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.

<table>
<tr>
<td colspan="2">Transportation Pooled Fund Program Project #
<i>TPF-5(519)</i></td>
<td colspan="3">Transportation Pooled Fund Program - Report Period:

☐ Quarter 1 (January 1 – March 31)

☐X   Quarter 2 (April 1 – June 30)

☐   Quarter 3 (July 1 – September 30)

☐   Quarter 4 (October 1 – December 31)</td>
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<tr>
<td colspan="5">TPF Study Number and Title: TPF-5(519) Expansion: Enhanced Traffic Signal Performance Measures</td>
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<tr>
<td colspan="2">Lead Agency Contact:
James R. Sturdevant</td>
<td colspan="2">Lead Agency Phone Number
317 691-9091:</td>
<td>Lead Agency E-Mail
jsturdevant@indot.in.gov</td>
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<tr>
<td colspan="2">Lead Agency Project ID:
TPF-5(519)</td>
<td colspan="2">Other Project ID (i.e., contract #):</td>
<td>Project Start Date:
July 1, 2023</td>
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<tr>
<td colspan="2">Original Project Start Date:
July 1, 2023</td>
<td colspan="2">Original Project End Date:
6/30/2026</td>
<td>If Extension has been requested, updated project End Date:</td>
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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
$230,000	$20,939.87	30%

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 with 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 xy 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

Anticipated work next quarter:
- Provide a thorough analysis of current commercially available CV data. Evaluate the feasibility of using this data set to derive actionable traffic signal performance measures. Compare it with previously available CV data sets.
- Evaluate traffic signal performance at intersections in all states with recently obtained CV trajectory data (May 5 – May 11, 2024).
- Evaluate LiDAR capabilities to derive operational traffic signal performance measures. Implement near real-time analysis of LiDAR data to provide practitioners with current conditions.
- Publish a paper on how to use LiDAR data to derive vehicle movement-level traffic signal performance measures, as well as the experience of pedestrians as they traverse the intersection.
- Publish a paper on new CV penetration at partner states.
- Pending publications:
  - Enrique D. Saldivar-Carranza, Darcy M. Bullock. (2024). Deriving Verified Vehicle Trajectories from LiDAR Sensor Data to Evaluate Traffic Signal Performance. Future Transportation. (**pending editor decision**).

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 (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-Resolution 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**)

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: