TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

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

INSTRUCTIONS:

Lead Agency contacts 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(519)*	**Transportation Pooled Fund Program - Report Period:** ☐ Quarter 1 (January 1 – March 31) ☐ Quarter 2 (April 1 – June 30) ☐ X Quarter 3 (July 1 – September 30) ☐ Quarter 4 (October 1 – December 31)

TPF Study Number and Title: TPF-5(519) Expansion: Enhanced Traffic Signal Performance Measures

Lead Agency Contact: **James R. Sturdevant**	**Lead Agency Phone Number** **317 691-9091:**	**Lead Agency E-Mail** jsturdevant@indot.in.gov
Lead Agency Project ID: **TPF-5(519)**	**Other Project ID (i.e., contract #):**	**Project Start Date:** July 1, 2023
Original Project Start Date: **July 1, 2023**	**Original Project End Date:** **6/30/2026**	**If Extension has been requested, updated project End Date:**

Project schedule status:

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

Overall Project Statistics:

Total Project Budget	Total Funds Expended This Quarter	Percentage of Work Completed to Date
$1,080,000	$27,247.08	75%

Project Description:

Background & Impact

The Indiana led pooled fund traffic signal research projects have a strong history of implementation. The first study, TPF-5(259), was recognized by EDC 4 and virtually all controllers now provide high resolution data logging. There is a strong commercial base of advanced traffic signal performance measure providers. The technical reports from TPF-5(259) listed below are widely distributed and cited.

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

Similarly, TPF 5(377) stimulated a second generation of commercial implementation of trajectory-based traffic signal performance measures. TPF-5(377) was led by Indiana and included participation from FHWA, California, Connecticut, Georgia, Minnesota, North Carolina, Ohio, Pennsylvania, Texas, Utah, and Wisconsin. The project developed methodologies and tools for using high resolution vehicle trajectory data to compute enhanced traffic signal performance measures. The technical report for TPF-5(377) was published July 6, 2023.

- Next Generation Traffic Signal Performance Measures https://doi.org/10.5703/1288284317625

Research Needs

During the April 2022 TPF-5(377) Panel Meeting in Columbus, OH, participating states supported a new PFS with the following objectives:

1. Broadening performance measures to additional modes that are impacted by traffic signal systems, particularly transit and pedestrians.
2. Identifying use cases for enhanced probe data beyond the current trajectory and hard braking/hard acceleration data.
3. Integrated Analysis of High-res Controller Data and Trajectory Probe Data

These initiatives for TPF-5(519) will complement and expand the past work the multi-state team has done in the area of enhanced traffic signal performance measures using connected vehicle data.

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

April 1 – June 30, 2023

The solicitation for TPF-5(519) was posted in Spring 2023.
The following states have committed a total of $1,020,000 to TPF-5(519) as of June 30, 2023.

Connecticut
Georgia
Minnesota
Mississippi
North Carolina
Ohio
Pennsylvania
Texas
Utah

The project has a start date of July 1, 2023, and will be funded incrementally by Purdue University as funds from the participating states are transferred.

July 1 – September 30, 2023

The following submissions to 2024 Transportation Research Board (TRB) Annual Meeting were accepted for presentation:

- TRBAM-24-00070: A Data-driven Intersection Geometry Mapping Technique to Enhance the Scalability of Trajec based Traffic Signal Performance Measures
- TRBAM-24-04389 Comparison of Estimated Cycle Split Failures from Detector and Connected Vehicle Data

To date, $40,000 in funding for TPF-5(519) has been received by Purdue University. Significant work on the PFS project is pending additional transfer of funds from the partner states.

October 1 – December 31, 2023

To date, $110,000 in funding for TRF-5(519) has been received by Purdue University.

During this quarter, the Purdue research team has been seeking to identify an alternative connected vehicle data source other then Wejo (which suspended operations on June 1, 2023).

One new data provider, and perhaps a second one, has been identified. These data sources are being reviewed and evaluated by the research team.

Scheduling is underway for a webinar with all partners during the first quarter of 2024 in order to share the new data sources, further define the scope of the study, and prioritize future activities.

January 1 – March 31, 2024

A webinar with held on February 16, 2024 with representatives from FHWA and partner states (CA, CT, GA, IN, MN, MS, NC, OH, PA, UT). Webinar included the following updates.

- The research team presented a comparison on high resolution and connected vehicle performance measures and provided the following references for more details**.**
  https://doi.org/10.1177/03611981231168116
  https://doi.org/10.4236/jtts.2023.134032
- Connected car data is transitioning from Wejo to Streetlight. The research team is reviewing data specifications And agreements with Streetlight and anticipates receiving data for evaluation purposes in April 2024.
- Mark Taylor shared an example of LiDAR data available at an intersection in Utah. Utah has two intersections wit LiDAR on-line and Ohio has one intersection in the early deployment stage. Further investigation into this data so planned for future meetings

Subsequent to the webinar, the research team began work on deriving traffic signal performance measures from LiDAR Sensors at a signalized intersection in Utah. This work included:

- Identifying dataset challenges and proposed a filtering approach to verify sampled trajectories
- Generating a Purdue Probe Diagram to estimate delay, arrivals on green, split failures, and downstream blockage
- Analyzing the same intersection with CV data to provide a comparison

A data set of LiDAR-derived trajectories at Intersections published in collaboration with Utah colleagues is available at Li, T.; Taylor, M.; Saldivar-Carranza, E. D.; Bullock, D. M. (2024). Traffic Signal LiDAR-derived Vehicle Trajectories Dataset. Purdue University Research Repository. https://doi.org:10.4231/MYZ4-8S55

The next PFS Webinar is scheduled for May 2, 2024.

April 1 – June 30, 2024

A webinar was held on May 2, 2024 with representatives from FHWA and partner states (CA, CT, GA, IN, MN, MS, NC, OH, PA, UT, WI). The webinar included the following updates:

- The team discussed the viability of using alternative CV data sources (Compass IOT) to derive traffic signal performance measures.
- LiDAR x-y object data provided by UDOT was demonstrated to be capable of constructing Purdue Probe Diagrams to estimate signal delay, split failures, downstream blockage, and arrivals on green. Recommendations were provided.
- Mark Taylor provided an update on UDOT's progress and lessons learned in the installation and usage of LiDAR systems. Other states, such as ODOT, also provided brief updates.

Additionally, the following progress has been accomplished:

- One week of national CV data has been obtained from StreetLight and is currently under review with the research team. Special attention will be given to the effects that data *fuzzification* has on movement level traffic signal analysis.
- The research team has gained access to LiDAR data at two new locations in Utah (provided by UDOT). Research work was focused on:
    - Deriving movement level trajectory-based traffic signal performance measures by time-of-day. This type of analysis can be executed near real-time to identify challenges and opportunities.
    - Deriving pedestrian traffic signal performance measures to estimate wait times and crossing patterns (one or two streets crossed).
    - A paper will be prepared and published with the relevant findings.
- Normalized hard-braking events have been evaluated at traffic signals, roundabouts, and all-way stops to evaluate similarities and discrepancies

July 1 – September 30, 2024

A webinar was held on September 13, 2024 with representatives from FHWA and partner states (CA, CT, GA, IN, MN, MS, NC, OH, TX, UT, WI). The webinar included updates on the following topics:

- Changes in commercial connected vehicle (CV) trajectory data, particularly the impact of privacy filters. Several examples were covered. This work was published in September (see below) and will be presented at TRB.
- LiDAR-derived vehicle and pedestrian performance measures
- Scaled normalized hard-braking (HB) events derived from CV trajectories at signalized intersections, roundabouts, and all-way stops
- Mark Taylor and Derek Lehrke shared UDOT's and MNDOT's progress in implementing LiDAR technology at equipped intersections.

Signal analytics were updated for each state. New signals were added for Mississippi (Amrik suggested two corridors with 18 signals).

QA/QC procedures were updated.

The following papers were published during this quarter:

Saldivar-Carranza, E.D.; Sakhare, R.S.; Desai, J.; Mathew, J.K.; Sivakumar, A.J.; Mukai, J.; Bullock, D.M. Impact of Privacy Filters and Fleet Changes on Connected Vehicle Trajectory Datasets for Intersection and Freeway Use Cases. *Smart Cities* **2024**, *7*, 2366-2391. https://doi.org/10.3390/smartcities7050093

Vajpayee, V.; Saldivar-Carranza, E.D.; Sakhare, R.S.; Bullock, D.M. Large Scale Evaluation of Normalized Hard-Braking Events Derived from Connected Vehicle Trajectory Data at Signalized Intersections, Roundabouts, and All-Way Stops. *Future Transp.* **2024**, *4*, 968-984. https://doi.org/10.3390/futuretransp4030046

Saldivar-Carranza, E.D.; Bullock, D.M. Deriving Verified Vehicle Trajectories from LiDAR Sensor Data to Evaluate Traffic Signal Performance. *Future Transp.* **2024**, *4*, 765-779. https://doi.org/10.3390/futuretransp4030036

September 1 – December 31, 2024

Ingestion has been done on a new CV data source (CompassIoT) using a sample of data from Texas. Analysis techniques have been developed that allow comparison across all of the Texas Permanent Count stations. Adding a second CV data source has two advantages: 1) Introduces redundancy if one of the OEM's decides to suspend CV data and 2) Establishes market competition.

Developed computational procedures to derive hard braking/acceleration from trajectory data to replace the hard braking data that was suspended by GM (https://www.ftc.gov/news-events/news/press-releases/2025/01/ftc-takes-action-against-general-motors-sharing-drivers-precise-location-driving-behavior-data).

The following paper was published during this quarter:

Saldivar-Carranza, E.D.; Desai, J.; Thompson, A.; Taylor, M.; Sturdevant, J.; Bullock, D.M. Vehicle and Pedestrian Traffic Signal Performance Measures Using LiDAR-Derived Trajectory Data. *Sensors* **2024**, *24*, 6410. https://doi.org/10.3390/s24196410

Prepared posters and slides for two presentations at TRB based upon the following manuscripts

Saldivar-Carranza, E.D.; Desai, J.; Thompson, A.; Taylor, M.; Sturdevant, J.; Bullock, D.M. Vehicle and Pedestrian Traffic Signal Performance Measures Using LiDAR-Derived Trajectory Data. *Sensors* **2024**, *24*, 6410. https://doi.org/10.3390/s24196410

Vajpayee, V.; Saldivar-Carranza, E.D.; Sakhare, R.S.; Bullock, D.M. Large Scale Evaluation of Normalized Hard-Braking Events Derived from Connected Vehicle Trajectory Data at Signalized Intersections, Roundabouts, and All-Way Stops. *Future Transp.* **2024**, *4*, 968-984. https://doi.org/10.3390/futuretransp4030046

January 1 – March 31, 2025

Ingestion and evaluation is in process for a new CV data source (CompassIoT) with a sample of nationwide data. The Team has received monthly data covering all 50 states for January and February. CompassIoT is in process of scaling to include additional vehicles and we anticipate April and May data sets to be the data sets we conduct penetration evaluations on.

Regional and National Presentations regarding work related to TPF-5(519) included the following:

- 2025 TRB Annual Meeting Presentations
  - Vehicle and Pedestrian Traffic Signal Performance Measures Using LiDAR-Derived Trajectory Data.
  - Large Scale Evaluation of Normalized Hard-Braking Events Derived from Connected Vehicle Trajectory Data at Signalized Intersections, Roundabouts, and All-Way Stops
- ATSSA Annual Conference (March 1, 2025): "Evolution of Traffic Signal Performance Measures"
- 2025 Purdue Road School Transportation Conference and Expo (March 18-19, 2025)
  - Impact of Privacy Filters and Fleet Changes on CV Trajectory Datasets for Intersection and Freeway
  - Evaluation of LiDAR Technology for Traffic Signal Performance Measures

April 1 – June 30, 2025

A webinar was held on June 23, 2025 with representatives from FHWA and partner states (CA, CT, GA, IN, MN, MS, NC, OH, PA, TX, UT, WI). The webinar included updates on the following topics:

- Update panel on activities since the previous meeting
- Update panel on the evolution of the CV data marketspace (new entrances, changes in privacy filters)
- Update panel on risks (and opportunities) associated with these changes in the CV Data marketplace.
- Emerging Opportunities and Developments

July 1 – September 30, 2025

- Procedures and tools have been developed to produce consolidated PDF reports of signalized corridors to facilitate easy visualization of monthly/quarterly variation in performance.
- To support this, a generalized performance measure data structure was developed and documented in the following paper that will be presented at TRB: entitled "A Scalable Data Model for Signalized Intersection Performance Measures," Paper ID # 26-02156
- In July we received word from Streetlight that further privacy protection will be applied that extends the privacy filters to the top 15 destinations. Early assessment is that this creates further challenges for signals adjacent to "big box" destinations such as Walmart by severely restricting the number of connected vehicles visible in movements in or out of those frequent destinations. We are currently developing a plan to systematically assess and document those new limitations.

Anticipated work next quarter:

- Purdue will purchase Streetlight CV data for member states for 1-2 weeks to conduct formal evaluation of the latest market penetration rates and impacts of privacy filters on deriving intersection performance measures. This was initially planned for last quarter, but with the privacy filters being phased in, we have delayed that until there is some stability in the data filtering.
- The Signal Performance Measure heatmap is being modified into a corridor performance report format. Justin in Wisconsin expressed interest in providing feedback on the tool. States will be able to request corridor reports using the 2025 Streetlight data.
- One-on-one calls with states can be scheduled to review their respective corridors and reports.
- A fall webinar panel meeting will be scheduled.
- Polling will be initiated for a Spring 2026 in-person panel meeting at location to be determined.

Significant Results:

Saldivar-Carranza, E. D., Li, H., Mathew, J. K., Desai, J., Platte, T., Gayen, S., Sturdevant, J., Taylor, M., Fisher, C., & Bullock, D. M. (2023). Next generation traffic signal performance measures: Leveraging connected vehicle data. West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317625

Saldivar-Carranza, E. D., Li, H., Gayen, S., Taylor, M., Sturdevant, J., & Bullock, D. M. (2023). Comparison of Arrivals on G Estimations from Vehicle Detection and Connected Vehicle Data. Transportation Research Record, 0(0). https://doi.org/10.1177/03611981231168116

Saldivar-Carranza, E. and Bullock, D. (2023) A Data-Driven Intersection Geometry Mapping Technique to Enhance the Scalability of Trajectory-Based Traffic Signal Performance Measures. Journal of Transportation Technologies, 13, 443-464 https://doi.org/10.4236/jtts.2023.133021

Gayen, S., Saldivar-Carranza, E. and Bullock, D. (2023) Comparison of Estimated Cycle Split Failures from High-Resolutic Controller Event and Connected Vehicle Trajectory Data. Journal of Transportation Technologies, 13, 689-707. https://doi.org/10.4236/jtts.2023.134032

Saldivar-Carranza, E.D., Gayen, S. & Bullock, D.M. Intersection Type Classification from Connected Vehicle Data Using a Convolutional Neural Network. *Data Sci. Transp.* **6**, 2 (2024). https://doi.org/10.1007/s42421-023-00087-6

Saldivar-Carranza, E.D.; Gayen, S.; Li, H.; Bullock, D.M. Comparison at Scale of Traffic Signal Cycle Split Failure Identification from High-Resolution Controller and Connected Vehicle Trajectory Data. Future Transp. 2024, 4, 236-256. https://doi.org/10.3390/futuretransp4010012

Li, T.; Taylor, M.; Saldivar-Carranza, E. D.; Bullock, D. M. (2024). Traffic Signal LiDAR-derived Vehicle Trajectories Dataset. Purdue University Research Repository. https://doi.org/10.4231/MYZ4-8S55 (**published April 2, 2024**)

Saldivar-Carranza, E.D.; Bullock, D.M. Deriving Verified Vehicle Trajectories from LiDAR Sensor Data to Evaluate Traffic Signal Performance. *Future Transp.* **2024**, *4*, 765-779. https://doi.org/10.3390/futuretransp4030036

Saldivar-Carranza, E.D.; Sakhare, R.S.; Desai, J.; Mathew, J.K.; Sivakumar, A.J.; Mukai, J.; Bullock, D.M. Impact of Privacy Filters and Fleet Changes on Connected Vehicle Trajectory Datasets for Intersection and Freeway Use Cases. *Smart Cities* **2024**, *7*, 2366-2391. https://doi.org/10.3390/smartcities7050093

Vajpayee, V.; Saldivar-Carranza, E.D.; Sakhare, R.S.; Bullock, D.M. Large Scale Evaluation of Normalized Hard-Braking Events Derived from Connected Vehicle Trajectory Data at Signalized Intersections, Roundabouts, and All-Way Stops. *Future Transp.* **2024**, *4*, 968-984. https://doi.org/10.3390/futuretransp4030046

Saldivar-Carranza, E.D.; Desai, J.; Thompson, A.; Taylor, M.; Sturdevant, J.; Bullock, D.M. Vehicle and Pedestrian Traffic S Performance Measures Using LiDAR-Derived Trajectory Data. *Sensors* **2024**, *24*, 6410. https://doi.org/10.3390/s2419641

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).

None

Potential Implementation: