# Collection and Analysis of 2013-2014 Travel Time Data

Kentucky Transportation Center Research Report — KTC-17-13/PL27-1F

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**Research Report**
KTC-17-13/PL27-1F

# Collection and Analysis of 2013-2014 Travel Time Data


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In Cooperation With
Kentucky Transportation Cabinet
Commonwealth of Kentucky

And

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## Executive Summary

This report documents the findings of Planning Study 27, *Collection and Analysis of 2013-2014 Travel Time Data*, which is a continuation of Planning Study 24, *Analysis of Historical Travel Time Data*. The main scope is to analyze newly acquired link-referenced speed data on Kentucky roads from 2013 and 2014.

Travel time-based performance measures developed in Planning Study 24 were calculated using these data. These measures were combined with those from 2011-2012 to evaluate performance trends over the four-year period. Additionally, at different points during the course of this study, the data vendor released multiple new datasets produced through refined data processing approaches. The research team evaluated those datasets at selected locations to better understand their characteristics. Further, a procedure was developed to calculate system performance measures established by FHWA's final rule on system performance measures to assist KYTC in its preparation process.

The performance measures generated in this study include travel time index, planning time index, buffer index, annual hours of delay, and percentage travel under congested conditions. Due to the requirement of traffic volume information by delay measures, network conflation was first undertaken by the Kentucky Transportation Cabinet (KYTC) to integrate the vendor's and state highway inventory networks. Analysis was based on the conflated network and results were provided to KYTC and metropolitan planning organization (MPO) stakeholders in the form of geodatabases. A web portal was also developed to facilitate dissemination of and access to the data.

Results of the analysis demonstrate the value of probe data in measuring and tracking the performance of roadways across several years. In addition, such data can help KYTC and MPOs identify bottlenecks in the network, prioritize improvement strategies, and assess the effectiveness of projects. As data collection techniques advance, the coverage and quality of probe data will continue to improve. It is advisable for KYTC to maintain a steady stream of such data to assist with data-driven decision making for a variety of applications.

# CHAPTER 1 Background

The Kentucky Transportation Cabinet (KYTC), in collaboration with the Kentucky Transportation Center (KTC) at the University of Kentucky, acquired link-referenced speed data from HERE for 2011-2014. In a previous study, KTC assessed the 2011-2012 speed data for use in generating travel time-based performance measures (*1*).

This project is a continuation of the effort begun with Planning Study 24 (PL-24) to process and analyze probe speed data for highway performance measurement and management. As part of this research, data from 2013 and 2014 were acquired and processed using a similar approach to the one used in that previous study.

The main objectives of the research were to (1) evaluate 2013-2014 probe speed data and update procedures in generating travel time-based performance measures, and (2) evaluate performance trends over the 2011-2014 period based on travel time index, planning time index, buffer index, and annual hours of delay.

During the execution of this study, the Federal Highway Administration (FHWA) issued a notice of proposed rulemaking and eventually the Final Rule on system performance measures. At the request of KYTC, the research team also programmed the procedure to calculate those measures using available data.

Throughout the study period, HERE published datasets generated by their enhanced processing algorithms. A major improvement in data accuracy on interrupted facilities resulted from the vendor's path-processing algorithm (*2*). In the final months of the study, additional enhanced data products became available, such as separated speeds for cars and trucks. A comparative analysis of these datasets was conducted on selected corridors.

## 1.1 Data Description

Like previously acquired probe speed data, the 2013-2014 data were attached to the links of the HERE street network. Speeds with both 5- and 15-minute epochs on the daily basis were obtained. Speeds were not reported on a link for periods when probe data were not available. In addition to average speeds, speed standard deviation, minimum speed, maximum speed, and the confidence score were reported for each link and time epoch. Free flow speed and speed limit were also among the items provided. To maintain consistency with the previous study, we decided that measures would be generated using data at 15-minute epochs.

The confidence score is based on the number of observations in that epoch, the variance of those observations, and other available information. According to data documentation (*2*), the confidence score can be interpreted as shown in Table 1-1.

**Table 1-1 Interpretation of confidence scores**

| Confidence | Meaning |
|---|---|
| 10 | Suggestive |
| 20 | Highly Suggestive |
| 30 | Confident |
| 40 | Highly Confident |

A major improvement in the 2013-2014 data is that speeds are reported for each day of the year, if available, whereas prior to 2013, they were reported in an aggregated format, for each day of the week for a given month. Table 1-2 lists the differences between the two datasets.

**Table 1-2 Difference in data item and format**

| Data Characteristics | 2011-2012 | 2013-2014 |
|---|---|---|
| Aggregation level | 5-min epoch, day of the week by month | 5-min epoch, daily |
| Sample size | 5-min epoch when probe data available | Not available; replaced by confidence score per 5-min epoch when probe data available |
| Standard deviation | 5-min epoch when probe data available | 5-min epoch when probe data available |
| Speed limit | Not available from the speed file but available from the NAVTEQ Street network data | Available |
| Free flow speed | Not available | Available (HERE estimated based on historical data and other factors) |
| Other | | Minimum and maximum probe Speeds per 5-min epoch |

The 2013-2014 data were initially available in two forms depending on how the speeds were processed by HERE. The GPS probe-based approach takes the instantaneous speed of the probes whenever they were polled and assigns the average to the link at the time polling occurred. This approach was also used in 2011-2012 data.

A GPS path-based approach was adopted for data starting in 2013. This approach involves tracking probe trajectories, computing space mean speed, and integrating it with the GPS point-based speed in a link to produce a path-processed dataset. This path-based speed is then assigned to all links that were part of the path. As a result, links that probe vehicles traversed but that were not polled for instantaneous speeds would then be included. A trial analysis of the Lexington area indicated that path-processed datasets contain about 50% more records than the probe-based data.

Both probe-based (i.e., traditional) and path-processed datasets are provided as part of the purchase. Due to time constraints, KYTC suggested the research team focus on the traditional (i.e., probe-based) dataset to ensure consistency with the data used in PL-24.

## 1.2 Data Quality Evaluation

### *1.2.1 Sample Adequacy*

Temporal coverage was first evaluated using the measures derived for different time periods, as shown in Table 1-3.

**Table 1-3 Sample adequacy measures**

| Measure | Description |
|---|---|
| TotalIntervals_Ideal | Number of 15-min epochs of the time period of interest. For example, 8,064 in the whole year. |
| TotalIntervals_Sampled | Number of 15-min epochs with probe data during the time period of interest. |
| PcntInterval_Sampled | Percentage of 15-min epochs with probe data during the time period of interest. It is calculated as 100*TotalIntervals_Sampled/TotalIntervals_Ideal |

Figure 1-1 shows the spatial coverage of 2013 data with at least one 15-minute epoch with probe data.

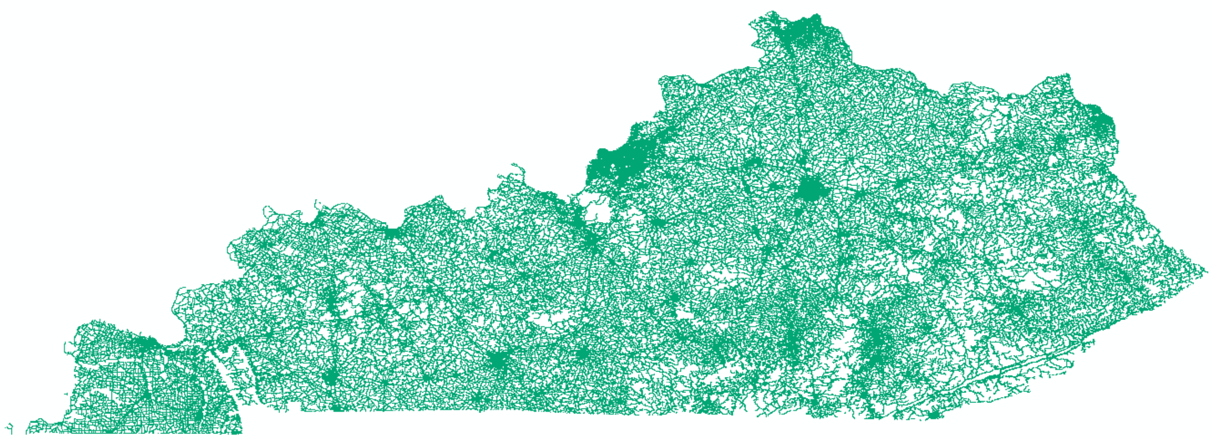


**Figure 1-1 2013 Probe sample coverage**

As the percentage of epochs that have probe data decreases, confidence in the data diminishes as well. A minimum threshold of 1% temporal coverage (measured by PcntInterval_Sampled) was considered acceptable. Based on the analysis period of interest, Table 1-4 shows the minimum values of the field TotalIntervals_Sampled to satisfy this threshold. The analysis period may be all days in the year, all non-holiday weekdays, all weekends, non-holiday weekday AM periods, non-holiday weekday midday periods, non-holiday weekday PM periods, and so forth. When the sample percentage (i.e., PcntInterval_Sampled value) of a link was less than 1%, it was flagged in the record.

**Table 1-4 Minimum sample size desired**

| Time Period | Total Epochs | Minimum Values of TotalIntervals_Sampled (1% Threshold) |
|---|---|---|
| All days | 35040 | 350 |
| Non-holiday weekdays | 24384 | 244 |
| Weekends | 9984 | 100 |
| Non-holiday weekday daytime(6am-8pm) | 14224 | 142 |

| | | |
|---|---|---|
| Non-holiday weekday AM period (6am-9am) | 3048 | 30 |
| Non-holiday weekday midday period (9am-3pm) | 6096 | 61 |
| Non-holiday weekday PM period (3pm-6pm) | 3048 | 30 |

Unlike previously acquired data, which were aggregated by day of the week and month, 2013 and 2014 speed data were available for each day. This resulted in $365 \times 24 \times 4 = 35{,}040$ time epochs per year, significantly more than the 8,064 in the previous case. Table 1-5 shows the distribution of the directional-miles of Kentucky roadways based on different temporal coverage ranges for both 2013 and 2014. The temporal coverage of the probe speeds were measured in terms of PcntInterval_Sampled, as defined in Table 1-3. For example, a temporal coverage range of (1, 2) indicates probe speeds were available for 1%-2% of the 35,040 epochs. This equates to approximately 350-700, 15-min epochs. According to Table 1-5, in 2013, 10.9% of the total directional-miles had speed data at this temporal coverage range, while the percentage increased to 11.8% in 2014. The total directional-miles of the conflated network in 2013 and 2014 were 53,157.7 miles and 53,188.1 miles, respectively. Due to base condition changes, it is inappropriate to make direct comparisons with sample sizes for 2011 and 2012 data.

Table 1-5 indicates that data availability improved slightly between 2013 and 2014, both in terms of year-round statistics and time period statistics. During this period, the percentage of directional-miles in higher temporal coverage ranges increased but decreased for lower temporal coverage ranges.

Table 1-6 partitions the data in Table 1-5 based on functional classification. Interstates and major arterials tended to have probe coverage at the high end, while roadways with lower functional classifications, especially those in rural areas, had very limited data. The improvement in probe data coverage was mostly concentrated in roads with higher functional classifications, such as interstates and major arterials.

**Table 1-5 Sample coverage of link-referenced data**

| Temporal Coverage Range | Year | | AM | | Mid-day | | PM | |
|---|---|---|---|---|---|---|---|---|
| | 2013 | 2014 | 2013 | 2014 | 2013 | 2014 | 2013 | 2014 |
| 0 | | | 6.8 | 5.1 | 0.7 | 0.5 | 3.5 | 2.6 |
| (0,0.012] | 1.7 | 1.4 | | | | | | |
| (0.012,0.5] | 51.9 | 47.0 | 39.3 | 35.5 | 30.8 | 27.2 | 37.1 | 31.8 |
| (0.5,1] | 14.5 | 15.1 | 12.0 | 12.5 | 16.6 | 16.3 | 14.5 | 14.2 |
| (1,2] | 10.9 | 11.8 | 11.6 | 12.5 | 16.1 | 16.2 | 13.5 | 14.2 |
| (2,5] | 9.6 | 11.2 | 12.8 | 13.9 | 15.7 | 16.6 | 13.8 | 15.2 |
| (5,10] | 4.6 | 5.5 | 6.8 | 7.9 | 7.8 | 8.7 | 6.9 | 8.4 |
| (10,20] | 2.6 | 3.2 | 4.3 | 5.3 | 5.2 | 6.1 | 4.5 | 5.7 |
| (20,50] | 2.4 | 2.6 | 3.5 | 4.0 | 3.8 | 4.5 | 3.3 | 4.1 |
| (50,100] | 1.8 | 2.2 | 2.9 | 3.4 | 3.5 | 3.9 | 3.2 | 3.9 |

**Table 1-6 Sample size by functional classification (FC)**

| Temporal Range | FC1 | FC2 | FC6 | FC7 | FC8 | FC9 | FC11 | FC12 | FC14 | FC16 | FC17 | FC19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2013** | | | | | | | | | | | | |
| (0,0.012] | | | | 0.2 | 2.4 | 5.2 | | | | | 0.2 | 1.0 |
| (0.012,0.5] | | 0.7 | 14.6 | 45.4 | 75.7 | 83.8 | | | 0.2 | 5.5 | 32.3 | 66.4 |
| (0.5,1] | | 3.1 | 16.2 | 24.8 | 14.3 | 8.1 | | | 1.1 | 10.7 | 25.3 | 15.4 |
| (1,2] | | 8.8 | 24.3 | 18.0 | 6.0 | 2.4 | | 1.0 | 5.0 | 21.8 | 23.1 | 9.9 |
| (2,5] | 0.2 | 26.7 | 29.3 | 9.4 | 1.5 | 0.5 | | 8.1 | 25.5 | 39.9 | 14.7 | 4.6 |
| (5,10] | 1.0 | 23.4 | 12.1 | 1.8 | 0.2 | 0.1 | 1.4 | 13.9 | 37.8 | 15.9 | 3.4 | 2.4 |
| (10,20] | 3.9 | 19.8 | 3.3 | 0.4 | | | 8.6 | 27.3 | 24.4 | 5.8 | 0.9 | 0.3 |
| (20,50] | 31.5 | 17.5 | 0.2 | | | | 43.2 | 42.2 | 6.0 | 0.5 | 0.1 | |
| (50,100] | 63.4 | | | | | | 46.8 | 7.4 | | | | |
| **2014** | | | | | | | | | | | | |
| Temporal Range | FC1 | FC2 | FC6 | FC7 | FC8 | FC9 | FC11 | FC12 | FC14 | FC16 | FC17 | FC19 |
| (0,0.012] | | | | 0.1 | 1.8 | 4.3 | | | | | | 0.4 |
| (0.012,0.5] | | 0.3 | 10.2 | 36.1 | 70.8 | 81.7 | | | 0.1 | 2.5 | 23.1 | 60.7 |
| (0.5,1] | | 1.4 | 12.5 | 25.1 | 16.9 | 9.8 | | | 0.2 | 7.1 | 23.5 | 18.3 |
| (1,2] | | 5.4 | 21.6 | 21.6 | 7.9 | 3.3 | | 0.2 | 2.0 | 15.1 | 26.2 | 12.5 |
| (2,5] | | 22.7 | 33.5 | 13.9 | 2.3 | 0.7 | | 3.6 | 17.9 | 41.7 | 20.6 | 5.8 |
| (5,10] | 0.3 | 25.0 | 16.3 | 2.5 | 0.2 | 0.2 | 0.1 | 11.6 | 35.0 | 23.5 | 5.0 | 1.8 |
| (10,20] | 1.9 | 22.1 | 5.4 | 0.6 | | | 2.4 | 22.6 | 34.3 | 8.8 | 1.3 | 0.5 |
| (20,50] | 23.0 | 22.2 | 0.4 | | | | 35.1 | 48.7 | 10.3 | 1.3 | 0.2 | |
| (50,100] | 74.8 | 0.9 | | | | | 62.4 | 13.4 | 0.1 | | | |

### *1.2.2 Data Quality Screening*

Data quality screening criteria were developed previously in PL-24 (*1*). Interested readers should refer to the final report of that project for details. This study follows the roughly the same concept, but criteria were modified slightly to fit the change in data format. Appendix A includes a complete list of criteria used to flag data items classified as outliers.

While records may be flagged at the link level, caution must be exercised when aggregating link-level data for corridor- or regional-level analysis. For example, a large number of extremely low speeds occurring randomly over a year on a section of rural interstate highway with no major construction or other incidents may raise some questions. However, it may be quite reasonable to have a large number of very low speed observations at locations such as approaches to signalized intersections, especially with probe- and vehicle-based processing (*2*). The flag in the database is intended to prompt users to conduct further evaluation based on their application and needs. As an illustration, the cyan-highlighted roads in Figure 1-2 indicate the 85$^{th}$ percentile speeds of all days in 2013 that were not flagged by any of the quality-screening rules.

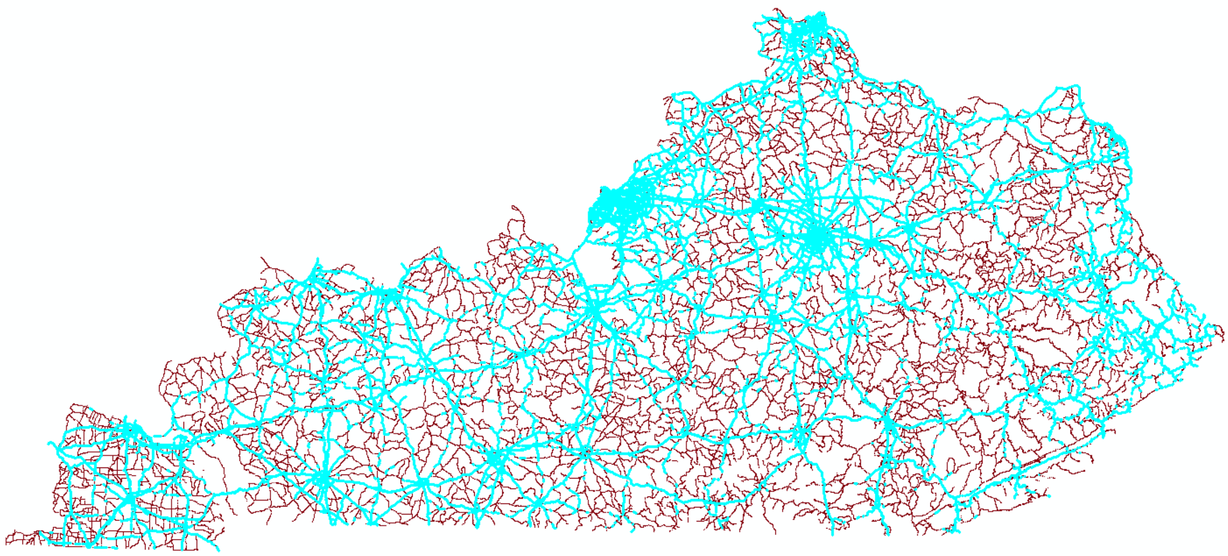


**Figure 1-2 2013 Network with highlighted routes satisfying sample adequacy requirement**

# CHAPTER 2 Performance Measures

This chapter presents the performance measures generated from the 2013-2014 speed data. These measures are consistent with those developed in the previous study (*1*). They are:

(1) Average speeds for AM (6-9am), Midday (9am-3pm), and PM (3-6pm) periods
(2) Travel time index for AM, Midday, and PM periods by direction
(3) Planning time index for AM, Midday, and PM periods by direction
(4) Buffer index for AM, Midday, and PM periods by direction
(5) Annual VMT under congested condition
(6) Annual VHT under congested condition
(7) Annual vehicle hours of delay

## 2.1 Reference Speed

Unlike the 2011-2012 analysis, 2013-2014 travel time analysis were based on each date throughout the year whenever and wherever data were available. For many of these performance measures (e.g., travel time index), it was necessary to define the uncongested benchmark condition. The speed value that separates congested from uncongested conditions is defined as reference speed.

Three different definitions of reference speed were adopted: (1) the $85^{th}$ percentile speed; (2) the $60^{th}$ percentile speed for urban arterials (FC14 and below); and (3) the speed limit. The previous report contains a detailed discussion about their selection (*1*).

## 2.2 Performance Measures Calculation

Most performance measures adopted in PL-24 were evaluated in this study, including measures such as average speeds, travel time index (TTI), planning time index (PTI), buffer index (BI), and vehicle hours of delay. For measures that require volume data (e.g., vehicle hours of delay), HIS and HERE network were conflated to integrate speeds with other road attributes, such as AADT and functional classification. The performance measures presented in this section were only computed for those conflated road sections. The results were also included in the attribute tables of the geodatabases generated for these years. These files have been delivered to KYTC and the MPO stakeholders. Appendix A contains the complete lists of measures and methodology used in their calculation.

An online web portal (https://goo.gl/PRdmvQ) was developed to display selected travel time based performance measures. Its user guide can be found in Appendix B.

### *2.2.1 Travel Delay*

Travel delay refers to additional time spent traveling due to the presence of congestion. Due to fluctuating demand, traffic incidents, adverse weather, and many other factors, it is unrealistic to assume that transportation systems continuously operate under ideal conditions. Many transportation agencies and MPOs use the vehicle hours of delay performance measure to evaluate the transportation system and trends in congestion. Annual hours of delay (AHD) can be calculated using the following equation. Formulas differ depending on data format.

$$AHD = 52 * \sum_{w} \sum_{h} VMT_{w,h} * \left( \frac{1}{V_{w,h}} - \frac{1}{RS} \right)$$

Where:
$w$ denotes the day of week;
$h$ denotes the hour of the day;
$VMT_{w,h}$ denotes the total vehicle miles traveled during hour of day $h$, day of week $w$ in a year;
$V_{w,h}$ denotes the hourly average speed during hour of day $h$, day of week $w$ in a year; and
$RS$ denotes the reference speed.

The delay measure should be used with caution, because data were not available for all time epochs. For epochs lacking data, delays could not be estimated. However, this is not to suggest that delays did not occur during those periods.

AHD is shown in Table 2-1, which displays the 85$^{th}$ percentile speed as the reference speed, and Table 2-2, which adopts the speed limit as the reference speed. For both cases, the delay seems to have fallen between 2013 and 2014 for each geographical area and the state as a whole.

**Table 2-1 Annual hours of delay (in thousands of vehicle hours) using the 85th percentile speed as reference speed**

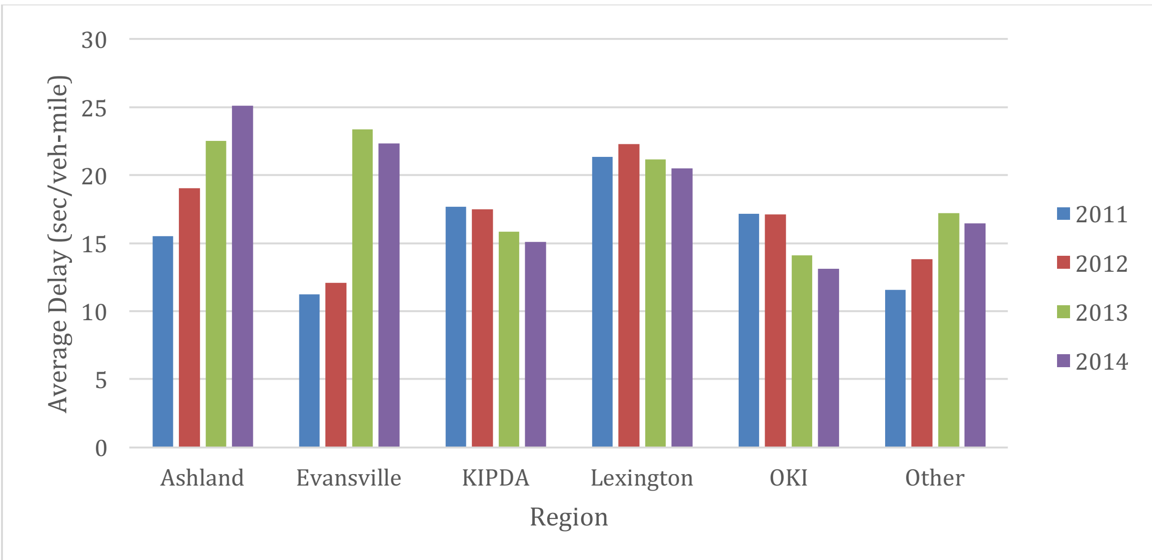
| Region | Year | FC1 | FC2 | FC6 | FC7 | FC8 | FC9 | FC11 | FC12 | FC14 | FC16 | FC17 | FC19 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ashland | 2013 | 86 | 197 | 96 | 318 | 155 | 54 | | | 1277 | 660 | 635 | 151 | 3628 |
| | 2014 | 86 | 209 | 79 | 287 | 292 | 60 | | | 1357 | 715 | 742 | 172 | 4000 |
| Evansville | 2013 | | 47 | 176 | 146 | 235 | 91 | | 70 | 489 | 447 | 205 | 2 | 1907 |
| | 2014 | | 48 | 156 | 116 | 237 | 86 | | 70 | 487 | 451 | 222 | 3 | 1875 |
| Lexington | 2013 | 330 | 187 | 205 | 365 | 355 | 34 | 410 | 546 | 6992 | 3385 | 2774 | 3 | 15586 |
| | 2014 | 464 | 163 | 205 | 383 | 369 | 38 | 510 | 566 | 6952 | 3244 | 2675 | 3 | 15573 |
| KIPDA | 2013 | 950 | 38 | 1146 | 666 | 951 | 278 | 5569 | 305 | 7404 | 15008 | 4992 | 186 | 37493 |
| | 2014 | 1319 | 44 | 1062 | 596 | 1006 | 303 | 6496 | 326 | 6993 | 13788 | 4466 | 180 | 36580 |
| OKI | 2013 | 310 | 18 | 79 | 458 | 254 | 59 | 3176 | 31 | 2099 | 4676 | 3089 | 97 | 14346 |
| | 2014 | 320 | 19 | 69 | 455 | 249 | 76 | 3188 | 27 | 2017 | 4401 | 2946 | 87 | 13855 |
| Other | 2013 | 6088 | 8580 | 10332 | 18734 | 13761 | 4673 | 1117 | 361 | 10395 | 18819 | 11908 | 820 | 105589 |
| | 2014 | 6286 | 8537 | 9691 | 18479 | 14698 | 5338 | 864 | 367 | 9992 | 17748 | 11658 | 954 | 104611 |
| Statewide | 2013 | 7764 | 9067 | 12033 | 20687 | 15712 | 5190 | 10271 | 1312 | 28655 | 42996 | 23603 | 1259 | 178549 |
| | 2014 | 8476 | 9020 | 11262 | 20315 | 16850 | 5901 | 11059 | 1356 | 27799 | 40347 | 22709 | 1399 | 176494 |

**Table 2-2 Annual hours of delay (in thousands of vehicle hours) using speed limit as reference speed**

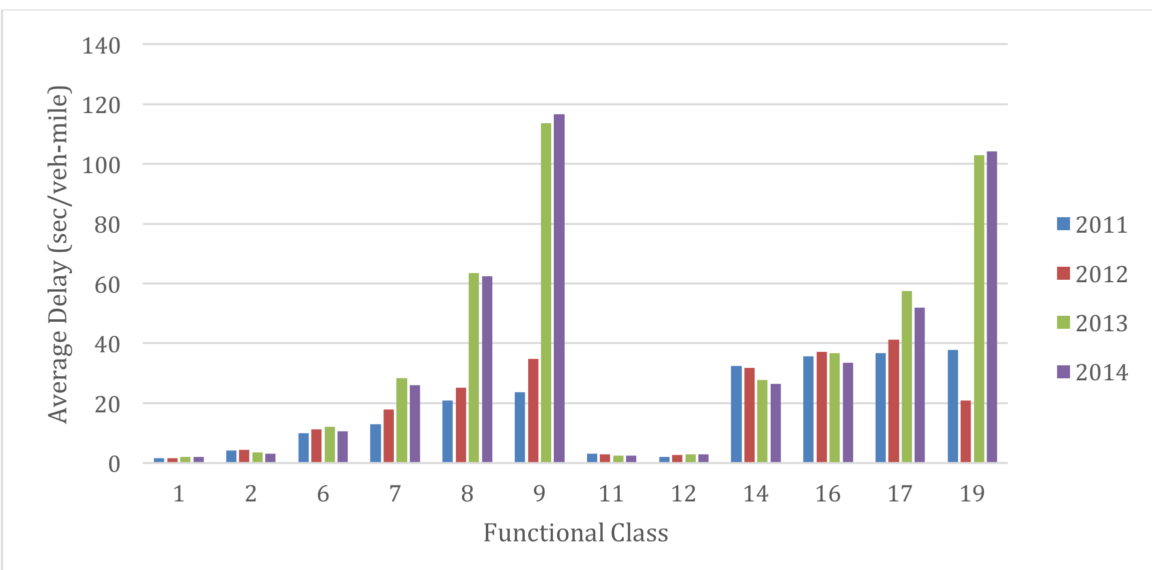
| Region | Year | FC1 | FC2 | FC6 | FC7 | FC8 | FC9 | FC11 | FC12 | FC14 | FC16 | FC17 | FC19 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ashland | 2013 | 43 | 96 | 62 | 368 | 184 | 66 | | | 1135 | 618 | 620 | 168 | 3361 |
| | 2014 | 38 | 109 | 46 | 339 | 330 | 74 | | | 1220 | 680 | 739 | 194 | 3768 |
| Evansville | 2013 | | 24 | 117 | 126 | 253 | 97 | | 115 | 421 | 480 | 200 | 3 | 1836 |
| | 2014 | | 21 | 94 | 96 | 257 | 93 | | 113 | 406 | 493 | 221 | 4 | 1798 |
| Lexington | 2013 | 93 | 88 | 175 | 403 | 420 | 45 | 198 | 100 | 7787 | 3414 | 2806 | 4 | 15534 |
| | 2014 | 246 | 43 | 176 | 425 | 443 | 49 | 245 | 104 | 7716 | 3325 | 2748 | 4 | 15523 |
| KIPDA | 2013 | 646 | 7 | 905 | 718 | 1072 | 323 | 1797 | 122 | 8093 | 15259 | 4786 | 192 | 33922 |
| | 2014 | 840 | 6 | 823 | 662 | 1166 | 357 | 2739 | 173 | 7568 | 13947 | 4253 | 187 | 32719 |
| OKI | 2013 | 140 | 2 | 68 | 531 | 299 | 72 | 1442 | 18 | 2154 | 4929 | 3123 | 103 | 12880 |
| | 2014 | 122 | 2 | 55 | 529 | 308 | 93 | 1200 | 14 | 2047 | 4658 | 2996 | 93 | 12117 |
| Other | 2013 | 2970 | 4402 | 8632 | 19149 | 15728 | 5507 | 707 | 231 | 10290 | 19995 | 12042 | 928 | 100581 |
| | 2014 | 2603 | 3993 | 7872 | 19042 | 16972 | 6300 | 293 | 213 | 9759 | 18887 | 11858 | 1079 | 98870 |
| Statewide | 2013 | 3893 | 4617 | 9960 | 21295 | 17956 | 6110 | 4144 | 587 | 29880 | 44695 | 23577 | 1398 | 168113 |
| | 2014 | 3849 | 4173 | 9067 | 21092 | 19476 | 6965 | 4476 | 618 | 28716 | 41989 | 22813 | 1561 | 164795 |

Due to unequal directional miles in the four years' networks (59,092; 57,332; 53,158; and 53,188 miles for 2011-2014, respectively), average delay per vehicle-mile – calculated as AHD/VMT – in each year was evaluated and grouped by functional classification and region. Comparison of average delay over the four years is shown in Figure 2-1, with speed limit as the reference speed.

For most MPO areas, average delay per vehicle-mile slightly improved between 2013 and 2014, except for Ashland metropolitan area. Roads with lower functional classifications and urban arterials experienced the highest average delays. Considering that many rural local roads have a default speed limit of 55mph, it would not be surprising to see the long average delay on these roads. Data showed that average speeds on these roads were typically between 20 mph and 40 mph.




(a) Regional level




(b) FC level

**Figure 2-1 Delay comparison in four years based on speed limit**

### 2.2.2 VMT and VHT under Congested Condition

In addition to delay, both vehicle miles traveled (VMT) and vehicle hours traveled (VHT) under congested conditions were calculated. These metrics reflect the number of vehicle miles and vehicle hours traveled when the observed traffic speed was less than the reference speed.

$$VMT_{Congested} = 52 * \sum_{w} \sum_{h} VMT_{w,h} * \Delta_{w,h}$$

$$VHT_{Congested} = 52 * \sum_{w} \sum_{h} \frac{VMT_{w,h}}{V_{w,h}} * \Delta_{w,h}$$

Where $\Delta_{w,h}$ is a binary indicator and $\Delta_{w,h} = \begin{cases} 1, & if\ V_{w,h} > 0\ and\ V_{w,h} < RS \\ 0, & otherwise \end{cases}$. Other terms are the same as in delay calculation formula.

### 2.2.3 Travel Time Index

The travel time index (TTI) measures the severity of congestion during the peak period. It is defined as the ratio of travel time during the peak period to the reference travel time. TTI is also unitless and therefore can be used to compare the congestion conditions across facilities with different geometric characteristics. The formula is:

$$TTI = \frac{Average\ Travel\ Time}{Reference\ Travel\ Time}$$

The above formula can be rewritten as:

$$TTI = \frac{Reference\ Speed}{Average\ Speed}$$

At the suggestion of the study advisory committee, 6-9am was designated as the AM peak period, 9am-3pm the Midday period, and 3-6pm the PM peak period.

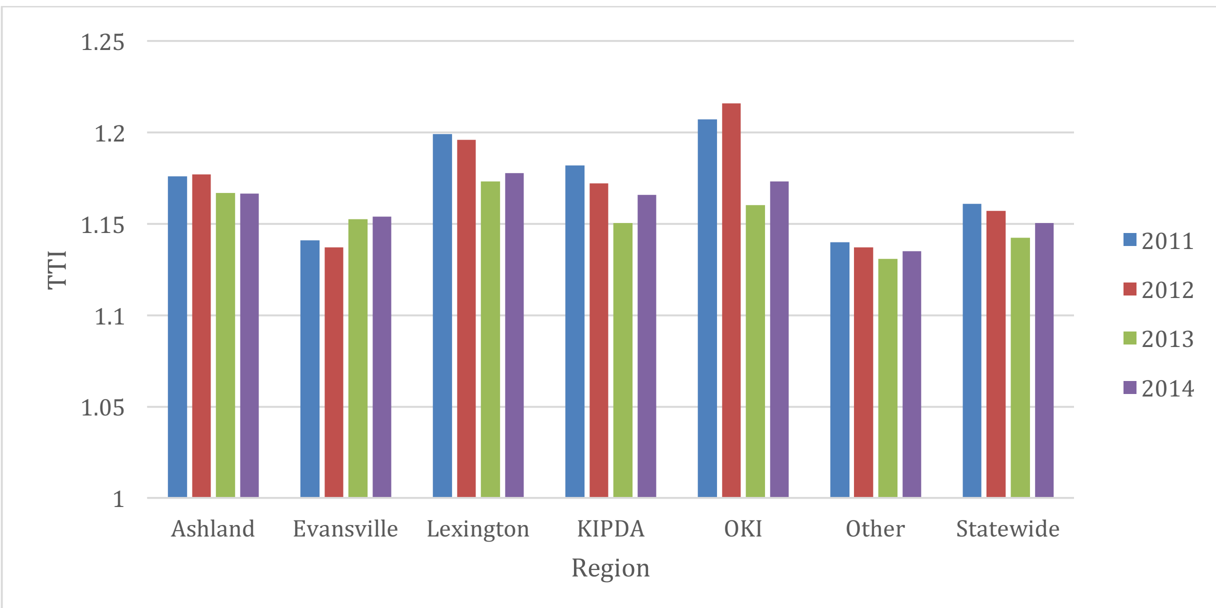
Corridor-level performance trends can be developed by combining link-level statistics. Similarly, region-level performance can be calculated by aggregating the link-based measures into regional measures, which may be further grouped by functional classifications. The weighting factor used was vehicle-miles traveled. Table 2-3 shows the region-wide travel time indices in 2013 and 2014.

Between 2013 and 2014, congestion levels increased slightly across the state. However, this increase appears mostly concentrated in Kentucky's three major metropolitan areas.

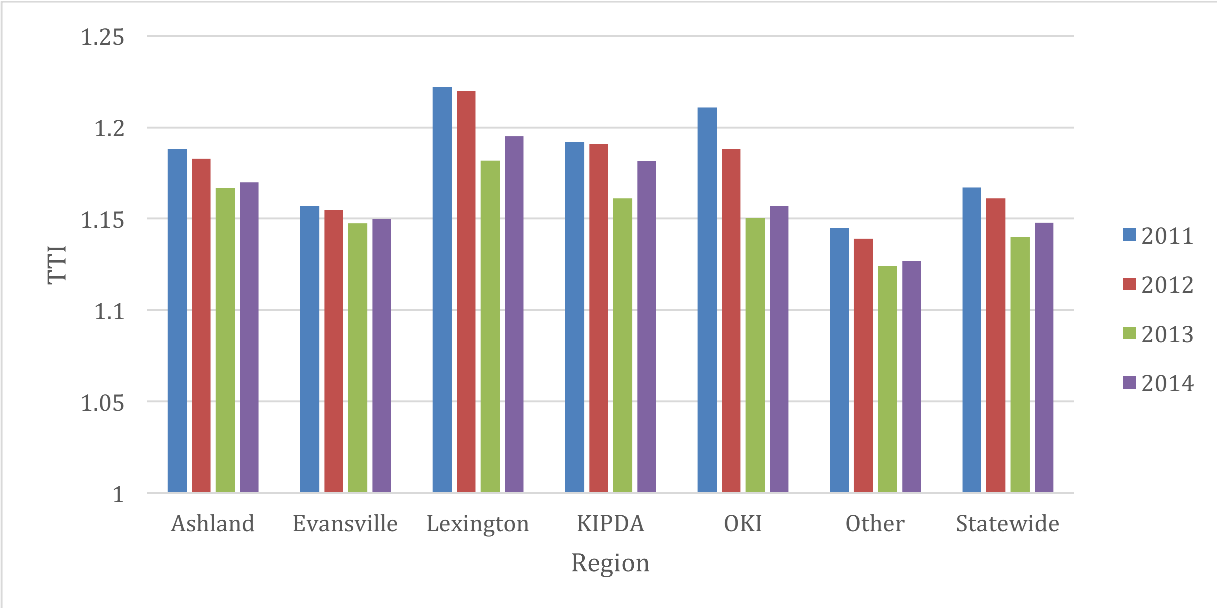
The four-year trend of TTI is shown in Figure 2-2 and Figure 2-3. Due to changes in data format between 2012 and 2013, readers should use caution when drawing conclusions about changes in congestion level. However, the measures between 2011 and 2012 are comparable, as are those between 2013 and 2014.

**Table 2-3 Travel time index**

| Region | 2013 | | | | | | 2014 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Based on 85th percentile | | | Based on speed limit | | | Based on 85th percentile | | | Based on speed limit | | |
| | AM | Midday | PM | AM | Midday | PM | AM | Midday | PM | AM | Midday | PM |
| Ashland | 1.17 | 1.17 | 1.17 | 1.10 | 1.12 | 1.11 | 1.17 | 1.17 | 1.17 | 1.10 | 1.11 | 1.11 |
| Evansville | 1.15 | 1.17 | 1.15 | 1.13 | 1.14 | 1.11 | 1.15 | 1.16 | 1.15 | 1.12 | 1.12 | 1.11 |
| Lexington | 1.17 | 1.18 | 1.18 | 1.14 | 1.15 | 1.15 | 1.18 | 1.18 | 1.19 | 1.14 | 1.16 | 1.16 |
| KIPDA | 1.15 | 1.14 | 1.16 | 1.09 | 1.09 | 1.10 | 1.17 | 1.15 | 1.18 | 1.10 | 1.10 | 1.11 |
| OKI | 1.16 | 1.13 | 1.15 | 1.10 | 1.09 | 1.09 | 1.17 | 1.14 | 1.16 | 1.11 | 1.08 | 1.09 |
| Other | 1.13 | 1.13 | 1.12 | 1.09 | 1.10 | 1.09 | 1.14 | 1.14 | 1.13 | 1.09 | 1.09 | 1.09 |
| Statewide | 1.14 | 1.14 | 1.14 | 1.09 | 1.10 | 1.09 | 1.15 | 1.15 | 1.15 | 1.10 | 1.10 | 1.10 |

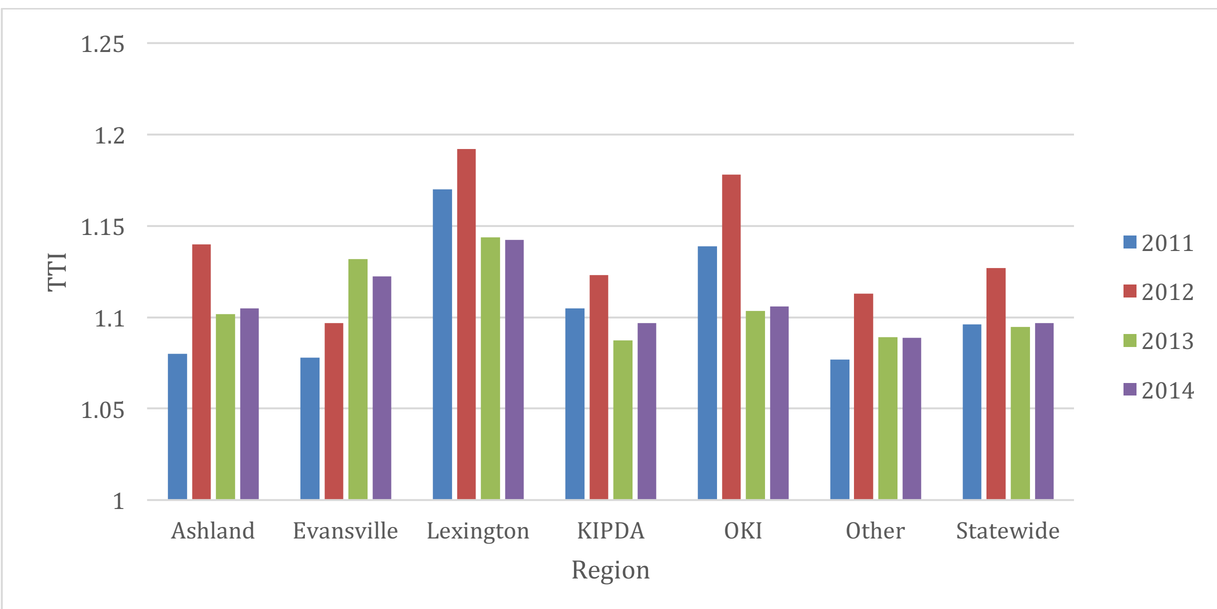



(a) AM period

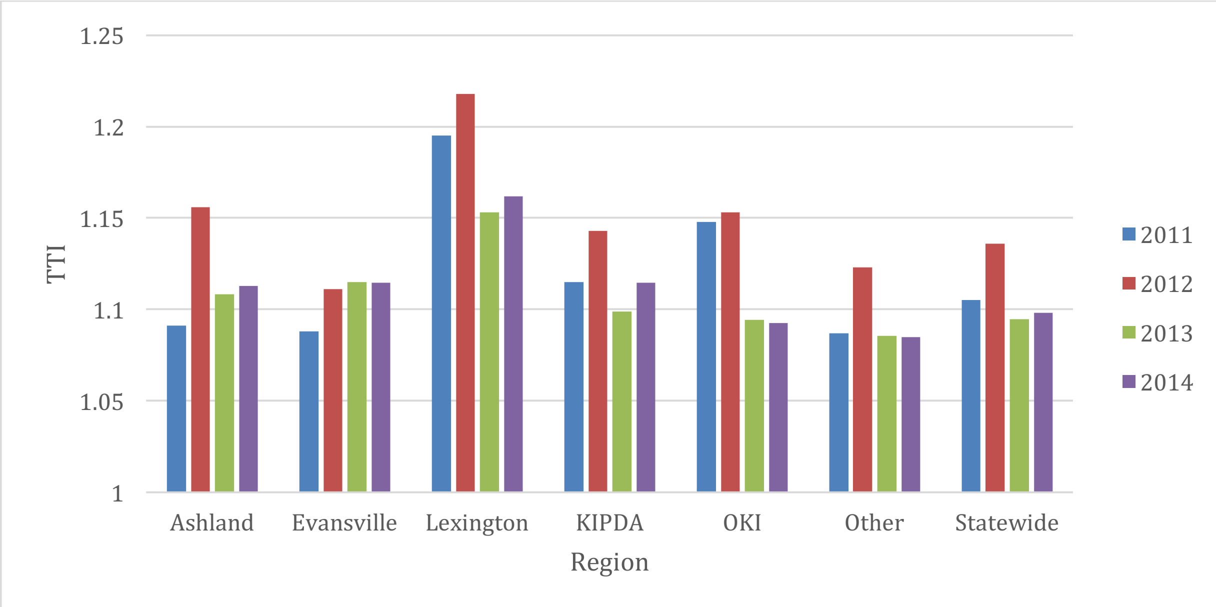



(b) PM period

**Figure 2-2 Regional performance trend based on TTI using the 85th percentile speed**




(a) AM period




(b) PM period

**Figure 2-3 Regional performance trend based on TTI using speed limit**

The congestion condition was further analyzed at the functional classification level. Similarly, the summary statistics were calculated using vehicle miles traveled as weights. According to Table 2-4 and Table 2-5, the congestion levels for different functional classifications are mostly comparable during 2013-2014. Roads in higher functional classes in both urban and rural areas are generally more congested than roads of lower functional classes.

**Table 2-4 Travel time index by functional classification based on the 85th percentile speed**

(a) AM period

| Region | Year | FC1 | FC2 | FC6 | FC7 | FC8 | FC9 | FC11 | FC12 | FC14 | FC16 | FC17 | FC19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ashland | 2013 | 1.11 | 1.14 | 1.11 | 1.20 | 1.16 | | | | 1.20 | 1.20 | 1.19 | 1.18 |
| | 2014 | 1.11 | 1.13 | 1.12 | 1.16 | 1.16 | | | | 1.20 | 1.22 | 1.21 | 1.22 |
| Evansville | 2013 | | 1.08 | 1.13 | 1.15 | 1.21 | 1.38 | | 1.13 | 1.18 | 1.29 | 1.35 | |
| | 2014 | | 1.09 | 1.13 | 1.15 | 1.20 | 1.36 | | 1.13 | 1.18 | 1.27 | 1.41 | |
| Lexington | 2013 | 1.07 | 1.11 | 1.13 | 1.18 | 1.20 | | 1.09 | 1.11 | 1.28 | 1.27 | 1.27 | |
| | 2014 | 1.10 | 1.10 | 1.14 | 1.19 | 1.22 | 1.39 | 1.10 | 1.12 | 1.28 | 1.27 | 1.27 | |
| KIPDA | 2013 | 1.08 | 1.08 | 1.14 | 1.16 | 1.17 | 1.16 | 1.13 | 1.09 | 1.23 | 1.25 | 1.28 | 1.37 |
| | 2014 | 1.11 | 1.08 | 1.14 | 1.17 | 1.19 | 1.23 | 1.15 | 1.10 | 1.23 | 1.25 | 1.28 | 1.32 |
| OKI | 2013 | 1.08 | 1.11 | 1.10 | 1.16 | 1.14 | | 1.15 | 1.19 | 1.23 | 1.24 | 1.25 | 1.20 |
| | 2014 | 1.09 | 1.12 | 1.12 | 1.17 | 1.16 | | 1.16 | 1.14 | 1.24 | 1.25 | 1.26 | 1.35 |
| Other | 2013 | 1.09 | 1.11 | 1.13 | 1.15 | 1.19 | 1.21 | 1.12 | 1.11 | 1.21 | 1.22 | 1.24 | 1.37 |
| | 2014 | 1.10 | 1.12 | 1.14 | 1.16 | 1.20 | 1.21 | 1.10 | 1.11 | 1.21 | 1.22 | 1.23 | 1.33 |
| Statewide | 2013 | 1.09 | 1.11 | 1.13 | 1.15 | 1.19 | 1.20 | 1.13 | 1.11 | 1.23 | 1.24 | 1.25 | 1.30 |
| | 2014 | 1.10 | 1.12 | 1.14 | 1.16 | 1.20 | 1.22 | 1.14 | 1.11 | 1.23 | 1.24 | 1.25 | 1.31 |

(b) Midday period

| Region | Year | FC1 | FC2 | FC6 | FC7 | FC8 | FC9 | FC11 | FC12 | FC14 | FC16 | FC17 | FC19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ashland | 2013 | 1.09 | 1.13 | 1.10 | 1.21 | 1.22 | | | | 1.21 | 1.25 | 1.20 | 1.21 |
| | 2014 | 1.10 | 1.13 | 1.10 | 1.20 | 1.24 | | | | 1.20 | 1.27 | 1.18 | 1.23 |
| Evansville | 2013 | | 1.08 | 1.13 | 1.15 | 1.29 | 1.26 | | 1.13 | 1.22 | 1.25 | 1.34 | |
| | 2014 | | 1.08 | 1.13 | 1.15 | 1.26 | 1.29 | | 1.14 | 1.21 | 1.25 | 1.28 | |
| Lexington | 2013 | 1.07 | 1.12 | 1.15 | 1.21 | 1.23 | | 1.08 | 1.10 | 1.29 | 1.25 | 1.27 | |
| | 2014 | 1.10 | 1.11 | 1.15 | 1.21 | 1.25 | 1.35 | 1.09 | 1.10 | 1.29 | 1.25 | 1.27 | |
| KIPDA | 2013 | 1.08 | 1.11 | 1.14 | 1.19 | 1.23 | 1.43 | 1.09 | 1.11 | 1.25 | 1.25 | 1.29 | 1.39 |
| | 2014 | 1.11 | 1.12 | 1.15 | 1.18 | 1.23 | 1.30 | 1.10 | 1.11 | 1.25 | 1.24 | 1.28 | 1.37 |
| OKI | 2013 | 1.08 | 1.12 | 1.11 | 1.19 | 1.16 | | 1.10 | 1.16 | 1.25 | 1.23 | 1.26 | 1.28 |
| | 2014 | 1.08 | 1.12 | 1.11 | 1.20 | 1.16 | | 1.10 | 1.14 | 1.24 | 1.23 | 1.26 | 1.30 |
| Other | 2013 | 1.08 | 1.11 | 1.14 | 1.17 | 1.22 | 1.23 | 1.11 | 1.11 | 1.23 | 1.25 | 1.25 | 1.29 |
| | 2014 | 1.09 | 1.11 | 1.14 | 1.17 | 1.21 | 1.21 | 1.09 | 1.11 | 1.23 | 1.24 | 1.24 | 1.29 |
| Statewide | 2013 | 1.08 | 1.11 | 1.14 | 1.17 | 1.22 | 1.25 | 1.10 | 1.11 | 1.25 | 1.25 | 1.26 | 1.28 |
| | 2014 | 1.09 | 1.11 | 1.14 | 1.17 | 1.22 | 1.22 | 1.10 | 1.11 | 1.25 | 1.24 | 1.26 | 1.29 |

(c) PM period

| Region | Year | FC1 | FC2 | FC6 | FC7 | FC8 | FC9 | FC11 | FC12 | FC14 | FC16 | FC17 | FC19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ashland | 2013 | 1.08 | 1.12 | 1.09 | 1.17 | 1.18 | | | | 1.21 | 1.24 | 1.20 | 1.23 |
| | 2014 | 1.08 | 1.13 | 1.09 | 1.18 | 1.23 | | | | 1.21 | 1.25 | 1.20 | 1.21 |
| Evansville | 2013 | | 1.07 | 1.12 | 1.13 | 1.21 | 1.13 | | 1.12 | 1.21 | 1.22 | 1.19 | |
| | 2014 | | 1.07 | 1.12 | 1.14 | 1.21 | 1.14 | | 1.12 | 1.21 | 1.22 | 1.26 | |
| Lexington | 2013 | 1.07 | 1.10 | 1.13 | 1.17 | 1.19 | | 1.08 | 1.12 | 1.32 | 1.25 | 1.24 | |
| | 2014 | 1.10 | 1.09 | 1.13 | 1.16 | 1.20 | 1.36 | 1.09 | 1.14 | 1.34 | 1.25 | 1.25 | |
| KIPDA | 2013 | 1.07 | 1.08 | 1.13 | 1.15 | 1.18 | 1.21 | 1.14 | 1.09 | 1.27 | 1.25 | 1.24 | 1.24 |
| | 2014 | 1.10 | 1.09 | 1.13 | 1.14 | 1.18 | 1.22 | 1.17 | 1.10 | 1.27 | 1.25 | 1.24 | 1.24 |
| OKI | 2013 | 1.07 | 1.07 | 1.10 | 1.15 | 1.17 | | 1.13 | 1.16 | 1.25 | 1.22 | 1.22 | 1.26 |
| | 2014 | 1.07 | 1.09 | 1.11 | 1.15 | 1.15 | | 1.14 | 1.15 | 1.26 | 1.23 | 1.23 | 1.29 |
| Other | 2013 | 1.08 | 1.10 | 1.12 | 1.14 | 1.17 | 1.21 | 1.12 | 1.10 | 1.22 | 1.23 | 1.23 | 1.30 |
| | 2014 | 1.08 | 1.10 | 1.13 | 1.14 | 1.17 | 1.19 | 1.09 | 1.10 | 1.22 | 1.23 | 1.22 | 1.26 |
| Statewide | 2013 | 1.08 | 1.10 | 1.12 | 1.14 | 1.18 | 1.21 | 1.13 | 1.11 | 1.25 | 1.24 | 1.23 | 1.26 |
| | 2014 | 1.09 | 1.10 | 1.13 | 1.14 | 1.17 | 1.20 | 1.15 | 1.12 | 1.26 | 1.24 | 1.23 | 1.25 |

Note: blank cells mean there is no facility with a designated functional class in the region or the percentage of epochs with speed data did not satisfy the 1% threshold.

**Table 2-5 Travel time index by functional classification based on speed limit**

(a) AM period

| Region | Year | FC1 | FC2 | FC6 | FC7 | FC8 | FC9 | FC11 | FC12 | FC14 | FC16 | FC17 | FC19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ashland | 2013 | 1.07 | 1.04 | 1.02 | 1.23 | 1.40 | | | | 1.13 | 1.13 | 1.19 | 1.20 |
| | 2014 | 1.05 | 1.04 | 1.02 | 1.23 | 1.35 | | | | 1.13 | 1.15 | 1.21 | 1.26 |
| Evansville | 2013 | | 1.04 | 1.05 | 1.10 | 1.27 | 1.31 | | 1.29 | 1.13 | 1.29 | 1.28 | |
| | 2014 | | 1.04 | 1.05 | 1.09 | 1.29 | 1.41 | | 1.28 | 1.12 | 1.28 | 1.24 | |
| Lexington | 2013 | 1.02 | 1.04 | 1.09 | 1.20 | 1.27 | 1.58 | 1.05 | 1.01 | 1.30 | 1.25 | 1.26 | |
| | 2014 | 1.05 | 1.01 | 1.10 | 1.22 | 1.31 | 1.46 | 1.05 | 1.01 | 1.29 | 1.25 | 1.25 | |
| KIPDA | 2013 | 1.05 | 1.00 | 1.08 | 1.17 | 1.22 | 1.37 | 1.04 | 1.02 | 1.23 | 1.22 | 1.22 | 1.35 |
| | 2014 | 1.07 | 1.00 | 1.09 | 1.18 | 1.25 | 1.39 | 1.05 | 1.03 | 1.22 | 1.21 | 1.21 | 1.32 |
| OKI | 2013 | 1.04 | 1.01 | 1.08 | 1.24 | 1.28 | 1.76 | 1.08 | 1.08 | 1.21 | 1.22 | 1.21 | 1.32 |
| | 2014 | 1.03 | 1.01 | 1.09 | 1.23 | 1.29 | 1.72 | 1.07 | 1.02 | 1.21 | 1.23 | 1.21 | 1.42 |
| Other | 2013 | 1.05 | 1.04 | 1.07 | 1.14 | 1.27 | 1.40 | 1.07 | 1.07 | 1.18 | 1.22 | 1.22 | 1.52 |
| | 2014 | 1.04 | 1.04 | 1.08 | 1.15 | 1.29 | 1.40 | 1.04 | 1.06 | 1.17 | 1.22 | 1.22 | 1.44 |
| Statewide | 2013 | 1.05 | 1.04 | 1.07 | 1.15 | 1.27 | 1.40 | 1.05 | 1.04 | 1.21 | 1.22 | 1.22 | 1.39 |
| | 2014 | 1.04 | 1.03 | 1.08 | 1.16 | 1.29 | 1.40 | 1.06 | 1.04 | 1.20 | 1.22 | 1.22 | 1.38 |

(b) Midday period

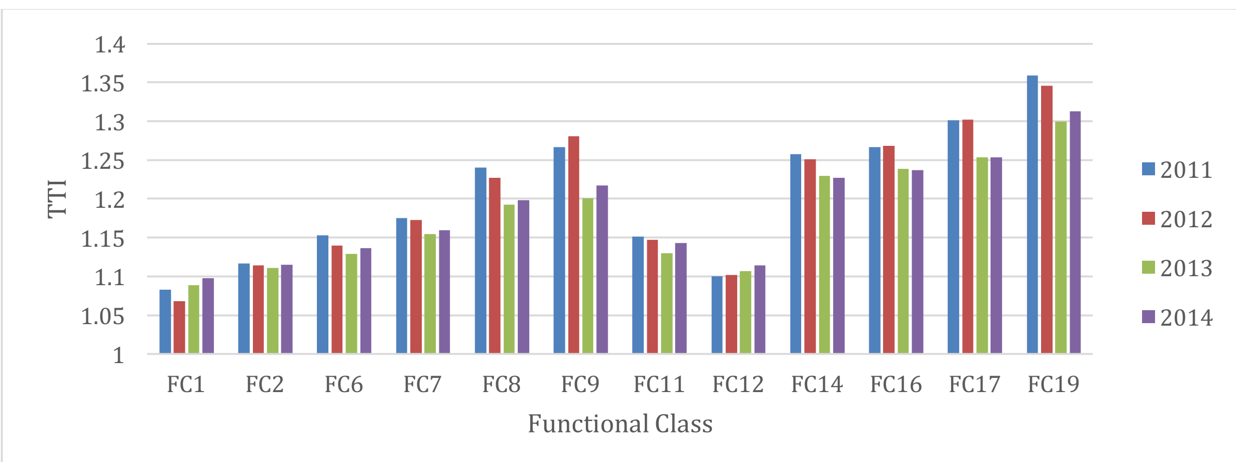
| Region | Year | FC1 | FC2 | FC6 | FC7 | FC8 | FC9 | FC11 | FC12 | FC14 | FC16 | FC17 | FC19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ashland | 2013 | 1.04 | 1.03 | 1.02 | 1.27 | 1.41 | 1.67 | | | 1.15 | 1.16 | 1.20 | 1.22 |
| | 2014 | 1.04 | 1.04 | 1.02 | 1.25 | 1.39 | 1.87 | | | 1.14 | 1.18 | 1.20 | 1.24 |
| Evansville | 2013 | | 1.04 | 1.06 | 1.10 | 1.39 | 1.43 | | 1.28 | 1.16 | 1.25 | 1.16 | |
| | 2014 | | 1.03 | 1.06 | 1.09 | 1.36 | 1.43 | | 1.27 | 1.14 | 1.24 | 1.09 | |
| Lexington | 2013 | 1.02 | 1.04 | 1.11 | 1.26 | 1.31 | 1.41 | 1.04 | 1.01 | 1.31 | 1.23 | 1.24 | 1.88 |
| | 2014 | 1.05 | 1.02 | 1.11 | 1.25 | 1.33 | 1.43 | 1.04 | 1.01 | 1.31 | 1.24 | 1.24 | 2.35 |
| KIPDA | 2013 | 1.05 | 1.02 | 1.08 | 1.20 | 1.31 | 1.49 | 1.02 | 1.03 | 1.24 | 1.21 | 1.21 | 1.52 |
| | 2014 | 1.07 | 1.01 | 1.09 | 1.20 | 1.33 | 1.46 | 1.03 | 1.04 | 1.23 | 1.20 | 1.21 | 1.45 |
| OKI | 2013 | 1.04 | 1.01 | 1.09 | 1.27 | 1.26 | | 1.03 | 1.05 | 1.23 | 1.21 | 1.21 | 1.40 |
| | 2014 | 1.03 | 1.01 | 1.09 | 1.27 | 1.28 | 2.16 | 1.02 | 1.03 | 1.22 | 1.22 | 1.21 | 1.42 |
| Other | 2013 | 1.04 | 1.04 | 1.08 | 1.16 | 1.30 | 1.39 | 1.07 | 1.07 | 1.20 | 1.24 | 1.22 | 1.43 |
| | 2014 | 1.03 | 1.03 | 1.08 | 1.16 | 1.29 | 1.41 | 1.03 | 1.06 | 1.19 | 1.23 | 1.22 | 1.39 |
| Statewide | 2013 | 1.04 | 1.04 | 1.08 | 1.16 | 1.30 | 1.40 | 1.03 | 1.04 | 1.23 | 1.22 | 1.22 | 1.39 |
| | 2014 | 1.04 | 1.03 | 1.08 | 1.17 | 1.29 | 1.42 | 1.03 | 1.04 | 1.22 | 1.22 | 1.22 | 1.38 |

(c) PM period

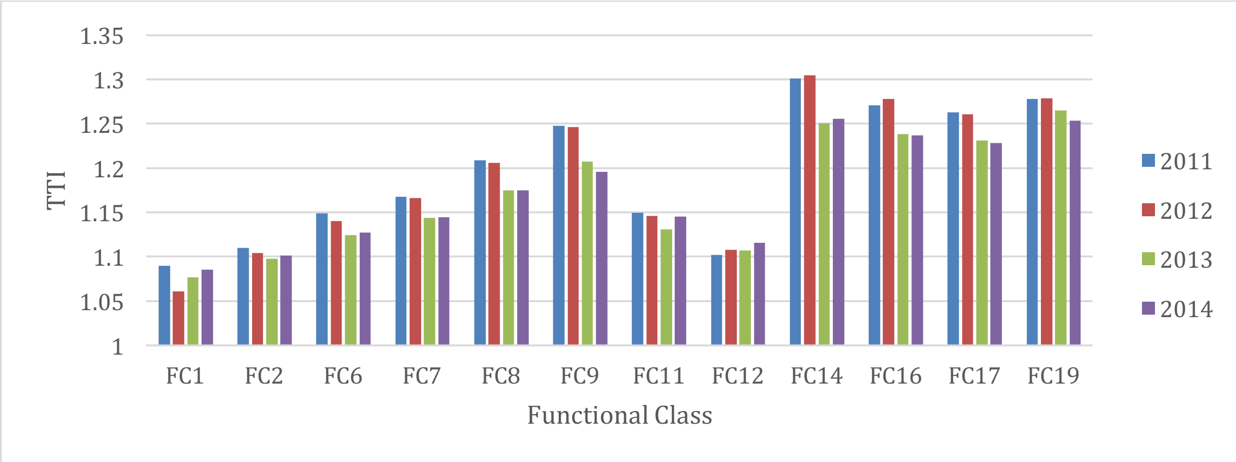
| Region | Year | FC1 | FC2 | FC6 | FC7 | FC8 | FC9 | FC11 | FC12 | FC14 | FC16 | FC17 | FC19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ashland | 2013 | 1.03 | 1.03 | 1.01 | 1.24 | 1.38 | | | | 1.15 | 1.13 | 1.19 | 1.26 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2014 | 1.03 | 1.04 | 1.02 | 1.24 | 1.45 | | | | 1.15 | 1.15 | 1.20 | 1.22 |
| Evansville | 2013 | | 1.03 | 1.05 | 1.06 | 1.26 | 1.25 | | 1.26 | 1.15 | 1.22 | 1.04 | 2.37 |
| | 2014 | | 1.03 | 1.04 | 1.08 | 1.29 | 1.31 | | 1.25 | 1.14 | 1.22 | 1.10 | |
| Lexington | 2013 | 1.01 | 1.04 | 1.09 | 1.21 | 1.27 | 1.41 | 1.04 | 1.02 | 1.34 | 1.23 | 1.22 | |
| | 2014 | 1.05 | 1.01 | 1.10 | 1.20 | 1.28 | 1.29 | 1.04 | 1.03 | 1.35 | 1.23 | 1.22 | |
| KIPDA | 2013 | 1.05 | 1.01 | 1.08 | 1.15 | 1.24 | 1.37 | 1.05 | 1.02 | 1.25 | 1.21 | 1.18 | 1.24 |
| | 2014 | 1.07 | 1.01 | 1.08 | 1.16 | 1.26 | 1.38 | 1.07 | 1.03 | 1.25 | 1.20 | 1.17 | 1.23 |
| OKI | 2013 | 1.03 | 1.00 | 1.08 | 1.21 | 1.32 | 1.44 | 1.06 | 1.05 | 1.23 | 1.20 | 1.17 | 1.31 |
| | 2014 | 1.02 | 1.00 | 1.08 | 1.21 | 1.25 | 1.53 | 1.05 | 1.04 | 1.24 | 1.20 | 1.18 | 1.39 |
| Other | 2013 | 1.03 | 1.03 | 1.07 | 1.13 | 1.25 | 1.35 | 1.07 | 1.06 | 1.18 | 1.22 | 1.20 | 1.41 |
| | 2014 | 1.03 | 1.03 | 1.07 | 1.14 | 1.26 | 1.36 | 1.02 | 1.05 | 1.18 | 1.22 | 1.20 | 1.37 |
| Statewide | 2013 | 1.03 | 1.03 | 1.07 | 1.14 | 1.25 | 1.35 | 1.05 | 1.04 | 1.23 | 1.21 | 1.19 | 1.33 |
| | 2014 | 1.03 | 1.03 | 1.07 | 1.14 | 1.27 | 1.36 | 1.06 | 1.04 | 1.23 | 1.21 | 1.19 | 1.32 |

Figure 2-4 and Figure 2-5 compare the TTI at the statewide level from 2011 to 2014. It appears that interstates and parkways experienced the least average vehicular delay, while urban surface roads saw the highest average delay. When using speed limit as the reference speed, the rural low functional class roads displayed the highest TTI. However, we should not immediately interpret this as congestion. The speed limit on many of these roads is 55 mph by default. Actual operating speed, however, is greatly constrained by terrain and geometric complexities. Again, caution should be exercised when inferring any trend between 2012 and 2013 due to the change in data format.

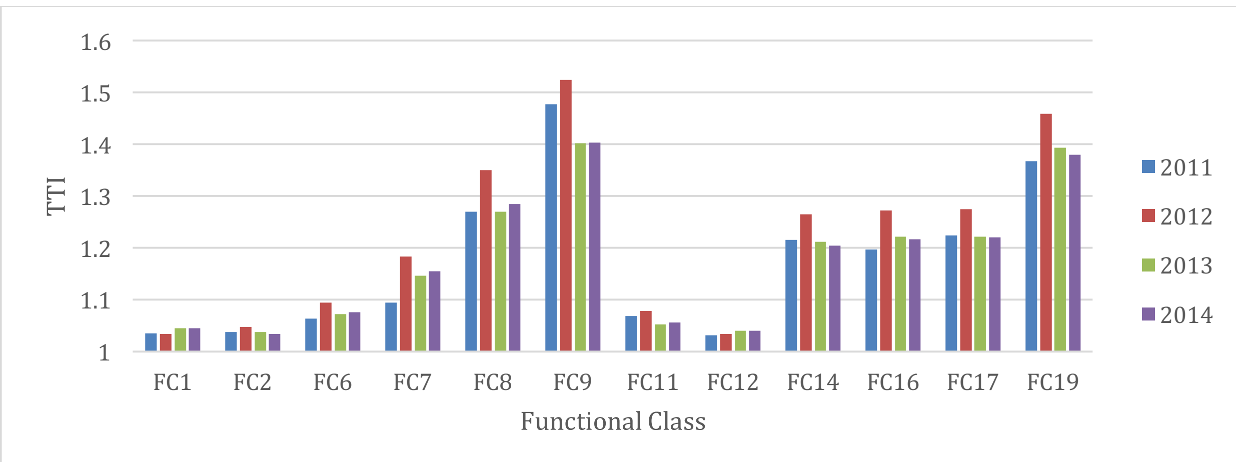



(a) AM period

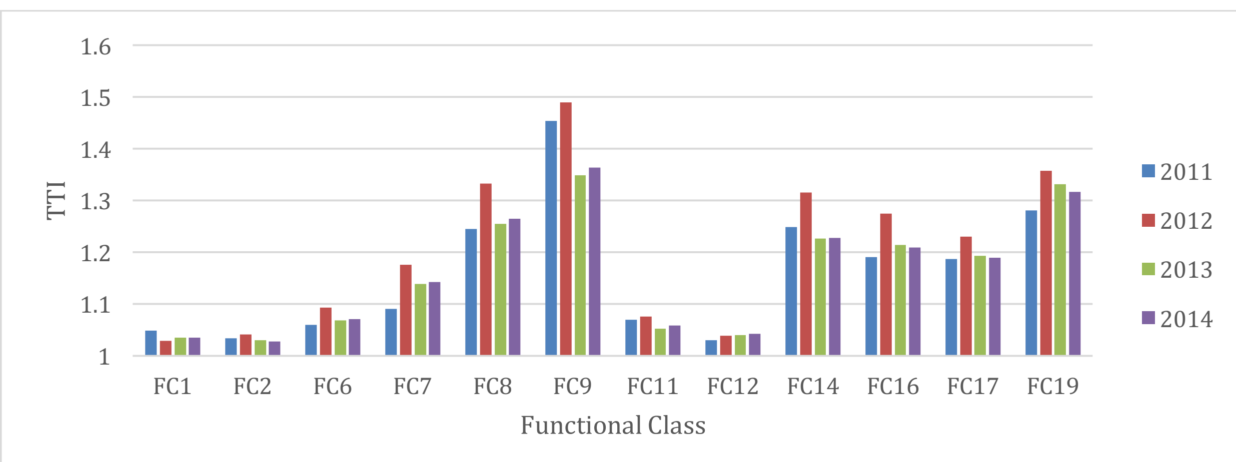



(b) PM period

**Figure 2-4 FC performance trend based on TTI using the 85th percentile speed**




(a) AM period




(b) PM period

**Figure 2-5 FC performance trend based on TTI using speed limit**

### 2.2.4 *Planning Time Index*

The planning time index (PTI) is a measure for travel time reliability and is often computed as the ratio of the 95th percentile travel time to the reference travel time. It reflects the travel time needed to ensure an on-time arrival at a destination on 19 days out of 20. The PTI's definition is not restricted to the 95th percentile travel time. For example, an agency may choose to use PTI(80), the ratio of the 80th percentile travel time to the reference travel time, to measure the amount of time needed to ensure an on-time arrival 4 out of 5 trips. The formula for PTI is:

$$PTI = \frac{\text{The } 95th\ Percentile\ Travel\ Time}{Reference\ Travel\ Time}$$

The above formula can be rewritten as:

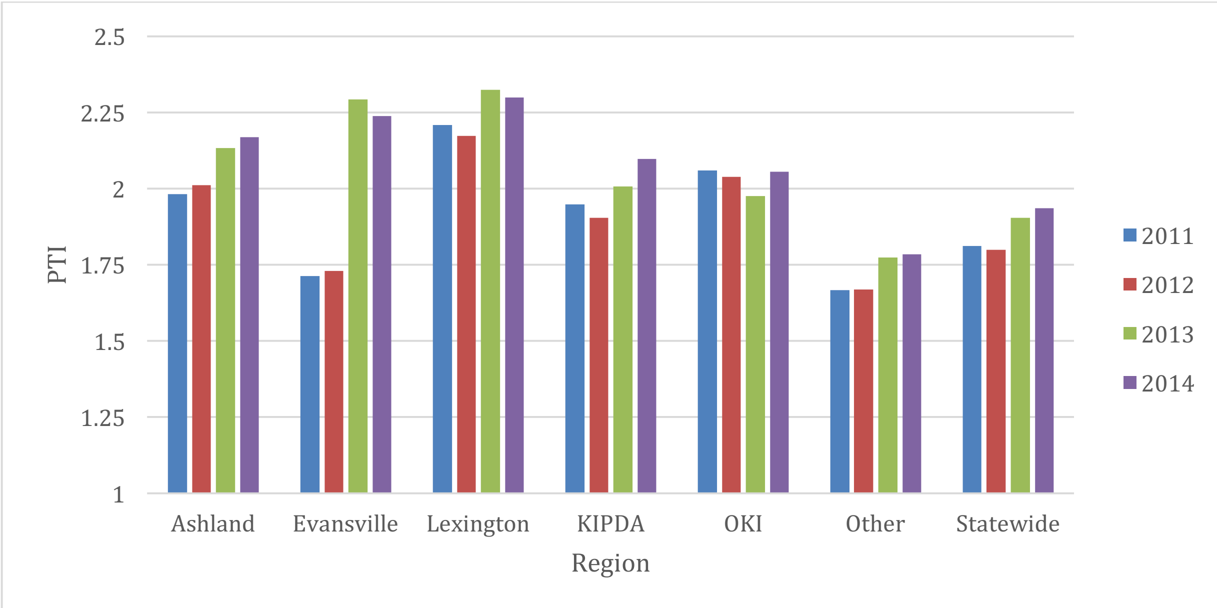
$$PTI = \frac{Reference\ Speed}{\text{The } 5th\ percentile\ speed}$$

PTI measures travel time reliability. The higher the PTI value, the less reliable the travel time. The breakdown of measures by regions can be found in Table 2-6. From a statewide point of view, the reliability condition worsened for all three time periods of interest, if the 85th percentile speed was used as reference speed. When using speed limit as reference speed, only AM and PM periods saw increases in PTI, whereas the midday period experienced a very slight decrease. Among MPOs, the largest jump was observed in the KIPDA area, where PTI increased from 2.24 to 2.43 during the PM period, with the 85th percentile speed as reference speed.

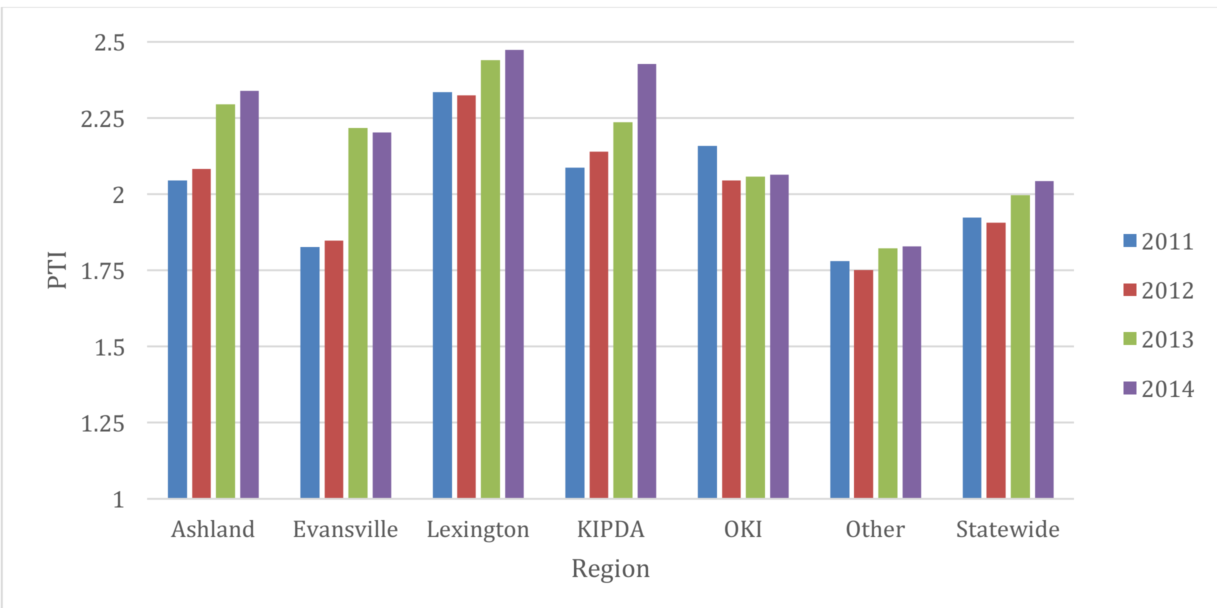
**Table 2-6 Planning time index**

| Region | 2013 | | | | | | 2014 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Based on 85th percentile | | | Based on speed limit | | | Based on 85th percentile | | | Based on speed limit | | |
| | AM | Midday | PM | AM | Midday | PM | AM | Midday | PM | AM | Midday | PM |
| Ashland | 2.13 | 2.27 | 2.30 | 2.01 | 2.19 | 2.19 | 2.17 | 2.25 | 2.34 | 2.06 | 2.18 | 2.25 |
| Evansville | 2.29 | 2.34 | 2.22 | 2.27 | 2.33 | 2.18 | 2.24 | 2.33 | 2.20 | 2.20 | 2.32 | 2.18 |
| Lexington | 2.32 | 2.34 | 2.44 | 2.31 | 2.34 | 2.42 | 2.30 | 2.33 | 2.47 | 2.27 | 2.32 | 2.45 |
| KIPDA | 2.01 | 1.96 | 2.24 | 1.89 | 1.90 | 2.12 | 2.10 | 1.99 | 2.43 | 1.97 | 1.90 | 2.29 |
| OKI | 1.98 | 1.84 | 2.06 | 1.88 | 1.80 | 1.97 | 2.06 | 1.89 | 2.06 | 1.94 | 1.82 | 1.95 |
| Other | 1.77 | 1.84 | 1.82 | 1.74 | 1.85 | 1.81 | 1.78 | 1.84 | 1.83 | 1.74 | 1.83 | 1.80 |
| Statewide | 1.90 | 1.91 | 2.00 | 1.84 | 1.90 | 1.95 | 1.94 | 1.93 | 2.04 | 1.86 | 1.89 | 1.98 |

Figure 2-6 and Figure 2-7 show the four-year region-level PTI. PTI increased in most areas, indicating less reliable travel time in 2014 compared to 2013. PTI values between 2012 and 2013 should not be compared without accounting for the change in data format.

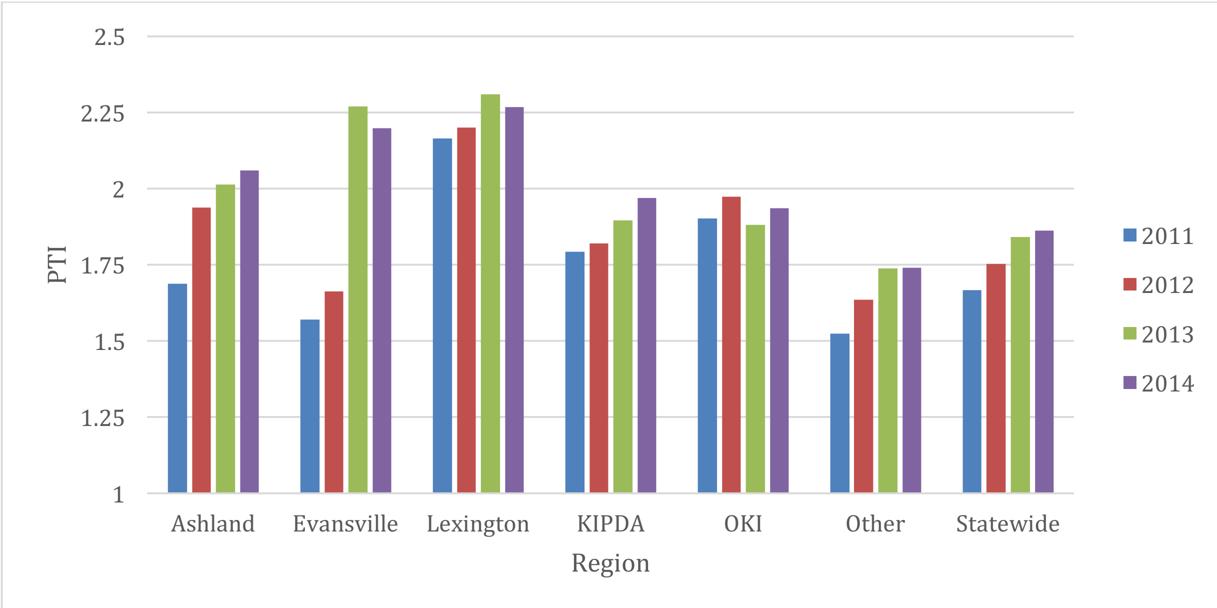



(a) AM period

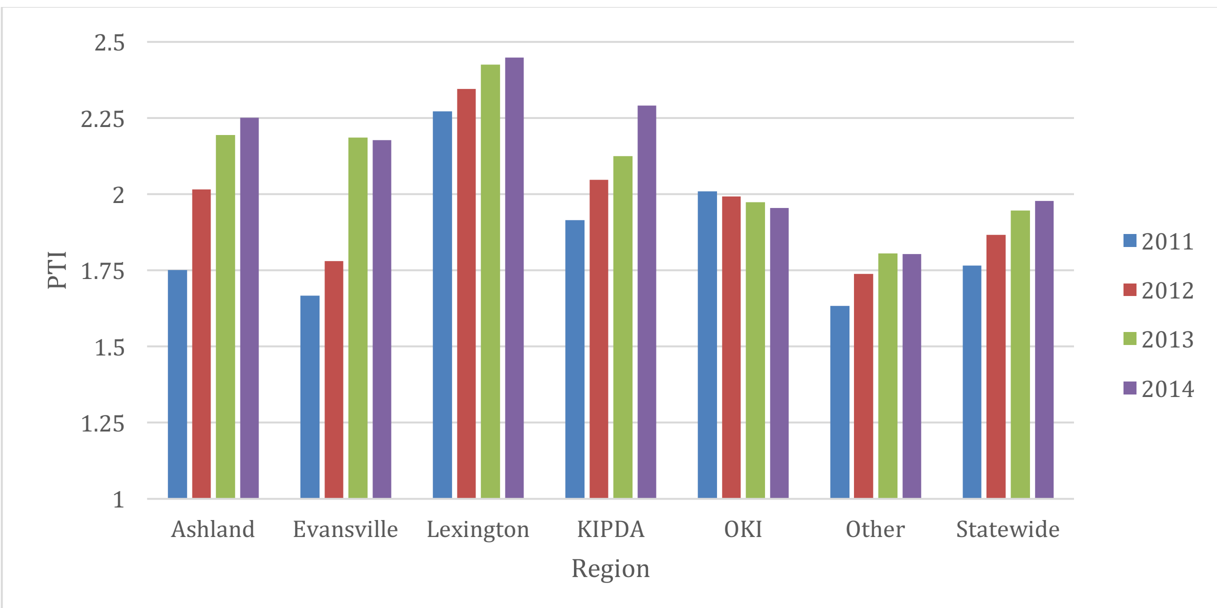



(b) PM period

**Figure 2-6 Regional performance trend based on PTI using the 85th percentile speed**




(a) AM period




(b) PM period

**Figure 2-7 Regional performance trend based on PTI using speed limit**

PTI values were further evaluated by functional classifications for each region and across the state (Table 2-7 and Table 2-8). PTI values are normally higher on surface roads, especially those in urban areas. Traffic control devices often present on such facilities would be a major contributor to the travel time variations.

**Table 2-7 Planning time index by functional classification based on the 85th percentile speed**

(a) AM period

| Region | Year | FC1 | FC2 | FC6 | FC7 | FC8 | FC9 | FC11 | FC12 | FC14 | FC16 | FC17 | FC19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ashland | 2013 | 1.33 | 1.67 | 1.36 | 2.12 | 1.61 | | | | 2.56 | 3.13 | 2.64 | 2.43 |
| | 2014 | 1.34 | 1.65 | 1.43 | 1.93 | 2.07 | | | | 2.58 | 3.36 | 2.95 | 3.26 |
| Evansville | 2013 | | 1.26 | 2.06 | 2.43 | 3.11 | 2.41 | | 1.59 | 2.87 | 4.13 | 3.94 | |
| | 2014 | | 1.29 | 1.87 | 2.31 | 2.77 | 4.13 | | 1.67 | 2.77 | 4.11 | 4.65 | |
| Lexington | 2013 | 1.20 | 1.47 | 1.75 | 2.13 | 2.36 | | 1.29 | 1.40 | 3.79 | 3.50 | 3.38 | |
| | 2014 | 1.29 | 1.35 | 1.79 | 2.36 | 2.48 | 4.10 | 1.29 | 1.49 | 3.65 | 3.47 | 3.38 | |
| KIPDA | 2013 | 1.24 | 1.34 | 1.84 | 2.01 | 2.14 | 2.15 | 1.63 | 1.31 | 3.28 | 3.33 | 3.64 | 4.12 |
| | 2014 | 1.35 | 1.36 | 1.82 | 2.01 | 2.34 | 2.76 | 1.79 | 1.37 | 3.13 | 3.25 | 3.54 | 3.82 |
| OKI | 2013 | 1.25 | 1.48 | 1.43 | 1.89 | 1.77 | | 1.72 | 2.29 | 3.10 | 3.30 | 3.20 | 3.20 |
| | 2014 | 1.25 | 1.51 | 1.55 | 2.07 | 1.74 | | 1.78 | 1.54 | 3.03 | 3.30 | 3.59 | 3.73 |
| Other | 2013 | 1.28 | 1.49 | 1.76 | 1.95 | 2.25 | 2.45 | 1.50 | 1.42 | 2.91 | 3.09 | 3.15 | 3.68 |
| | 2014 | 1.28 | 1.51 | 1.79 | 2.00 | 2.32 | 2.49 | 1.30 | 1.41 | 2.81 | 3.04 | 3.19 | 3.49 |
| Statewide | 2013 | 1.27 | 1.49 | 1.76 | 1.96 | 2.25 | 2.41 | 1.62 | 1.40 | 3.15 | 3.24 | 3.30 | 3.36 |
| | 2014 | 1.29 | 1.51 | 1.79 | 2.02 | 2.33 | 2.54 | 1.70 | 1.44 | 3.05 | 3.18 | 3.37 | 3.56 |

(b) Midday period

| Region | Year | FC1 | FC2 | FC6 | FC7 | FC8 | FC9 | FC11 | FC12 | FC14 | FC16 | FC17 | FC19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ashland | 2013 | 1.31 | 1.71 | 1.36 | 2.78 | 2.35 | | | | 2.80 | 3.21 | 2.74 | 3.01 |
| | 2014 | 1.31 | 1.77 | 1.43 | 2.32 | 2.64 | | | | 2.65 | 3.76 | 2.78 | 3.52 |
| Evansville | 2013 | | 1.26 | 2.06 | 2.35 | 3.58 | 2.16 | | 1.66 | 2.97 | 3.37 | 5.20 | |
| | 2014 | | 1.26 | 1.94 | 2.22 | 3.21 | 2.34 | | 1.76 | 2.94 | 3.65 | 3.98 | |
| Lexington | 2013 | 1.19 | 1.42 | 1.85 | 2.42 | 2.56 | | 1.25 | 1.32 | 3.61 | 3.28 | 3.50 | |
| | 2014 | 1.28 | 1.37 | 1.90 | 2.53 | 2.85 | 4.65 | 1.25 | 1.32 | 3.51 | 3.25 | 3.51 | |
| KIPDA | 2013 | 1.21 | 1.35 | 1.86 | 2.22 | 2.72 | 3.90 | 1.29 | 1.34 | 3.26 | 3.39 | 3.96 | 4.81 |
| | 2014 | 1.39 | 1.36 | 1.87 | 2.17 | 2.77 | 3.36 | 1.34 | 1.40 | 3.13 | 3.20 | 3.75 | 4.74 |
| OKI | 2013 | 1.24 | 1.51 | 1.58 | 2.16 | 2.05 | | 1.36 | 1.71 | 3.17 | 3.19 | 3.50 | 3.78 |
| | 2014 | 1.24 | 1.52 | 1.58 | 2.21 | 1.86 | | 1.36 | 1.57 | 3.08 | 3.19 | 3.58 | 3.80 |
| Other | 2013 | 1.30 | 1.50 | 1.82 | 2.16 | 2.55 | 2.72 | 1.54 | 1.43 | 2.99 | 3.27 | 3.41 | 3.37 |
| | 2014 | 1.29 | 1.50 | 1.81 | 2.12 | 2.52 | 2.46 | 1.27 | 1.39 | 2.93 | 3.23 | 3.43 | 3.57 |
| Statewide | 2013 | 1.28 | 1.50 | 1.83 | 2.18 | 2.56 | 2.83 | 1.34 | 1.37 | 3.17 | 3.30 | 3.56 | 3.46 |
| | 2014 | 1.30 | 1.50 | 1.82 | 2.14 | 2.57 | 2.55 | 1.33 | 1.38 | 3.09 | 3.22 | 3.54 | 3.79 |

(c) PM period

| Region | Year | FC1 | FC2 | FC6 | FC7 | FC8 | FC9 | FC11 | FC12 | FC14 | FC16 | FC17 | FC19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ashland | 2013 | 1.30 | 1.68 | 1.39 | 2.55 | 1.94 | | | | 2.84 | 3.24 | 2.99 | 2.84 |
| | 2014 | 1.29 | 1.69 | 1.40 | 2.70 | 2.70 | | | | 2.90 | 3.65 | 2.72 | 3.06 |
| Evansville | 2013 | | 1.25 | 1.80 | 1.96 | 2.85 | 3.01 | | 1.63 | 2.95 | 3.57 | 3.36 | |
| | 2014 | | 1.26 | 1.65 | 2.13 | 2.96 | 2.18 | | 1.56 | 2.96 | 3.49 | 3.68 | |
| Lexington | 2013 | 1.19 | 1.36 | 1.67 | 2.21 | 2.39 | | 1.25 | 1.71 | 4.05 | 3.37 | 3.33 | |
| | 2014 | 1.36 | 1.38 | 1.72 | 2.09 | 2.56 | 3.27 | 1.27 | 1.74 | 4.07 | 3.38 | 3.38 | |
| KIPDA | 2013 | 1.22 | 1.31 | 1.86 | 2.11 | 2.52 | 2.62 | 1.83 | 1.32 | 3.71 | 3.57 | 3.60 | 4.30 |
| | 2014 | 1.58 | 1.33 | 1.77 | 1.99 | 2.47 | 3.01 | 2.18 | 1.37 | 3.60 | 3.39 | 3.43 | 3.68 |
| OKI | 2013 | 1.22 | 1.36 | 1.80 | 2.11 | 2.26 | | 1.73 | 2.12 | 3.35 | 3.14 | 3.29 | 3.76 |
| | 2014 | 1.22 | 1.35 | 1.58 | 1.96 | 2.06 | | 1.69 | 1.97 | 3.26 | 3.13 | 3.50 | 4.83 |
| Other | 2013 | 1.30 | 1.46 | 1.77 | 2.04 | 2.35 | 2.59 | 1.72 | 1.43 | 2.97 | 3.21 | 3.40 | 3.27 |
| | 2014 | 1.35 | 1.46 | 1.77 | 2.01 | 2.31 | 2.58 | 1.27 | 1.41 | 2.91 | 3.16 | 3.33 | 3.19 |
| Statewide | 2013 | 1.28 | 1.46 | 1.78 | 2.06 | 2.37 | 2.60 | 1.75 | 1.52 | 3.34 | 3.34 | 3.41 | 3.39 |
| | 2014 | 1.38 | 1.46 | 1.76 | 2.02 | 2.35 | 2.63 | 1.86 | 1.54 | 3.29 | 3.26 | 3.38 | 3.52 |

Note: blank cells mean there is no facility with a designated functional class in the region or facilities do not satisfy quality screening criteria.

**Table 2-8 Planning time index by functional classification based on speed limit**

(a) AM period

| Region | Year | FC1 | FC2 | FC6 | FC7 | FC8 | FC9 | FC11 | FC12 | FC14 | FC16 | FC17 | FC19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ashland | 2013 | 1.27 | 1.50 | 1.22 | 2.10 | 2.10 | | | | 2.42 | 2.83 | 2.65 | 2.64 |
| | 2014 | 1.27 | 1.48 | 1.33 | 2.16 | 2.49 | | | | 2.45 | 3.02 | 2.91 | 3.33 |
| Evansville | 2013 | | 1.21 | 1.93 | 2.34 | 3.00 | 2.86 | | 1.84 | 2.76 | 4.11 | 3.34 | |
| | 2014 | | 1.24 | 1.75 | 2.20 | 2.81 | 3.75 | | 1.93 | 2.61 | 4.16 | 3.72 | |
| Lexington | 2013 | 1.14 | 1.35 | 1.67 | 2.19 | 2.48 | 2.67 | 1.24 | 1.25 | 3.90 | 3.44 | 3.34 | |
| | 2014 | 1.23 | 1.21 | 1.72 | 2.41 | 2.69 | 3.60 | 1.24 | 1.31 | 3.73 | 3.43 | 3.32 | |
| KIPDA | 2013 | 1.21 | 1.22 | 1.75 | 2.01 | 2.27 | 2.61 | 1.46 | 1.22 | 3.30 | 3.25 | 3.38 | 4.18 |
| | 2014 | 1.30 | 1.22 | 1.74 | 2.05 | 2.46 | 2.97 | 1.61 | 1.28 | 3.13 | 3.14 | 3.32 | 3.78 |
| OKI | 2013 | 1.19 | 1.29 | 1.41 | 2.08 | 2.22 | 3.66 | 1.59 | 2.08 | 3.08 | 3.25 | 3.10 | 3.42 |
| | 2014 | 1.18 | 1.31 | 1.52 | 2.17 | 2.15 | 2.97 | 1.62 | 1.33 | 3.01 | 3.26 | 3.41 | 3.94 |
| Other | 2013 | 1.23 | 1.38 | 1.68 | 1.96 | 2.40 | 2.76 | 1.44 | 1.36 | 2.86 | 3.12 | 3.09 | 4.06 |
| | 2014 | 1.22 | 1.38 | 1.69 | 2.01 | 2.47 | 2.86 | 1.22 | 1.34 | 2.77 | 3.06 | 3.17 | 3.79 |
| Statewide | 2013 | 1.22 | 1.38 | 1.68 | 1.97 | 2.40 | 2.75 | 1.48 | 1.30 | 3.15 | 3.21 | 3.18 | 3.72 |
| | 2014 | 1.23 | 1.38 | 1.69 | 2.03 | 2.48 | 2.88 | 1.54 | 1.33 | 3.03 | 3.15 | 3.25 | 3.73 |

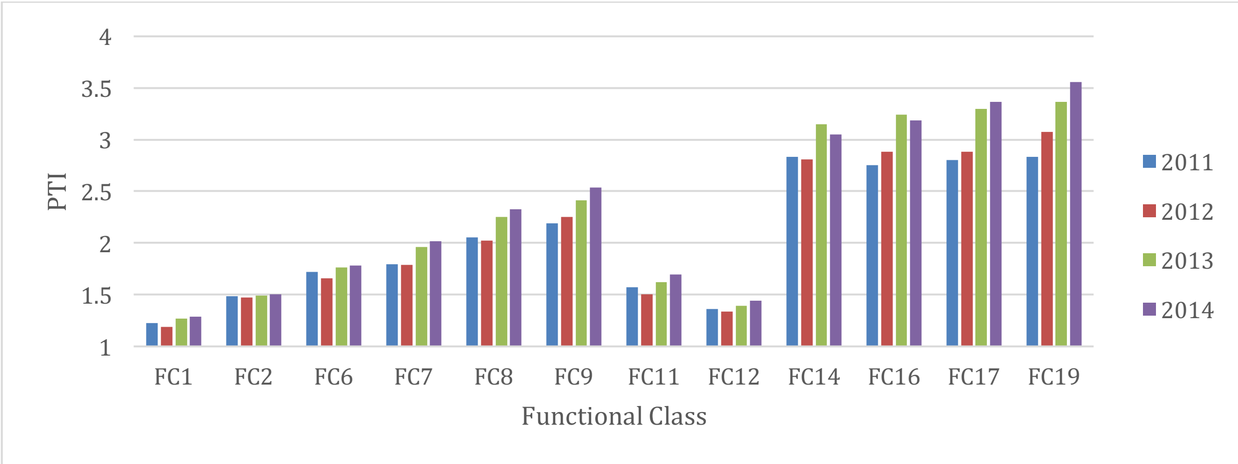
(b) Midday period

| Region | Year | FC1 | FC2 | FC6 | FC7 | FC8 | FC9 | FC11 | FC12 | FC14 | FC16 | FC17 | FC19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ashland | 2013 | 1.25 | 1.52 | 1.26 | 2.66 | 2.87 | 3.11 | | | 2.65 | 2.92 | 2.88 | 3.02 |
| | 2014 | 1.25 | 1.59 | 1.35 | 2.38 | 2.96 | 4.15 | | | 2.52 | 3.38 | 2.98 | 3.40 |
| Evansville | 2013 | | 1.21 | 1.95 | 2.33 | 3.69 | 3.26 | | 1.92 | 2.86 | 3.35 | 3.79 | |
| | 2014 | | 1.20 | 1.83 | 2.23 | 3.21 | 3.01 | | 2.02 | 2.79 | 3.72 | 3.14 | |
| Lexington | 2013 | 1.13 | 1.30 | 1.79 | 2.52 | 2.82 | 3.57 | 1.20 | 1.18 | 3.71 | 3.23 | 3.40 | |
| | 2014 | 1.22 | 1.22 | 1.84 | 2.62 | 3.01 | 4.41 | 1.19 | 1.16 | 3.62 | 3.22 | 3.40 | |
| KIPDA | 2013 | 1.18 | 1.24 | 1.80 | 2.26 | 2.95 | 3.87 | 1.16 | 1.24 | 3.28 | 3.30 | 3.70 | 5.25 |
| | 2014 | 1.34 | 1.22 | 1.80 | 2.21 | 3.01 | 3.53 | 1.20 | 1.31 | 3.12 | 3.10 | 3.51 | 4.83 |
| OKI | 2013 | 1.18 | 1.32 | 1.61 | 2.39 | 2.26 | | 1.25 | 1.53 | 3.12 | 3.15 | 3.39 | 4.16 |
| | 2014 | 1.17 | 1.32 | 1.55 | 2.38 | 2.30 | 4.79 | 1.24 | 1.36 | 3.04 | 3.16 | 3.39 | 4.28 |
| Other | 2013 | 1.25 | 1.38 | 1.76 | 2.19 | 2.76 | 3.08 | 1.48 | 1.36 | 2.94 | 3.29 | 3.42 | 4.10 |
| | 2014 | 1.22 | 1.37 | 1.73 | 2.16 | 2.72 | 3.01 | 1.20 | 1.32 | 2.88 | 3.24 | 3.42 | 4.08 |
| Statewide | 2013 | 1.23 | 1.38 | 1.76 | 2.21 | 2.78 | 3.16 | 1.23 | 1.27 | 3.16 | 3.27 | 3.46 | 4.00 |
| | 2014 | 1.24 | 1.37 | 1.74 | 2.18 | 2.75 | 3.08 | 1.21 | 1.27 | 3.07 | 3.18 | 3.42 | 4.10 |

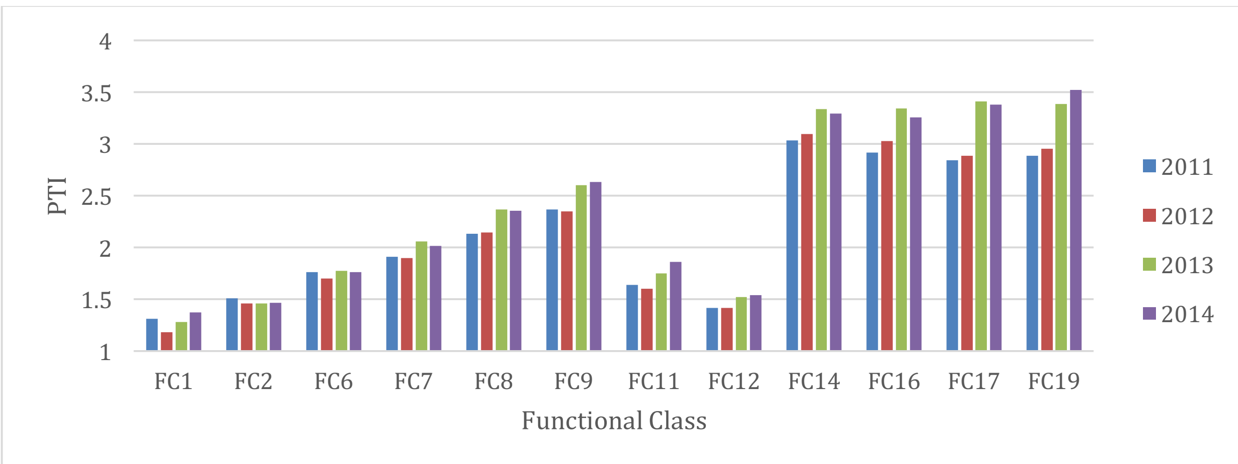
(c) PM period

| Region | Year | FC1 | FC2 | FC6 | FC7 | FC8 | FC9 | FC11 | FC12 | FC14 | FC16 | FC17 | FC19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ashland | 2013 | 1.24 | 1.50 | 1.28 | 2.70 | 2.76 | | | | 2.68 | 2.82 | 2.97 | 2.93 |
| | 2014 | 1.23 | 1.51 | 1.30 | 2.53 | 3.00 | | | | 2.75 | 3.34 | 2.95 | 3.04 |
| Evansville | 2013 | | 1.21 | 1.69 | 1.90 | 2.91 | 3.64 | | 1.86 | 2.82 | 3.52 | 2.84 | |
| | 2014 | | 1.20 | 1.56 | 2.12 | 2.88 | 3.26 | | 1.77 | 2.81 | 3.50 | 3.22 | |
| Lexington | 2013 | 1.13 | 1.25 | 1.61 | 2.31 | 2.56 | 3.35 | 1.20 | 1.53 | 4.15 | 3.28 | 3.28 | |
| | 2014 | 1.30 | 1.23 | 1.66 | 2.20 | 2.69 | 2.89 | 1.22 | 1.54 | 4.18 | 3.32 | 3.26 | |
| KIPDA | 2013 | 1.19 | 1.19 | 1.79 | 2.17 | 2.74 | 2.92 | 1.64 | 1.22 | 3.68 | 3.45 | 3.37 | 4.05 |
| | 2014 | 1.53 | 1.19 | 1.69 | 2.07 | 2.71 | 3.11 | 1.97 | 1.28 | 3.56 | 3.27 | 3.20 | 3.56 |
| OKI | 2013 | 1.17 | 1.18 | 1.79 | 2.28 | 2.45 | 2.38 | 1.59 | 1.90 | 3.33 | 3.11 | 3.11 | 3.80 |
| | 2014 | 1.15 | 1.17 | 1.54 | 2.14 | 2.34 | 2.87 | 1.53 | 1.70 | 3.26 | 3.08 | 3.26 | 5.22 |
| Other | 2013 | 1.24 | 1.35 | 1.71 | 2.08 | 2.50 | 2.91 | 1.66 | 1.36 | 2.92 | 3.23 | 3.35 | 3.99 |
| | 2014 | 1.28 | 1.34 | 1.69 | 2.05 | 2.53 | 2.90 | 1.19 | 1.33 | 2.85 | 3.16 | 3.30 | 3.74 |
| Statewide | 2013 | 1.23 | 1.35 | 1.71 | 2.09 | 2.53 | 2.93 | 1.60 | 1.41 | 3.31 | 3.30 | 3.29 | 3.75 |
| | 2014 | 1.31 | 1.34 | 1.68 | 2.06 | 2.55 | 2.92 | 1.69 | 1.42 | 3.27 | 3.20 | 3.26 | 3.74 |

Combining the four years (Figure 2-8 and Figure 2-9) reveals that travel time reliability deteriorated for most facilities from 2011 to 2012 and from 2013 to 2014.

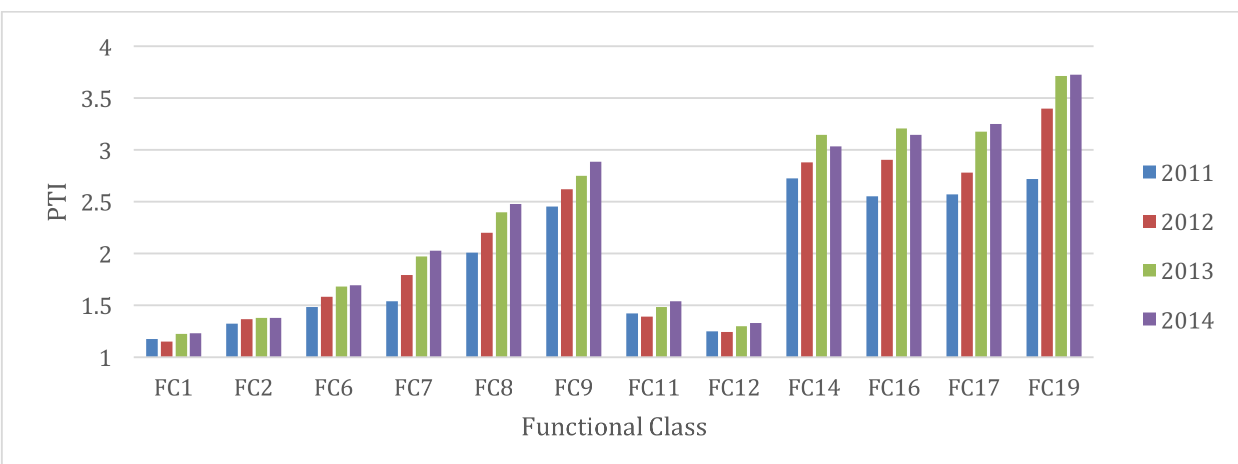



(a) AM period

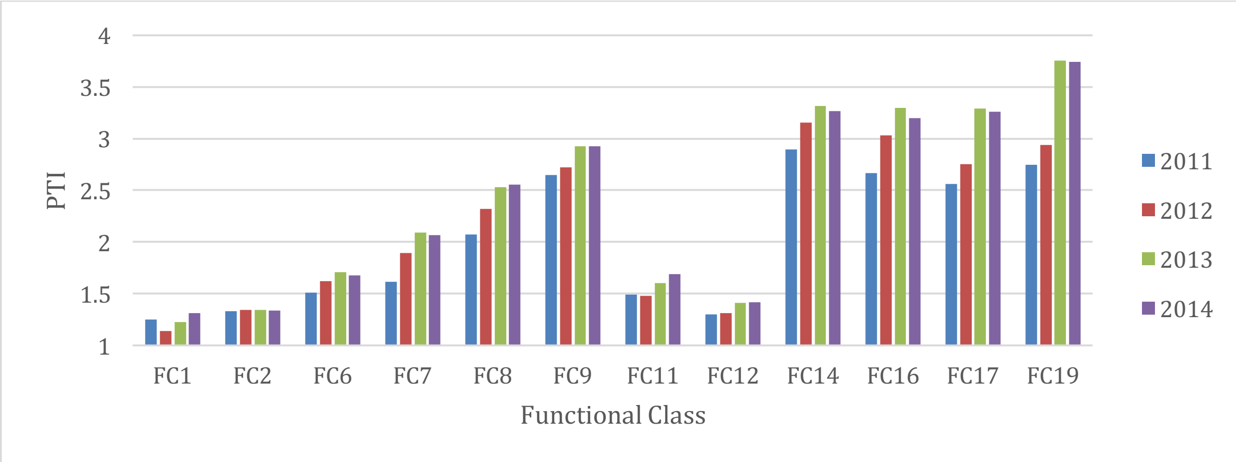



(b) PM period

**Figure 2-8 FC performance trend based on PTI using the 85th percentile speed**




(a) AM period




(b) PM period

**Figure 2-9 FC performance trend based on PTI using speed limit**

*2.2.5 Buffer Index*

The buffer index (BI) is closely related to the travel time and planning time indices. It is the percentage time that a traveler needs to plan, relative to their own average travel time, to ensure a 95% chance of on time arrival. It indicates the extra effort a traveler needs to ensure an on-time arrival at a destination. It is calculated using this formula:

$$BI = \frac{\text{The } 95th\ Percentile\ Travel\ Time - Average\ Travel\ Time}{Average\ Travel\ Time}$$

The above formula can be rewritten as:

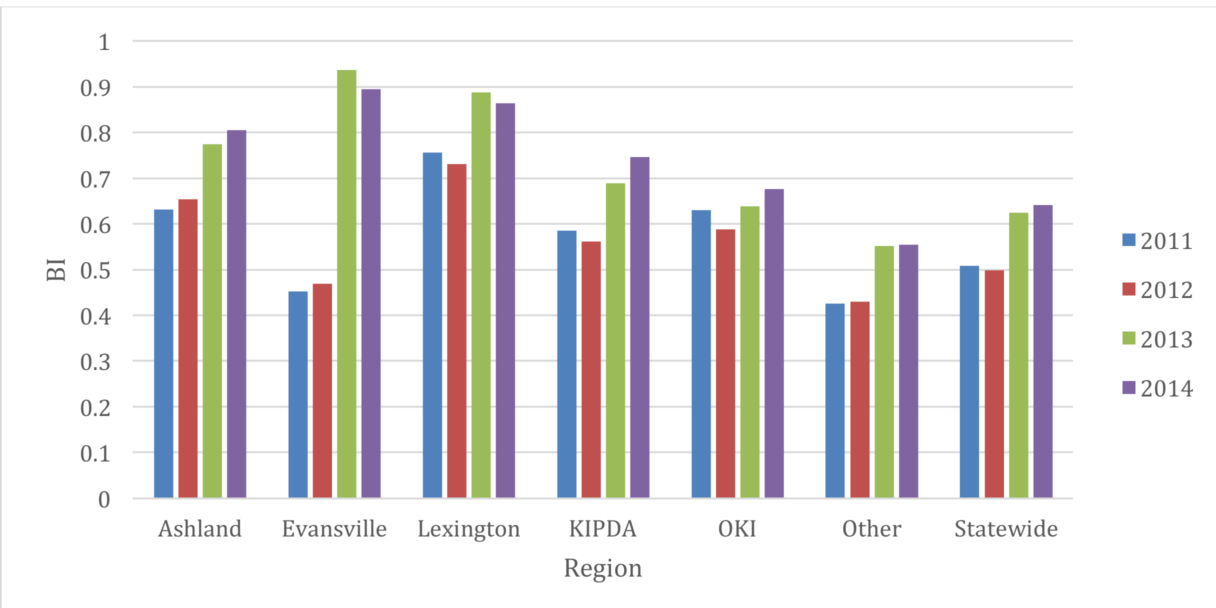
$$BI = \frac{Average\ speed}{\text{The } 5th\ percentile\ speed} - 1$$

Buffer index indicates the variability of travel time experienced by users relative to their average commute. Table 2-9 shows the regional and statewide buffer indices for different time of day, and Table 2-10 shows the distribution of BI by functional class and by time of day. Travel time variability increased slightly from 2013 to 2014 for all three time periods evaluated. KIPDA had the largest increase in buffer index during AM and PM periods among all MPOs. Some MPOs showed slightly reduced variability; for example, Lexington during AM and Midday periods. This indicates that the variability in travel time — for the average user — during peak periods decreased. However, considering the slight increase in congestion (measured by TTI), we conclude that travel time in these areas has consistently increased.

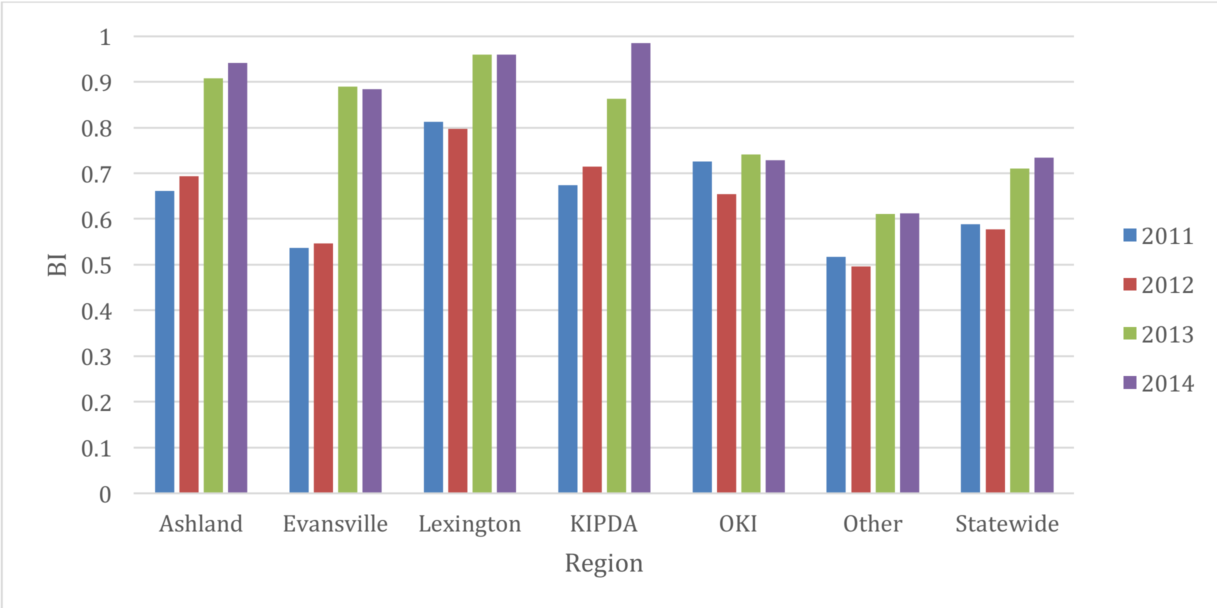
**Table 2-9 Buffer index by region**

| Region | 2013 | | | 2014 | | |
|---|---|---|---|---|---|---|
| | AM | Midday | PM | AM | Midday | PM |
| Ashland | 0.77 | 0.89 | 0.91 | 0.80 | 0.89 | 0.94 |
| Evansville | 0.94 | 0.97 | 0.89 | 0.89 | 0.98 | 0.88 |
| Lexington | 0.89 | 0.90 | 0.96 | 0.86 | 0.88 | 0.96 |
| KIPDA | 0.69 | 0.67 | 0.86 | 0.75 | 0.68 | 0.98 |
| OKI | 0.64 | 0.59 | 0.74 | 0.68 | 0.61 | 0.73 |
| Other | 0.55 | 0.63 | 0.61 | 0.56 | 0.62 | 0.61 |
| Statewide | 0.62 | 0.66 | 0.71 | 0.64 | 0.65 | 0.73 |

The four-year trend in variability is shown in Figure 2-10. Although direct comparison of 2012 and 2013 data is cautioned against, it is evident that travel time variability in the OKI region was consistently less than in other metropolitan areas.




(a) AM period




(b) PM period

**Figure 2-10 Regional performance trend based on buffer index**

**Table 2-10 Buffer index by functional classification**

(a) AM period

| Region | Year | FC1 | FC2 | FC6 | FC7 | FC8 | FC9 | FC11 | FC12 | FC14 | FC16 | FC17 | FC19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ashland | 2013 | 0.19 | 0.45 | 0.23 | 0.68 | 0.51 | | | | 1.06 | 1.53 | 1.23 | 1.09 |
| | 2014 | 0.20 | 0.44 | 0.33 | 0.73 | 0.89 | | | | 1.07 | 1.58 | 1.40 | 1.52 |
| Evansville | 2013 | | 0.16 | 0.81 | 1.11 | 1.39 | 1.22 | | 0.38 | 1.34 | 2.08 | 1.64 | |
| | 2014 | | 0.19 | 0.65 | 1.01 | 1.15 | 1.68 | | 0.46 | 1.25 | 2.16 | 2.17 | |
| Lexington | 2013 | 0.12 | 0.32 | 0.53 | 0.80 | 0.93 | | 0.18 | 0.26 | 1.87 | 1.69 | 1.60 | |
| | 2014 | 0.17 | 0.23 | 0.55 | 0.96 | 1.00 | 1.44 | 0.18 | 0.32 | 1.76 | 1.68 | 1.62 | |
| KIPDA | 2013 | 0.15 | 0.24 | 0.59 | 0.70 | 0.86 | 0.93 | 0.42 | 0.20 | 1.59 | 1.61 | 1.77 | 2.05 |
| | 2014 | 0.22 | 0.25 | 0.57 | 0.72 | 0.96 | 1.16 | 0.53 | 0.24 | 1.48 | 1.54 | 1.72 | 1.86 |
| OKI | 2013 | 0.15 | 0.33 | 0.31 | 0.68 | 0.74 | 1.07 | 0.44 | 0.87 | 1.43 | 1.58 | 1.53 | 1.49 |
| | 2014 | 0.15 | 0.34 | 0.40 | 0.76 | 0.65 | 0.75 | 0.46 | 0.35 | 1.37 | 1.56 | 1.79 | 1.72 |
| Other | 2013 | 0.17 | 0.34 | 0.56 | 0.70 | 0.88 | 0.98 | 0.33 | 0.27 | 1.31 | 1.48 | 1.50 | 1.67 |
| | 2014 | 0.17 | 0.34 | 0.57 | 0.74 | 0.91 | 1.04 | 0.18 | 0.26 | 1.25 | 1.43 | 1.55 | 1.60 |
| Statewide | 2013 | 0.17 | 0.34 | 0.56 | 0.71 | 0.88 | 0.98 | 0.40 | 0.25 | 1.48 | 1.56 | 1.57 | 1.61 |
| | 2014 | 0.17 | 0.34 | 0.56 | 0.74 | 0.91 | 1.05 | 0.44 | 0.28 | 1.40 | 1.51 | 1.64 | 1.66 |

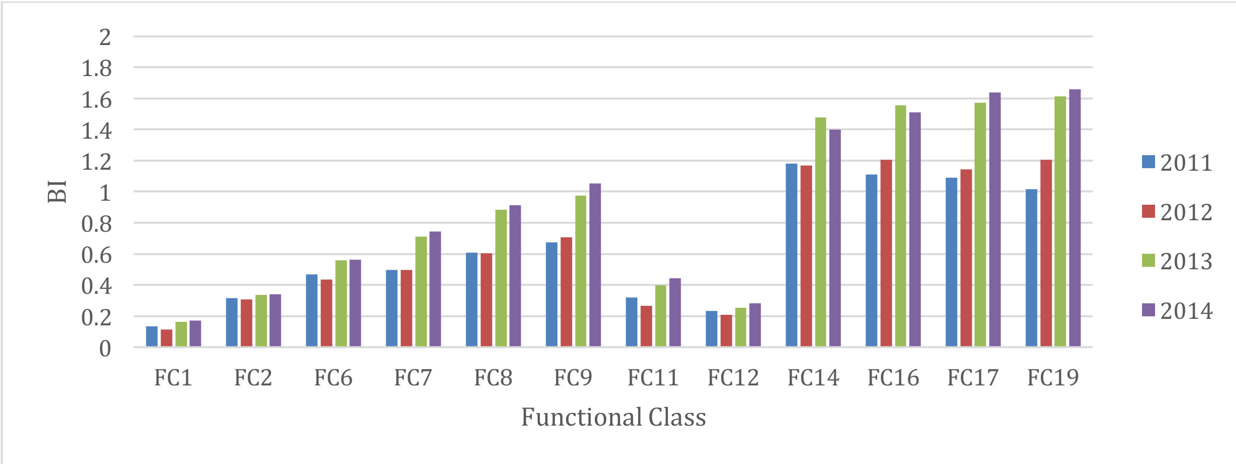
(b) Midday period

| Region | Year | FC1 | FC2 | FC6 | FC7 | FC8 | FC9 | FC11 | FC12 | FC14 | FC16 | FC17 | FC19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ashland | 2013 | 0.20 | 0.49 | 0.28 | 1.10 | 1.00 | 0.87 | | | 1.20 | 1.51 | 1.38 | 1.40 |
| | 2014 | 0.20 | 0.54 | 0.35 | 0.89 | 1.12 | 1.23 | | | 1.11 | 1.84 | 1.48 | 1.58 |
| Evansville | 2013 | | 0.16 | 0.82 | 1.08 | 1.67 | 1.27 | | 0.45 | 1.34 | 1.60 | 2.30 | |
| | 2014 | | 0.16 | 0.71 | 1.01 | 1.37 | 1.09 | | 0.52 | 1.33 | 1.91 | 1.94 | |
| Lexington | 2013 | 0.11 | 0.27 | 0.59 | 0.98 | 1.10 | 1.55 | 0.15 | 0.20 | 1.71 | 1.56 | 1.70 | 2.92 |
| | 2014 | 0.16 | 0.23 | 0.63 | 1.08 | 1.23 | 2.11 | 0.15 | 0.20 | 1.63 | 1.53 | 1.71 | 2.37 |
| KIPDA | 2013 | 0.12 | 0.22 | 0.64 | 0.89 | 1.25 | 1.59 | 0.18 | 0.20 | 1.54 | 1.67 | 2.05 | 2.44 |
| | 2014 | 0.25 | 0.21 | 0.62 | 0.83 | 1.27 | 1.41 | 0.21 | 0.25 | 1.43 | 1.53 | 1.91 | 2.35 |
| OKI | 2013 | 0.14 | 0.34 | 0.46 | 0.89 | 0.79 | | 0.23 | 0.47 | 1.44 | 1.51 | 1.77 | 1.97 |
| | 2014 | 0.14 | 0.35 | 0.44 | 0.88 | 0.81 | 1.24 | 0.23 | 0.37 | 1.39 | 1.50 | 1.78 | 2.02 |
| Other | 2013 | 0.19 | 0.34 | 0.61 | 0.88 | 1.11 | 1.23 | 0.36 | 0.28 | 1.33 | 1.57 | 1.76 | 1.84 |
| | 2014 | 0.18 | 0.34 | 0.59 | 0.85 | 1.09 | 1.13 | 0.17 | 0.25 | 1.29 | 1.54 | 1.77 | 1.94 |
| Statewide | 2013 | 0.18 | 0.34 | 0.61 | 0.89 | 1.12 | 1.26 | 0.21 | 0.23 | 1.45 | 1.60 | 1.81 | 1.83 |
| | 2014 | 0.19 | 0.34 | 0.59 | 0.86 | 1.11 | 1.17 | 0.21 | 0.24 | 1.39 | 1.53 | 1.79 | 1.95 |

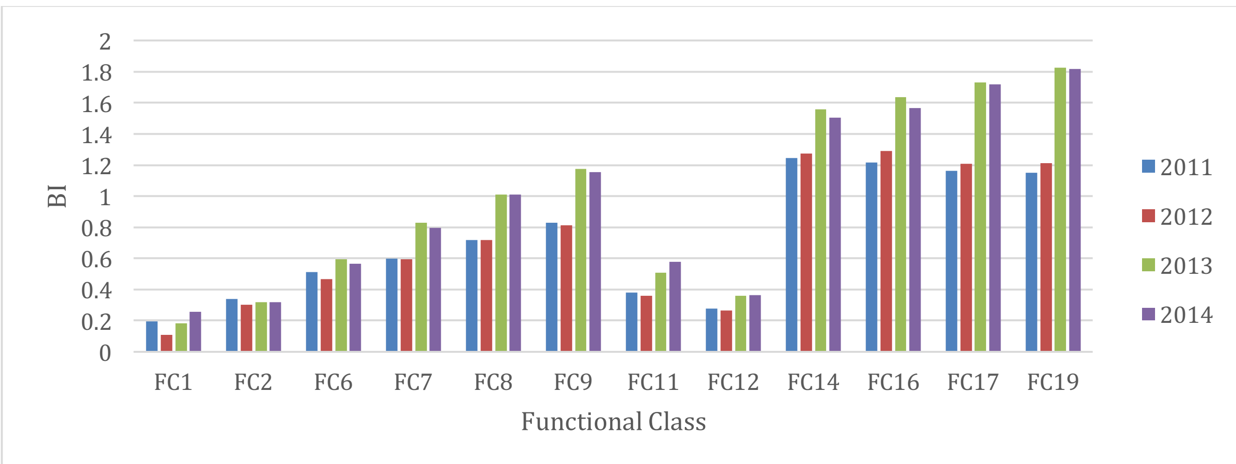
(c) PM period

| Region | Year | FC1 | FC2 | FC6 | FC7 | FC8 | FC9 | FC11 | FC12 | FC14 | FC16 | FC17 | FC19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ashland | 2013 | 0.19 | 0.47 | 0.31 | 1.17 | 0.96 | | | | 1.23 | 1.52 | 1.49 | 1.27 |
| | 2014 | 0.19 | 0.48 | 0.32 | 1.05 | 1.08 | | | | 1.26 | 1.90 | 1.47 | 1.39 |
| Evansville | 2013 | | 0.17 | 0.60 | 0.76 | 1.32 | 1.87 | | 0.44 | 1.35 | 1.80 | 1.77 | 3.16 |
| | 2014 | | 0.17 | 0.48 | 0.94 | 1.24 | 1.46 | | 0.39 | 1.35 | 1.79 | 1.97 | |
| Lexington | 2013 | 0.11 | 0.23 | 0.46 | 0.89 | 0.98 | 1.31 | 0.15 | 0.50 | 1.96 | 1.63 | 1.65 | |
| | 2014 | 0.23 | 0.25 | 0.50 | 0.81 | 1.10 | 1.25 | 0.17 | 0.50 | 1.91 | 1.63 | 1.65 | |
| KIPDA | 2013 | 0.13 | 0.21 | 0.64 | 0.87 | 1.21 | 1.14 | 0.56 | 0.21 | 1.84 | 1.79 | 1.86 | 2.35 |
| | 2014 | 0.41 | 0.22 | 0.56 | 0.77 | 1.14 | 1.29 | 0.80 | 0.24 | 1.73 | 1.66 | 1.74 | 1.88 |
| OKI | 2013 | 0.14 | 0.26 | 0.64 | 0.88 | 0.87 | 0.64 | 0.49 | 0.82 | 1.55 | 1.49 | 1.63 | 1.86 |
| | 2014 | 0.14 | 0.24 | 0.43 | 0.75 | 0.88 | 0.91 | 0.46 | 0.69 | 1.48 | 1.46 | 1.75 | 2.73 |
| Other | 2013 | 0.20 | 0.32 | 0.59 | 0.82 | 0.99 | 1.17 | 0.50 | 0.29 | 1.34 | 1.56 | 1.74 | 1.85 |
| | 2014 | 0.24 | 0.32 | 0.57 | 0.80 | 0.99 | 1.13 | 0.17 | 0.27 | 1.28 | 1.51 | 1.72 | 1.74 |
| Statewide | 2013 | 0.18 | 0.32 | 0.59 | 0.83 | 1.01 | 1.18 | 0.51 | 0.36 | 1.56 | 1.64 | 1.73 | 1.83 |
| | 2014 | 0.26 | 0.32 | 0.56 | 0.80 | 1.01 | 1.15 | 0.58 | 0.36 | 1.51 | 1.57 | 1.72 | 1.82 |

The statewide trend in variability for each functional class during AM and PM periods is shown in Figure 2-11 — there is clear evidence of increasing variability. Higher travel time variability on surface streets, especially those in urban areas, is also expected.




(a) AM period



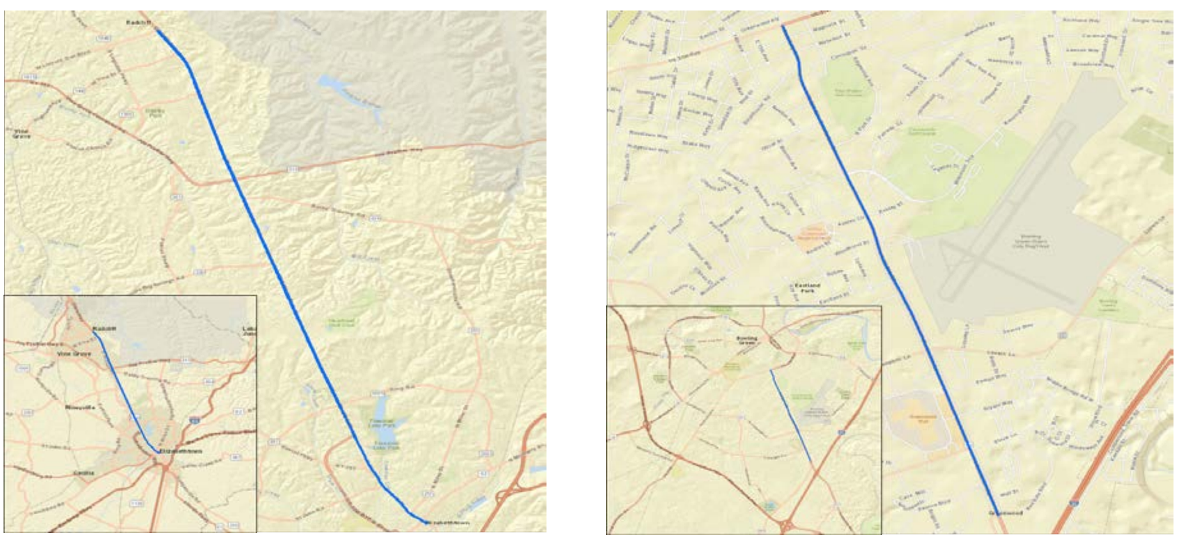

(b) PM period

**Figure 2-11 FC performance trend based on buffer index**

## CHAPTER 3    Additional Data Evaluation

In addition to probe speed data KYTC acquired for the previous 2011-2012 study and current 2013-2014 study, the vendor made other data types available after implementing updated data processing techniques. Probe speed data are based on individual GPS polling records and could contain multiple readings from the same vehicle on a link. In contrast, vehicle speed data consolidates multiple readings (if available) from the same vehicle on a link into a single reading to give each probe vehicle equal representation. The path-speed data instead provide space mean speed derived from vehicle trajectories. This is the distance traveled between two points divided by the time needed to traverse the path. As the path may cover multiple links, the space mean speed is assigned to all the links covered, even though some links may not have GPS readings. Therefore, the path-processing approach can cover more links and more time periods compared to probe- and vehicle-based approaches. It also smooths the impact of outliers, such as low speeds, on a signalized intersection approach. The path option is only available on arterials. Different speed types are also partitioned by vehicle type (i.e., passenger cars, trucks, and combination of these two).

To better understand characteristics of each data type and their impact on performance measurement, nine speed datasets (3 processing types × 3 vehicle types) were obtained for in-depth analysis. Two urban arterials in Hardin County (US-31W) and Warren County (US-231) were selected as test sites, as shown in Figure 3-1.

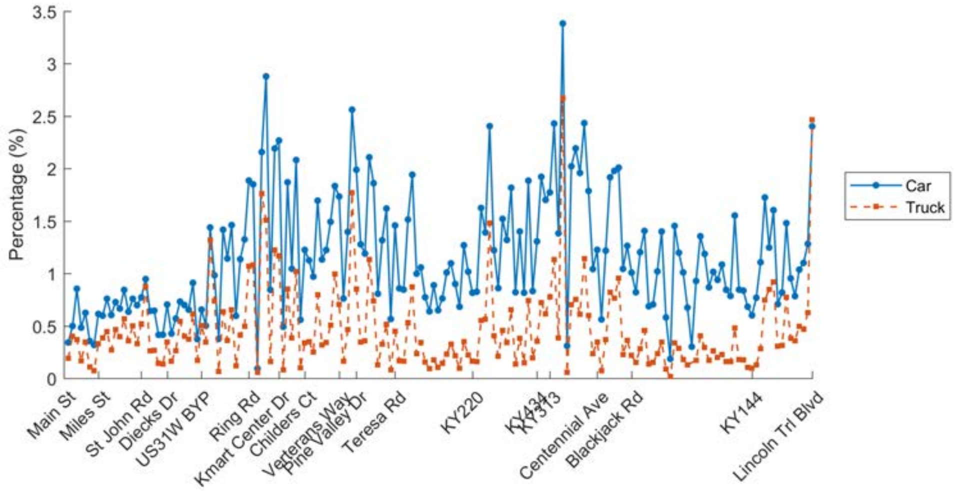


(a) US-31W    (b) US-231

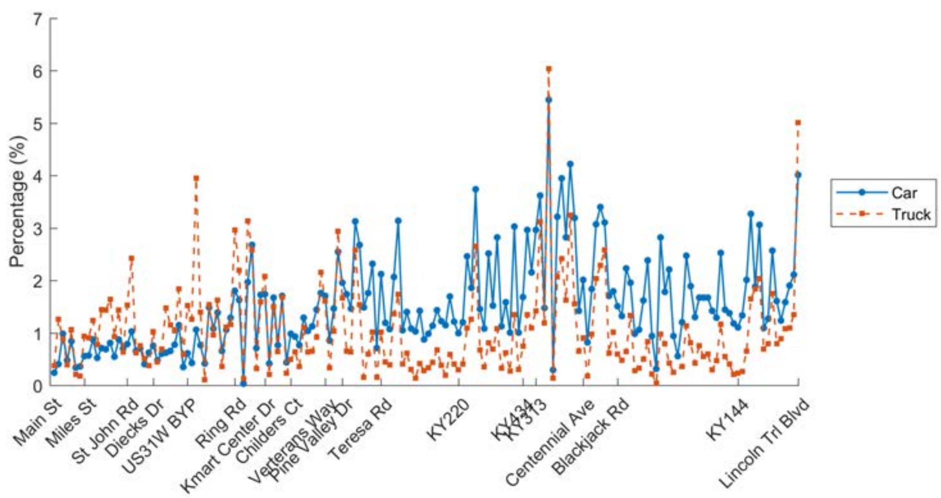
**Figure 3-1 Data evaluation sites**

### 3.1 Sample Sizes

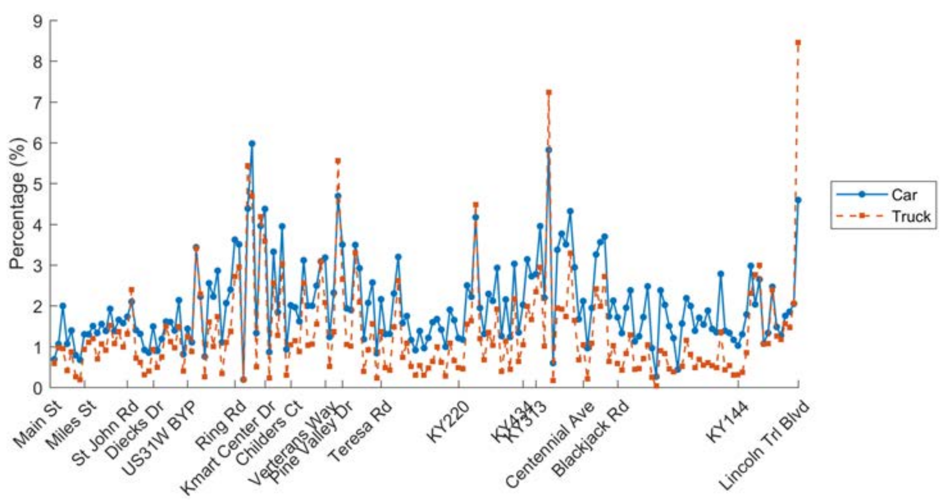
To facilitate discussion, comparison graphs for US-31W in northbound direction are presented. Figure 3-2 shows the sample coverage percentage (measured by PcntInterval_Sampled in Table 1-3) between car and truck using vehicle-based data. The direction of travel is always from left to right on the horizontal axis. The same graphs for US-31W (southbound direction) and US-231 (both directions) can be found in Appendix C.



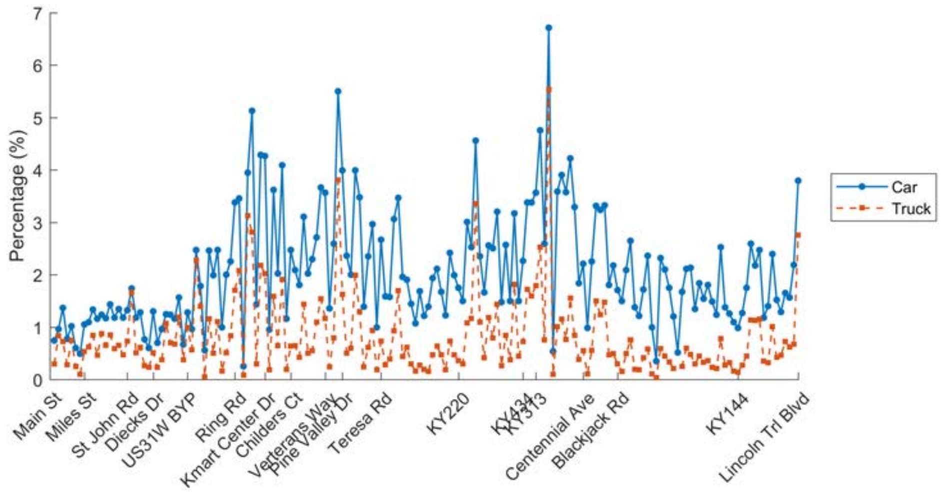

(a) All Year




(b) AM period




(c) Midday period

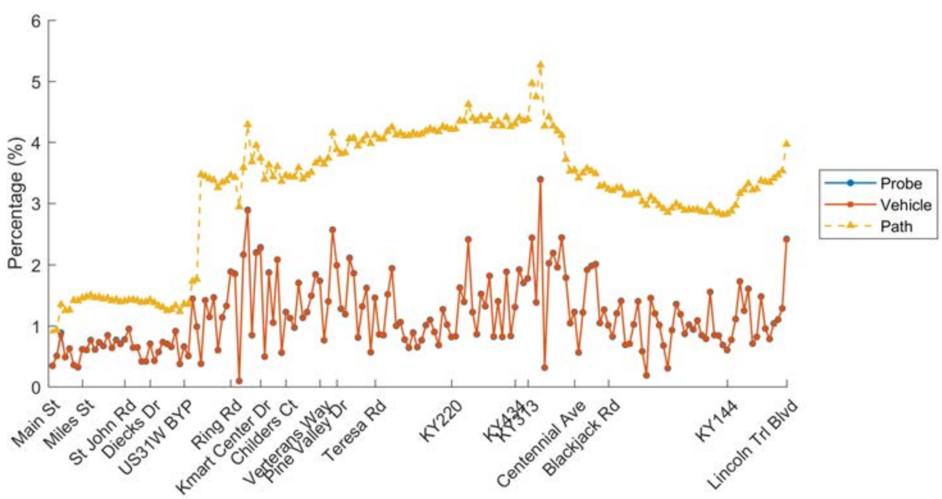



(d) PM period

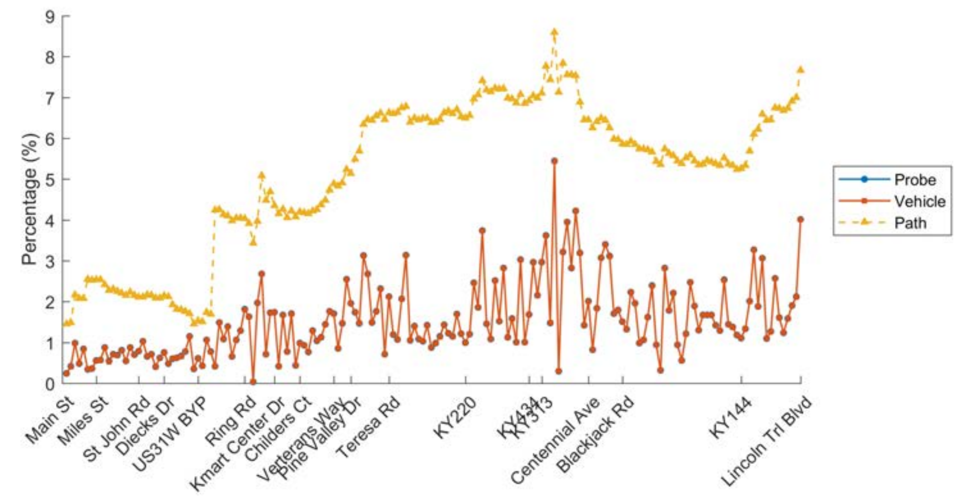
**Figure 3-2 US-31W northbound vehicle data sample coverage between car and truck**

The speed data collected from cars generally offer more coverage along the corridor throughout the day. However, trucks appear to cover more time epochs during AM peak period from Main St to Ring Rd.

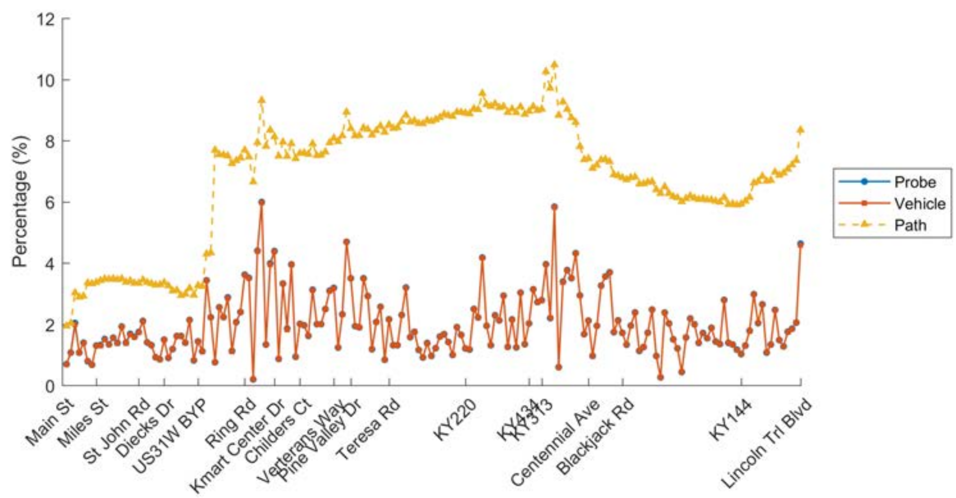
Also Figure 3-3 and Figure 3-4 show that probe- and vehicle-based approaches essentially provide the same coverage, regardless of vehicle type. However, path-based data from either car or truck offer much better spatial and temporal coverage. For many links, the sample percentage of path data are more than twice the amount of probe or vehicle data.



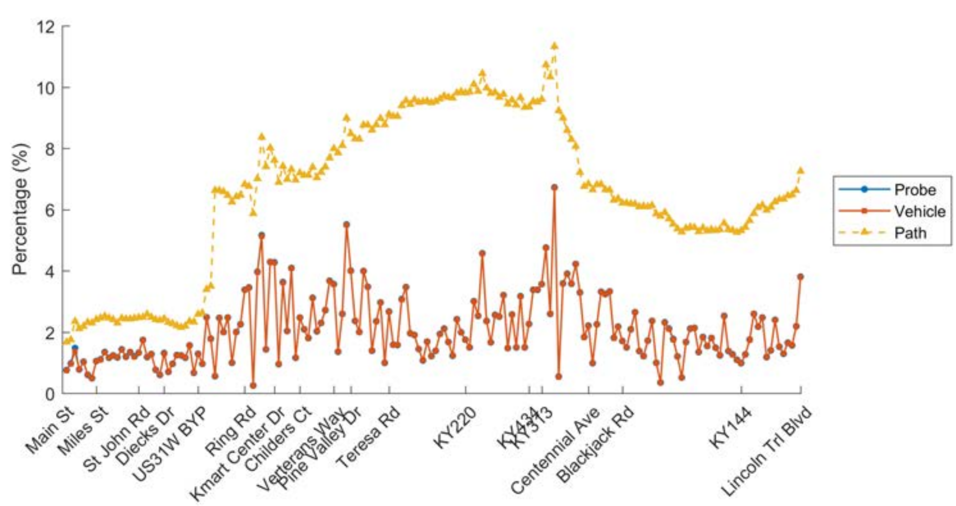

(a) All Year




(b) AM period

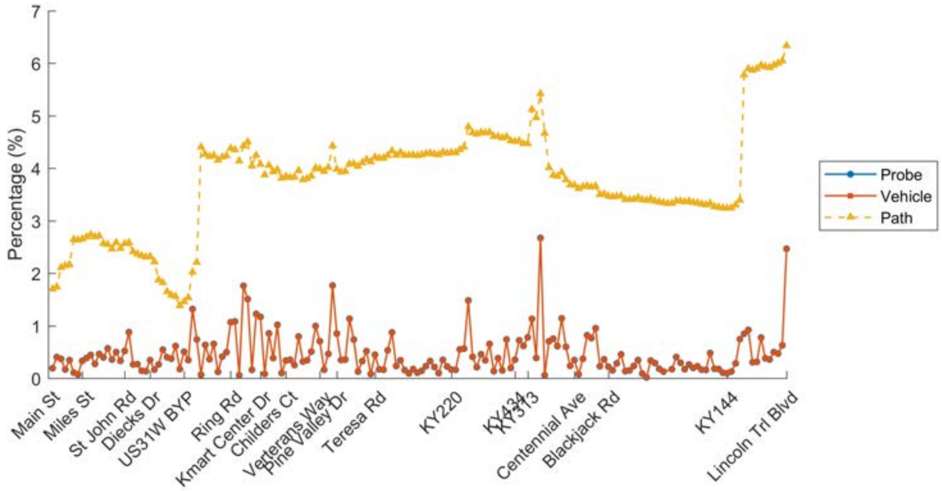



(c) Midday period

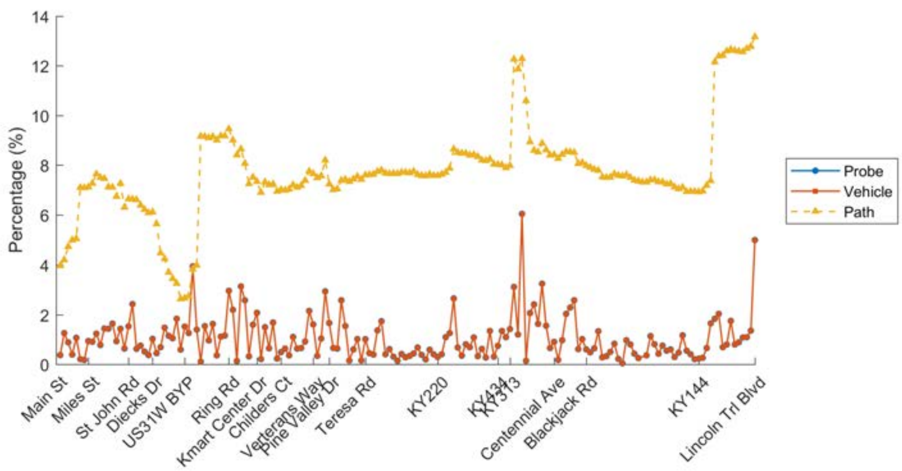



(d) PM period

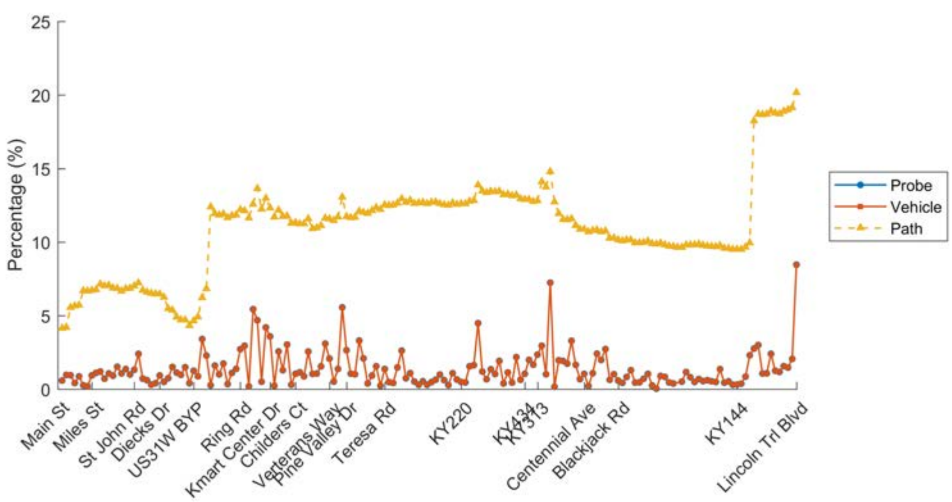
**Figure 3-3 US-31W northbound car sample coverage among probe, vehicle and path**



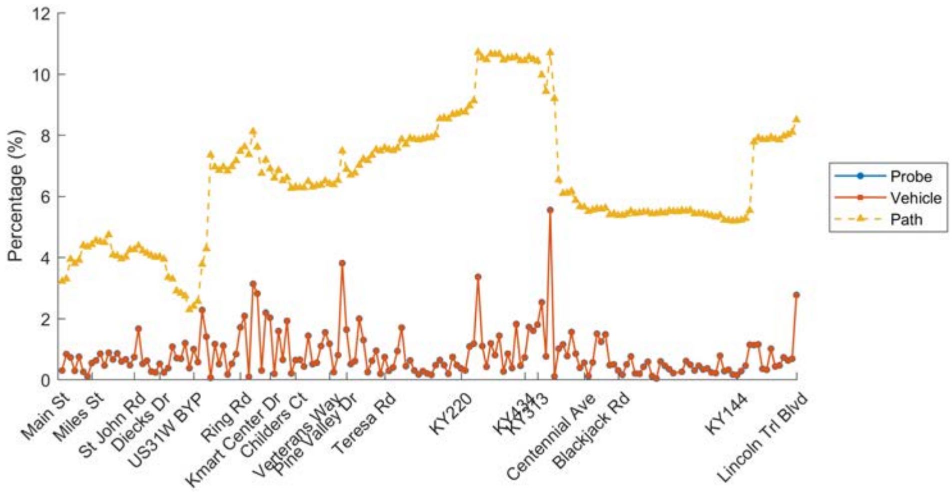

(a) All Year




(b) AM period




(c) Midday period




(d) PM period

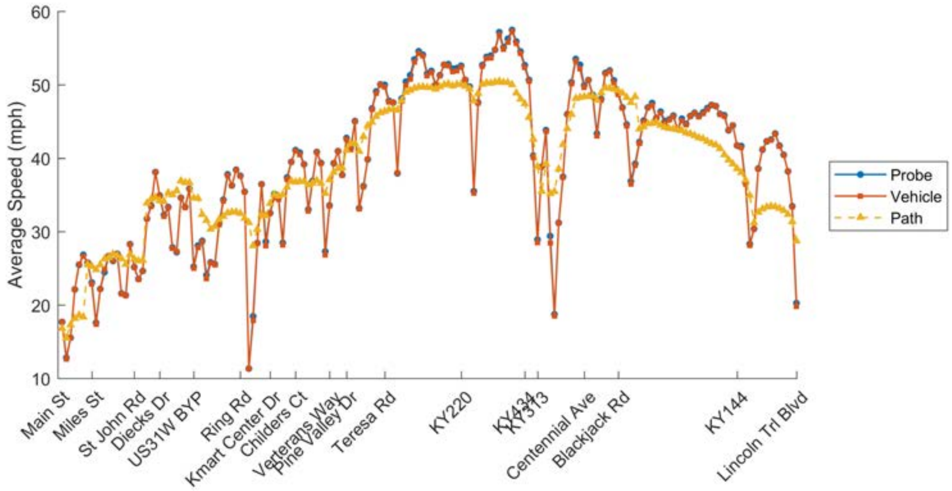
**Figure 3-4 US-31W northbound truck sample coverage among probe, vehicle and path**

### 3.2 Performance Measures

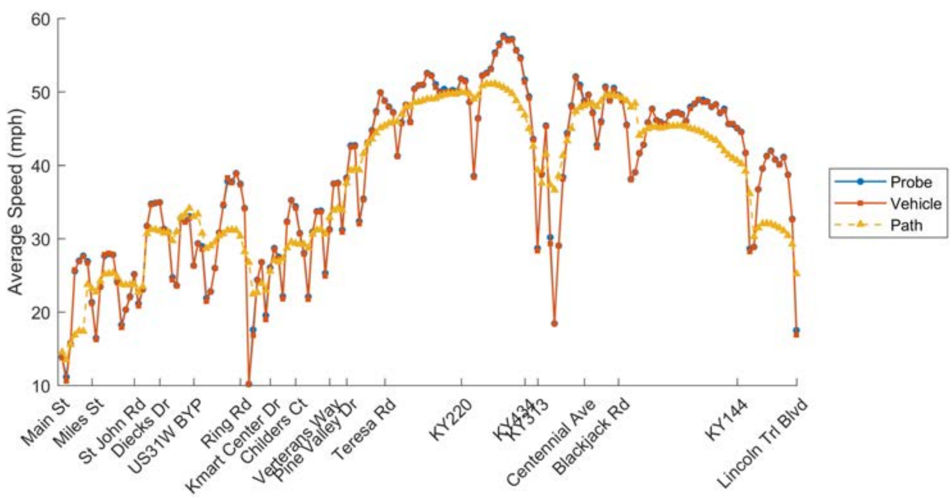
Next, we evaluated performance measures derived from respective data sources. Speeds from all vehicles (i.e., combined car and truck speeds) were used for this analysis. As Figure 3-5 to Figure 3-8 show, probe and vehicle data provided very similar, and many times, essentially the same performance measures in terms of average speed, speed variation, TTI, and PTI for all three time periods under evaluation.

In contrast, path data tended to generate lower average speeds on midblock links bounded by signalized intersections. However, on links near signalized intersections, path data generally produced higher speeds compared to probe and vehicle data. This can be attributed to the processing approach for each data type. At signalized intersections, traffic flow is frequently interrupted by red signals, and low speeds are often observed as vehicles decelerate, stop, or accelerate. Consequently, the average speed could be significantly impacted by low speeds on approaching links. On the other hand, traffic moves at relatively high speeds without interruption on links between intersections; therefore, those links tend to have higher speeds. The path approach accounts for the whole vehicle path, which may contain multiple intersections. The stopping time at intersections and shorter travel time at mid-block links collectively impact the space mean speed. As a result, the obtained speed would be higher than speeds at intersections and lower than those on midblock links. This also explains why there is less speed variability for path speed than for probe- and vehicle-based speeds (Figure 3-6).

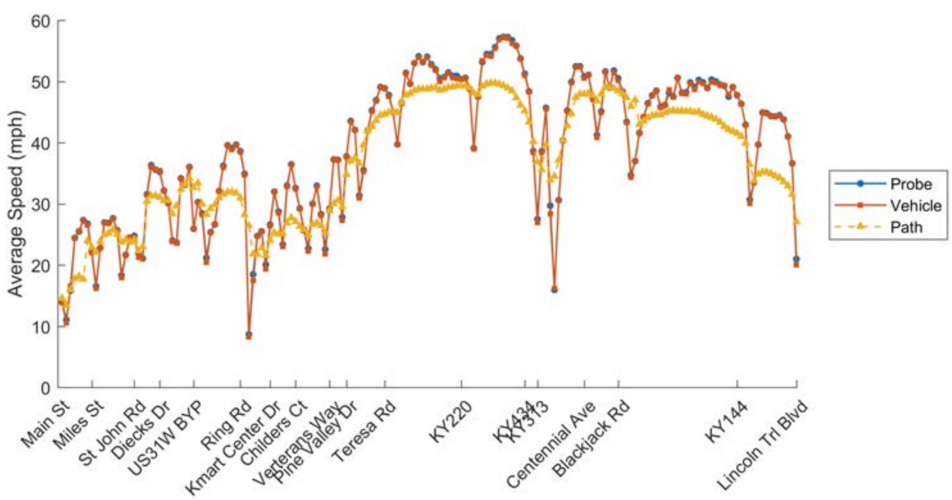
TTI and PTI were calculated using the speed limit as the reference speed and are shown in Figure 3-7 and Figure 3-8. Since TTI is negatively correlated with average speed, path data tend to generate lower TTI values on links near intersections while producing relatively higher TTI values on links between two intersections. This is compared to probe- or vehicle-based data. Since PTI is calculated using the 5$^{th}$ percentile speed, outliers could have a more apparent impact on the index, as evident in Figure 3-8. Probe- and vehicle-based data are more likely to include extremely low speeds than path data, especially at signalized intersections. Therefore, PTI values in those cases were significantly higher compared to those based on path data.




(a) AM period

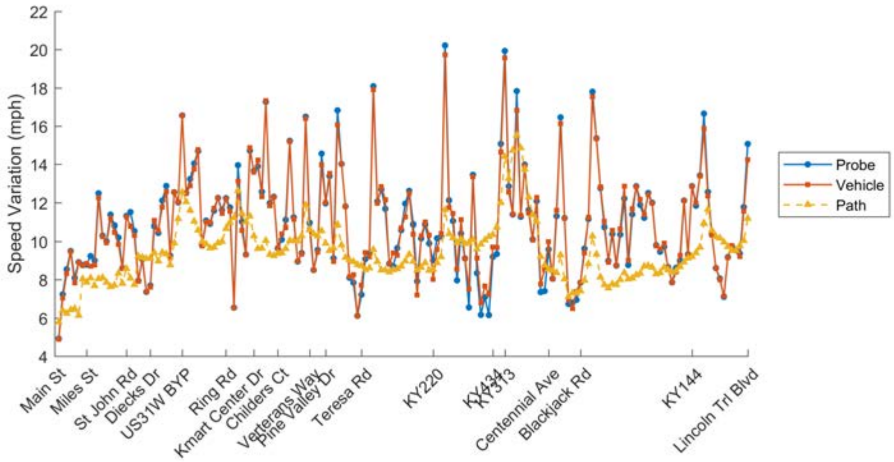



(b) Midday period

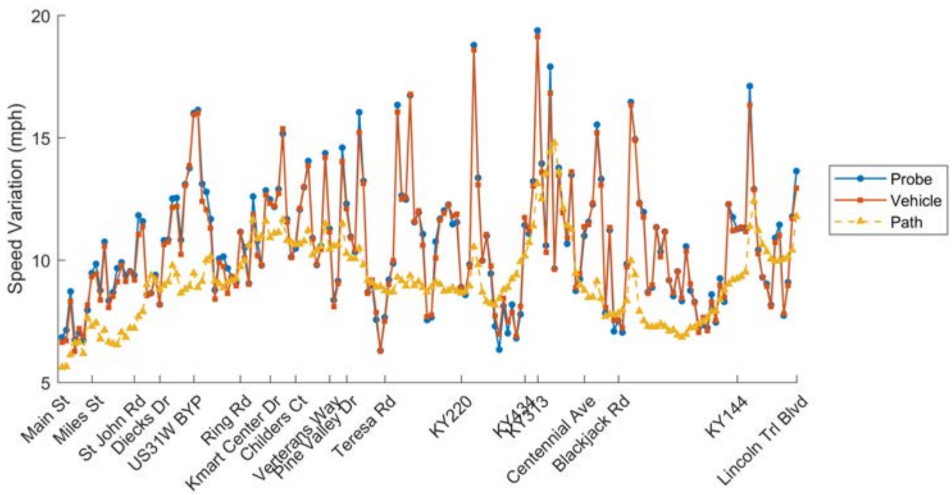



(c) PM period

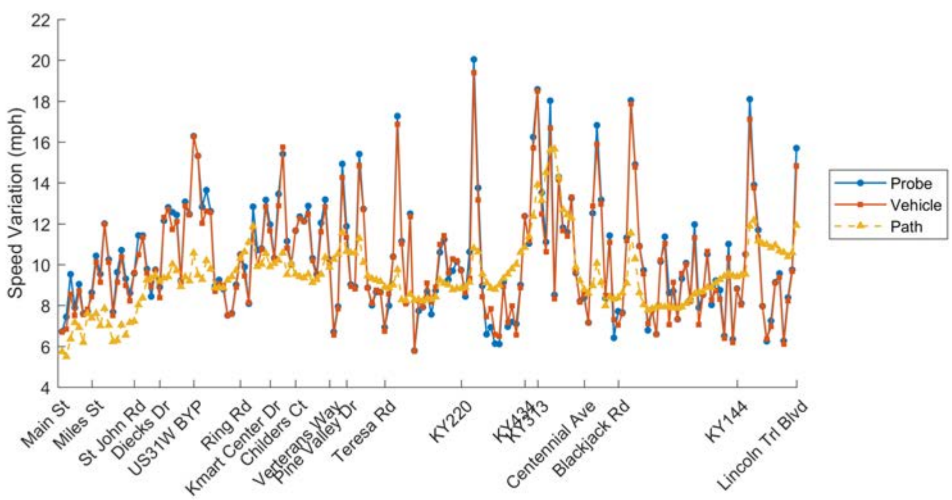
**Figure 3-5 US-31W northbound average speed from probe, vehicle and path**




(a) AM period

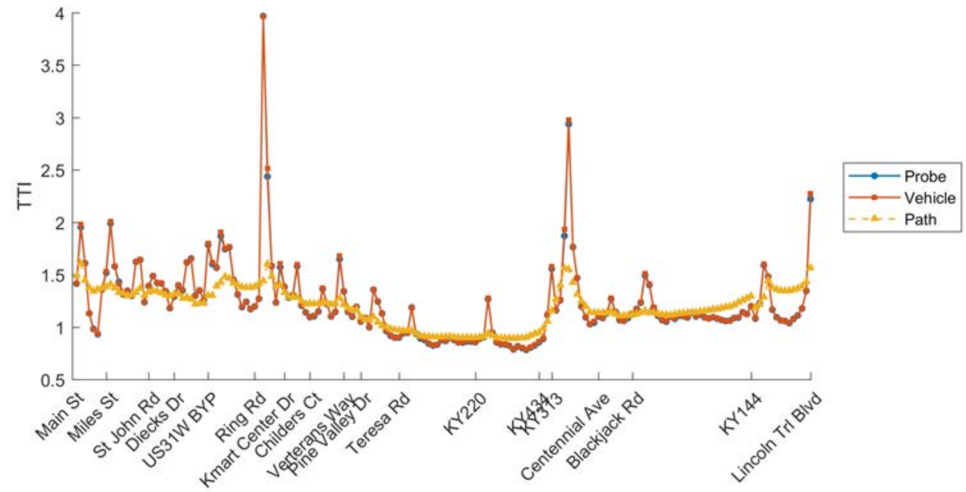



(b) Midday period

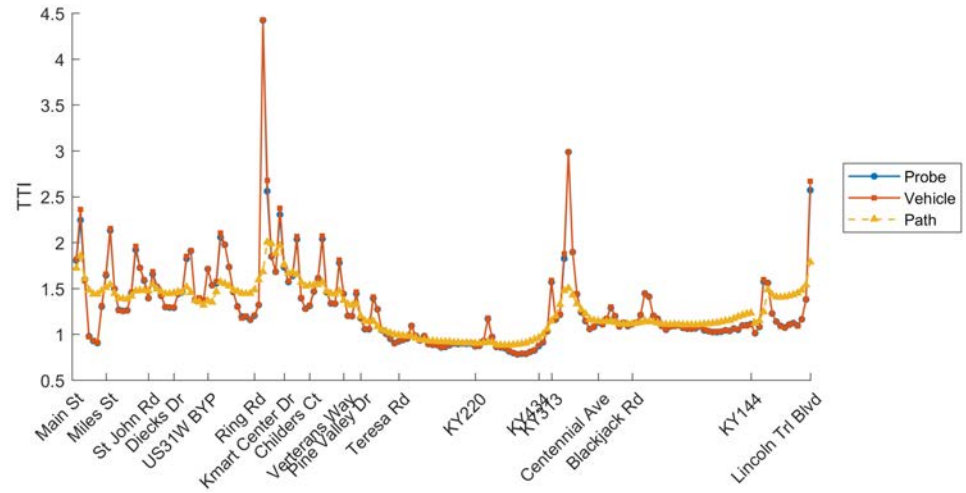



(c) PM period

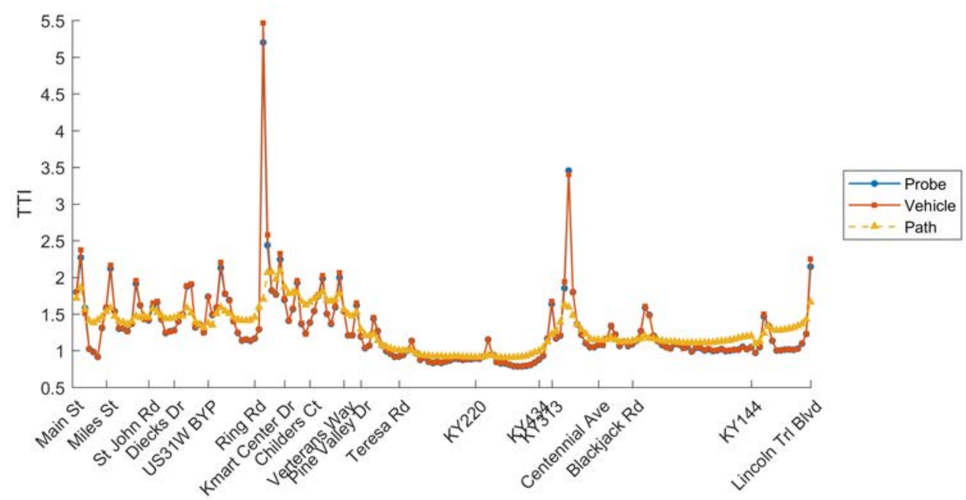
**Figure 3-6 US-31W northbound speed variation from probe, vehicle and path**




(a) AM period

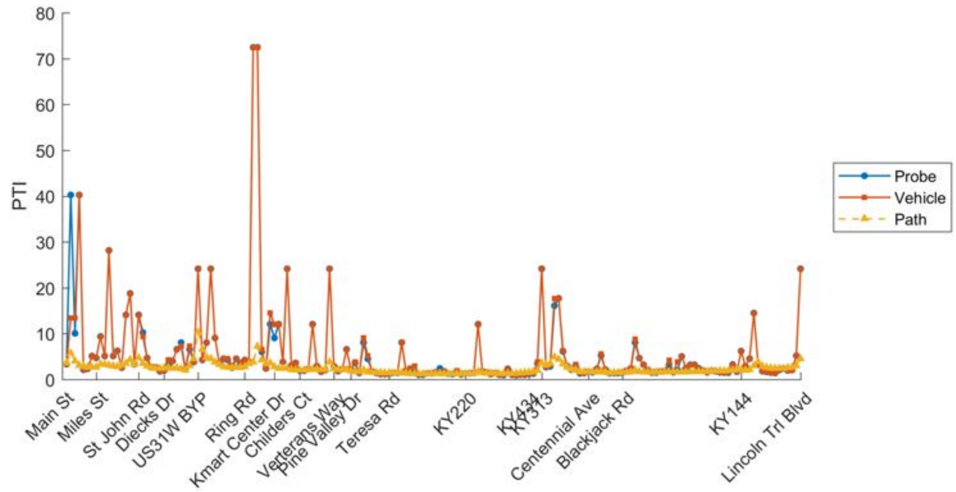



(b) Midday period

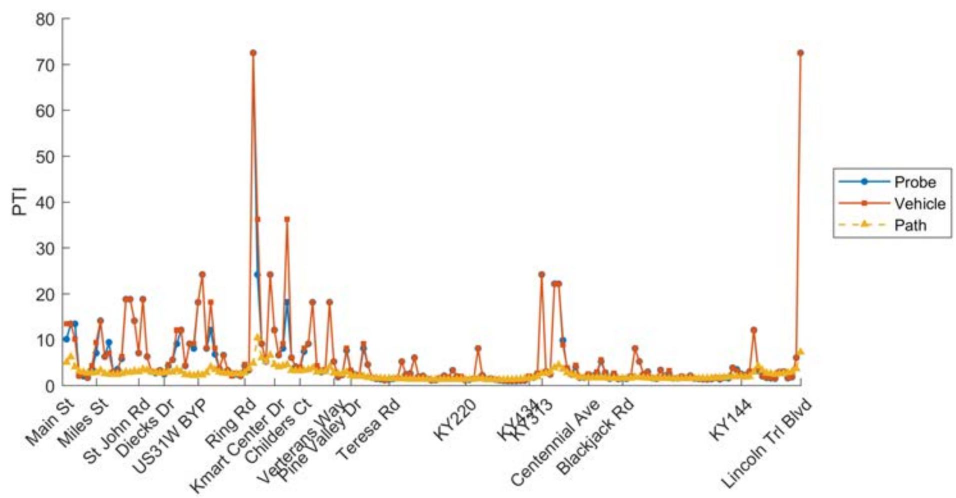



(c) PM period

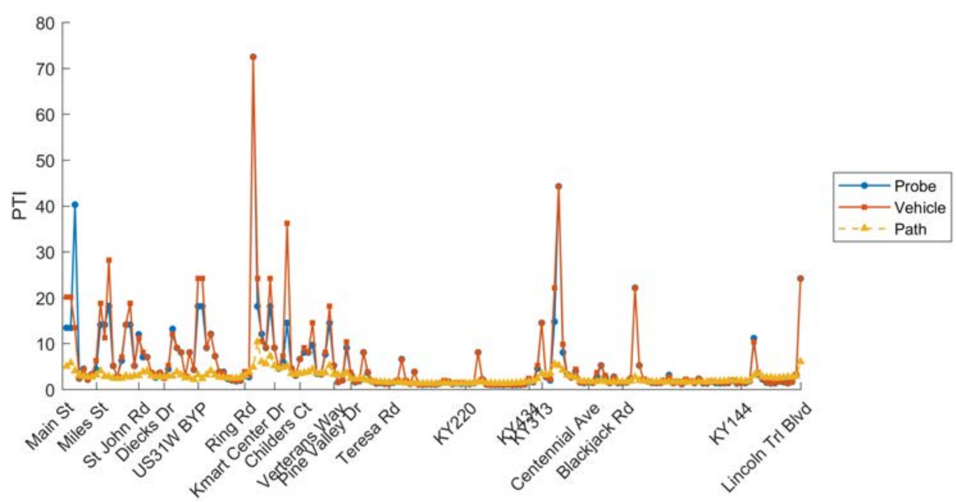
**Figure 3-7 US-31W northbound travel time index from probe, vehicle and path**




(a) AM period




(b) Midday period

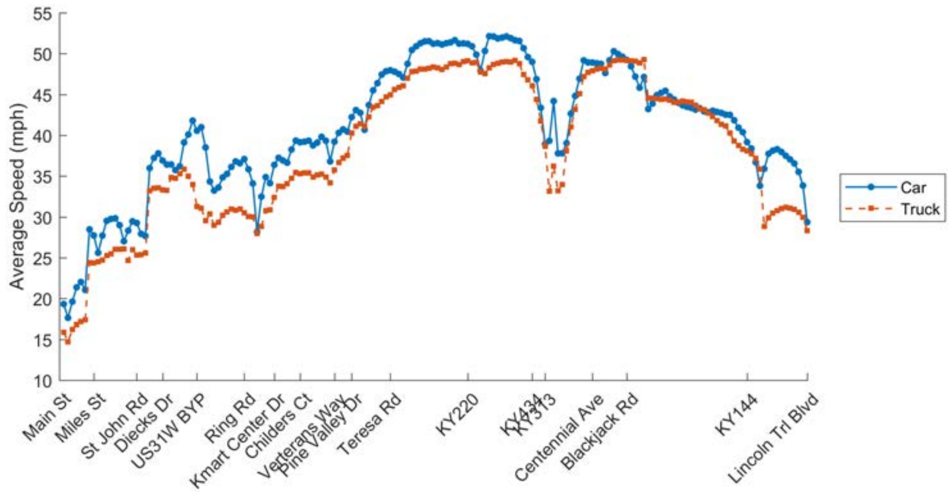



(c) PM period

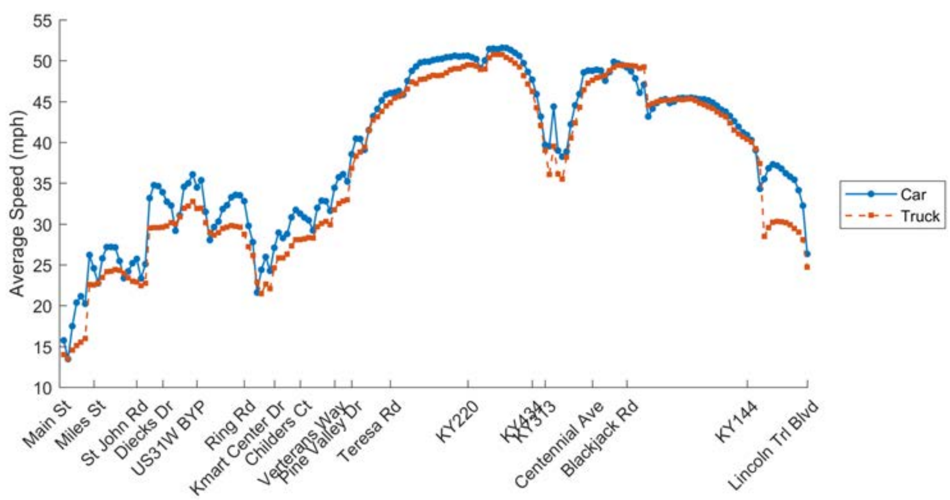
**Figure 3-8 US-31W northbound planning time index from probe, vehicle and path**

Performance measures for cars and trucks were also compared in light of their different operating characteristics. Figure 3-9 through Figure 3-12 show the distribution of average speed, standard deviation of speed, TTI, and PTI on the northbound of US31W, grouped by time of day. As Figure 3-9 illustrates, passenger cars generally traveled at higher speeds along the corridor, which is consistent with our daily experience. For some locations, such as between KY-144 and Lincoln Trail Blvd and between US-31W BYP and Ring Rd, the speed difference between cars and trucks appeared higher than the rest of the corridor. This may result from trucks entering and exiting commercial properties more frequently along those sections.

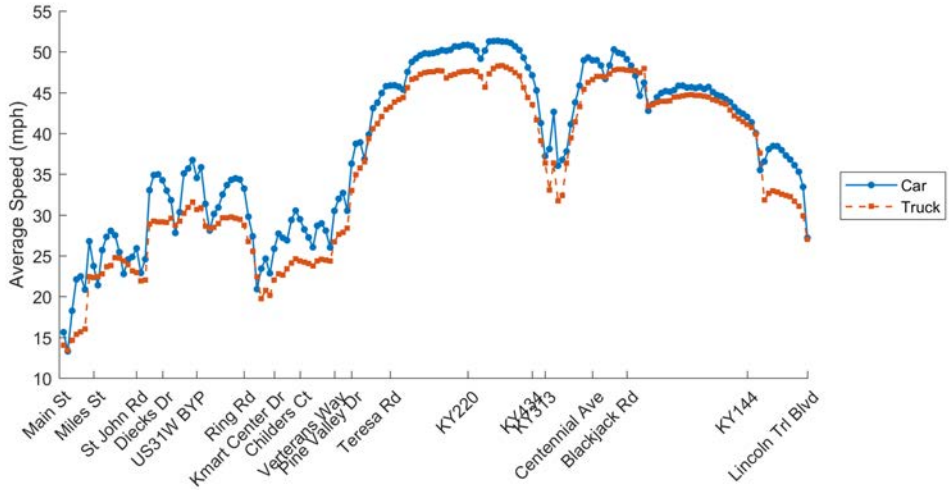
Due to the interrelationship between average speed and TTI, Figure 3-11 confirms that most of the time trucks have higher TTI values than cars.




(a) AM period

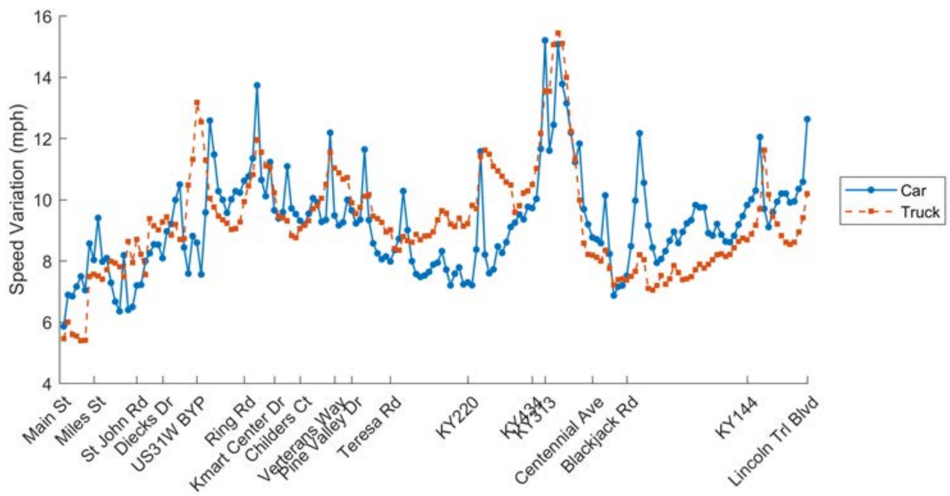



(b) Midday period

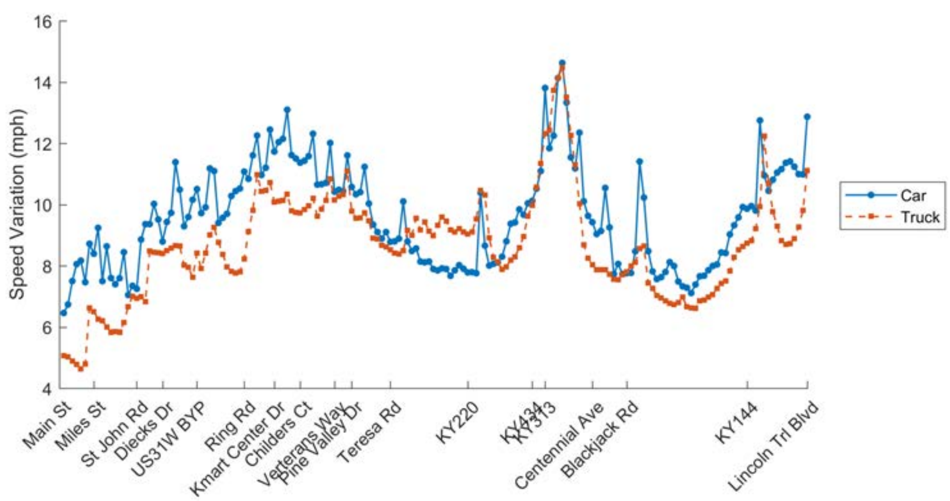



(c) PM period

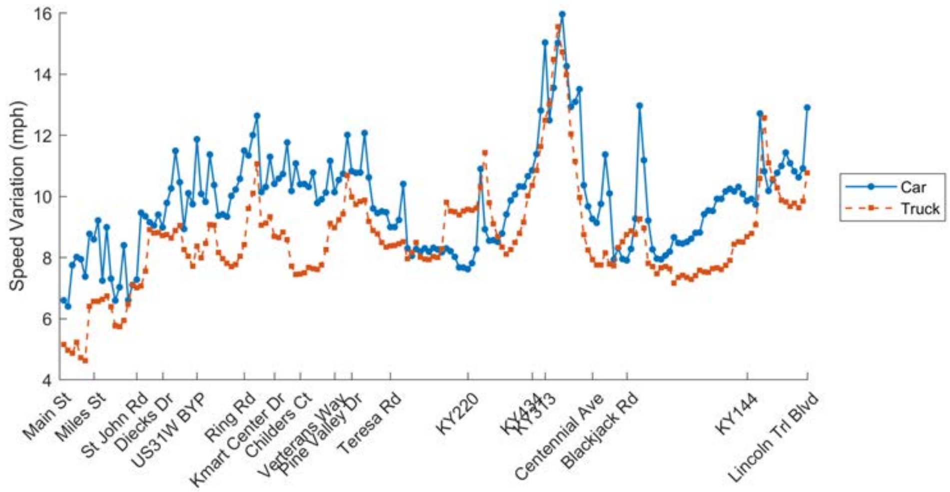
**Figure 3-9 US-31W northbound average speed comparison between car and truck**




(a) AM period

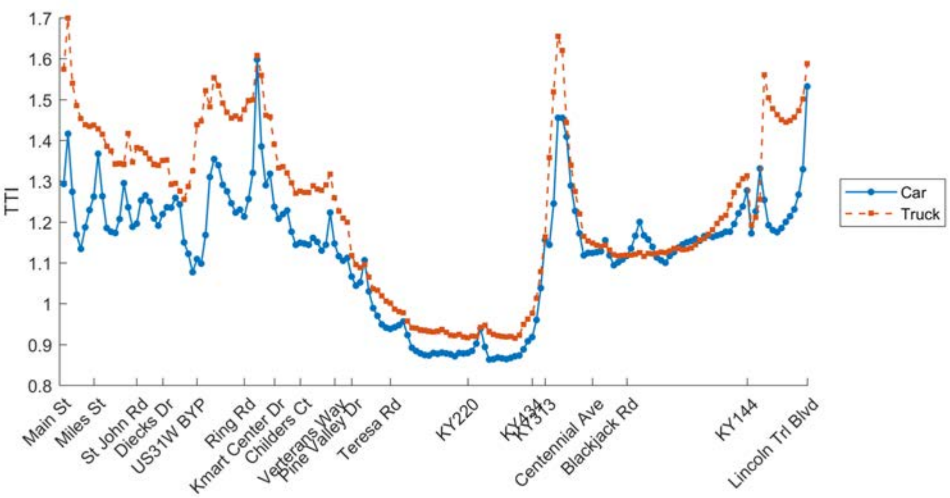



(b) Midday period

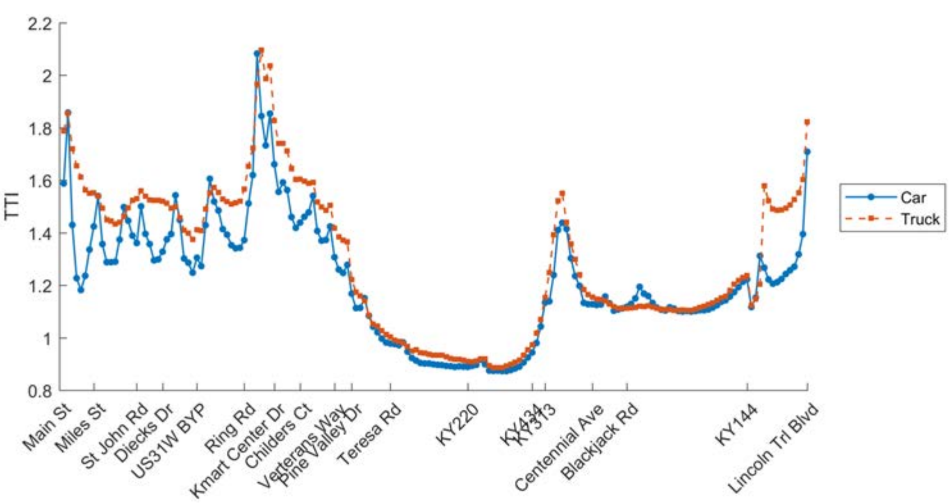



(c) PM period

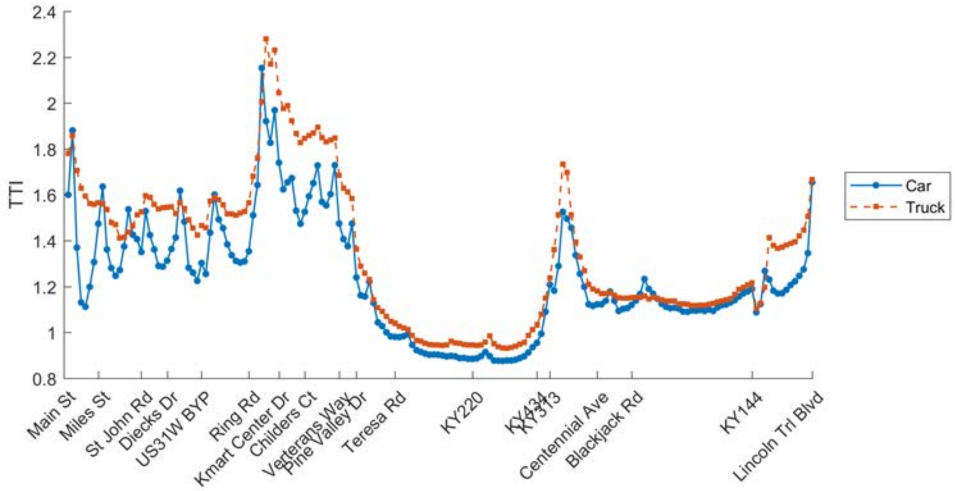
**Figure 3-10 US-31W northbound speed variation comparison between car and truck**




(a) AM period

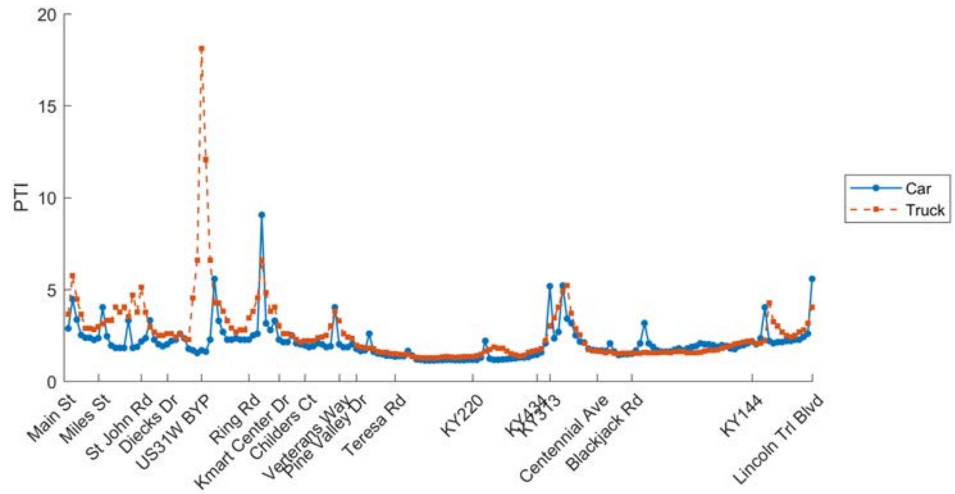



(b) Midday period

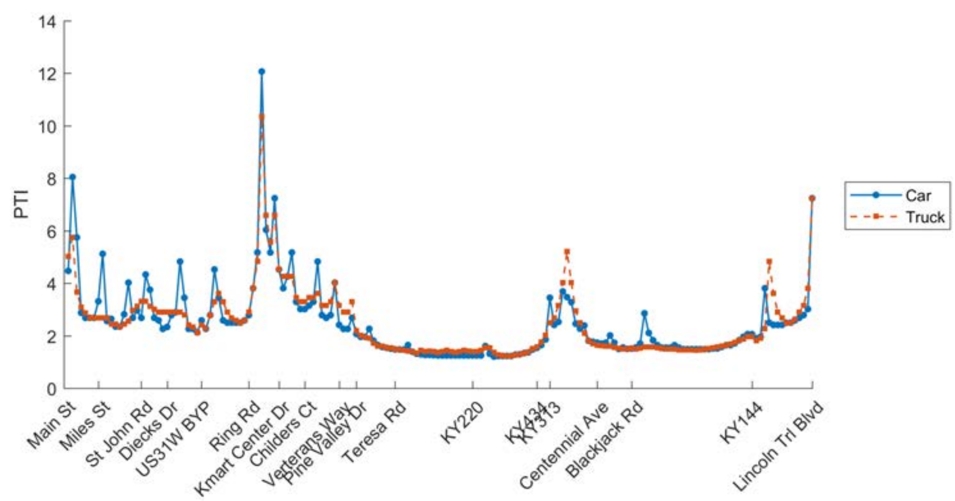



(c) PM period

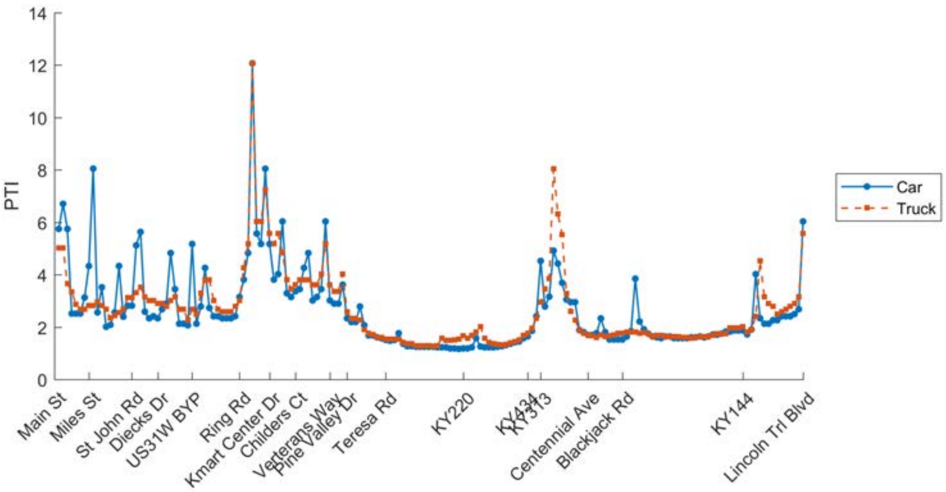
**Figure 3-11 US-31W northbound travel time index comparison between car and truck**




(a) AM period




(b) Midday period




(c) PM period

**Figure 3-12 US-31W northbound planning time index comparison between car and truck**

# CHAPTER 4 Highway System Performance Measures

The Moving Ahead Progress in the 21st Century (MAP-2)1 and Fixing America's Surface Transportation (FAST) Acts require state DOTs and MPOs to establish performance management programs on the National Highway System (NHS). To meet this requirement, state DOTs and MPOs evaluate existing performance, establish targets, and report on progress toward meeting the targets. In April 2016, Federal Highway Administration (FHWA) published a Notice of Proposed Rulemaking (NPRM) that put forward eight measures to assess the performance of NHS system reliability, freight movement, and improvements in congestion, mitigation, and air quality (*3*). As part of this study, these performance measures, except for GHG, were calculated using National Performance Management Research Data Set (NPMRDS) for selected counties based on the interest of KYTC. This chapter defines each measure, describes procedures for calculating them, and summarizes our findings.

## 4.1 NPRM Measures

### *4.1.1 Level of Travel Time Reliability*

The level of travel time reliability (LOTTR) is defined as the ratio of the 80th percentile travel time to the average travel time, represented by the 50th percentile travel time. The measure can be calculated using the following equation:

$$LOTTR = \frac{80th\ percentile\ travel\ time}{50th\ percentile\ travel\ time}$$

Calculations are required for the following periods: AM peak (6:00 to 10:00 am on non-holiday weekdays [i.e., Monday through Friday]), Midday (10:00 am to 4:00 pm on non-holiday weekdays), PM peak (4:00 to 8:00 pm on non-holiday weekdays), and weekends (6:00 am to 8:00 pm on Saturdays and Sundays).

Because NPMRDS lacks speeds for all time epochs, missing travel times on a segment should be imputed with the travel time calculated based on the segment length and speed limit. According to NPRM, a segment is considered reliable if the LOTTR for all time periods is less than the threshold value of 1.5. Accordingly, the percentage of the interstate and non-interstate system supporting reliable travel times can be determined with following equations:

$$PI_{LOTTR} = 100 \times \frac{\sum_{s=1}^{RI} L_s}{\sum_{s=1}^{SI} L_s}$$

$$PN_{LOTTR} = 100 \times \frac{\sum_{s=1}^{RN} L_s}{\sum_{s=1}^{SN} L_s}$$

Where:
$PI_{LOTTR}$ and $PN_{LOTTR}$ denote the percentage of the interstate and non-interstate systems that provide reliable travel times, respectively;
$RI$ and $RN$ denote the total number of Interstate and non-Interstate segments that provide reliable travel times, respectively;
$SI$ and $SN$ denote the total number of Interstate and non-Interstate segments within NHS system, respectively;
$L_s$ denotes length of segment $s$.

### *4.1.2 Peak Hour Travel Time Ratio*

Peak hour travel time ratio (PHTTR) is the ratio of the peak hour travel time to a desired peak period travel time. The equation is:

$$PHTTR = \frac{Peak\ hour\ travel\ time}{Desired\ peak\ period\ travel\ time}$$

To calculate PHTTR, the peak hour travel time is the maximum value of the annual average travel times for six individual hours within the peak periods (6:00 to 9:00 am and 4:00 to 7:00 pm). The desired peak period travel time is specified by state DOTs and represents the acceptable level of performance for a segment. Travel times associated with speeds that are less than 2 mph or greater than 100 mph are treated as outliers and removed from the calculation. The measure is only required for urbanized areas with populations over one million. A threshold value of 1.5 is also used to determine whether the segment meets expectations.

The system-level performance based on PHTTR is calculated with the following equations:

$$PI_{PHTTR} = 100 \times \frac{\sum_{s=1}^{EI} L_s}{\sum_{s=1}^{SI} L_s}$$

$$PN_{PHTTR} = 100 \times \frac{\sum_{s=1}^{EN} L_s}{\sum_{s=1}^{SN} L_s}$$

Where:
$PI_{PHTTR}$ and $PN_{PHTTR}$ denote the percentage of the Interstate and non-Interstate systems that meet pre-specified expectations, respectively;
$EI$ and $EN$ denote total number of Interstate and non-Interstate segments that meet pre-specified expectations, respectively.

*4.1.3 Truck Travel Time Reliability*

LOTTR and PHTTR measure the performance of NHS system reliability. To assess the truck movement condition on interstates, two specific measures — truck travel time reliability (TTTR) and average truck speed (ATS) — are proposed. TTTR is calculated with the following formula:

$$TTTR = \frac{95th\ percentile\ travel\ time}{50th\ percentile\ travel\ time}$$

An entire year of data should be used to derive percentiles, and accordingly, TTTR. It would be ideal to calculate TTTR using travel times collected directly from trucks, however, travel times for some time epochs could be unavailable. To deal with this, a missing truck travel time can be imputed with travel time from all traffic at the same time epoch, provided it is not greater than the time traveling at the speed limit. However, if travel time from all traffic is also unknown, the void is imputed with the time traveling at the speed limit. The segment being evaluated is considered reliable if TTTR is less than the threshold value of 1.5.

Accordingly, the percentage of the interstate providing for reliable truck travel times can be determined as follows:

$$PI_{TTTR} = 100 \times \frac{\sum_{s=1}^{TI} L_s}{\sum_{s=1}^{SI} L_s}$$

Where:
$PI_{TTTR}$ denotes the percentage of the Interstate system providing reliable truck travel times;
$TI$ denotes the total number of Interstate segments providing reliable truck travel times.

*4.1.4 Average Truck Speed*

Average truck speed (ATS) uses same dataset as TTTR and it can be derived from:

$$ATS = 3600 \times \frac{\sum_{i=1}^{N} \frac{L}{t_i}}{N}$$

Where:
$N$ denotes total number of time epochs in a year;
$L$ denotes the length of segment;
$t_i$ denotes travel time at time epoch $i$.

A segment is considered uncongested if its ATS is greater than 50 mph. The aggregate system-level performance (i.e., the percent of uncongested Interstate system mileage) can be computed using the following equation:

$$PI_{ATS} = 100 \times \frac{\sum_{s=1}^{UI} L_s}{\sum_{s=1}^{SI} L_s}$$

Where:
$PI_{ATS}$ denotes the percentage of the Interstate system that is uncongested;
$UI$ denotes total number of Interstate segments that are uncongested.

*4.1.5 Annual Hours of Excessive Delay per Capita*

Annual hours of excessive delay per capita (AHEDPC) is proposed to assess the effectiveness of congestion mitigation efforts in urban areas with populations over one million people. It is calculated as the annual hours of excessive delay (AHED) divided by the population of the area. More specifically, AHED can be calculated as follows:

$$AHED = \sum_{d} \sum_{h} \sum_{i} \frac{AADT}{2} * \frac{HF_{d,h}}{12} * D_{d,h,i}$$

Where:
$d$ denotes $d$th day in a year;
$h$ denotes $h$th hour in that day;
$i$ denotes $i$th 5-min epoch in that hour;
$HF_{d,h}$ denotes hourly volume factor for $h$th hour and $d$th day;
$D_{d,h,i}$ denotes delay for $i$th 5-min epoch, $h$th hour and $d$th day; it can be determined by:

$$D_{d,h,i} = \begin{cases} 300, if\ t_{d,h,i} - t_r > 300 \\ t_{d,h,i} - t_r, if\ 0 \le t_{d,h,i} - t_r \le 300 \\ 0, if\ t_{d,h,i} - t_r < 0 \end{cases}$$

with $t_{d,h,i}$ representing the travel time at the $i$th 5-min epoch, $h$th hour and $d$th day, and $t_r$ representing the threshold travel time. The threshold speed used for calculations is 35 mph on Interstates, freeways, or expressways, and 15 mph for principal arterials and all other NHS roads.

Accordingly, AHEDPC is derived as follows:

$$AHEDPC = \frac{\sum_{s=1}^{S} AHED_s}{pop}$$

Where:
$S$ denotes total number of segments within the urban area of interest;
$AHED_s$ denotes AHED of segment $s$;
$pop$ denotes total population of the urban area of interest.

### 4.2 Final Rule Measures

In January 2017, the FHWA published its final rule on performance management. The final guidance contains performance measures that differ significantly from those outlined in NPRM. The complete rule can be found in the Federal Register (*4*). Table 4-1 compares NPRM and final rules.

One particularly noticeable change in final rule is the removal of PHTTR for both Interstate and non-Interstate NHS systems and ATS measure for truck movement on interstates, and the addition of a multi-modal measure (i.e., percentage of non-single occupancy vehicle travel). Another major change is the application of a vehicle occupancy factor in calculations for system-level reliability and excessive delays. Those changes were made in response to comments about NPRM's overreliance on vehicle travel times and underrepresentation of multi-modal travel.

Other changes include but are not limited to the use of 15-minute epochs instead of 5-minute epochs for all measure calculations, removal of the imputation requirement for LOTTR and TTTR, calculating weighted TTTR instead of a percentage of interstate providing reliable truck travel, and aligning delay calculation with other measures in terms of AM and PM periods.

**Table 4-1 Comparison between NPRM and Final Rule**

| Program Area | NPRM | | Final Rule | | Changes in Final Rule |
|---|---|---|---|---|---|
| | Performance Measures | Segment-Level Metrics | Performance Measures | Segment-Level Metrics | |
| National Highway Performance Program (NHPP) | Percent of the Interstate System providing for Reliable Travel | Level of Travel Time Reliability (LOTTR) | Percent of Person-Miles Traveled on the Interstate That Are Reliable | LOTTR | (1) Uses 15 minute travel time epochs instead of 5 minute epochs (same for all the other performance measures);<br>(2) Changes the maximum length for reporting segments to one mile in urban areas (0.5 miles previously), unless an individual Travel Time Segment is longer;<br>(3) Removes the requirement to "fill" missing data with posted speed limits; |
| | Percent of the non-Interstate NHS providing for Reliable Travel | LOTTR | Percent of Person-Miles Traveled on the Non-Interstate NHS That Are Reliable. | LOTTR | |
| | Percent of the Interstate System where peak hour travel times meet expectations | Peak Hour Travel Time Ratio (PHTTR) | | | |

| Program Area | NPRM | | Final Rule | | Changes in Final Rule |
|---|---|---|---|---|---|
| | Performance Measures | Segment-Level Metrics | Performance Measures | Segment-Level Metrics | |
| | Percent of the non-Interstate NHS where peak hour travel times meet expectations | PHTTR | | | (4) Requires holidays be included when determining LOTTR<br>(5) Changes the weighting of LOTTR from system miles to person-miles traveled using overall occupancy factors from national surveys. |
| Freight movement on the Interstate System (NHFP) | Percent of the Interstate System Mileage providing for Reliable Truck Travel Time | Truck Travel Time Reliability (TTTR) Index | Truck Travel Time Reliability (TTTR) Index | TTTR Index | (1) Removes the requirement to "fill" missing data with posted speed limits;<br>(2) Uses all vehicle travel times, regardless of speed, to replace missing truck travel times;<br>(3) Removes the 1.50 threshold in the definition of "reliable travel";<br>(4) Break into 5 time periods of a day and select the period with maximum TTTR index into performance measure calculation. |
| | Percent of the Interstate System Mileage Uncongested | Average Truck Speed | | | |
| Congestion Mitigation and Air Quality Improvement (CMAQ) Program | Annual Hours of Excessive Delay Per Capita (>1M population starting from 2018) | Total Excessive Delay | Annual Hours of Peak-Hour Excessive Delay Per Capita (>1M population starting from 2018; >200K starting from 2020) | Total Peak-Hour Excessive Delay person-hours | (1) Changes previously proposed threshold from 15/35 mph to 20 mph or 60 percent of the posted speed limit, whichever is greater;<br>(2) Uses average vehicle occupancy (AVO) factors and hourly traffic volumes to calculate person-hours of excessive delay;<br>(3) Peak hours include AM peak (6-10AM) and PM peak (3-7PM or 4-8PM whichever reflects local condition better). |

| Program Area | NPRM | | Final Rule | | Changes in Final Rule |
|---|---|---|---|---|---|
| | Performance Measures | Segment-Level Metrics | Performance Measures | Segment-Level Metrics | |
| | | | Percent of Non-SOV Travel (>1M population starting from 2018; >200K starting from 2020) | n/a | FHWA provides three options for calculating this new multi-modal measure: (1) American Community Survey; (2) Local surveys; (3) Actual volume of each transportation mode |

According to the final rule, the following equations for performance measures should be updated.

The percent of the Interstate system and non-Interstate NHS providing for reliable travel times:

$$PI'_{LOTTR} = 100\times\frac{\sum_{s=1}^{RI} PMT_s}{\sum_{s=1}^{SI} PMT_s}$$
$$PN'_{LOTTR} = 100\times\frac{\sum_{s=1}^{RN} PMT_s}{\sum_{s=1}^{SN} PMT_s}$$

Where:
$PI'_{LOTTR}$ and $PN'_{LOTTR}$ denote the percentage of the Interstate and non-Interstate system that provide reliable travel times with respect to person-miles traveled, respectively;
$PMT_s$ denotes person-miles traveled on segment $s$, and it can be calculated as $PMT_s = \frac{AADT}{2}\times L_s\times o$, where $o$ represents average occupancy factor.

For truck movement, instead of calculating the reliability measure using all speed data in a year, the Final Rule breaks the day into five periods: Overnight (all days 8:00pm-6:00am), AM (weekday 6:00-10:00am), Midday (weekday 10:00am-4:00pm), PM (weekday 4:00-8:00pm), and Weekend (weekend 6:00am-8:00pm). TTTR is calculated for each time period. The period with the maximum TTTR index should be chosen for system-level performance measure calculations. In addition, the threshold is removed in the final rule, and a weighted reliability measure is calculated as such:

$$TTTR_I = 100\times\frac{\sum_{s=1}^{TI} TTTR_{s,max} * L_s}{\sum_{s=1}^{SI} L_s}$$

Where:
$TTTR_I$ denotes system-level truck travel time reliability;
$TTTR_{s,max}$ denotes the maximum TTTR value among five periods for segment $s$.

Compared to AHEDPC, proposed in NPRM, only AM and PM peak hours are considered in the final rule. The occupancy factor is also applied to derive the delay in terms of person-hours. Accordingly, the peak hour excessive delay (PHED) can be determined as:

$$PHED = \text{o} * \sum_d \sum_h \sum_i \frac{AADT}{2} * \frac{HF_{d,h}}{4} * D_{d,h,i}$$

Where:

$$D_{d,h,i} = \begin{cases} 900, if\ t_{d,h,i} - t_r > 900 \\ t_{d,h,i} - t_r, if\ 0 \leq t_{d,h,i} - t_r \leq 900 \\ 0, if\ t_{d,h,i} - t_r < 0 \end{cases}$$

Because speeds in 15-minute epochs are used, the segment delay is now capped at 900 seconds. Also, the threshold for determining $t_r$ is changed to 60% of the posted speed limit or 20 mph, whichever is greater, for all functional classes.

Peak hour excessive delay per capita (PHEDPC) is obtained with following equation:

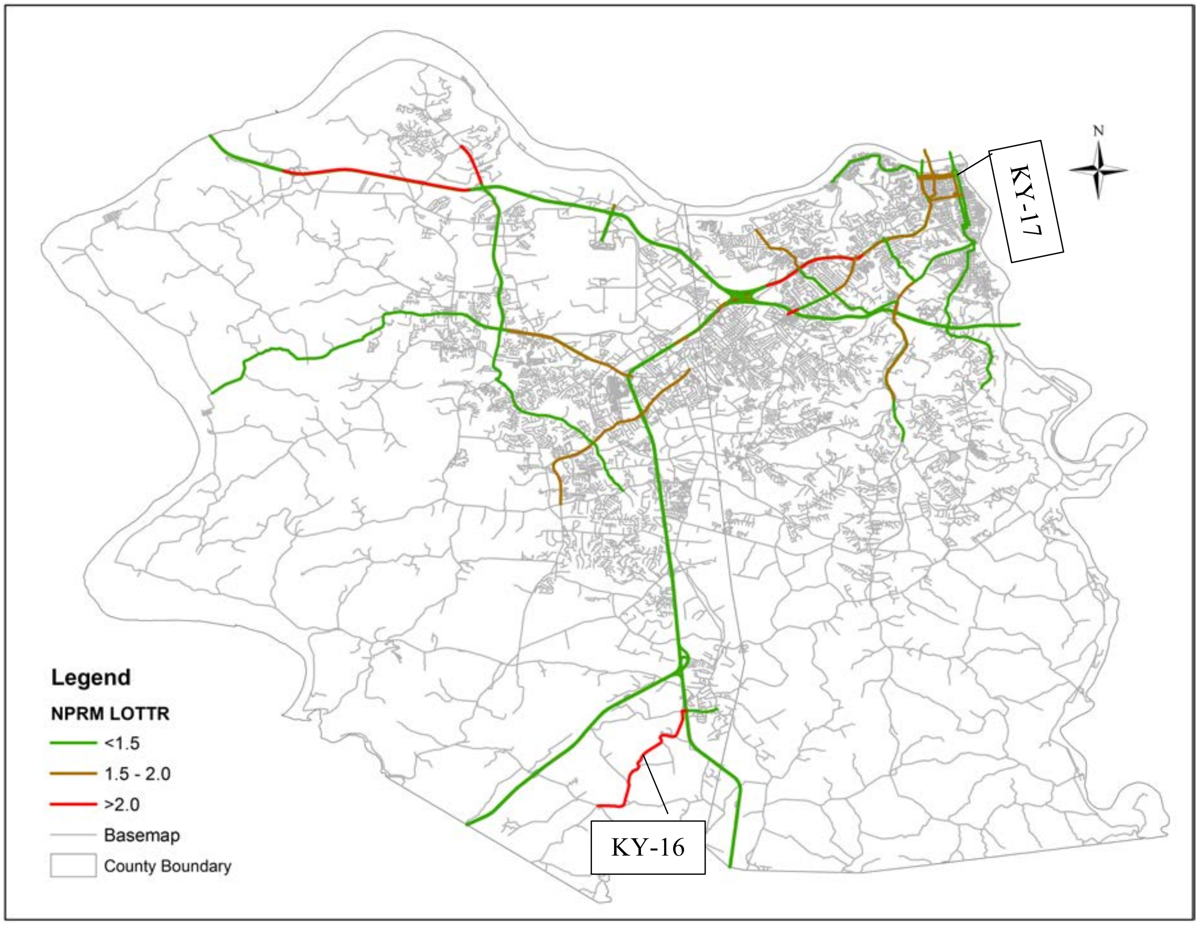
$$PHEDPC = \frac{\sum_{s=1}^{S} PHED_s}{pop}$$

### 4.3 Results and Analysis

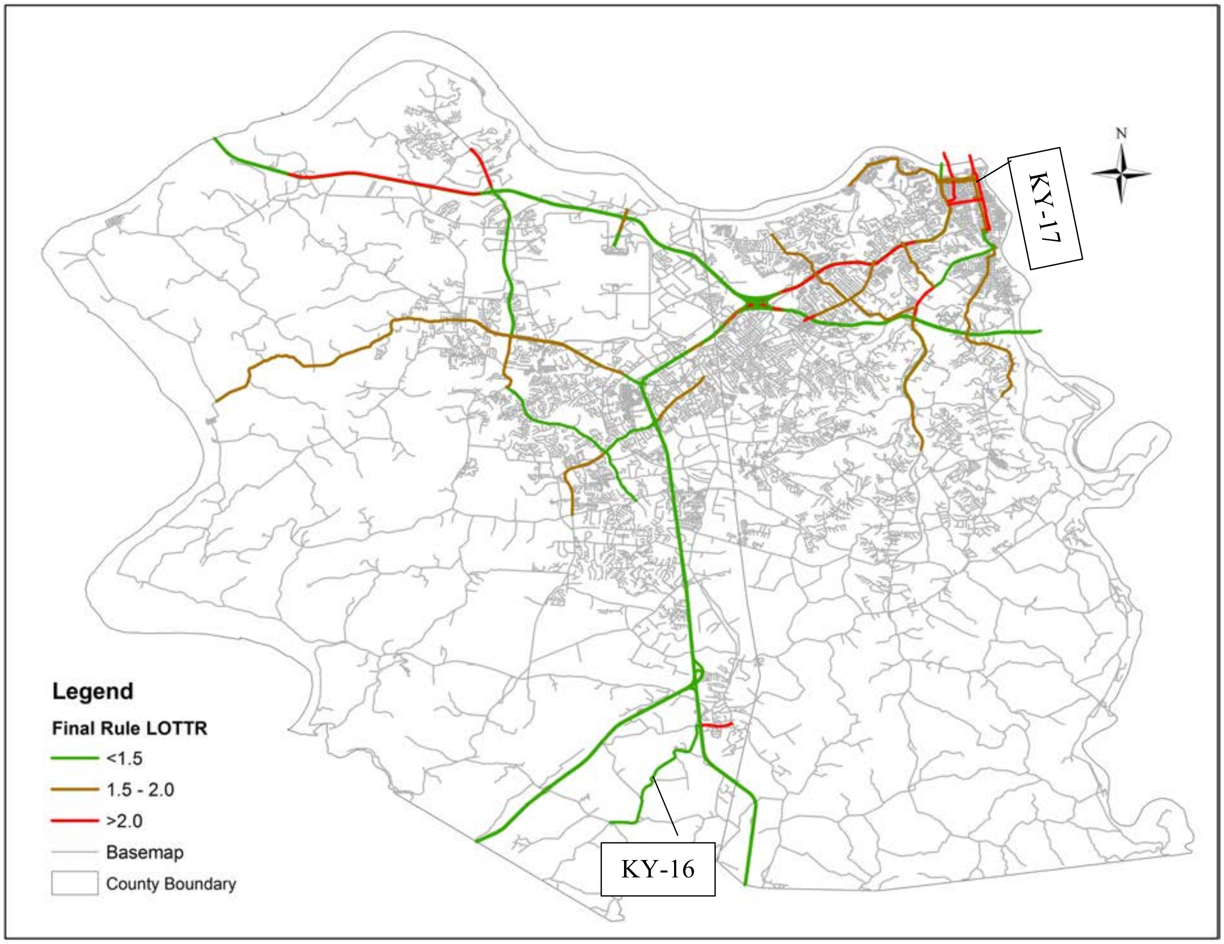
For the purpose of demonstration, we analyzed four counties using NPMRDS data from September 2015. Data preprocessing determined roadway type, speed limit, and AADT for each TMC. In cases with multiple speed limits in a TMC, an average rounded down to the nearest 5 mph was used. The speed limit was later used as the desired speed for to calculate PHTTR and determine the threshold for computing PHED.

Based on procedures in the NPRM, 89.1% of the Interstate system and 75.1% of non-Interstate NHS provide reliable travel times for all traffic. In contrast, the performance measures were 81.8% and 33.5% for respective roadway types, based on the updated procedure in final rule. The difference in performance, especially on the non-Interstate NHS, can be attributed to the removal of the data imputation requirement in the final rule, where a large portion of imputed speeds using the speed limit would skew the results toward greater reliability.

A more detailed comparison at the individual TMC level in Boone and Kenton Counties is shown below. Under the final rule, several more roads exhibited higher LOTTR values based on the one month of data tested.


KY-17
N
KY-16
Legend
NPRM LOTTR
<1.5
1.5 - 2.0
>2.0
Basemap
County Boundary

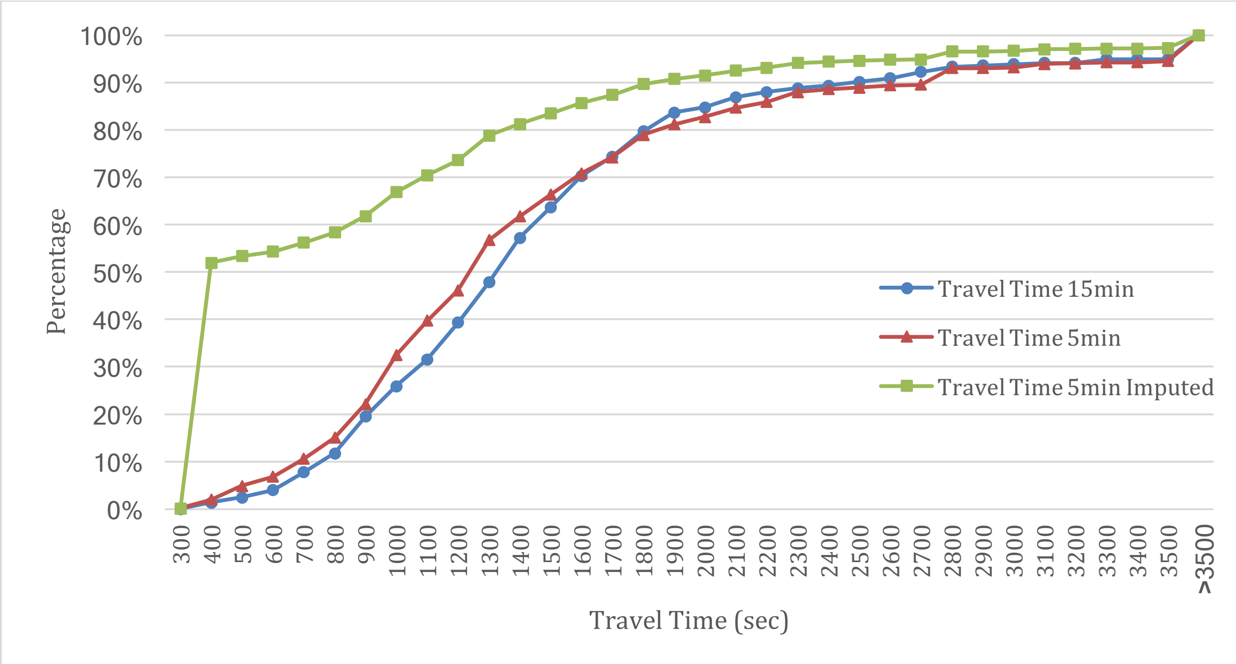
(a) NPRM



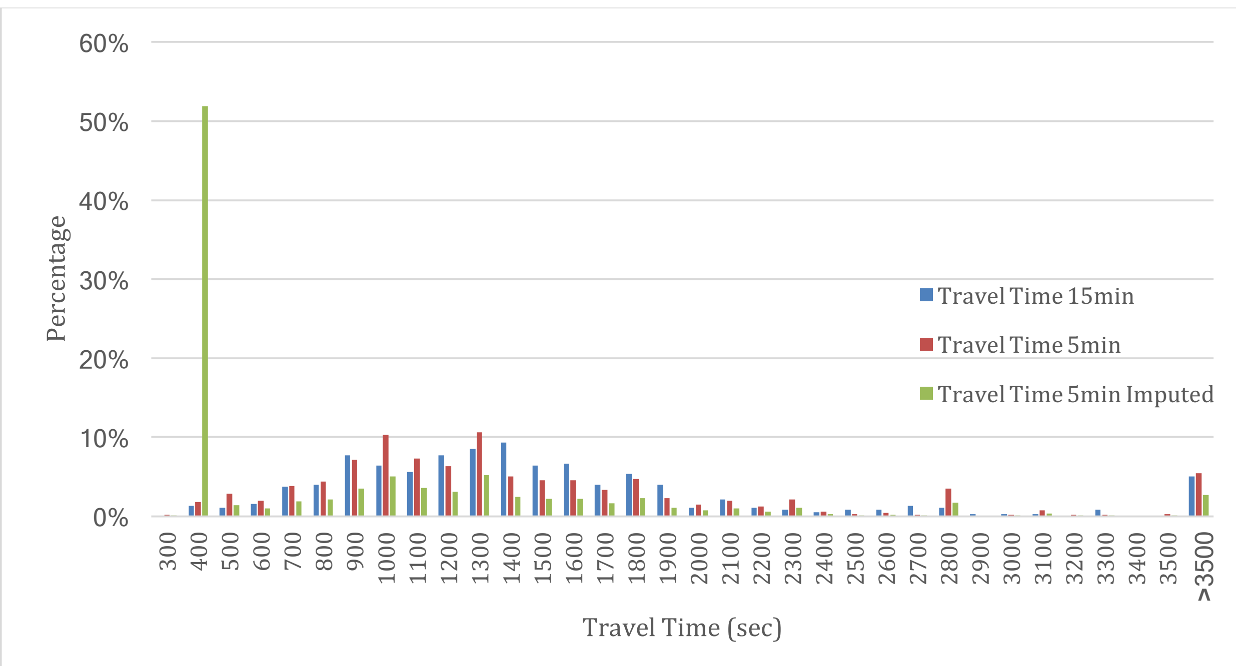

(b) Final Rules

**Figure 4-1 LOTTR index in Boone and Kenton Counties**

Unlike other TMCs, one TMC on KY-16 appears more reliable under the updated final rule. Travel time distributions for each scenario are shown in Figure 4-2. The travel time distribution used to calculate LOTTR based on NPRM is shown with the green line with square markers. About 51% of time epochs were missing observations, which were inserted with travel time (337 seconds) based on speed limit as required by NPRM. As a result, the 50th percentile travel time was 337 seconds, while the 80th percentile travel time was 1,358 seconds, which results in a LOTTR of 4.03. In contrast, the travel time distribution after aggregating data into 15-minute epochs (pursuant to the final rule) is shown by blue line with circles. In this case, the 50th and 80th percentile travel times were 1,318 and 1,805 seconds, respectively. Although both values increased, the relative difference between them narrowed. Therefore, the obtained LOTTR fell significantly compared to the LOTTR derived using NPRM guidance.




(a) Cumulative distribution




(b) Probability distribution

**Figure 4-2 Travel time distribution**

Using speed limit as desired peak hour speed, the percentage of Interstate system and non-Interstate NHS where peak hour travel times met expectations was 66.6% and 6.1%, respectively. This finding indicates traffic could barely attain the speed limit during the worst hour of AM and PM peak periods on non-Interstate NHS roadways. An experiment was conducted to determine the desired speeds necessary to achieve the 80% goal for Interstates and non-Interstate NHS. Results indicated the desired peak hour speed for Interstates was 52 mph or lower, and for non-interstates 17 mph or lower. However, this analysis used September 2015 data only, and ramp TMCs were not part of freeways or non-Interstates. This measure is not required by the final rule.

For freight truck movement performance, 84.8% Interstates could provide reliable travel times for trucks. Using 50 mph as benchmark, 98.2% Interstates would be uncongested. To calculate delay, we acquired the population for Boone and Kenton county from American Community Survey (*5*). According to NPRM, the area would have 0.48 excessive vehicle-hour delay per capita. In contrast, under requirement of the final rule, there would be 0.92 excessive person-hour delay per capita during peak hours. Note that the threshold for delay calculations are different in NPRM and the final rule.

# CHAPTER 5 Conclusion

This study built on KTC's previous efforts to assess the use of private sector speed data for performance measurements. Table 5-1 summarizes the data items evaluated in both studies. As data quality improves over time, more versatile options have become available for 2013 and 2014 data.

**Table 5-1 Summary of travel speed data**

| Dataset | Roadway Coverage | Data | Speed Data Source | Measured or Blended |
|---|---|---|---|---|
| 2010 TMC-based ATP | TMC network (interstates and most arterials) | 15-min speeds by month and by day of the week | Mostly current year probe vehicle speeds; data from other sources | Proprietary algorithm used to estimate speeds when probe data are insufficient |
| 2010 TP | All links | 15-min speeds by month and by day of the week | Three-year probe speeds and data from other sources | Proprietary algorithm used to estimate speeds for all links |
| 2011&2012 Link-Referenced ATP | All links with probe data | 5-min speeds by month and by day of the week | Current year probe speeds | No blending with other data or historical average. Probe sample counts and standard deviation of sample speeds are also reported. |
| 2013&2014 Link-Referenced ATP | All links with probe data | 5-min speeds by each day | Current year probe, vehicle, or path speeds, separated by cars and trucks | No blending with other data or historical average. Standard deviation and confidence of sample speeds are also reported. |

A variety of travel time-based performance measures were generated based on the data. Due to the requirement of traffic volume information by delay measures, KYTC performed network conflation to integrate the vendor's network and the Cabinet's highway inventory network. The results presented in this report were based on a conflated network and provided to KYTC and MPO stakeholders in the form of geodatabases. A web portal was also developed for to facilitate dissemination and access.

With continuously acquired data, performance trends could be established for certain corridors, areas, or the state as a whole. While four-year trend analysis was limited by the changes in data format that took place between 2012 and 2013, it is reasonable to observe that delay and travel time reliability slowly deteriorated in urban areas between 2013 and 2014. With the increase in trackable devices, the probe sample size and coverage steadily improved.

Additional analyses were performed with datasets that recently became available, including HERE vehicle- and path-based data. HERE path data were shown to noticeably increase data coverage on interrupted facilities, especially during the daytime period. It also limited the impact of outliers, particularly at signalized intersections. It is considered a more stable source of corridor performance tracking.

The recent offering of separate datasets for cars and trucks enables the analysis of freight network performance using truck-specific data. In addition, these data may offer additional users an understanding of truck movement on unmonitored rural roads.

As agencies embrace data-driven performance management and decision making, detailed travel speed data are a major source of highway performance tracking they can rely on. Further, the application of such data is not limited to estimating performance measures. It has many other uses, including operational analysis, incident/work zone management, and calibration and validation of simulation and/or demand models. We recommend that KYTC maintain a steady stream of such data because it has demonstrated, and will continue to demonstrate, its value in multiple agency business areas.

## References


[1] Chen, M., X. Zhang, and E. Green. Analysis of Historical Travel Time Data. Kentucky Transportation Center, 2015. p. 66.
[2] HERE. Traffic Analytics V1.1 Specification. 2015.
[3] Federal Highway Administration. *Notice of proposed rulemaking (NPRM)*. https://www.federalregister.gov/documents/2016/04/22/2016-08014/national-performance-management-measures-assessing-performance-of-the-national-highway-system.
[4] Federal Highway Administration. *Final Rule*. https://www.federalregister.gov/documents/2017/01/18/2017-00681/national-performance-management-measures-assessing-performance-of-the-national-highway-system.
[5] American Community Survey. https://www.census.gov/programs-surveys/acs/. Accessed June 20, 2017.

# APPENDIX A 2013-2014 Geodatabases List of Attributes

| Field Name | Description |
|---|---|
| RID | Unique identifier for a given roadway section from KYTC's HIS network |
| FMEAS | Beginning milepoint of a given roadway section from the conflation process. |
| TMEAS | Ending milepoint of a given roadway section from the conflation process. |
| District | Highway district |
| Cnty_Name | County name |
| County | County ID |
| RT_Prefix | Roadway prefix from the HIS network |
| RT_Number | Roadway number from the HIS network |
| RT_Suffix | Roadway suffix from the HIS network |
| RT_Section | Roadway section from the HIS network |
| RT_Descr | Description of the roadway section |
| URBAREA | Urban area code |
| URBTYPE | Type of area |
| URBTEXT | Description of the area |
| FC | New functional classification code |
| Funct | Previous functional classification code |
| NHS | National highway system code from the HIS network |
| TYPEOP | Type of operation; 1 means one-way roadway, 2 means two-way roadway |
| SPDLIMIT | Speed limit |
| AADT | Annual Average Daily Traffic |
| LinkID | Unique identifier for the link from HERE street network |
| Direction | Travel direction of a navigable link from HERE street network, including F as from reference node and T as to reference node. |
| Link_Dir | The combination of LinkID and Direction |
| Length | Length of the link |
| All_85thSp | The 85th percentile speed for all days and time periods in a year |
| All_85thCn | Number of 15-min epochs with probe data in a year |
| All_85thPc | Percentage of 15-min epochs with probe data in a year. It is calculated as 100*TotalIntervals_85thAll/(number of days in that year*24*4). |

| Field Name | Description |
|---|---|
| All_85thSd | Standard deviation of speeds in a year. It is calculated as $\sigma = \sqrt{\frac{\sum_{i=1}^{N}(\bar{x}_i - X)^2}{N-1} + \frac{\sum_{i=1}^{N} s_i^2}{N}}$, where $\bar{x}_i$, $s_i$ is the average speed and standard deviation of epoch $i$, respectively; X is the average speed of the time period of interest which is calculated as $X = \frac{\sum_{i=1}^{N}(\bar{x}_i)}{N}$; N is the total number of epochs with probe data. |
| Wdy_85thSp | The 85th percentile speed based on non-holiday weekday data |
| Wdy_85thCn | Number of 15-min epochs with probe data during non-holiday weekdays. |
| Wdy_85thPc | Percentage of 15-min epochs with probe data during non-holiday weekdays. It is calculated as 100*TotalIntervals_85thWd/(Number of non-holiday weekdays*24*4). |
| Wdy_85thSd | Standard deviation of all 15-min speeds during non-holiday weekdays. It is calculated as $\sigma = \sqrt{\frac{\sum_{i=1}^{N}(\bar{x}_i - X)^2}{N-1} + \frac{\sum_{i=1}^{N} s_i^2}{N}}$, where $\bar{x}_i$, $s_i$ is the average speed and standard deviation of epoch $i$, respectively; X is the average speed of the time period of interest which is calculated as $X = \frac{\sum_{i=1}^{N}(\bar{x}_i)}{N}$; N is the total number of epochs with probe data. |
| Wnd_85thSp | The 85th percentile speed for weekends |
| Wnd_85thCn | Number of 15-min epochs with probe data during weekends. |
| Wnd_85thPc | Percentage of 15-min epochs with probe data during weekends. It is calculated as 100*TotalIntervals_85thWend/(number of weekends*24*4). |
| Wnd_85thSd | Standard deviation of all the speeds during weekends. It is calculated as $\sigma = \sqrt{\frac{\sum_{i=1}^{N}(\bar{x}_i - X)^2}{N-1} + \frac{\sum_{i=1}^{N} s_i^2}{N}}$, where $\bar{x}_i$, $s_i$ is the average speed and standard deviation of epoch $i$, respectively; X is the average speed of the time period of interest which is calculated as $X = \frac{\sum_{i=1}^{N}(\bar{x}_i)}{N}$; N is the total number of epochs with probe data. |
| DyT_60thSp | The $60^{th}$ percentile speed during non-holiday weekday daytime from 6am to 8pm on urban interrupted facilities |
| DyT_85thSp | The $85^{th}$ percentile speed during non-holiday weekday daytime from 6am to 8pm on urban interrupted facilities |
| DyT_85thCn | Number of 15-min epochs with probe data during non-holiday weekday daytime from 6am to 8pm |
| DyT_85thPc | Percentage of 15-min epochs with probe data during non-holiday weekday daytime from 6am to 8pm. It is calculated as 100*TotalIntervals_Wdtime/(number of non-holiday weekdays*14*4). |
| DyT_85thSd | Standard deviation of all the speeds during non-holiday weekday daytime from 6am to 8pm. |
| WDyA_5thSp | 5th percentile speed during non-holiday weekday AM peak from 6am to 9am |
| WDyA_AvgSp | Average speed during non-holiday weekday AM peak from 6am to 9am. It is calculated as $\mu = \frac{\sum_{i=1}^{N}(\bar{x}_i)}{N}$, where $\bar{x}_i$is the average speed of epoch $i$; N is the total number of epochs that have probe data. |

| Field Name | Description |
|---|---|
| WDyA_AvgCn | Number of 15-min epochs with probe data during non-holiday weekday AM peak from 6am to 9am |
| WDyA_AvgPc | Percentage of 15-min epochs that have probe data during non-holiday weekday AM peak from 6am to 9am. It is calculated as 100*TotalIntervals_WdayAM/(number of non-holiday weekdays*3*4). |
| WDyA_AvgSd | Standard deviation of all the speeds during non-holiday weekday AM peak from 6am to 9am. It is calculated as $\sigma = \sqrt{\frac{\sum_{i=1}^{N}(\bar{x}_i - X)^2}{N-1} + \frac{\sum_{i=1}^{N} s_i^2}{N}}$, where $\bar{x}_i$, $s_i$ is the average speed and standard deviation of epoch $i$, respectively; X is the average speed of the time period of interest which is calculated as $X = \frac{\sum_{i=1}^{N}(\bar{x}_i)}{N}$; N is the total number of epochs with probe data. |
| WDyM_5thSp | 5th percentile speed during non-holiday weekday mid-day period from 9am to 3pm |
| WDyM_AvgSp | Average speed during non-holiday weekday mid-day period from 9am to 3pm. It is calculated as $\mu = \frac{\sum_{i=1}^{N}(\bar{x}_i)}{N}$, where $\bar{x}_i$is the average speed of epoch $i$; N is the total number of epochs that have probe data. |
| WDyM_AvgCn | Number of 15-min epochs with probe data during non-holiday weekday mid-day period from 9am to 3pm |
| WDyM_AvgPc | Percentage of 15-min epochs with probe data during non-holiday weekday mid-day period from 9am to 3pm. It is calculated as 100*TotalIntervals_WdayMD/(number of non-holiday weekdays*6*4).. |
| WDyM_AvgSd | Standard deviation of all the speeds during non-holiday weekday mid-day period from 9am to 3pm. It is calculated as $\sigma = \sqrt{\frac{\sum_{i=1}^{N}(\bar{x}_i - X)^2}{N-1} + \frac{\sum_{i=1}^{N} s_i^2}{N}}$, where $\bar{x}_i$, $s_i$ is the average speed and standard deviation of epoch $i$, respectively; X is the average speed of the time period of interest which is calculated as $X = \frac{\sum_{i=1}^{N}(\bar{x}_i)}{N}$; N is the total number of epochs with probe data. |
| WDyP_5thSp | 5th percentile speed during non-holiday weekday PM peak from 3pm to 6pm |
| WDyP_AvgSp | Average speed during non-holiday weekday PM peak from 3pm to 6pm. It is calculated as $\mu = \frac{\sum_{i=1}^{N}(\bar{x}_i)}{N}$, where $\bar{x}_i$is the average speed of epoch $i$; N is the total number of epochs that have probe data. |
| WDyP_AvgCn | Number of 15-min epochs with probe data during non-holiday weekday PM peak from 3pm to 6pm |
| WDyP_AvgPc | Percentage of 15-min epochs with probe data during non-holiday weekday PM peak from 3pm to 6pm. It is calculated as 100*TotalIntervals_WdayPM/(number of non-holiday weekdays*3*4). |
| WDyP_AvgSd | Standard deviation of all the speeds during non-holiday weekday PM peak from 3pm to 6pm. It is calculated as $\sigma = \sqrt{\frac{\sum_{i=1}^{N}(\bar{x}_i - X)^2}{N-1} + \frac{\sum_{i=1}^{N} s_i^2}{N}}$, where $\bar{x}_i$, $s_i$ is the average speed and standard deviation of epoch $i$, respectively; X is the average speed of the time period of interest which is calculated as $X = \frac{\sum_{i=1}^{N}(\bar{x}_i)}{N}$; N is the total number of epochs with probe data. |
| T_SL_A | Travel time index using speed limit as reference speed during AM peak period |

| Field Name | Description |
|---|---|
| T_SL_M | Travel time index using speed limit as reference speed during mid-day period |
| T_SL_P | Travel time index using speed limit as reference speed during PM peak period |
| P_SL_A | Planning time index using speed limit as reference speed during AM peak period |
| P_SL_M | Planning time index using speed limit as reference speed during mid-day period |
| P_SL_P | Planning time index using speed limit as reference speed during PM peak period |
| T_ALL_A | Travel time index using the 85th percentile speed of all day as reference speed during AM peak period |
| T_ALL_M | Travel time index using the 85th percentile speed of all day as reference speed during Mid-day period |
| T_ALL_P | Travel time index using the 85th percentile speed of all day as reference speed during PM peak period |
| P_ALL_A | Planning time index using the 85th percentile speed of all day as reference speed during AM peak period |
| P_ALL_M | Planning time index using the 85th percentile speed of all day as reference speed during mid-day period |
| P_ALL_P | Planning time index using the 85th percentile speed of all day as reference speed during PM peak period |
| T_Wdy85_A | Travel time index using the 85th percentile speed of non-holiday weekdays as reference speed during AM peak period |
| T_Wdy85_M | Travel time index using the 85th percentile speed of non-holiday weekdays as reference speed during mid-day period |
| T_Wdy85_P | Travel time index using the 85th percentile speed of non-holiday weekdays as reference speed during PM peak period |
| P_Wdy85_A | Planning time index using the 85th percentile speed of non-holiday weekdays as reference speed during AM peak period |
| P_Wdy85_M | Planning time index using the 85th percentile speed of non-holiday weekdays as reference speed during mid-day period |
| P_Wdy85_P | Planning time index using the 85th percentile speed of non-holiday weekdays as reference speed during PM peak period |
| T_DyT60_A | Travel time index using the 60th percentile speed of non-holiday weekday daytime as reference speed during AM peak period |
| T_DyT60_M | Travel time index using the 60th percentile speed of non-holiday weekday daytime as reference speed during mid-day period |
| T_DyT60_P | Travel time index using the 60th percentile speed of non-holiday weekday daytime as reference speed during PM peak period |
| P_DyT60_A | Planning time index using the 60th percentile speed of non-holiday weekday daytime as reference speed during AM peak period |
| P_DyT60_M | Planning time index using the 60th percentile speed of non-holiday weekday daytime as reference speed during mid-day period |
| P_DyT60_P | Planning time index using the 60th percentile speed of non-holiday weekday daytime as reference speed during PM peak period |
| T_DyT85_A | Travel time index using the 85th percentile speed of non-holiday weekday daytime as reference speed during AM peak period |
| T_DyT85_M | Travel time index using the 85th percentile speed of non-holiday weekday daytime as reference speed during mid-day period |

| Field Name | Description |
|---|---|
| T_DyT85_P | Travel time index using the 85th percentile speed of non-holiday weekday daytime as reference speed during PM peak period |
| P_DyT85_A | Planning time index using the 85th percentile speed of non-holiday weekday daytime as reference speed during AM peak period |
| P_DyT85_M | Planning time index using the 85th percentile speed of non-holiday weekday daytime as reference speed during mid-day period |
| P_DyT85_P | Planning time index using the 85th percentile speed of non-holiday weekday daytime as reference speed during PM peak period |
| BTI_A | Buffer time index during AM peak period |
| BTI_M | Buffer time index during midday period |
| BTI_P | Buffer time index during PM peak period |
| WdyD_SL | Total vehicle-hours of travel delay during weekdays using speed limit as reference speed |
| WdyD_All | Total vehicle-hours of travel delay during weekdays using the 85th percentile speed of all days (PcntSpeed_85thAll) as reference speed |
| WdyD_Wdy85 | Total vehicle-hours of travel delay during weekdays using the 85th percentile speed of non-holiday weekdays (PcntSpeed_85thWd) as reference speed |
| WdyD_DyT85 | Total vehicle-hours of travel delay during weekdays: using the 85th percentile speed of non-holiday weekday daytime (PcntSpeed_85thWdtime ) as reference speed for daytime period (6am-8pm); using the 85th percentile speed of non-holiday weekdays (PcntSpeed_85thWd) as reference speed for night-time period (8pm-6am) |
| WdyD_Dyt60 | Total vehicle-hours of travel delay during weekdays: using the 60th percentile speed of non-holiday weekday daytime (PcntSpeed_60thWdtime ) as reference speed for daytime period (6am-8pm); using the 85th percentile speed of non-holiday weekdays (PcntSpeed_85thWd) as reference speed for night-time period (8pm-6am) |
| WndD_SL | Total vehicle-hours of travel delay during weekends using speed limit as reference speed |
| WndD_All | Total vehicle-hours of travel delay during weekends using the 85th percentile speed of all days (PcntSpeed_85thAll) as reference speed |
| WndD_Wnd85 | Total vehicle-hours of travel delay during weekends using the 85th percentile speed of weekend (PcntSpeed_85thWend) as reference speed |
| YearD_SL | Total vehicle-hours of travel delay for a whole year using speed limit as reference speed, it can be calculated as YearDelay_SL =WdayDelay_SL + WendDelay_SL |
| YearD_All | Total vehicle-hours of travel delay for a whole year using the 85th percentile speed of all days as reference speed, it can be calculated as YearDelay_ All85 =WdayDelay_ All85 + WendDelay_ All85 |
| WdyM | Total vehicle miles traveled during weekdays |
| WdyM_SL | Vehicle miles traveled with speed below speed limit during weekdays |

| Field Name | Description |
|---|---|
| WdyM_All | Vehicle miles traveled with speed below 85th percentile speed of all days (PcntSpeed_85thAll) during weekdays |
| WdyM_Wdy85 | Vehicle miles traveled with speed below 85th percentile speed of non-holiday weekdays (PcntSpeed_85thWd) during weekdays |
| WdyM_DyT85 | Vehicle miles traveled with speed below the reference speed during weekdays: using the 85th percentile speed of non-holiday weekday daytime (PcntSpeed_85thWdtime ) as reference speed for daytime period (6am-8pm); using the 85th percentile speed of non-holiday weekdays (PcntSpeed_85thWd) as reference speed for night-time period (8pm-6am) |
| WdyM_Dyt60 | Vehicle miles traveled with speed below the reference speed during weekdays: using the 60th percentile speed of non-holiday weekday daytime (PcntSpeed_60thWdtime ) as reference speed for daytime period (6am-8pm); using the 85th percentile speed of non-holiday weekdays (PcntSpeed_85thWd) as reference speed for night-time period (8pm-6am) |
| WdyH | Total vehicle hours traveled during weekdays |
| WdyH_SL | Vehicle hours traveled with speed below speed limit during weekdays |
| WdyH_All | Vehicle hours traveled with speed below 85th percentile speed of all days (PcntSpeed_85thAll) during weekdays |
| WdyH_Wdy85 | Vehicle hours traveled with speed below 85th percentile speed of non-holiday weekdays (PcntSpeed_85thWd) during weekdays |
| WdyH_DyT85 | Vehicle hours traveled with speed below the reference speed during weekdays: using the 85th percentile speed of non-holiday weekday daytime (PcntSpeed_85thWdtime ) as reference speed for daytime period (6am-8pm); using the 85th percentile speed of non-holiday weekdays (PcntSpeed_85thWd) as reference speed for night-time period (8pm-6am) |
| WdyH_Dyt60 | Vehicle hours traveled with speed below the reference speed during weekdays: using the 60th percentile speed of non-holiday weekday daytime (PcntSpeed_60thWdtime ) as reference speed for daytime period (6am-8pm); using the 85th percentile speed of non-holiday weekdays (PcntSpeed_85thWd) as reference speed for night-time period (8pm-6am) |
| WndM | Total vehicle miles traveled during weekends |
| WndM_SL | Vehicle miles traveled with speed below speed limit during weekends |
| WndM_All | Vehicle miles traveled with speed below 85th percentile speed of all day (PcntSpeed_85thAll) during weekends |
| WndM_Wnd85 | Vehicle miles traveled with speed below 85th percentile speed of weekend (PcntSpeed_85thWend) during weekends |
| WndH | Total vehicle hours traveled during weekends |
| WndH_SL | Vehicle hours traveled with speed below speed limit during weekends |
| WndH_All | Vehicle hours traveled with speed below 85th percentile speed of all days (PcntSpeed_85thAll) during weekends |
| WndH_Wnd85 | Vehicle hours traveled with speed below 85th percentile speed of weekend (PcntSpeed_85thWend) during weekends |
| YearM | Total vehicle miles traveled in a year: Wday_VMT + Wend_VMT |
| YearM_SL | Vehicle miles traveled with speed below speed limit in a year: Wday_VMT_SL + Wend_VMT_SL |
| YearM_All | Vehicle miles traveled with speed below 85th percentile speed of all days in a year: Wday_VMT_All85 + Wend_VMT_All85 |

| Field Name | Description |
|---|---|
| YearH | Total vehicle hours traveled in a year: Wday_VHT + Wend_VHT |
| YearH_SL | Vehicle hours traveled with speed below speed limit in a year: Wday_VHT_SL + Wend_VHT_SL |
| YearH_All | Vehicle hours traveled with speed below 85$^{th}$ percentile speed of all days in a year: Wday_VHT_All85 + Wend_VHT_All85 |
| Flag_Cn | Flag of the sample size of all year. “Y” if the percent of epochs with speed data is less than 1% out of total 8064 epochs in a year; “N” otherwise |
| Flag_All85 | Reference speed flag for the 85$^{th}$ percentile speed: “Y” = percent epoch in a year is less than 1% or obtained 85$^{th}$ percentile speed from probe data is less than half of the speed limit; “N” = otherwise. |
| Flag_Wdy85 | Reference speed flag for the 85$^{th}$ percentile speed of weekdays: “Y” = the percent epoch in weekdays is less than 1% or obtained 85$^{th}$ percentile speed from probe data is less than half of the speed limit; “N” = otherwise. |
| Flag_Wnd85 | Reference speed flag for the 85$^{th}$ percentile speed of weekends: “Y” = the percent epoch in weekends is less than 1% or obtained 85$^{th}$ percentile speed from probe data is less than half of the speed limit; “N” = otherwise. |
| Flag_DyT | Reference speed flag for the 60$^{th}$ and 85$^{th}$ percentile speed of weekday daytime period: “Y” = the percent epoch in weekday daytime period is less than 1% or obtained 85$^{th}$ percentile speed from probe data is less than half of the speed limit; “N” = otherwise. |
| Flag_AM | Flag for AM peak measures. For roadways with functional class less than 14: “Y” = the percent epoch in AM peak is less than 1% or 5th percentile speed<10mph; “N” = otherwise. For roadways with functional class equal to or larger than 14: “Y” = the percent epoch in AM peak is less than 1% or 5$^{th}$ percentile speed<5mph; “N” = otherwise. |
| Flag_MD | Flag for Midday period measures. For roadways with functional class less than 14: “Y” = the percent epoch in PM peak is less than 1% or 5th percentile speed<10mph; “N” = otherwise. For roadways with functional class equal to or larger than 14: “Y” = the percent epoch in PM peak is less than 1% or 5$^{th}$ percentile speed<5mph; “N” = otherwise. |
| Flag_PM | Flag for PM peak measures. For roadways with functional class less than 14: “Y” = the percent epoch in PM peak is less than 1% or 5th percentile speed<10mph; “N” = otherwise. For roadways with functional class equal to or larger than 14: “Y” = the percent epoch in PM peak is less than 1% or 5$^{th}$ percentile speed<5mph; “N” = otherwise. |

# APPENDIX B Travel Time-Based Performance Measures Web Portal User's Guide

This user's guide provides an introduction to the web portal for the display of selected travel time based performance measures. The portal can be found at: https://goo.gl/PRdmvQ

The page may take some time to load due to large amount of data being transmitted.

**Data Items**

The performance measures were estimated using HERE link-reference speed data from 2011-2014. For 2011-2012, the source data were provided for each day of the week in each month, while 2013-2014 data were available for each day of a month.

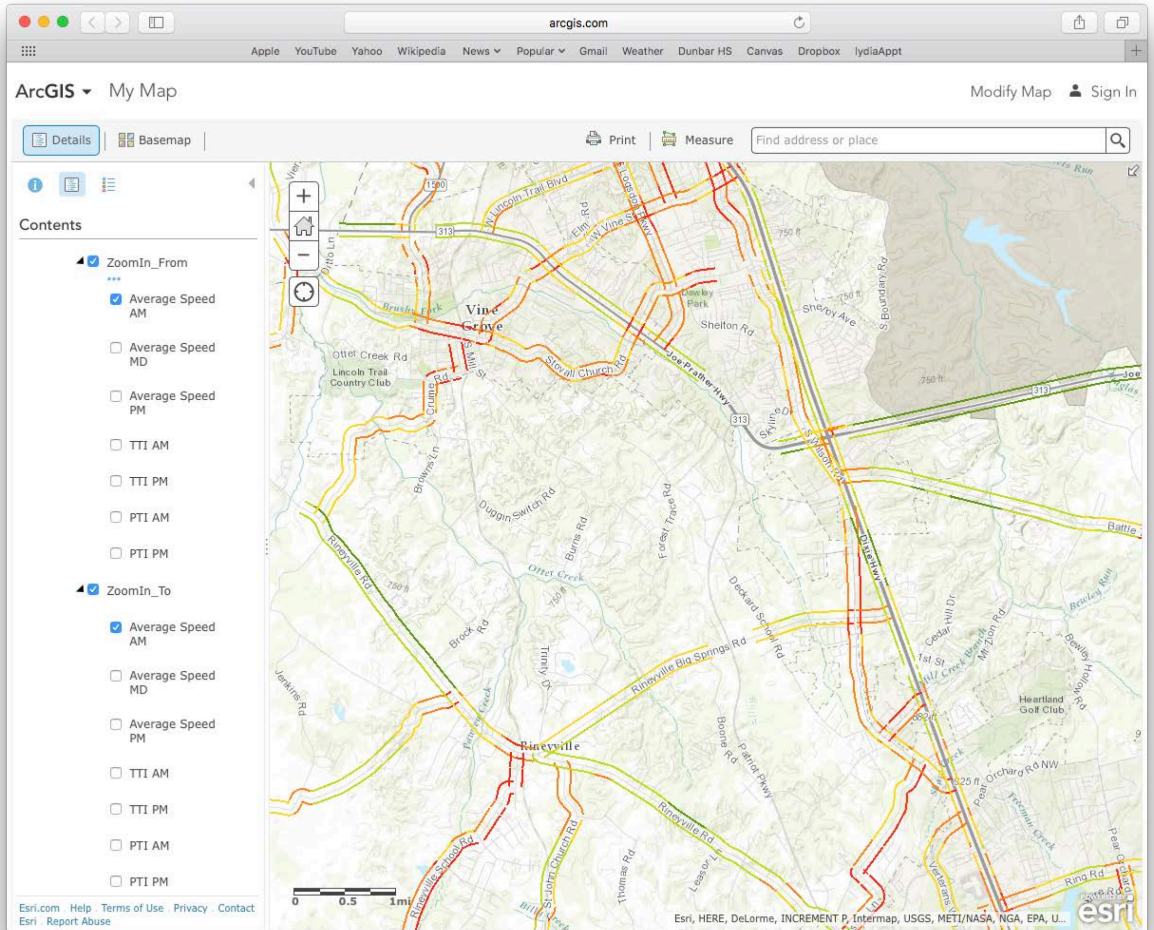
The conflated network for the 2011-2012 dataset enables display of performance measures by cardinality, while the 2013-2014 network allows for display of the measures by HERE-defined "direction of travel" (i.e., "To" or "From"). "To" refers to the direction of traveling toward the reference node, while "From" refers to the direction of traveling from the reference node. The reference node is the end node (between the two end nodes of the link) with lower latitude. If both end points have the same latitude, the point with lower longitude would be the reference node.

The selected performance measures are:

- Average Peak Period Speeds
    - AM: 6-9am
    - PM: 3-6pm
    - MD (Midday): 11am-2pm – for 2013-2014 only
- Travel Time Index (TTI, using speed limit as reference speed)
    - AM
    - PM
- Planning Time Index (PTI, using speed limit as reference speed)
    - AM
    - PM

**Display Options**

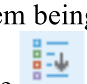
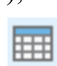
By default, all years of data are selected for display at the statewide scale ("ZoomOut") . Users can deselect the year(s) that are not of interest to them. Once zoomed in enough, the display automatically switches to ZoomIn level and presents a detailed display of link performance measures. The figure below shows a sample screenshot of AM speeds on both directions (with display offset).




Users can select or deselect performance measures for display. To show the legend, users can press the "Show Map Legend" button (third from left below the Details button on the upper left corner of the screen).

For each data item (e.g., Average PM Speed) users have several display options. By hovering the cursor over the data item being display (shown below), 

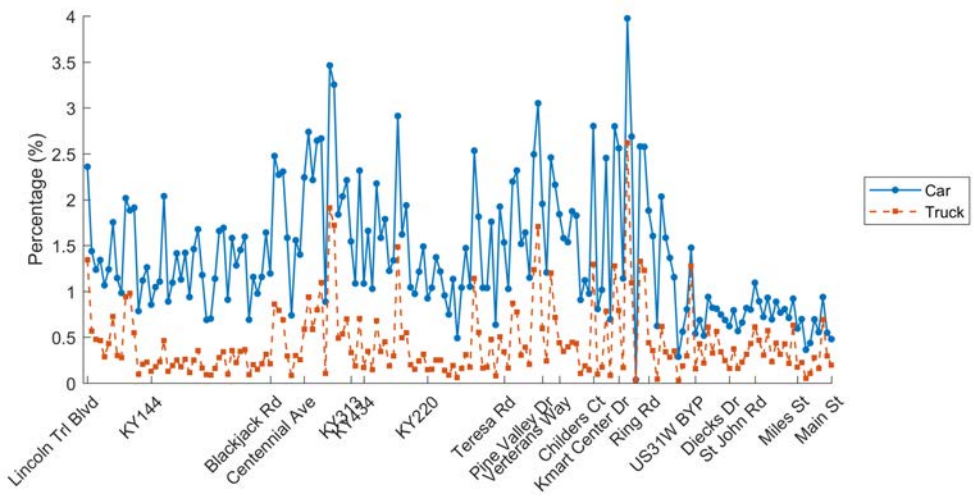
,

users can choose  to display map legend,  to display attribute table, and  to filter the display by given attribute. To facilitate the filtering operation, the following is a list of attribute field names:

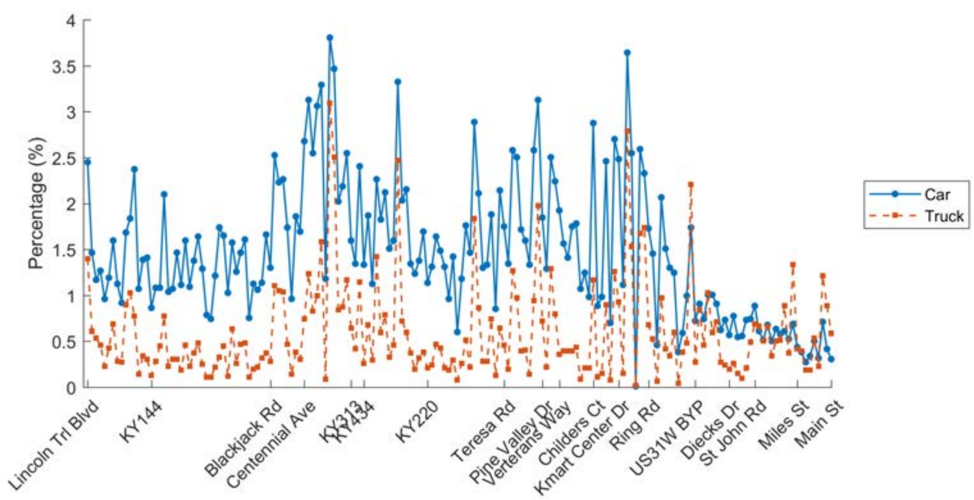
- RID: route identifier
- FMEAS: beginning milepoint
- TMEAS: ending milepoint
- Cnty_Name: county name
- Direction: HERE travel direction (defined above)
- WDyA_AvgSp: weekday AM peak period average speed

- WDyM_AvgSp: weekday Midday period average speed
- WDyP_AvgSp: weekday PM peak period average speed
- T_SL_A: AM peak travel time index with speed limit as reference speed
- T_SL_P: PM peak travel time index with speed limit as reference speed
- P_SL_A: AM peak planning time index with speed limit as reference speed
- P_SL_P: PM peak planning time index with speed limit as reference speed

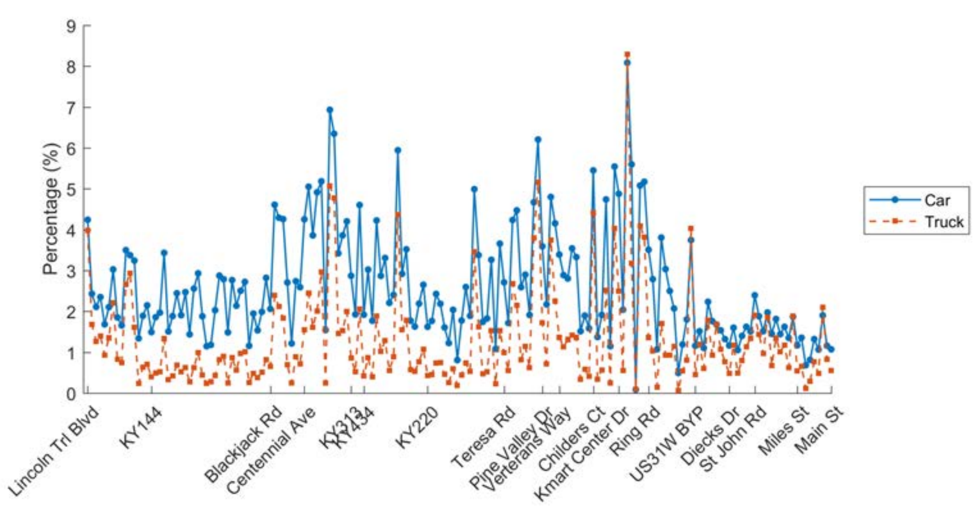
# APPENDIX C Data Comparison on Urban Arterials



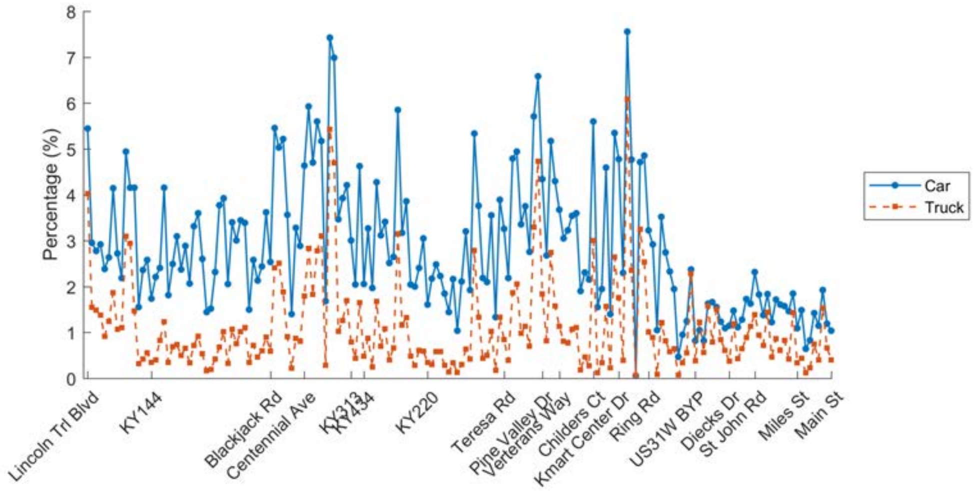
(a) All year



(b) AM period

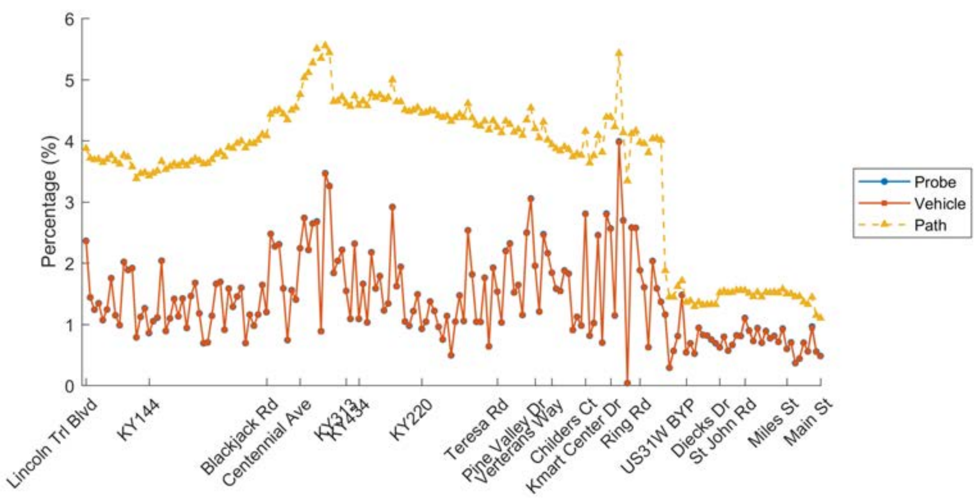


(c) Midday period

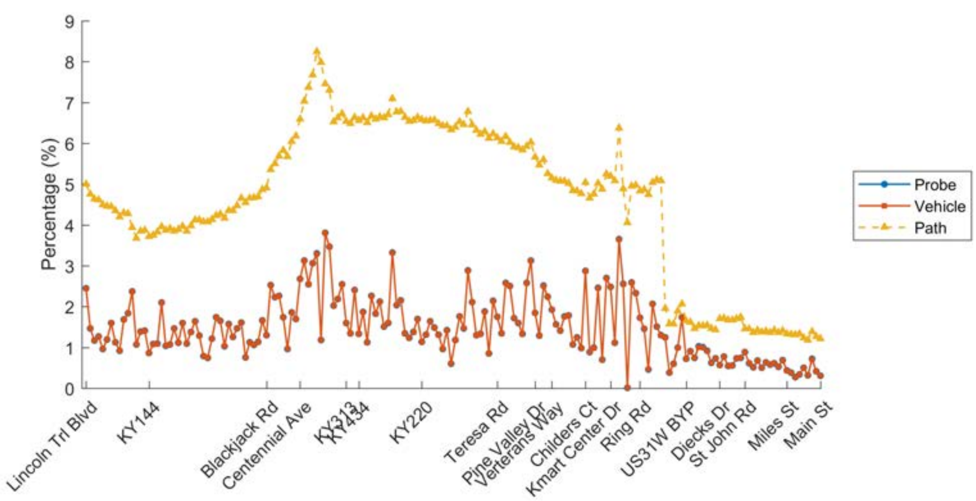



PM period

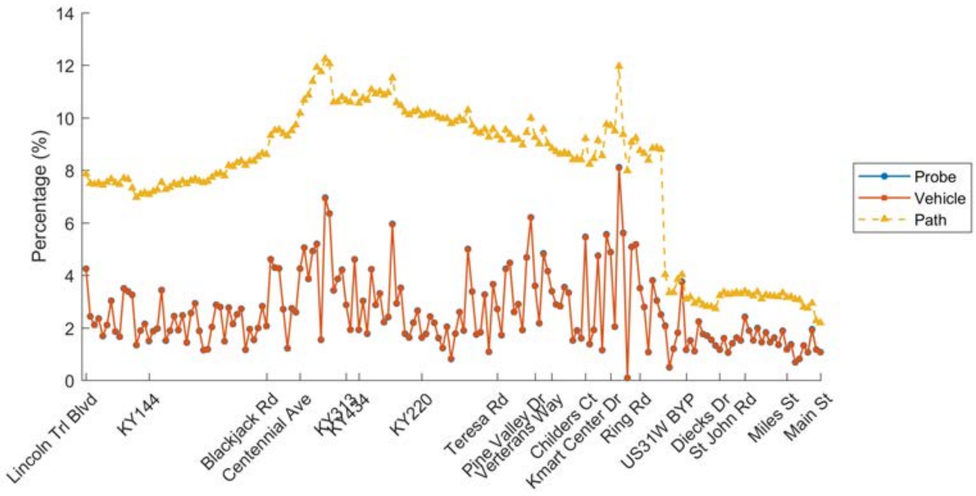
**Figure C-1 US-31W southbound vehicle data sample coverage between car and truck**



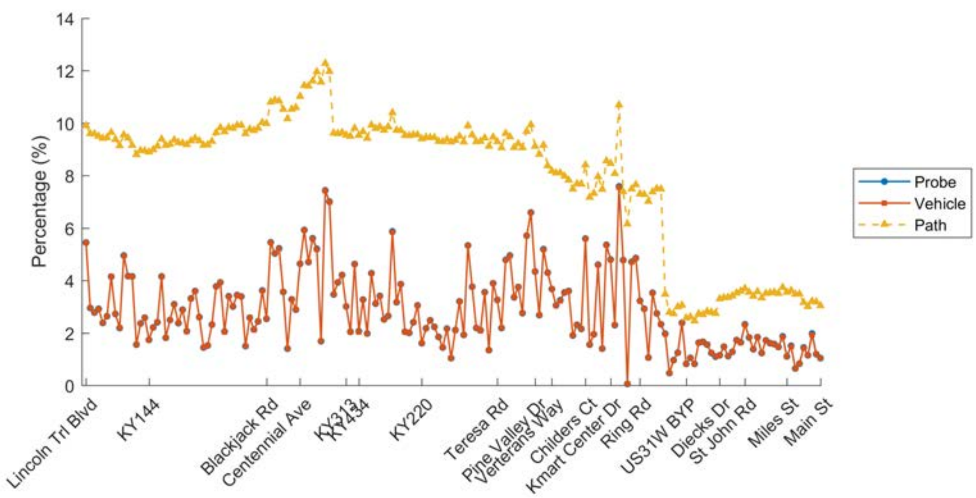

(a) All year




(b) AM period

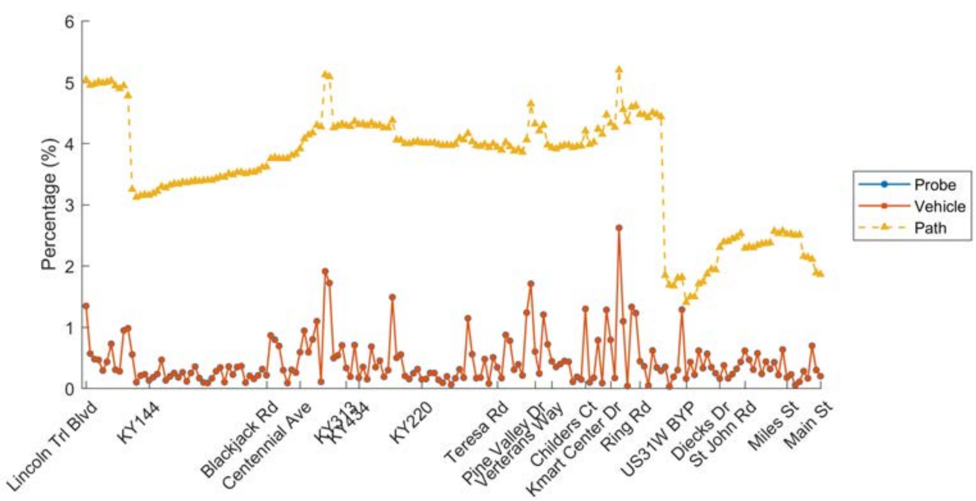



(c) Midday period

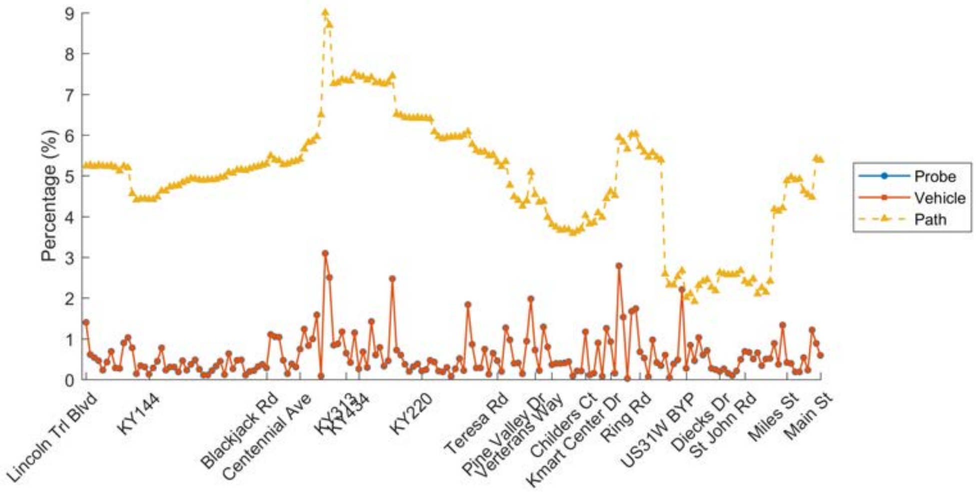



(d) PM period

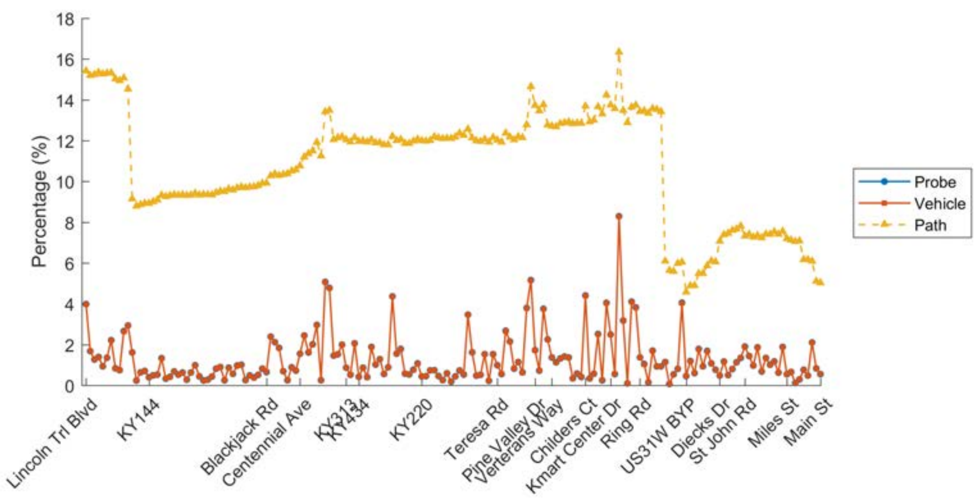
**Figure C-2 US-31W southbound car sample coverage among probe, vehicle, and path**



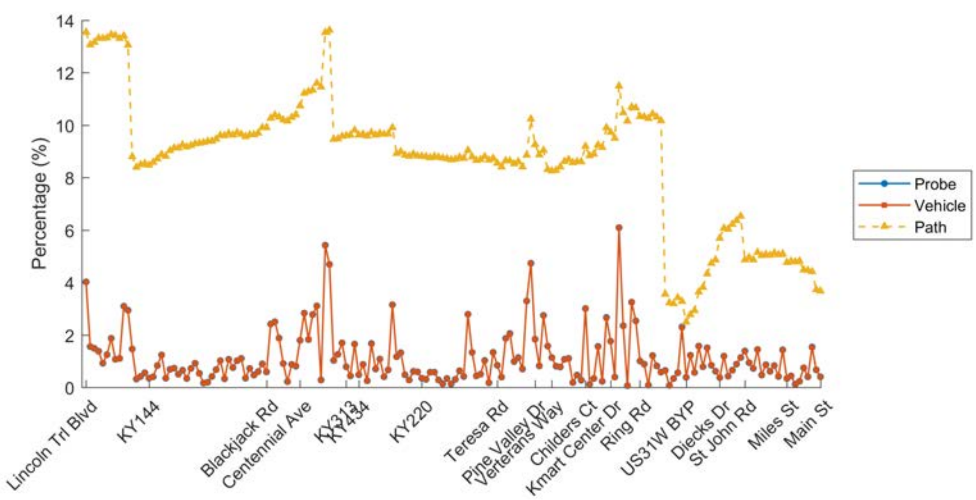

(a) All year




(b) AM period

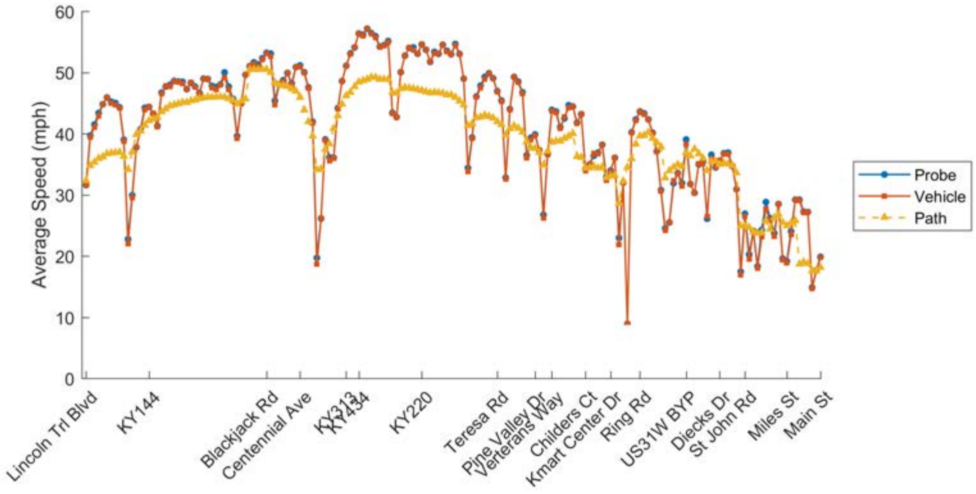



(c) Midday period

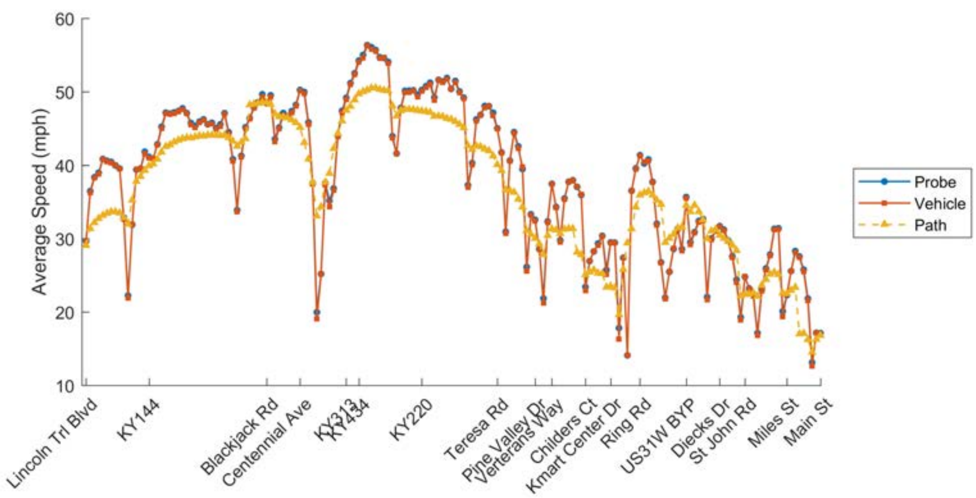



(d) PM period

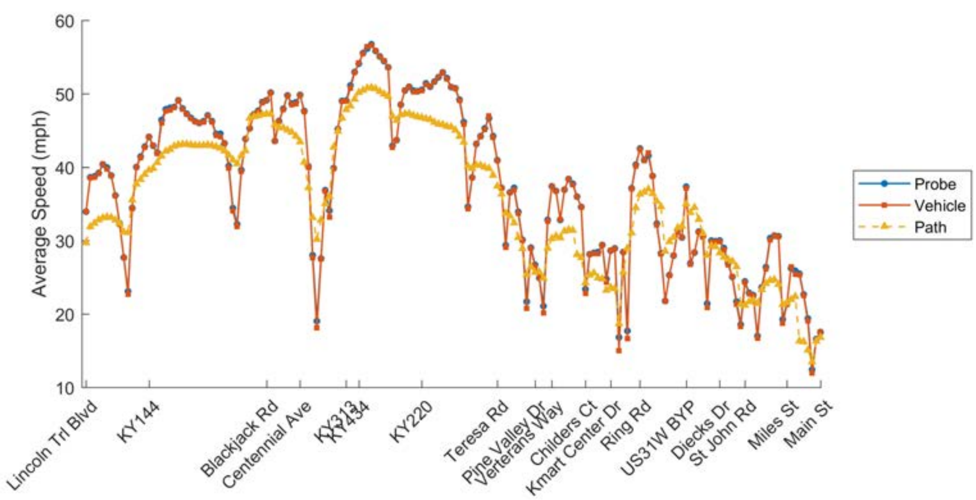
**Figure C-3 US-31W southbound truck sample coverage among probe, vehicle, and path**




(a) AM period

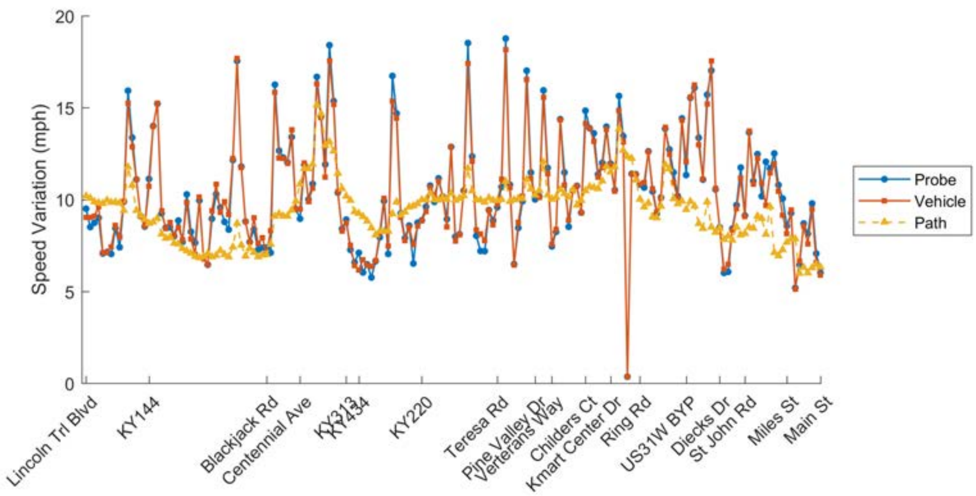



(b) Midday period

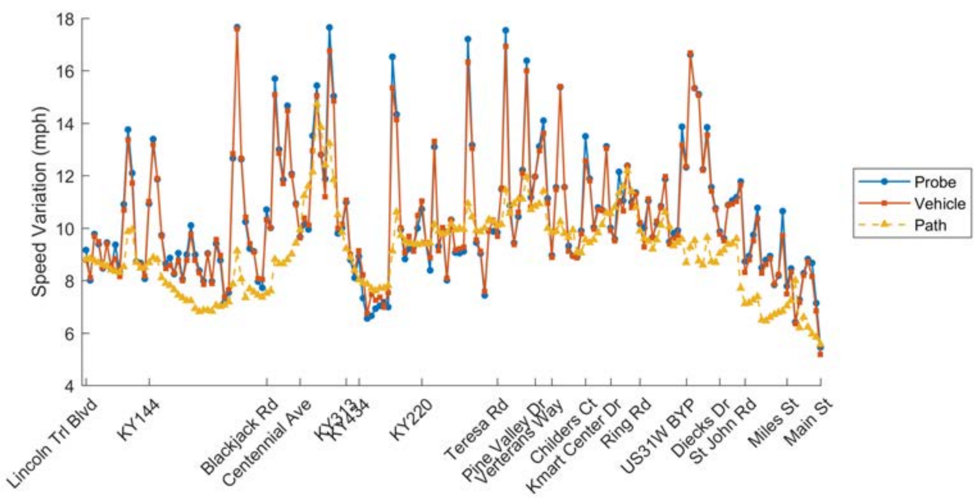



(c) PM period

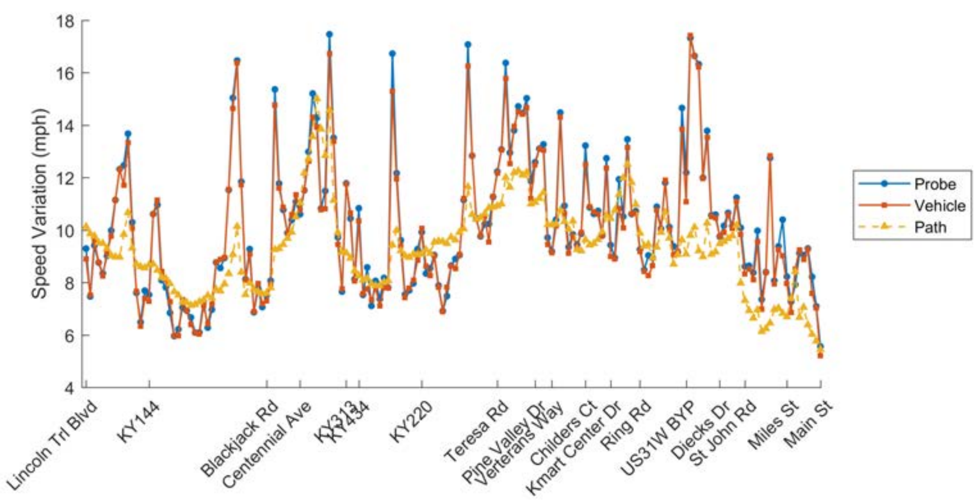
**Figure C-4 US-31W southbound average speed from probe, vehicle and path**




