documents these algorithms and will be applied to the large data set.
- o Purdue University submitted the following papers:
  - o ASCE International Conference on Transportation & Development (ICTD 2020): "Methodology for Evaluating Impact of Actuated Traffic Signal Control on Connected Vehicle Green Light Prediction"
  - o ITS World Congress 2020: "Using Crowdsourced Vehicle Braking Data to Identify Road Hazards"
  - o Journal of Transportation Engineering, Part A: Systems: "Leveraging Connected Vehicles to Provide Enhanced Roadway Condition Information"
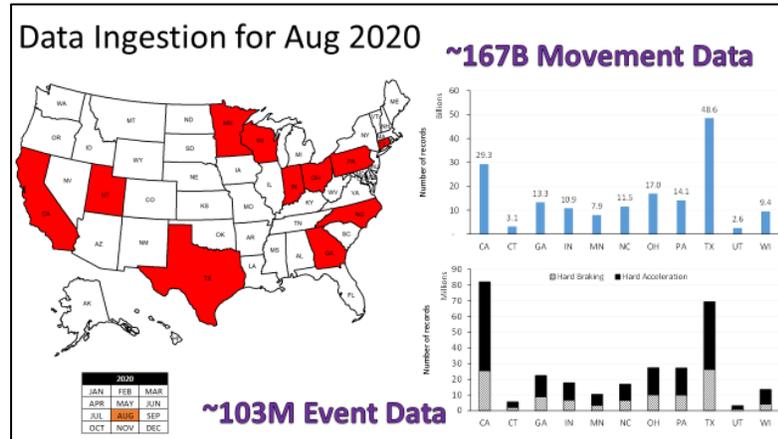
April 1 – June 30, 2020
- o A PFS Webinar was held on June 22, 2020, with member participation from 11 states, FHWA, Purdue University, and University of Alabama. Updates included the following:
  - o Enumerations - University Alabama
    - Vendors agreed to implement the new enumerations in 2020, but some progress has been delayed due to COVID-19.
    - Alabama team met with vendors regarding automated testing. Due to fact that detector inputs are proprietary information, it was determined that automated testing is not a scalable approach.
  - o Alternative Architecture Analysis
    - Howell Li provided a high level comparison of on-premises vs Google Cloud solution for data storage/efficiency/costs for running trajectory queries.
    - Purdue team is designing Performance Measures to be architecture agnostic.
    - Purdue team has performed corridor level analysis using both on premise and cloud architectures. With careful planning, cloud based queries cost only a few dollars. But Howell provided examples where query costs can be several thousand, if proper query planning is not performed.
  - o Probe Data Analytics
    - Purdue team presented traffic signal analytics derived from trajectory and hard braking data

collected from three corridors in Indiana (SR 37, US 40, US 231). The proposed performance measures included visualization of Delay Measurements/Level of Service, Progression and Arrivals on Green, Split Failure, Downstream Blockage, Left Turn Movements, and Hard Braking Events/Dilemma Zone

July 1 – September 30, 2020
- o Purdue University obtained access to 167 billion vehicle records from 11 states from August 2020 for selected analysis.

- o A PFS Webinar was held on September 23, 2020, with member participation from 11 states, FHWA, Purdue University, and University of Alabama. Updates included the following:
  - o Enumerations - University Alabama
    - Alex Hainen reviewed the revised enumerations document, which will be updated on the Purdue e-Pubs site: https://docs.lib.purdue.edu/jtrpdata/4/
    - Alex Hainen provided implementation updates from vendors and noted that automated testing is not a scalable approach
  - o The following TRB Submissions from July 2020 were distributed in advance of the webinar.
    - TRBAM-S-20-02656: Deriving Operational Traffic Signal Performance Measures from Vehicle Trajectory Data
    - TRBAM-S-20-02755: A Proactive Approach to Evaluating Intersection Safety Using Hard-braking Data
  - o Purdue Enhanced Probe Data Analytics Update
    - Howell Li summarized the cloud data costs associated with storing and processing the data.
    - Indiana team discussed the information that can be extracted from the enhanced probe data using case studies developed for SR 37, US 40 and US 30 in Indiana.
  - o Review of Peer States Analysis using August 2020 Enhanced Probe Data
    - Reviewed the performance measures for an 11-intersection corridor in Philadelphia, PA region.
    - Reviewed the performance measures for a 9-intersection corridor in Utah.