(a) AM period

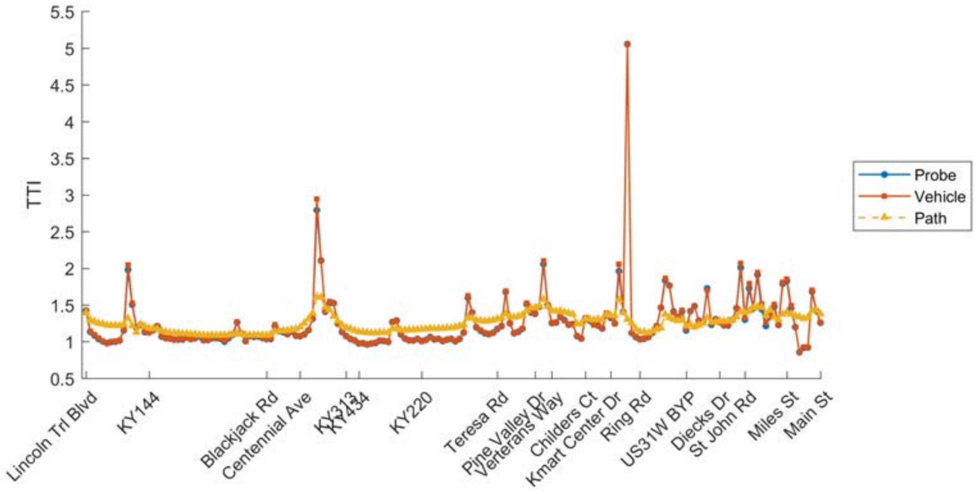



(b) Midday period

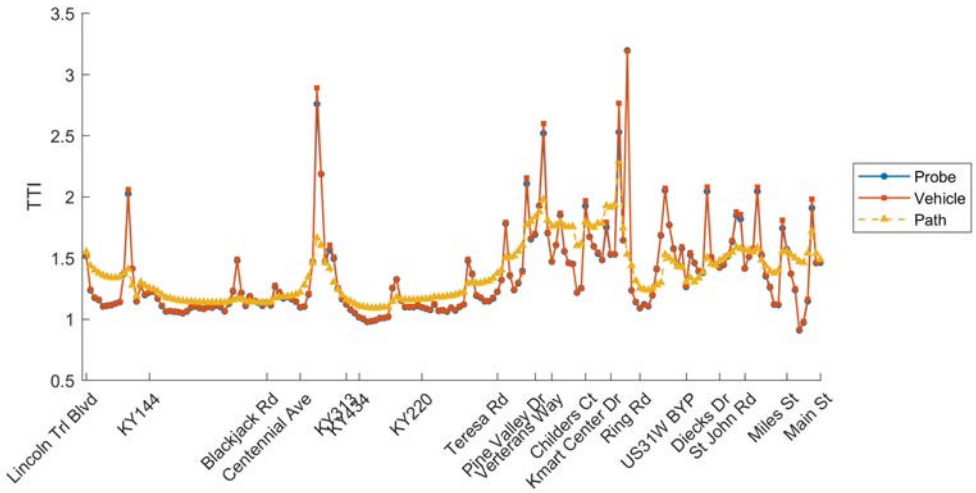



(c) PM period

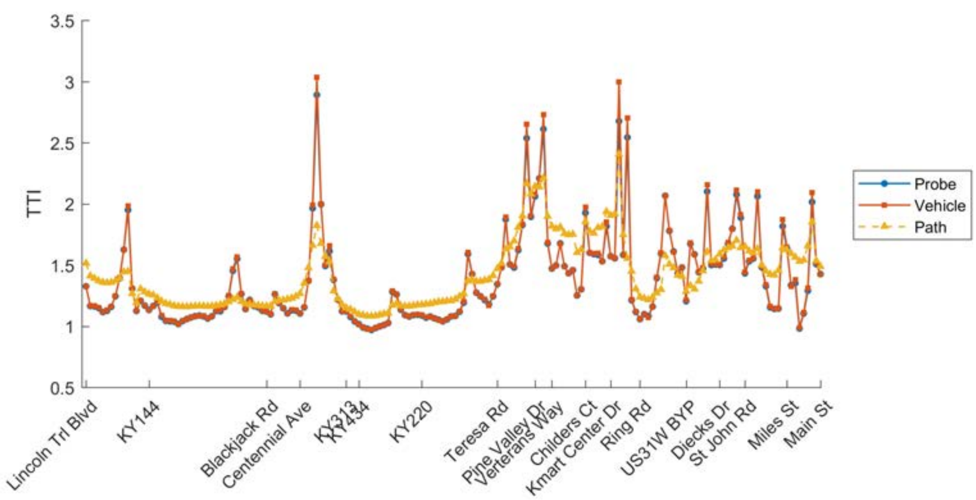
**Figure C-5 US-31W southbound speed variation from probe, vehicle and path**




(a) AM period

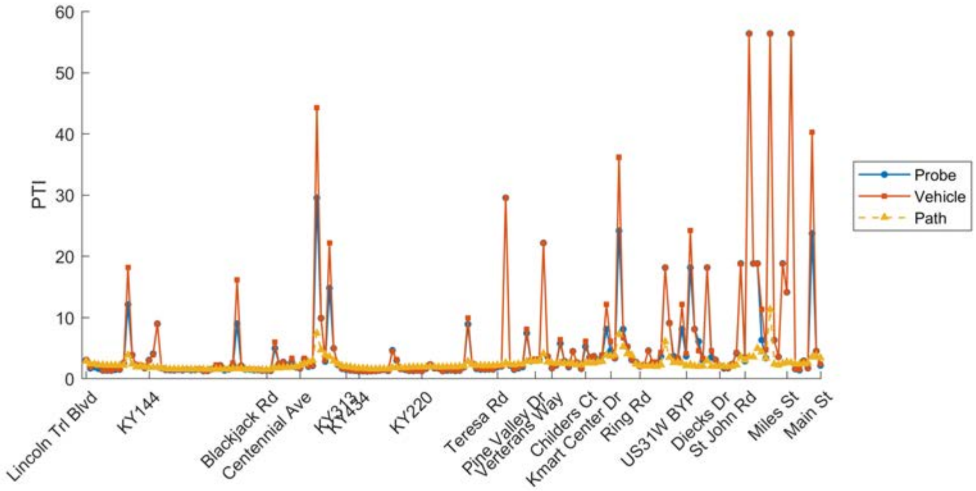



(b) Midday period

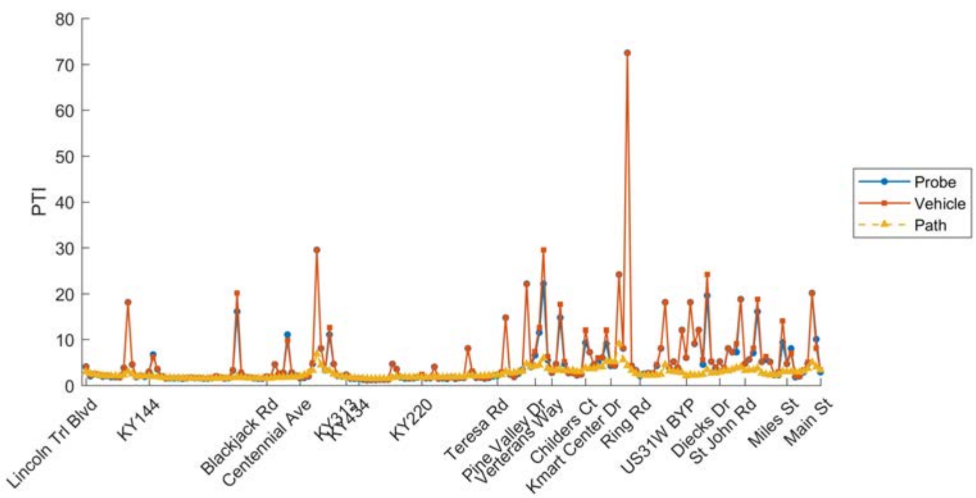



(c) PM period

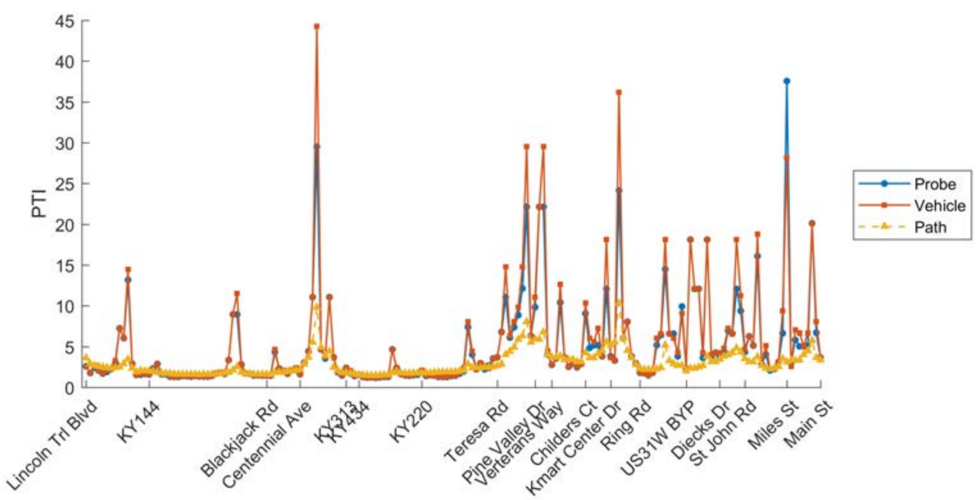
**Figure C-6 US-31W southbound travel time index from probe, vehicle and path**




(a) AM period

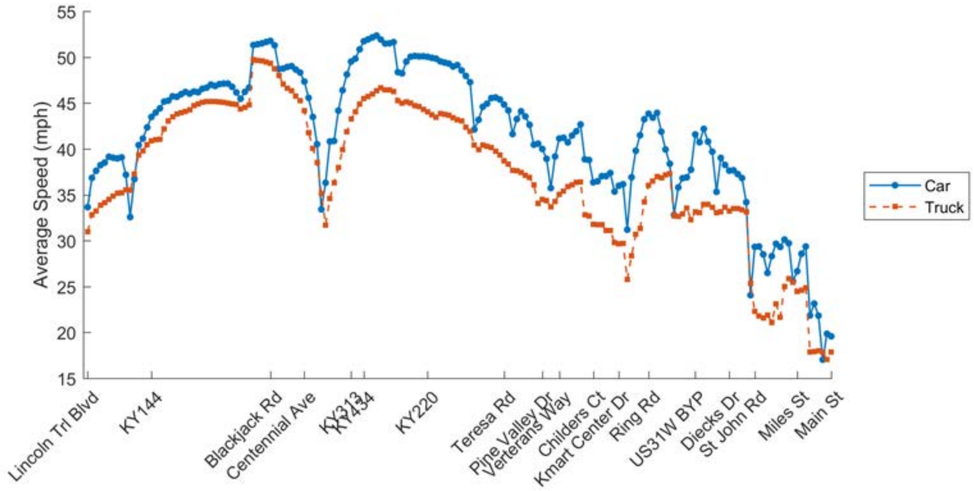



(b) Midday period

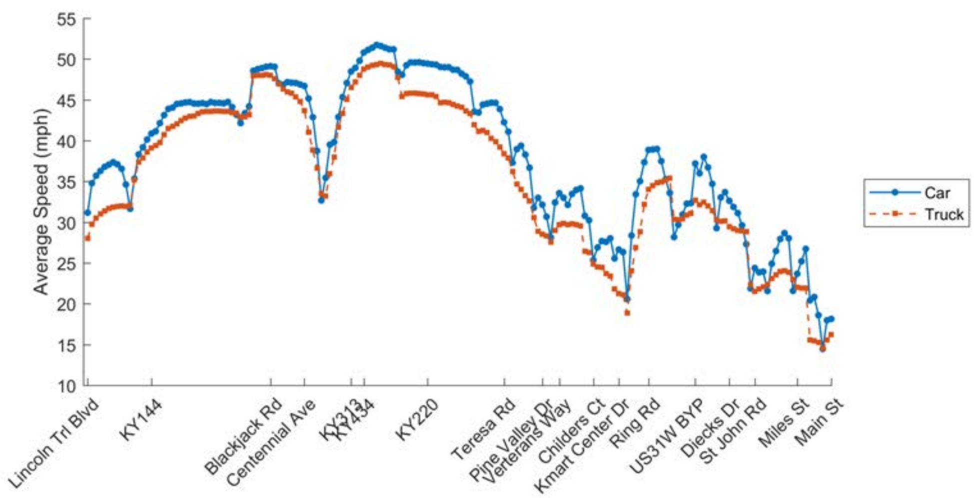



(c) PM period

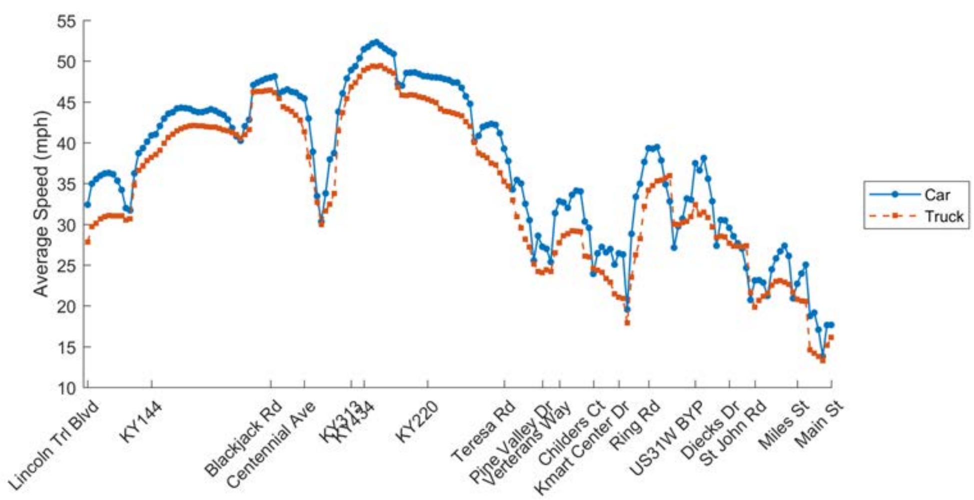
**Figure C-7 US-31W southbound planning time index from probe, vehicle and path**




(a) AM period

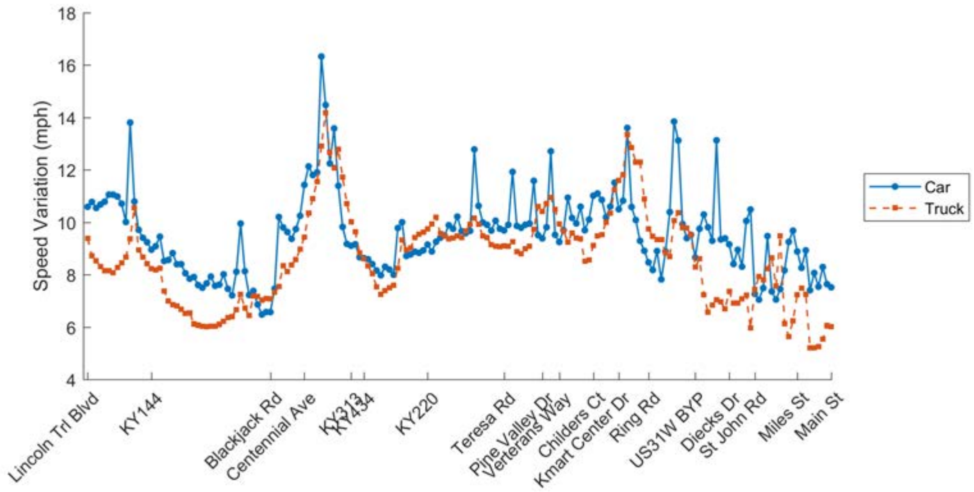



(b) Midday period

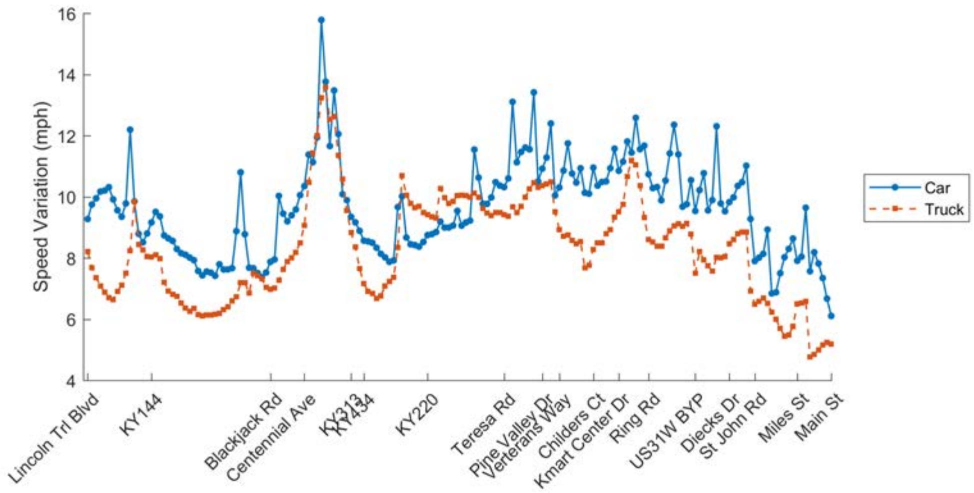



(c) PM period

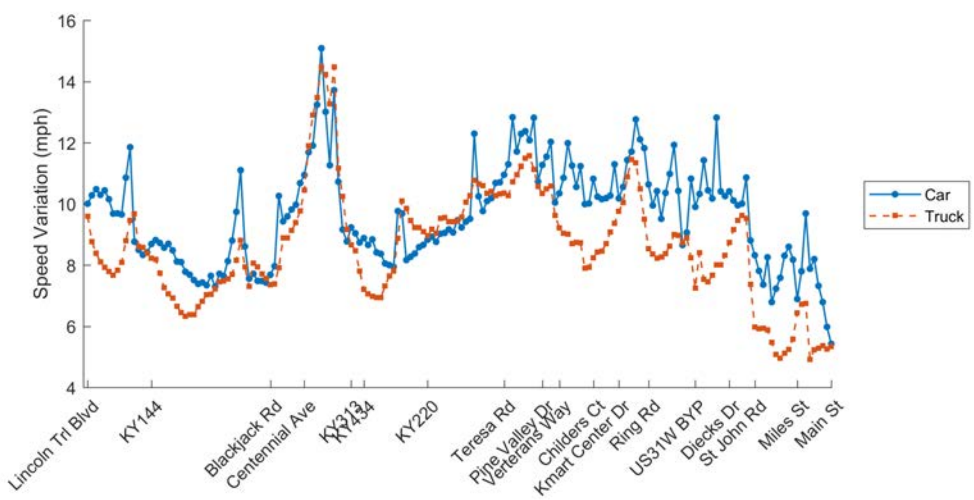
**Figure C-8 US-31W southbound average speed comparison between car and truck**




(a) AM period

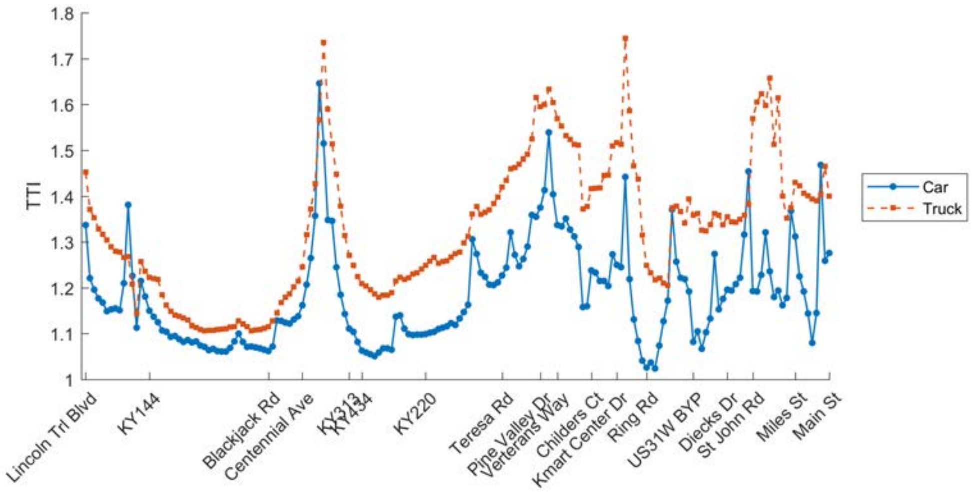



(b) Midday period

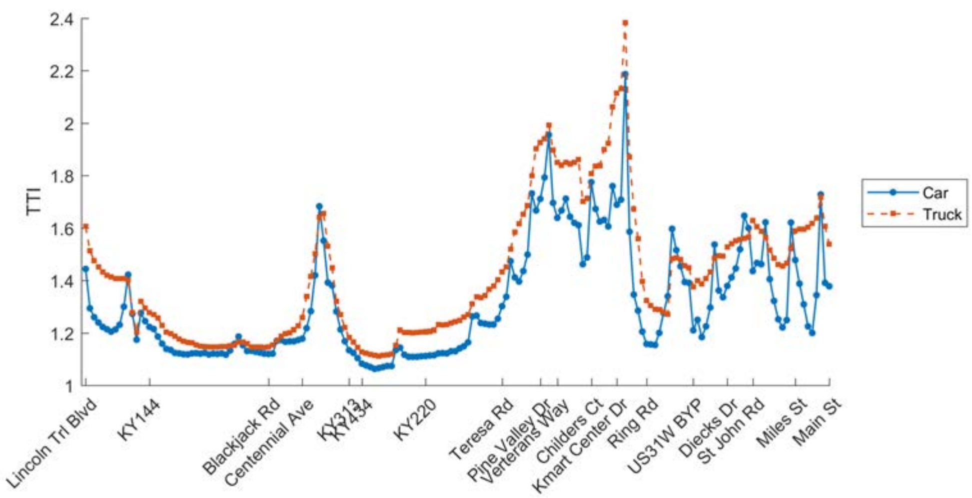



(c) PM period

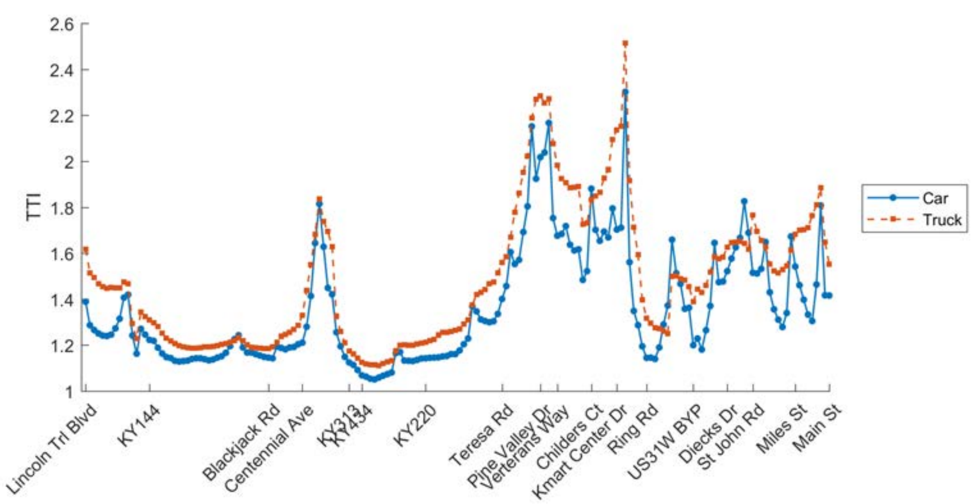
**Figure C-9 US-31W southbound speed variation comparison between car and truck**




(a) AM period

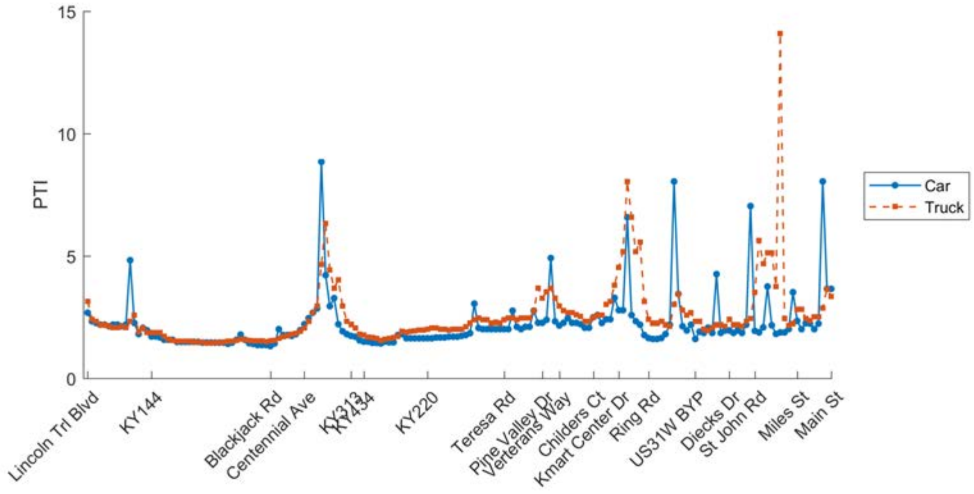



(b) Midday period

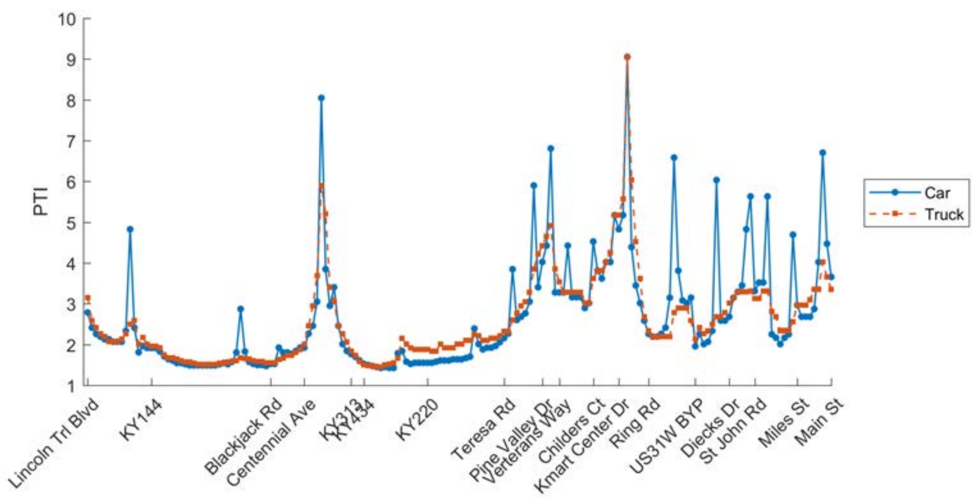



(c) PM period

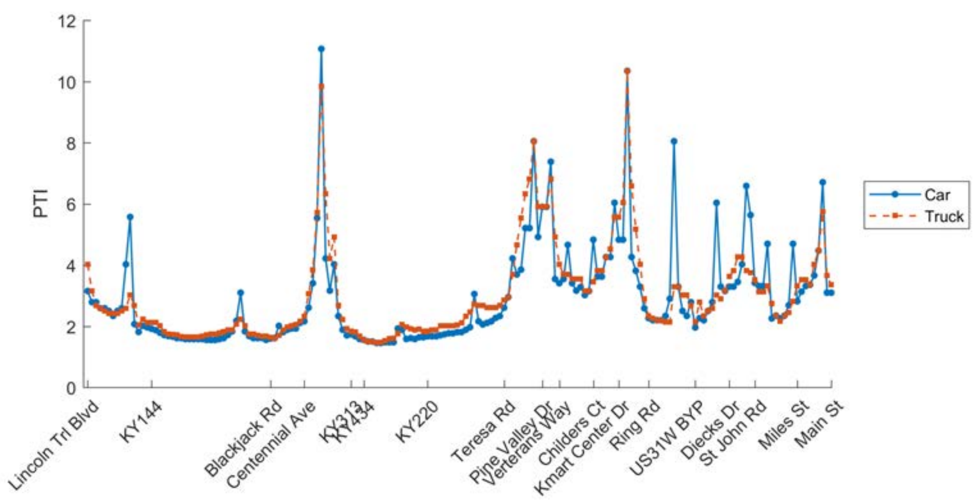
**Figure C-10 US-31W southbound travel time index comparison between car and truck**




(a) AM period

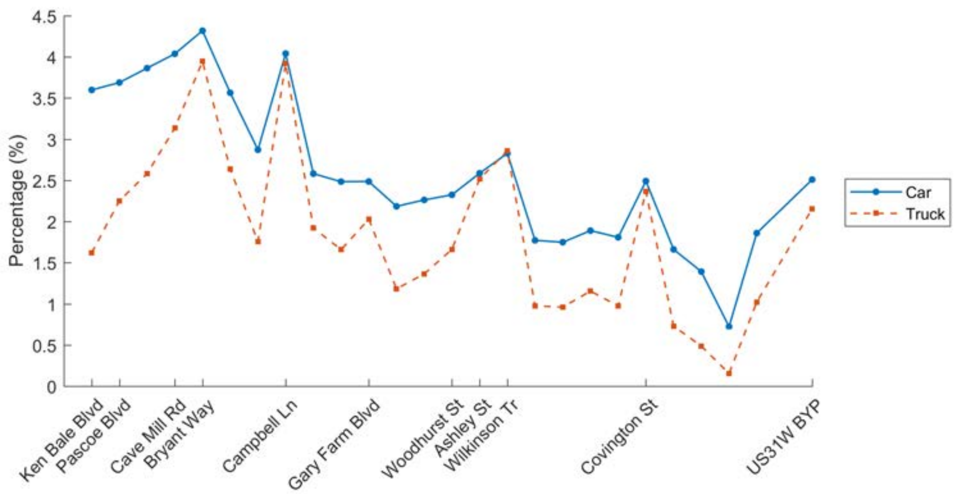



(b) Midday period

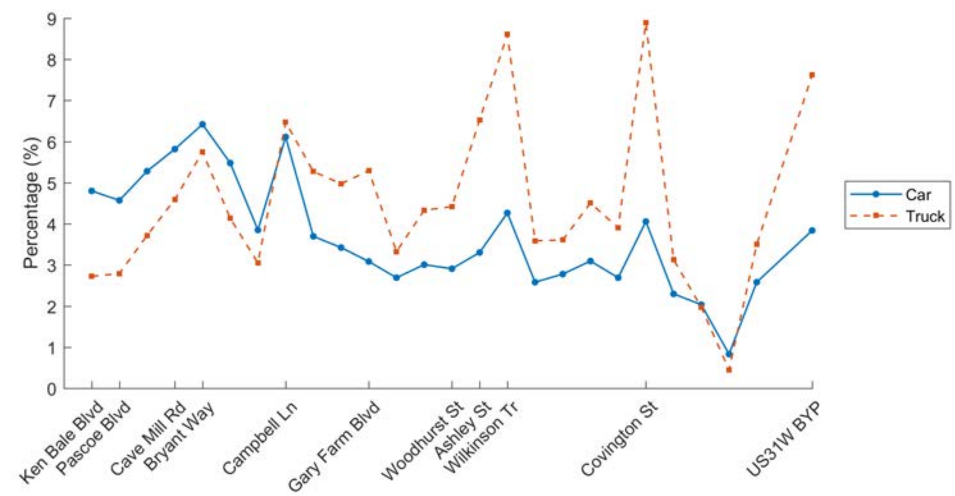



(c) PM period

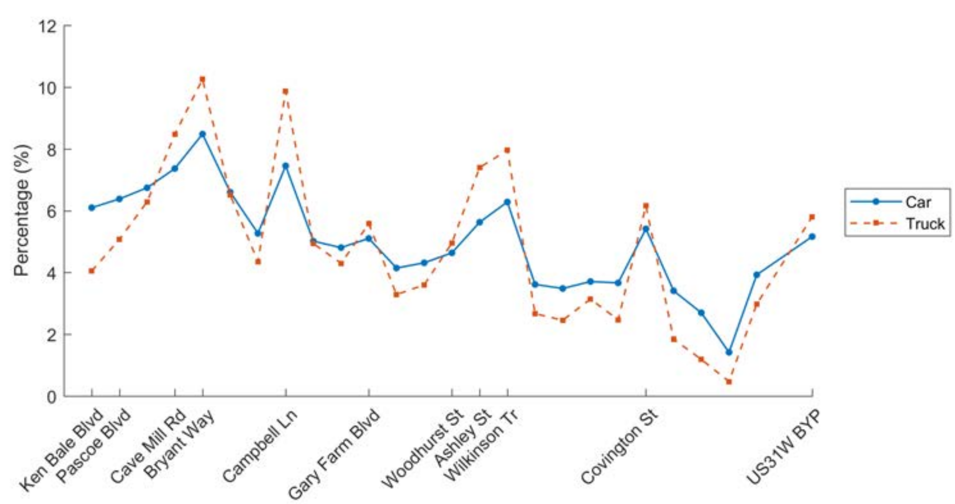
**Figure C-11 US-31W southbound planning time index comparison between car and truck**



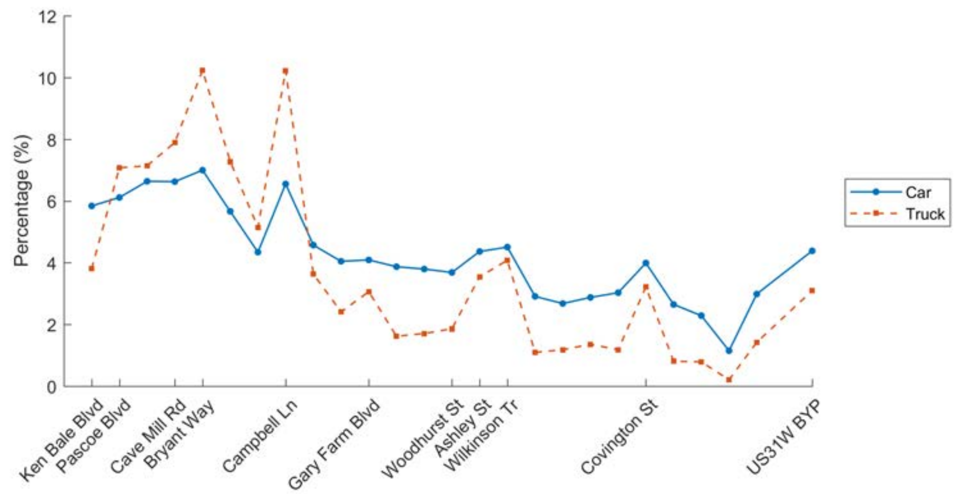

(a) All year




(b) AM period

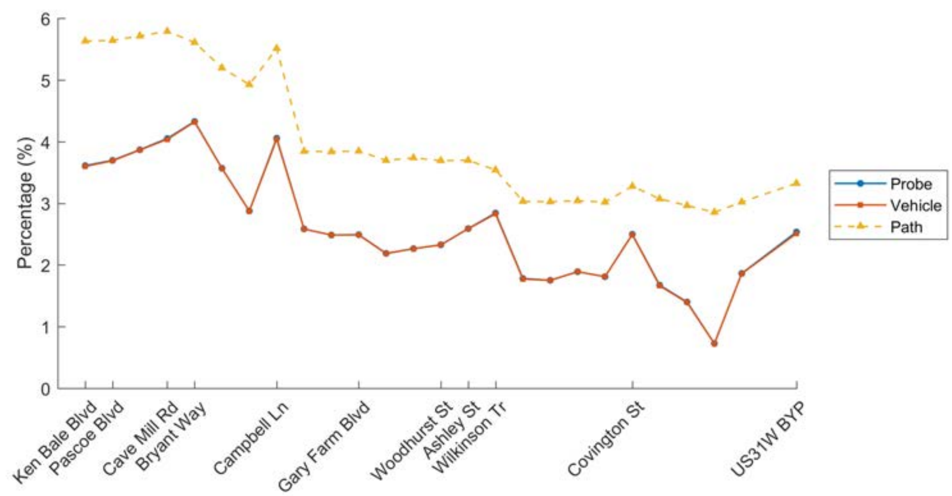



(c) Midday period

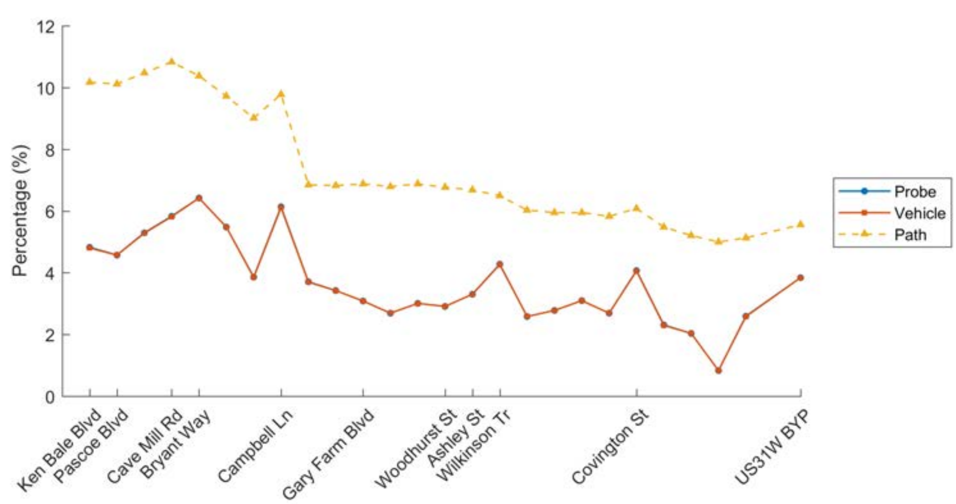



(d) PM period

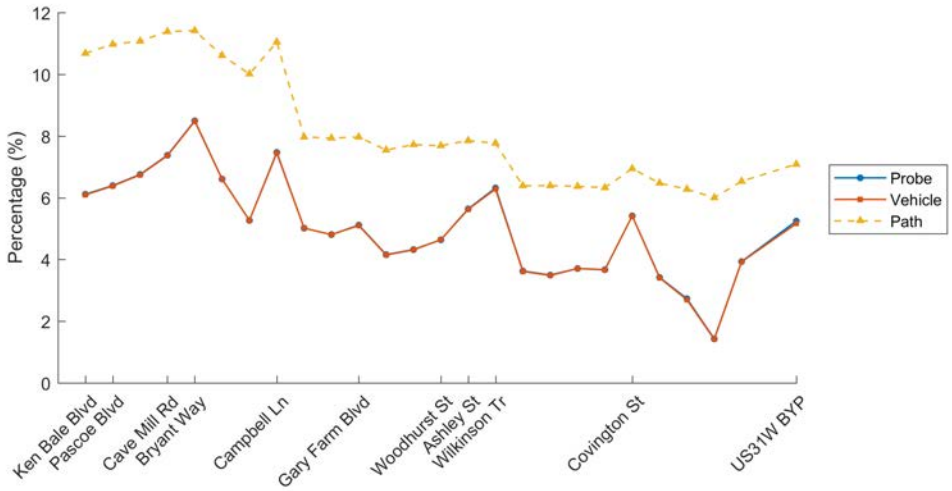
**Figure C-12 US-231 northbound vehicle data sample coverage between car and truck**



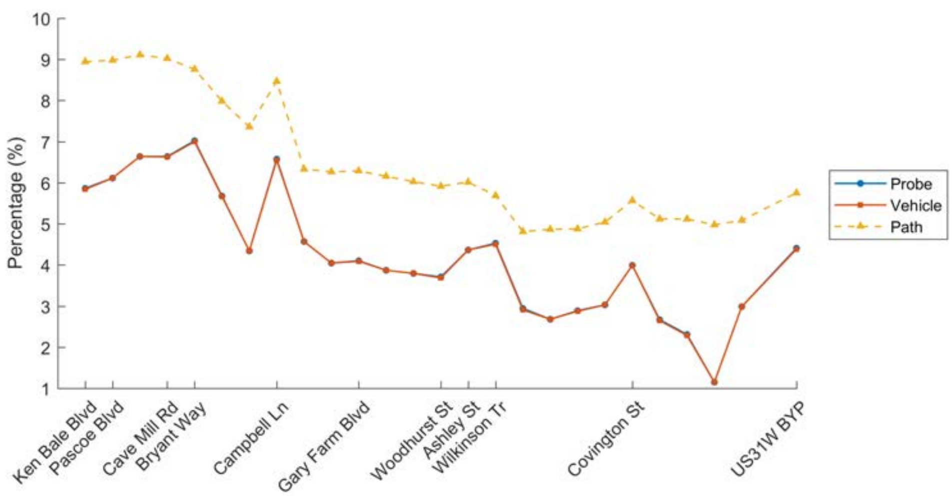

(a) All year




(b) AM period

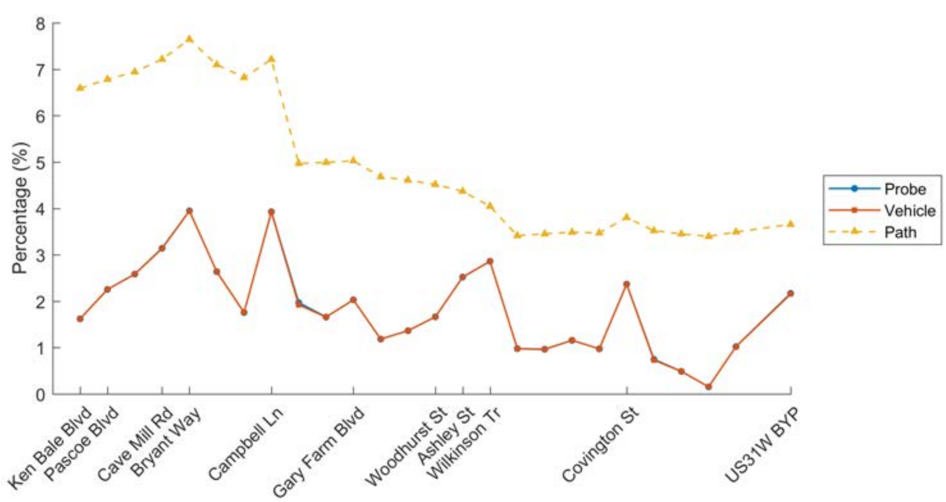



(c) Midday period

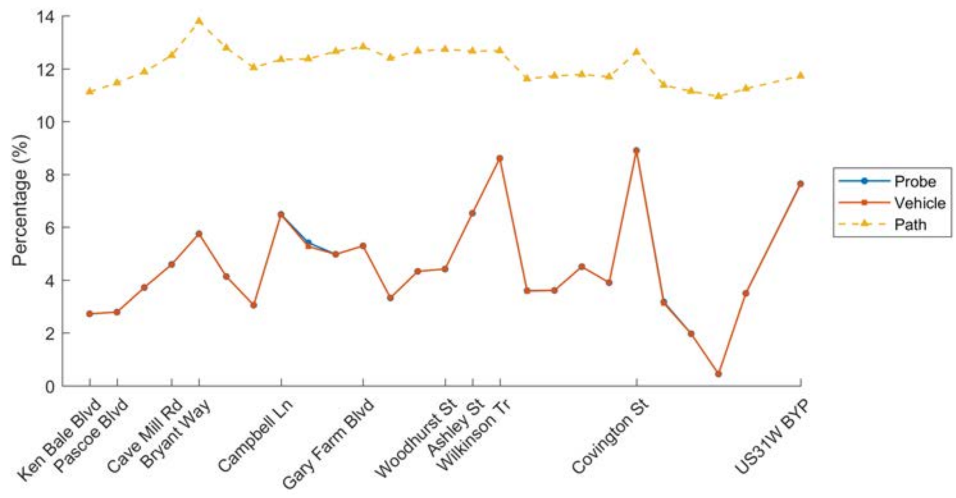



(d) PM period

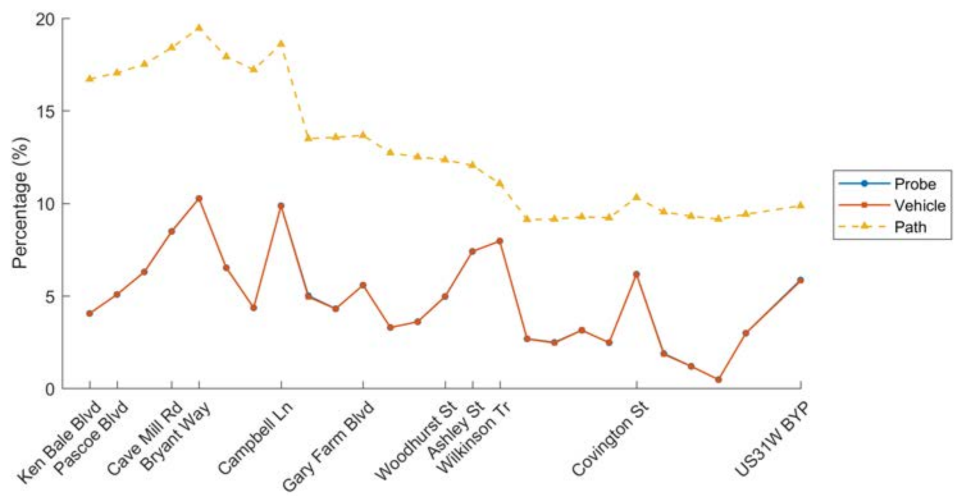
**Figure C-13 US-231 northbound car sample coverage among probe, vehicle and path**