October 1 – December 31, 2020

- o Purdue team has conducted analysis from trajectory data for traffic signal corridors submitted by California, Texas, North Carolina, Pennsylvania, Utah, and Indiana. Analysis of additional corridors in North Carolina, California, Georgia and Pennsylvania are on-going. The table and map below summarize the corridor analyses that have been completed.
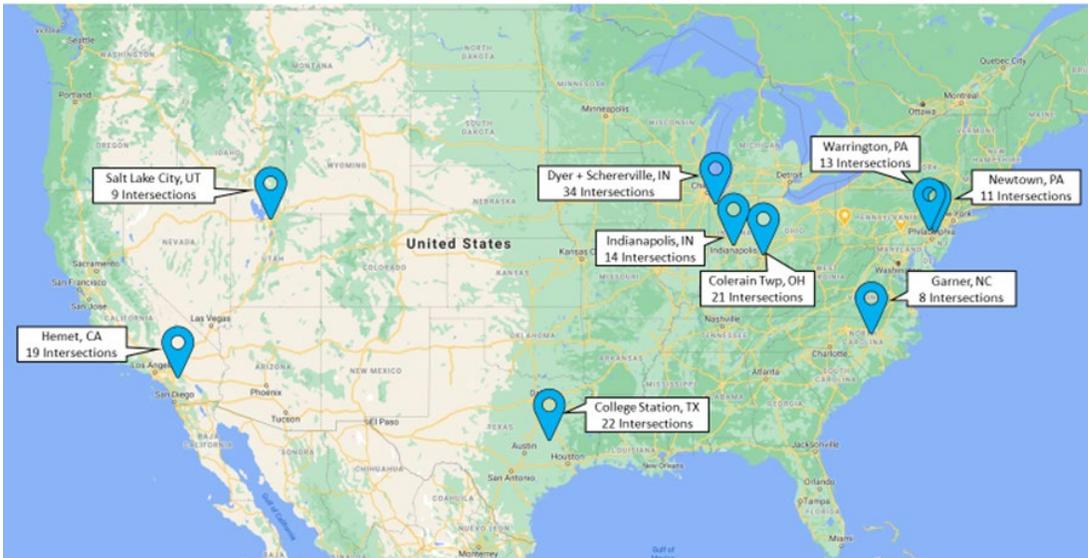
Summary of Corridor Analysis

State	City	Corridor Name Poster Link	Date Shared with State	Number Intersections	Number Trajectories (K)	Number GPS Points (M)
CA	Hemet	CA-74	11/23/2020	19	249	4.9
TX	College Station	University Dr	11/11/2020	9	193	3.5
TX	College Station	Texas Ave	11/11/2020	13	396	7.3
IN	Dyer + Schererville	US-30[2]	9/23/2020	34	1340	19.8
IN	Indianapolis	SR-37	9/23/2020	8	127	1.8
IN	Indianapolis	US-40[3]	9/23/2020	6	244	3.0
OH	Colerain Township	US-27	11/19/2020	31	613	9.1
NC	Garner	US-70	11/10/2020	8	185	2.8
PA	Warrington	PA-611	11/21/2020	13	298	3.9
PA	Newtown	Newtown Bypass	9/23/2020	11	189	3.1
UT	Salt Lake City	Foothill Dr	9/23/2020	9	124	1.7
Totals				**151**	**3958**	**60.9**

- o The following TRB papers were approved for the 2021 TRB Annual Meeting in January 2021:
  - o Saldivar-Carranza E., H. Li, J. Mathew, M. Hunter, J. Sturdevant, D.M. Bullock, "Deriving Operational Traffic Signal Performance Measures from Vehicle Trajectory Data," Transportation Research Board Annual Meeting. Presentation No. TRBAM-21-01472, recommended for publication.
  - o Hunter, M., E. Saldivar-Carranza, J. Desai, J. Mathew, H. Li, and D.M. Bullock, "A Proactive Approach to Evaluating Intersection Safety Using Hard-Braking Data," Transportation Research Board Annual Meeting. Presentation No. TRBAM-21-01539.
- o Pooled Fund Study research related to enhanced probe data was presented through the following media coverage and national webinars:
  - o Webinar: "Big Data Applications for Managing U.S. Roadways," Wejo Inc, and Purdue University, October 28, 2020. https://youtu.be/vwpG13VxzAA?t=492
  - o Webinar: "Optimizing traffic signal performance to enhance safety and reduce infrastructure cost," Reuters, Wejo Inc., and Purdue University, December 8, 2020. https://youtu.be/3zZx6Uoj7Hw

- o Case Study: Purdue University traffic research program cuts data analysis and batching from hours to minutes with BigQuery," Google.com., December 14, 2020. https://cloud.google.com/customers/purduejtrp

January 1 – March 31, 2021
- o The following TRB papers were presented at 2021 TRB Annual Meeting Virtual Poster Sessions:
  - o Saldivar-Carranza E., H. Li, J. Mathew, M. Hunter, J. Sturdevant, D.M. Bullock, "Deriving Operational Traffic Signal Performance Measures from Vehicle Trajectory Data," Transportation Research Board Annual Meeting. Presentation No. TRBAM-21-01472, in press. **(Received TRB AHB25 Committee Best Paper Award).**
  - o Hunter, M., E. Saldivar-Carranza, J. Desai, J. Mathew, H. Li, and D.M. Bullock, "A Proactive Approach to Evaluating Intersection Safety Using Hard-Braking Data," Transportation Research Board Annual Meeting. Presentation No. TRBAM-21-01539.

- o The Purdue team presented "Deriving Operational Traffic Signal Performance Measures from Vehicle Trajectory Data" for the ATSPM Monthly Web-Conference hosted by Eddie Curtis on March 22, 2021.

- o A PFS Webinar was held on March 23, 2021, with member participation from 11 states, FHWA, Purdue University, and University of Alabama. Updates included the following:
  - o Summary of the Traffic Signal Corridor Analysis completed by the research team (see Table below)
  - o Recent Case Studies from Peer State Analysis
  - o Data Management and Cloud Concepts

State	City	Corridor Name	Date Shared with State	No. Intersections	No. Trajectories (K)	No. GPS Points (M)
IN	Dyer + Schererville	US-30[2]	9/23/2020[1]	34	1340	19.8
IN	Indianapolis	SR-37	9/23/2020[1]	8	127	1.8
IN	Indianapolis	US-40[3]	9/23/2020[1]	6	244	3
PA	Newtown	Newtown Bypass	9/23/2020[1]	11	189	3.1
UT	Salt Lake City	Foothill Dr	9/23/2020[1]	9	124	1.7
NC	Garner	US-70	11/10/2020	20	460	6.9
TX	College Station	University Dr	11/11/2020	9	193	3.5
TX	College Station	Texas Ave	11/11/2020	13	396	7.3
OH	Colerain Township	US-27	11/19/2020	21	613	9.1
PA	Warrington	PA-611	11/21/2020	13	298	3.9
CA	Hemet	CA-74	11/23/2020	19	249	4.9
GA	Hiram	SR-92	1/22/2021	7	92	1.4
CA	Chino	RTE-83	2/8/2021	13	195	3.3
GA	Centerville	SR-247	3/19/2021	23	414	6.4
GA	Marietta	SR-5	3/19/2021	20	384	5.7
PA	Elizabethtown	PA-230	3/22/2021	10	68	0.9
Total				236	5386	82.7

- o PFS Members approved a 12 month no-cost extension for the TPF-5(377) project in order to continue corridor analysis and refinement of trajectory-based traffic signal performance measures.

April 1 – June 30, 2021
- o Technical papers were prepared and submitted to IEEE-International Conference on Intelligent Transportation. The following papers were accepted for presentation and publication. A webinar with the PFS panel will be scheduled to review the papers next quarter.
  - o **"**Identifying Vehicle Turning Movements at Intersections from Trajectory Data." Enriquie D. Salivar-Carranza, Howell Li, and Darcy M. Bullock.
  - o "Using Connected Vehicle Data to Evaluate Traffic Signal Performance and Driver Behavior after Changing Left Turns Phasing." Enrique D. Saldivar-Carranza, Jijo K. Mathew, Howell Li, Margaret Hunter, Tom Platte, and Darcy M. Bullock.
  - o "Methodology for Applying Connected Vehicle Data to Evaluate Impact of Interstate Construction Work Zone Diversions." Jairaj Desai, Enrique Saldivar-Carranza, Jijo K. Mathew, Howell Li, tom Platte, and Darcy Bullock.

July 1 – September 30, 2021
- o The following papers were published during this quarter:
  - o Saldivar-Carranza, E.D., Hunter, M., Li, H., Mathew, J., and Bullock, D.M. "Longitudinal Performance Assessment of Traffic Signal System Impacted by Long-term Interstate Construction Diversion using Connected Vehicle Data." Journal of Transportation Technologies, 11, 644-659. (2021) https://doi.org/10.4236/jtts.2021.114040
  - o Saldivar-Carranza, E.D., Li, H. and Bullock, D.M. "Diverging Diamond Interchange Performance Measures using Connected Vehicle Data." Journal of Transportation Technologies, 11, 628-643. (2021) https://doi.org/10.4236/jtts.2021.114039
  - o Hunter, M., Mathew, J.K, Li, H. and Bullock, D.M. "Estimation of Connected Vehicle Penetration on US Roads in Indiana, Ohio, and Pennsylvania." Journal of Transportation Technologies, 11, 597-610. (2021) https://doi.org/10.4236/jtts.2021.114037

- o The following papers were presented at the IEEE-International Conference on Intelligent Transportation in September 2021. These papers are currently in press with publication pending.
  - o Saldivar-Carranza, E.D., Mathew, J., Li, H., Hunter, M., Platte, T., and Bullock, D.M. "Using Connected Vehicle Data to Evaluate Traffic Signal Performance and Driver Behavior after Changing Left-turns Phasing." IEEE Transactions on Intelligent Transportation Systems, September 2021. In press.
  - o Saldivar-Carranza, E.D., Li, H., and Bullock, D.M. "Identifying Vehicle Turning Movements at Intersections from Trajectory Data." IEEE Transactions on Intelligent Transportation Systems, September 2021. In press.
  - o Desai, J., Saldivar-Carranza, E.D., Mathew, J., Li, H., Platte, T., and Bullock, D.M. "Methodology for Applying Connected Vehicle Data to Evaluate Impact of Interstate Construction Work Zone Diversions." IEEE Transactions on Intelligent Transportation Systems, September 2021. In press.

- o The following paper was presented at ITE Great Lakes Conference in Columbus, OH in August 2021:
  - o Saldivar-Carranza, E.D., Hunter, M., Li, H., Mathew, J., and Bullock, D.M. "Longitudinal Performance Assessment of Traffic Signal System Impacted by Long-term Interstate Construction Diversion using Connected Vehicle Data." Journal of Transportation Technologies, 11, 644-659. (2021) https://doi.org/10.4236/jtts.2021.114040

- o The following papers were submitted for presentation at the 2022 TRB Annual Meeting:
  - o "Longitudinal Performance Assessment of Traffic Signal System Impacted by Long Term Interstate Construction Diversion," Enrique Saldivar-Carranza, Margaret Hunter, Jijo K. Mathew, Howell Li, Darcy M. Bullock. TRBAM-22-01996
  - o "Diverging Diamond Interchange Performance Measures from Connected Vehicle Data," Enrique Saldivar-Carranza, Howell Li, Darcy M. Bullock. TRBM-22-01920
  - o "Estimation of Connected Vehicle Penetration on US Roads in Indiana, Ohio, and Pennsylvania," Margaret Hunter, Jijo K. Mathew, Howell Lil, Darcy M. Bullock. TRBAM-22-02064

October 1 – December 31, 2021
- o Poster presentations for the 2022 TRB Annual Meeting were prepared for the following papers:
  - o "Longitudinal Performance Assessment of Traffic Signal System Impacted by Long Term Interstate Construction Diversion," Enrique Saldivar-Carranza, Margaret Hunter, Jijo K. Mathew, Howell Li, Darcy M. Bullock. TRBAM-22-01996
  - o "Diverging Diamond Interchange Performance Measures from Connected Vehicle Data," Enrique Saldivar-Carranza, Howell Li, Darcy M. Bullock. TRBM-22-01920
  - o "Estimation of Connected Vehicle Penetration on US Roads in Indiana, Ohio, and Pennsylvania," Margaret Hunter, Jijo K. Mathew, Howell Lil, Darcy M. Bullock. TRBAM-22-02064

- o A PFS Webinar was held on November 17, 2021, with member participation from 11 states, FHWA, and Purdue University. Updates included the following:
  - o CV-Based Traffic Signal Performance Measures Case Studies
  - o Scalability and Data Penetration
  - o Framework for comparing roundabout and traffic signal performance measures for agencies with diverse intersections (signalized and roundabouts).

- o Procedures were developed for ranking, by delay, over 400 approaches at 100 roundabouts. These techniques were published in the following paper and serve a roadmap for applying these techniques to signalized intersections by either approach (same as roundabout), or movement.

- o Saldivar-Carranza, E., Mathew, J.K., Li, H. and Bullock, D.M. (2022) Roundabout Performance Analysis Using Connected Vehicle Data. Journal of Transportation Technologies, 12, 42-58. https://doi.org/10.4236/jtts.2022.121003

- o The following national webinars and presentations were conducted:
  - o Webinar: "Traffic Signal Performance Measures – Transition from Infrastructure to Trajectory Data," National Operations Academy, October 29, 2021.
  - o Webinar: "Indiana Connected Vehicles Dashboards for Monitoring Operations Spotlight Presentation," 2021 MAASTO CAV e-Summit, November 4, 2021.
  - o Webinar: "Panel Discussion - The Business Case for ATSPM," 2021 Transportation Engineering and Safety Conference, PennDOT, December 9, 2021.
  - o Presentation: "Scalable Cloud-based Vehicle Trajectory Traffic Signal Performance Measures," ITS America 2021, December 8, 2021.
  - o Panel Presentation: "Findings and Reducing Delay and Emissions Thousands of Signals at a Time," ITS America 2021, December 9, 2021.

January 1 – March 31, 2022
- o The following TRB papers were presented at 2022 TRB Annual Meeting Poster Sessions:
  - o "Longitudinal Performance Assessment of Traffic Signal System Impacted by Long Term Interstate Construction Diversion," Enrique Saldivar-Carranza, Margaret Hunter, Jijo K. Mathew, Howell Li, Darcy M. Bullock. TRBAM-22-01996
  - o "Diverging Diamond Interchange Performance Measures from Connected Vehicle Data," Enrique Saldivar-Carranza, Howell Li, Darcy M. Bullock. TRBM-22-01920
  - o "Estimation of Connected Vehicle Penetration on US Roads in Indiana, Ohio, and Pennsylvania," Margaret Hunter, Jijo K. Mathew, Howell Lil, Darcy M. Bullock.TRBAM-22-02064

- o The following manuscript was submitted for publication during this quarter:
  - o Journal of Transportation Technologies: "Signalized Corridor Timing Plan Change Assessment Using Connected Vehicle Data"

- o The Purdue team presented "Application of CV Data for Analyzing Arterials with Embedded Diamond Interchanges" for the ATSPM Monthly Web-Conference hosted by Eddie Curtis on February 28, 2022.

- o Purdue team continued traffic signal analysis from trajectory data for corridors submitted by partner states. The map below summarizes the corridor analyses that have been completed to date.
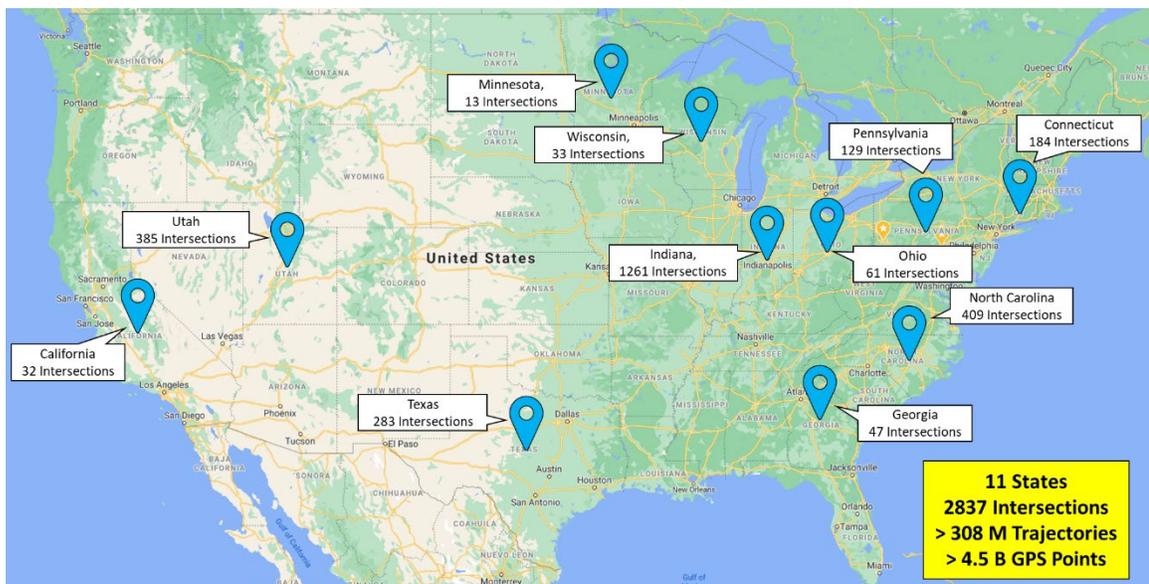
- o The Purdue team planned for the 11 state in-person PFS Panel Meeting to be held in Columbus, OH on April 26-28, 2022.

Anticipated work next quarter:
- Conduct PFS Panel Meeting in Columbus, OH on April 26 – 28, 2022.
- Continue case studies of corridors for participating states
- Continue to strengthen private sector partnerships for collecting and analyzing enhanced probe data for traffic signal performance measures.
- Continue outreach activities to share findings with a broader audience.
- Integrate PFS member feedback on trajectory-based traffic signal analytics and continue to refine the performance measures.
- Submit relevant papers for publication.
- Continue development of cloud based analysis procedures.

Significant Results:

The enhanced enumerations document has been published: https://docs.lib.purdue.edu/jtrpdata/4/

Li, H., A. M. Hainen, J. R. Sturdevant, T. Atkison, S. Talukder, J. K. Mathew, D. M. Bullock, D. Nelson, D. M. Maas, Jr., J. Fink, and T. Stiles. Indiana Traffic Signal Hi Resolution Data Logger Enumerations. Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2019. https://doi.org/10.5703/1288284316998

Mathew, Jijo, H. Li, and D.M. Bullock, "Using Stochastic Variation of Cyclic Green Distributions to Populate SAE J2735 Message Confidence Values along a Signalized Corridor", Transportation Research Record: Journal of the Transportation Research Board, Transportation Research Board of the National Academies, Washington, D.C., 2020. https://doi.org/10.1177/0361198120929337

Desai, J., H. Li, J.K. Mathew, Y. Cheng, A. Habib, and D.M. Bullock, "Correlating Hard-Braking Activity with Crash Occurrences on Interstate Construction Projects in Indiana." Journal of Big Data Analytics in Transportation, October 2020. https://doi.org/10.1007/s42421-020-00024-x

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Circumstance affecting project or budget. (Please describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).

Potential Implementation:
- Traffic signal vendors begin deploying the new enumerations in 2020.
- We anticipate deployment of the trajectory based performance measures, based upon techniques described in TRBAM 21-01472, in several states in 2021 and 2022.