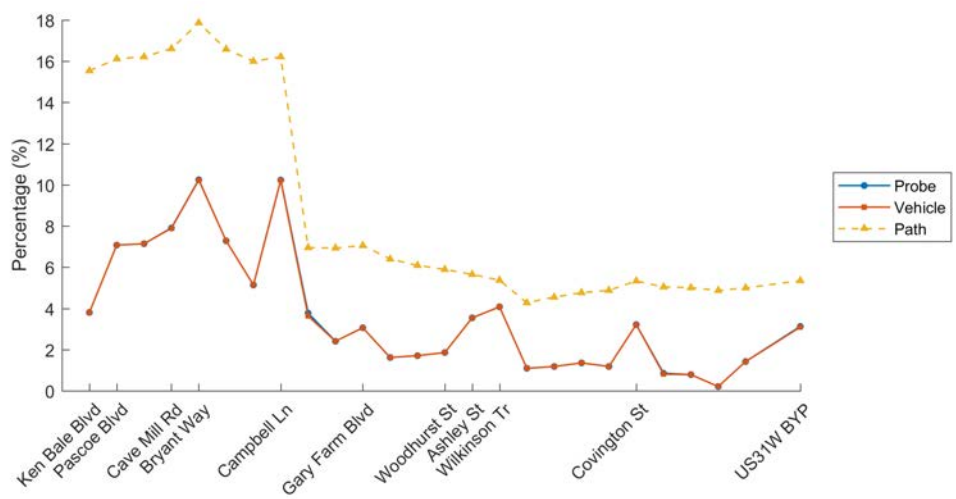

(a) All year




(b) AM period

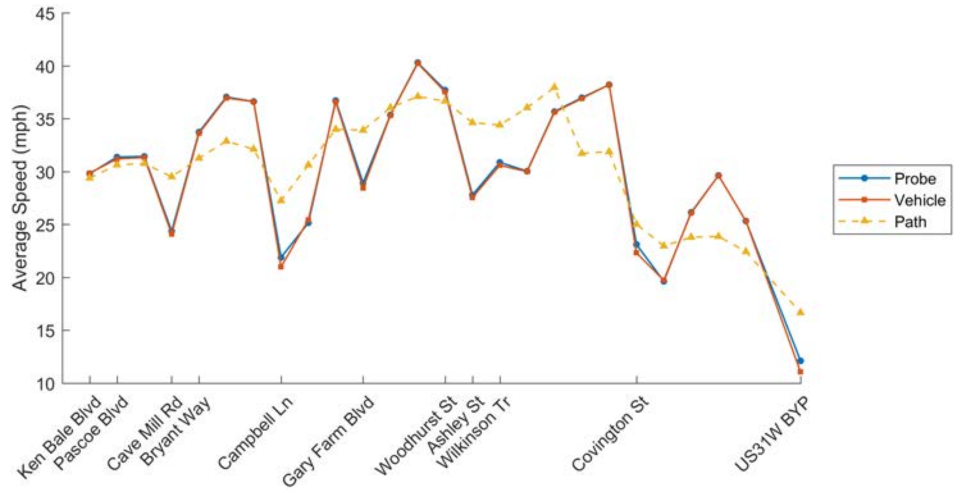



(c) Midday period

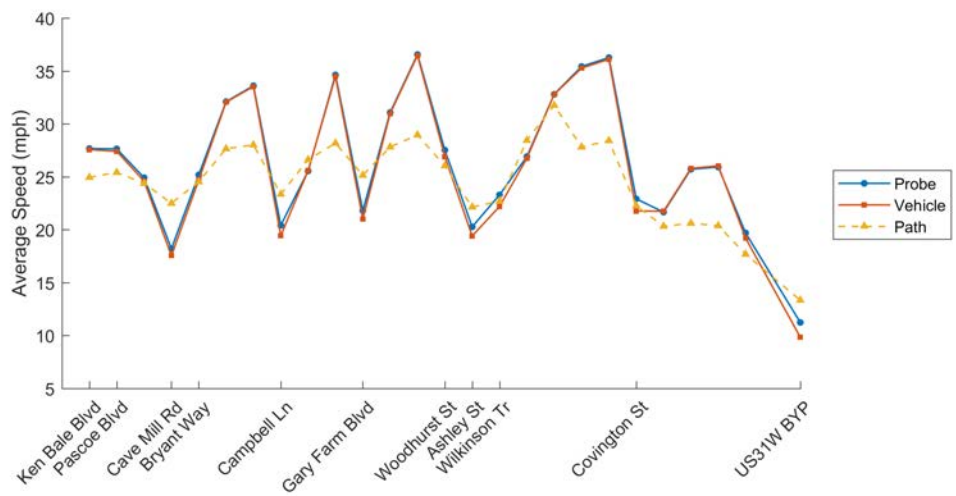



(d) PM period

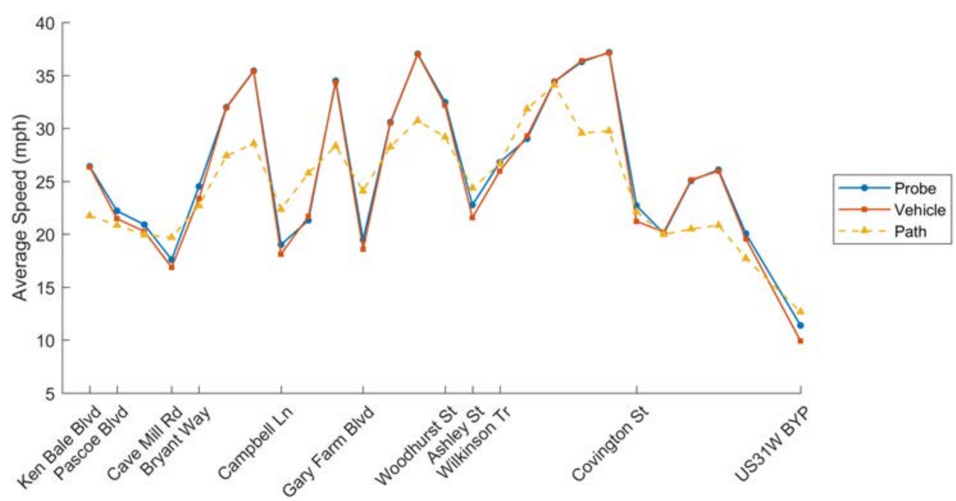
**Figure C-14 US-231 northbound truck sample coverage among probe, vehicle and path**




(a) AM period

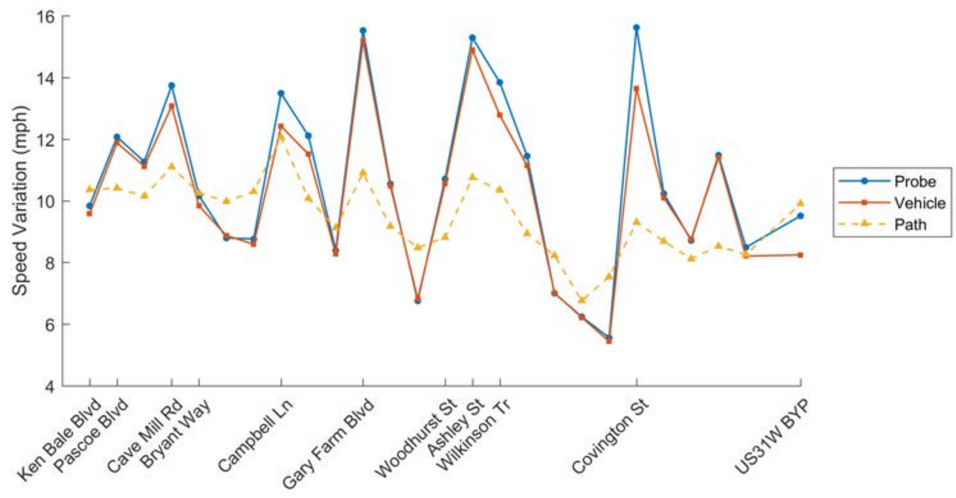



(b) Midday period

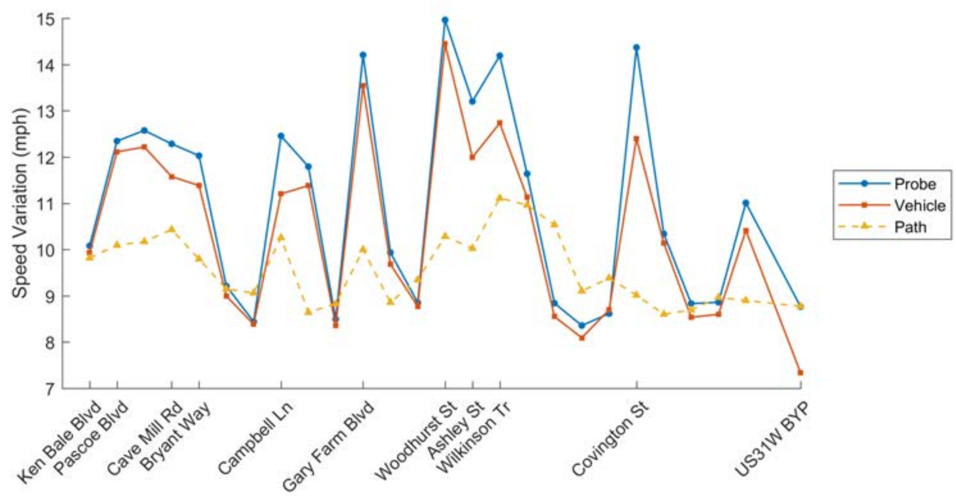



(c) PM period

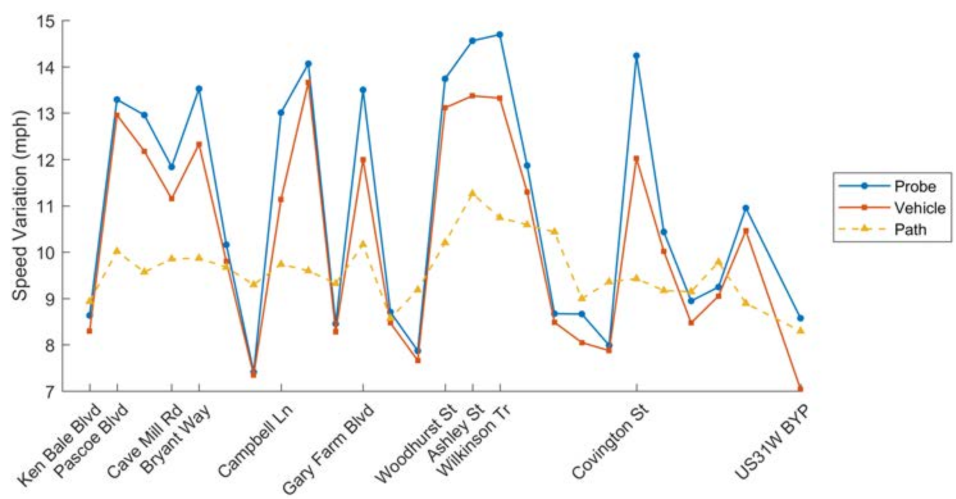
**Figure C-15 US-231 northbound average speed from probe, vehicle and path**




(a) AM period

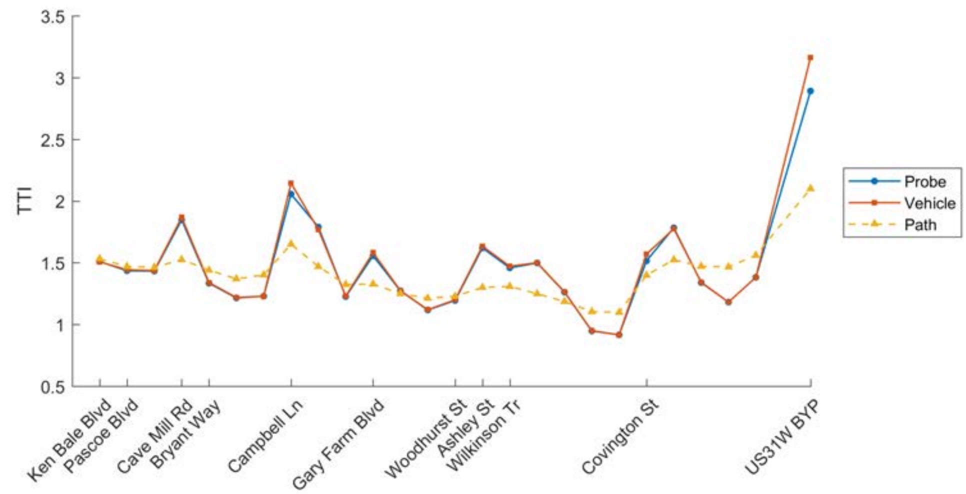



(b) Midday period

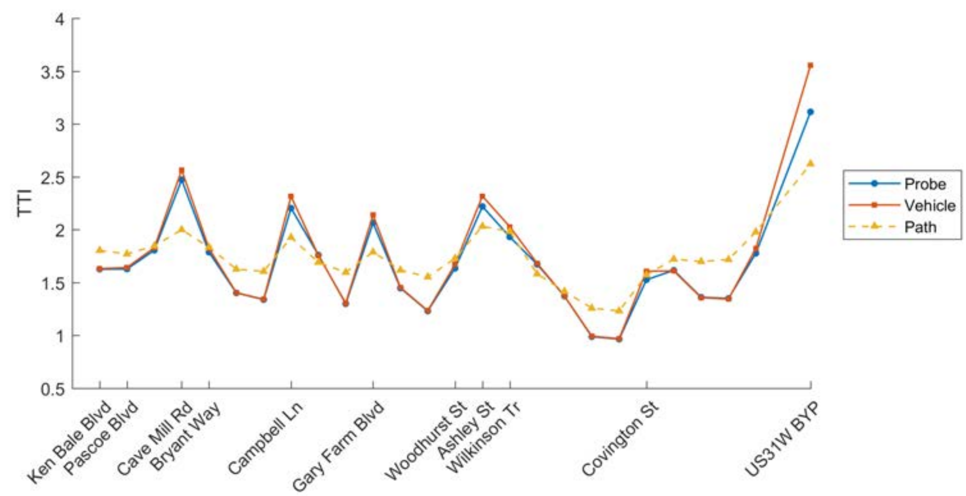



(c) PM period

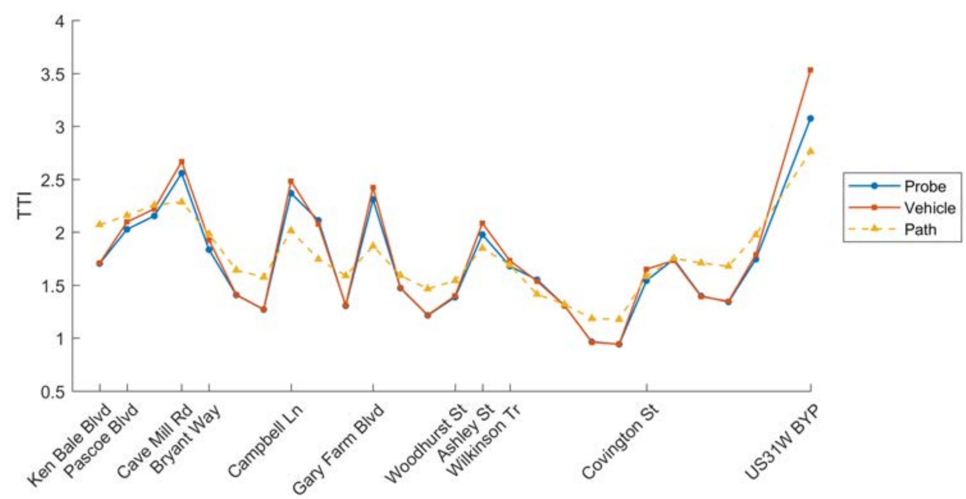
**Figure C-16 US-231 northbound speed variation from probe, vehicle and path**




(a) AM period

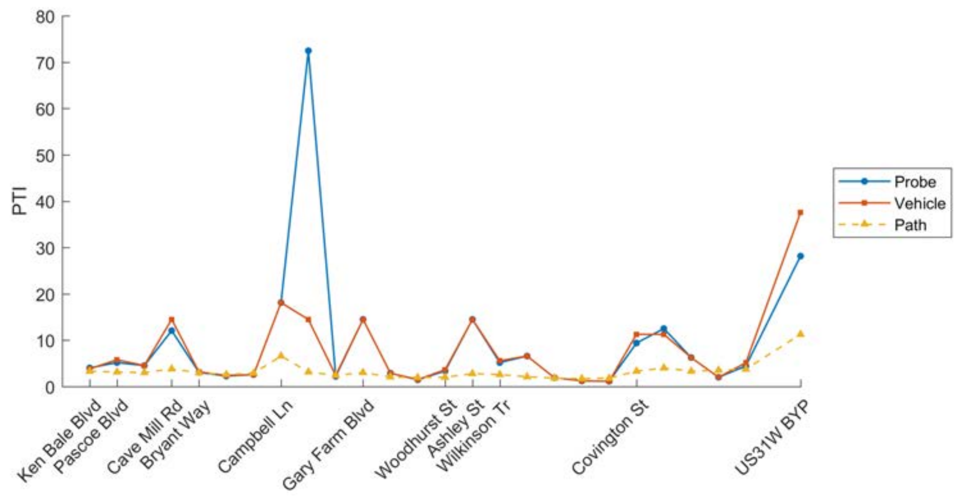



(b) Midday period

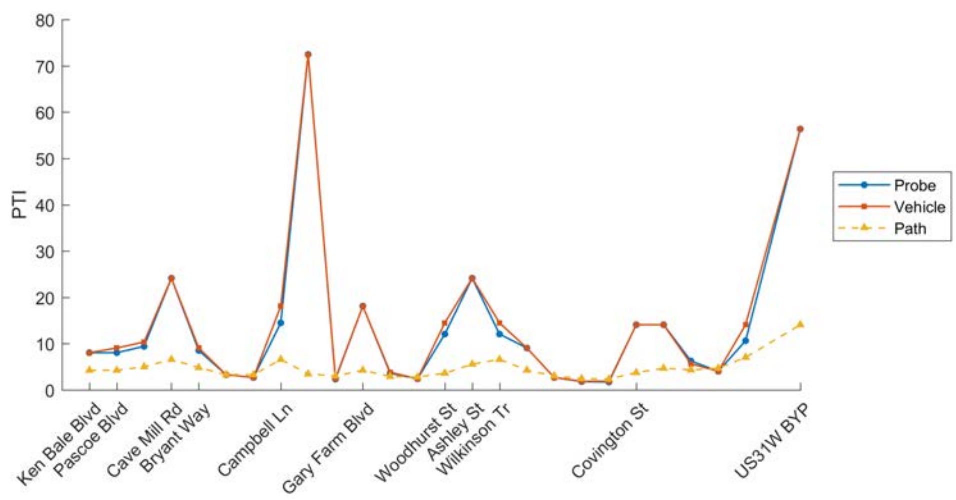



(c) PM period

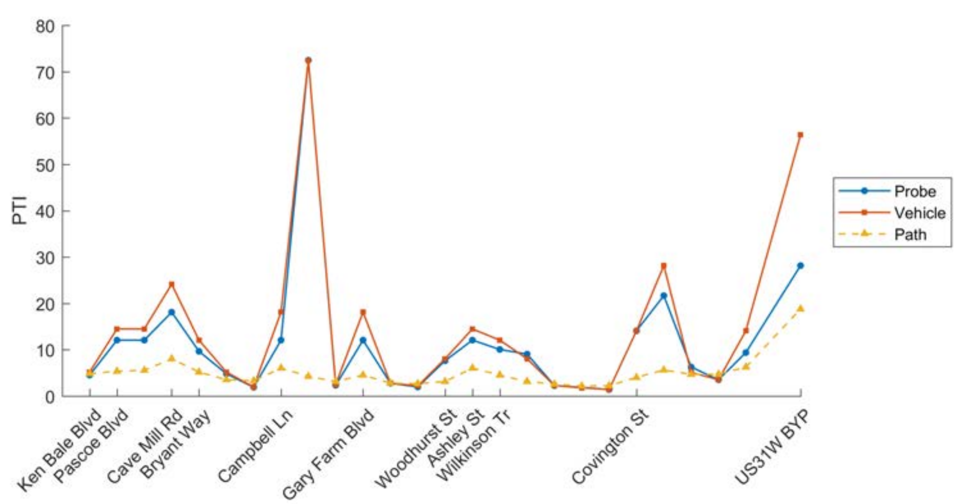
**Figure C-17 US-231 northbound travel time index from probe, vehicle and path**




(a) AM period

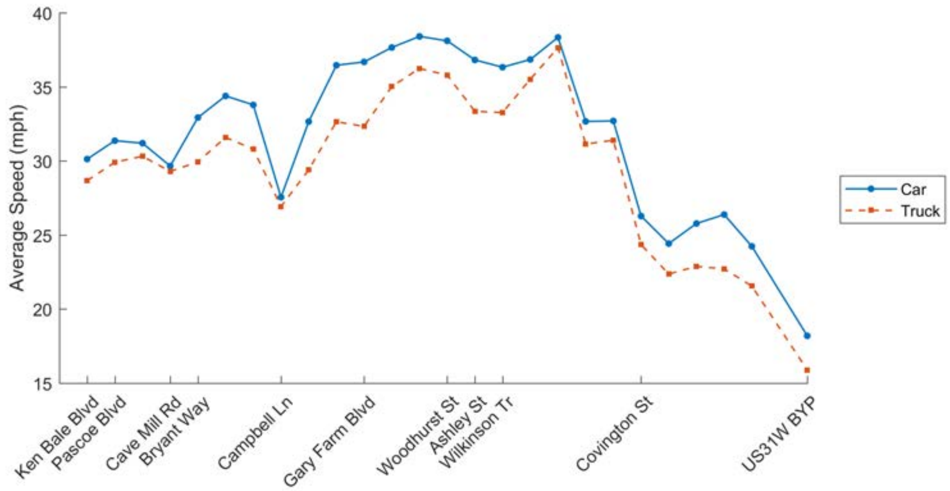



(b) Midday period

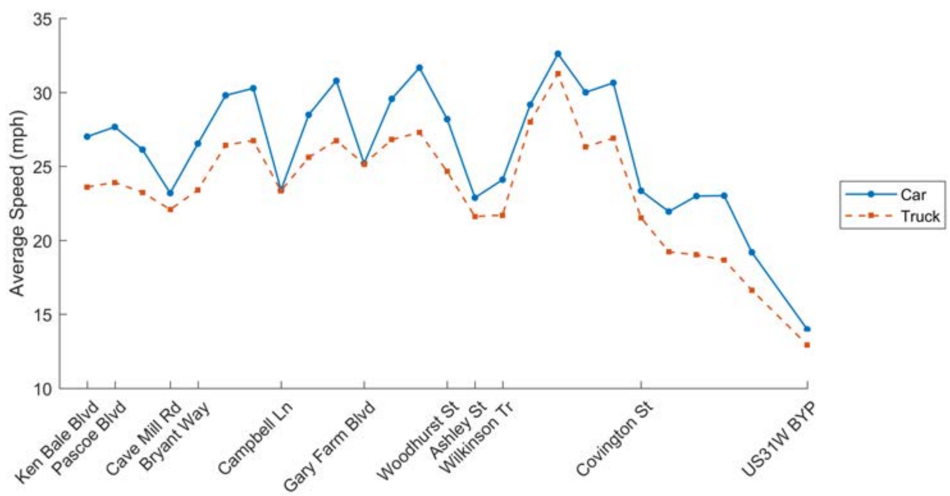



(c) PM period

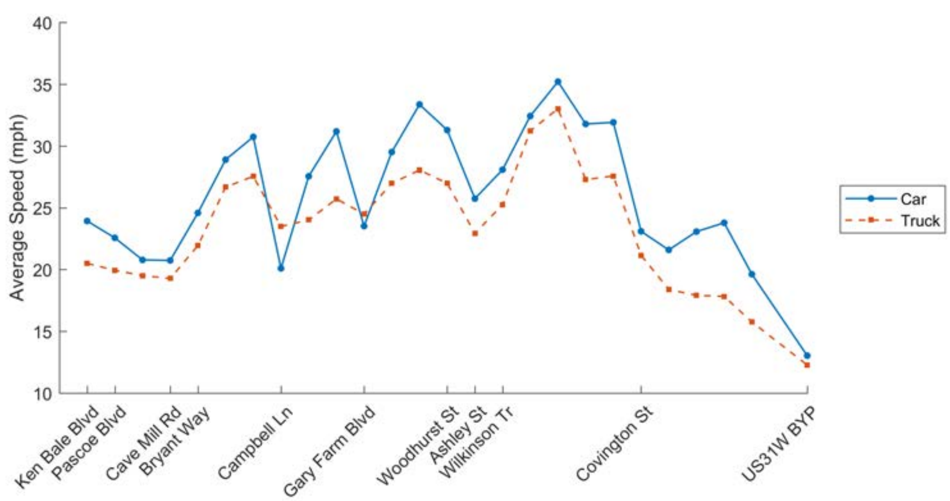
**Figure C-18 US-231 northbound planning time index from probe, vehicle and path**




(a) AM period

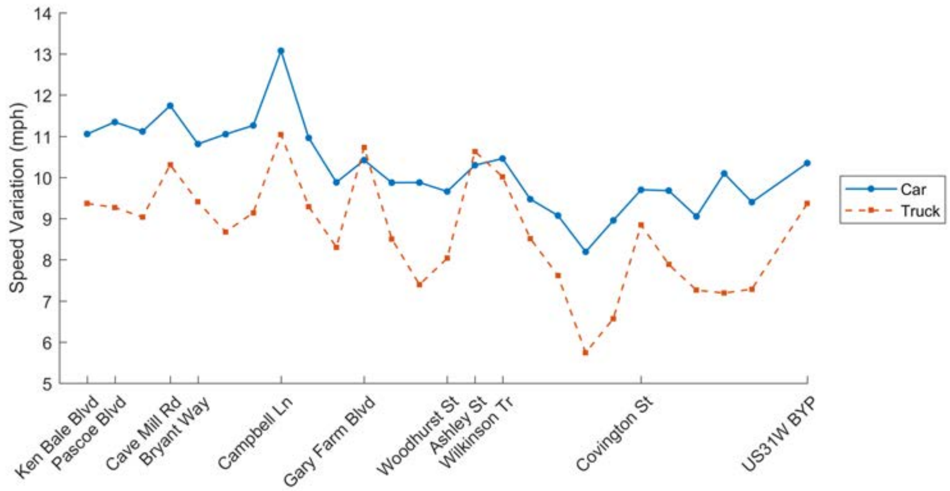



(b) Midday period

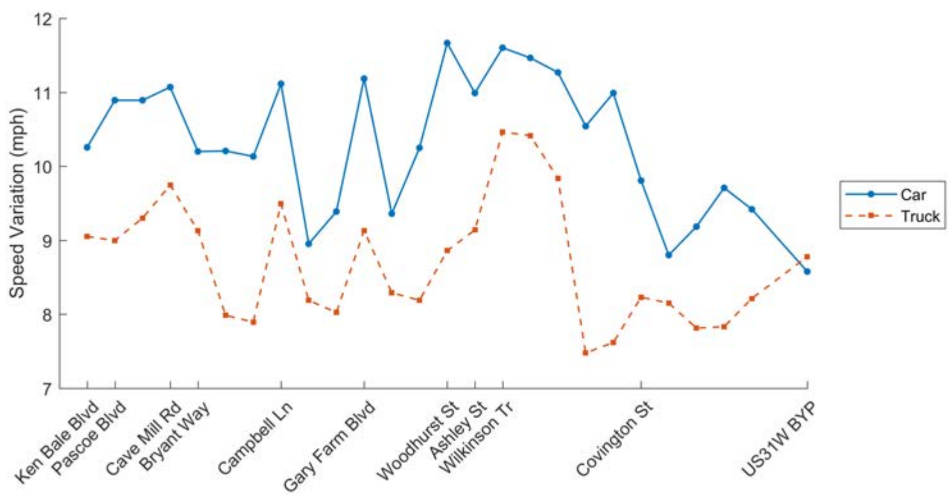



(c) PM period

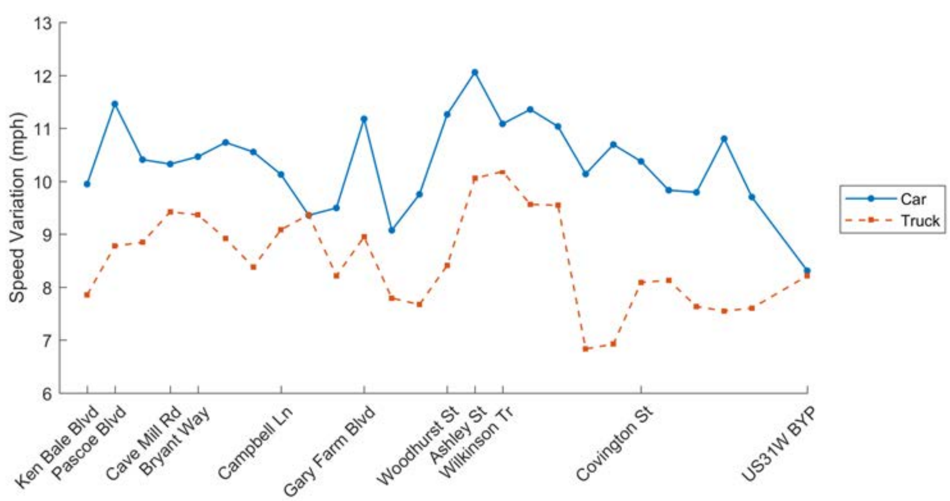
**Figure C-19 US-231 northbound average speed comparison between car and truck**




(a) AM period

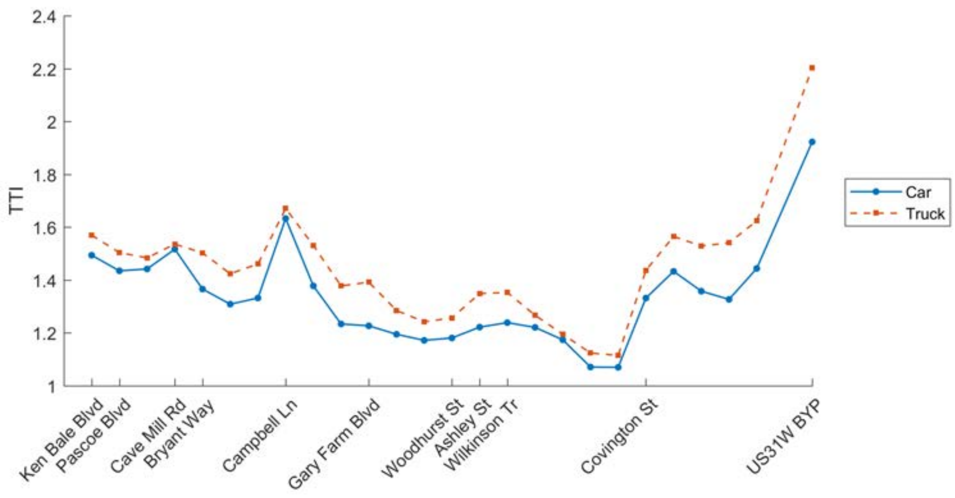



(b) Midday period

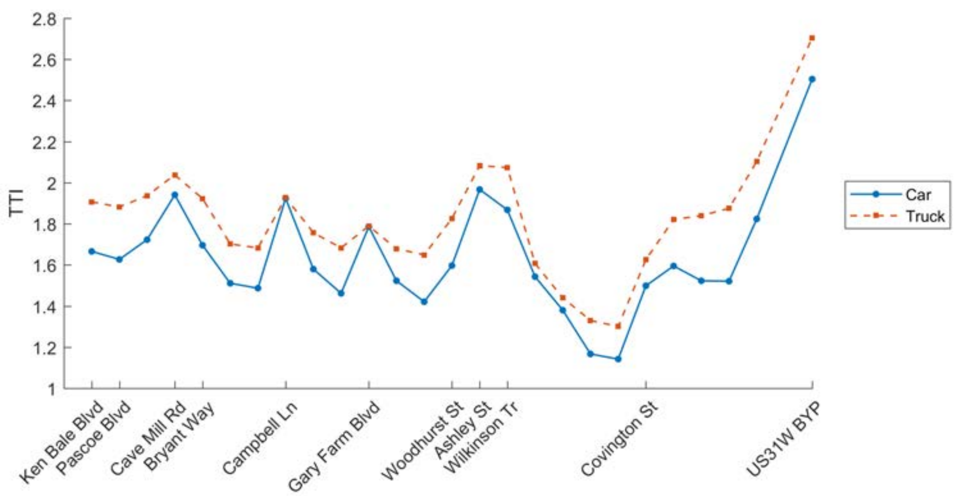



(c) PM period

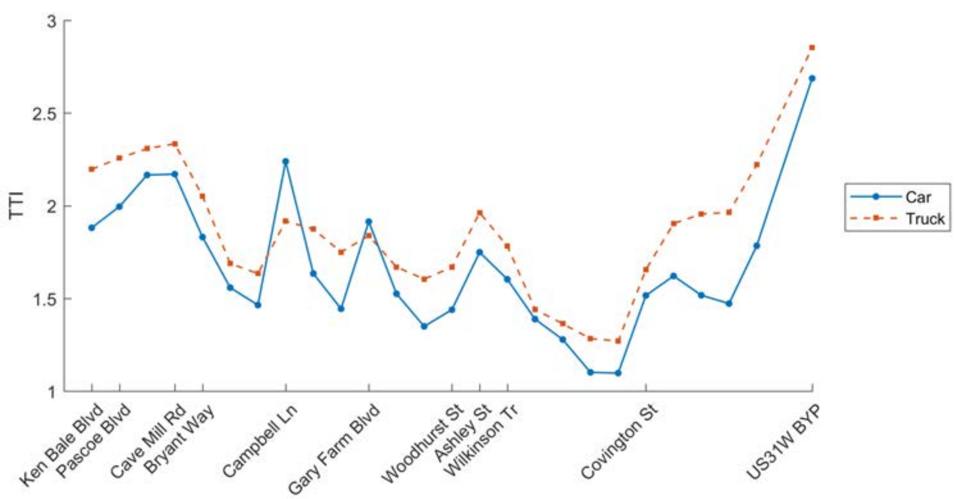
**Figure C-20 US-231 northbound speed variation comparison between car and truck**




(a) AM period

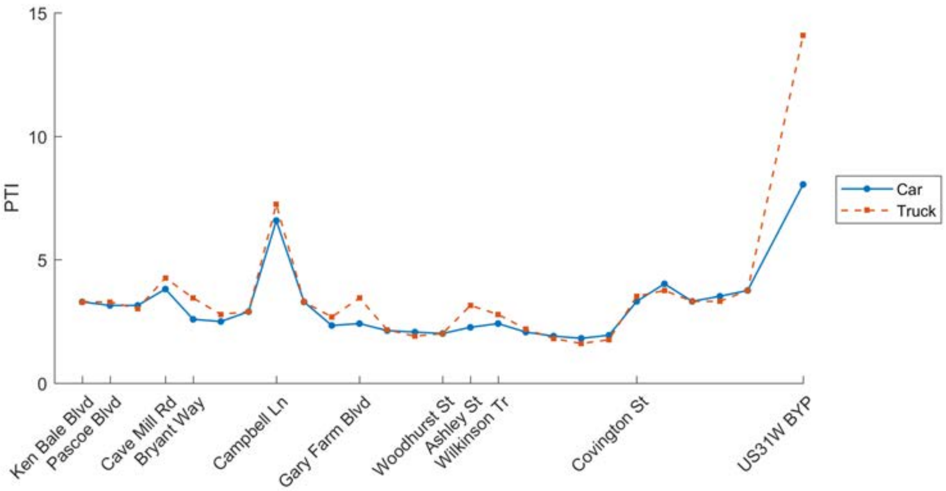



(b) Midday period

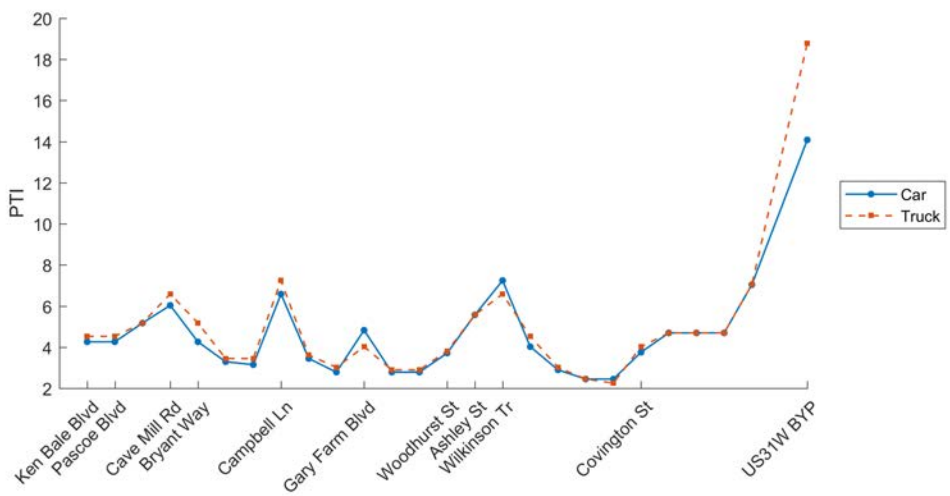



(c) PM period

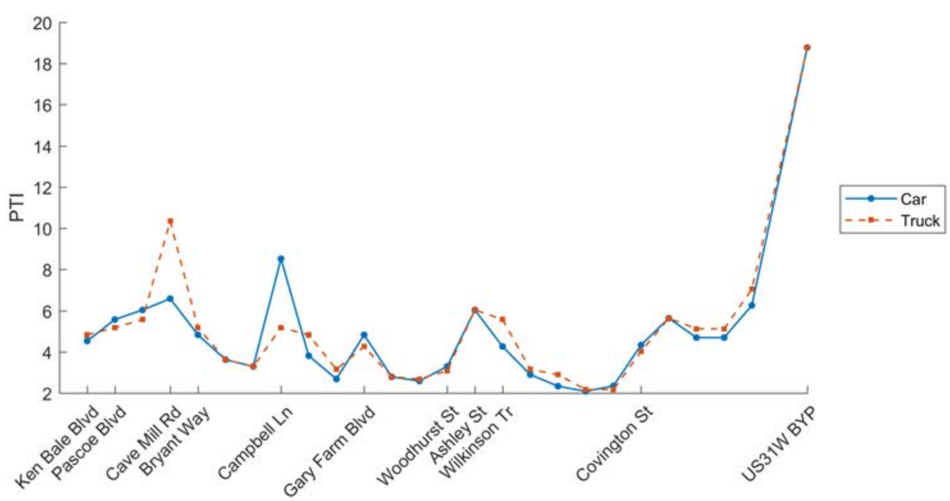
**Figure C-21 US-231 northbound travel time index comparison between car and truck**




(a) AM period

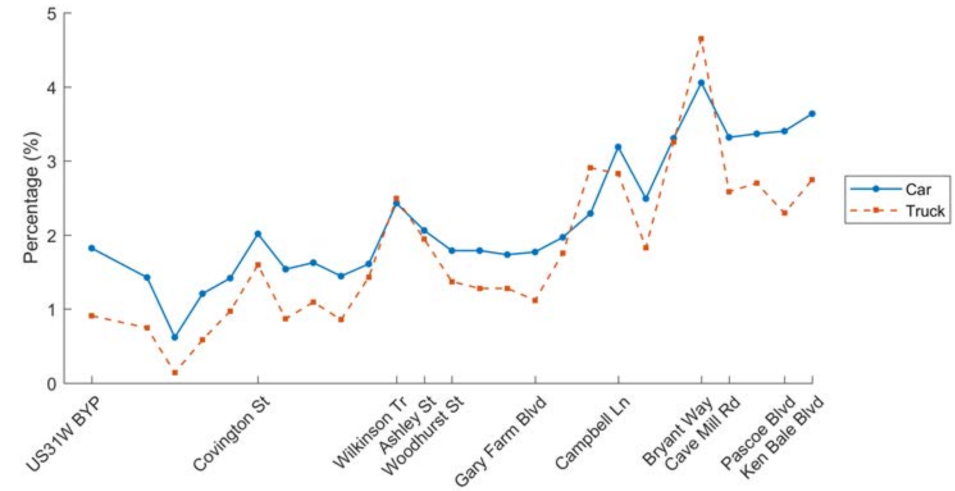



(b) Midday period

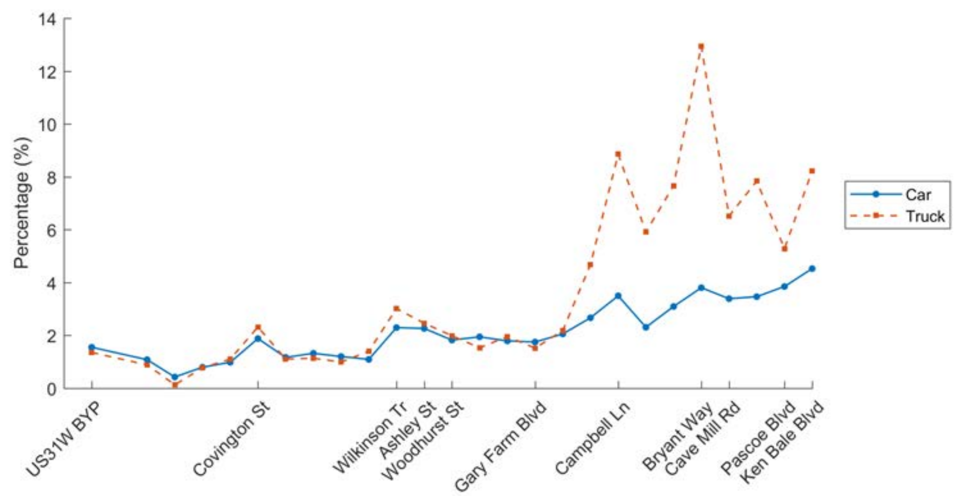



(c) PM period

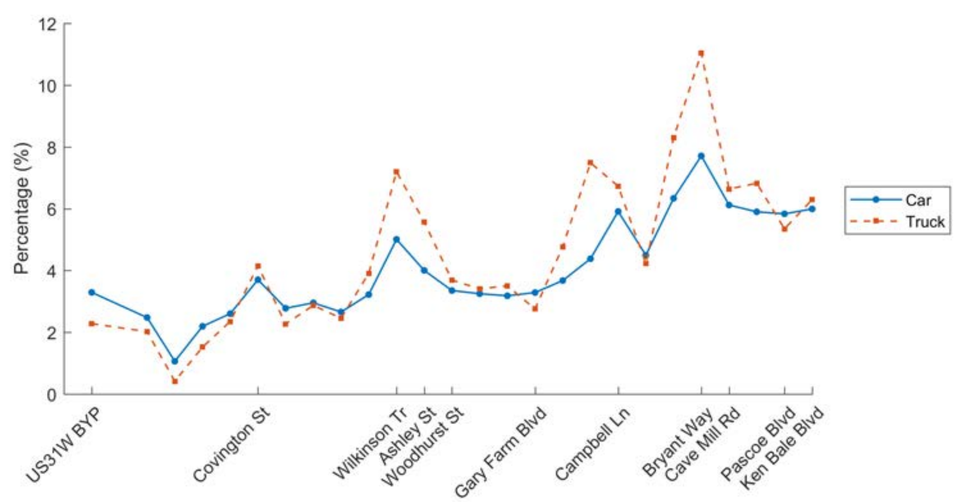
**Figure C-22 US-231 northbound planning time index comparison between car and truck**



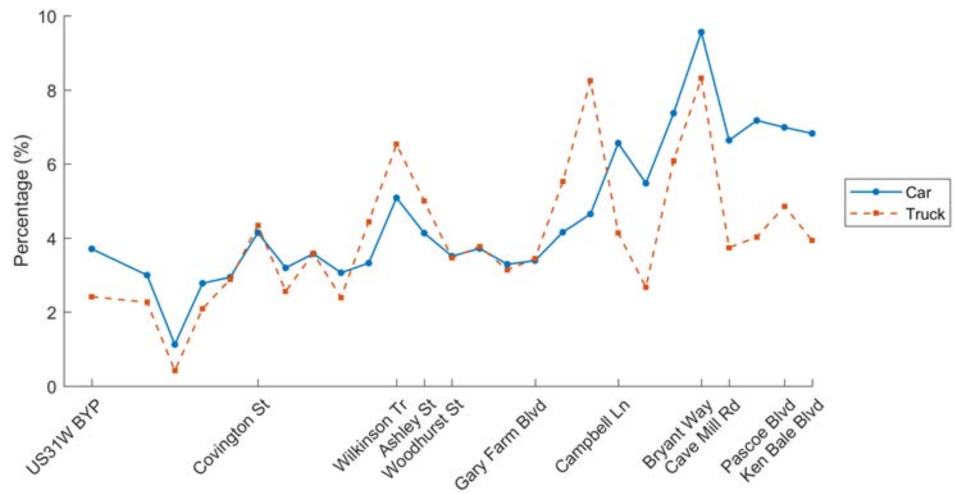

(a) All year




(b) AM period

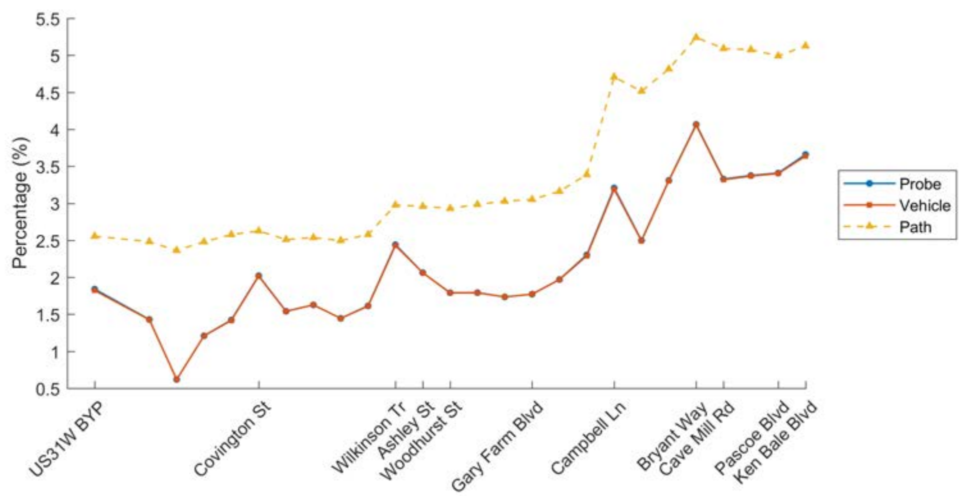



(c) Midday period

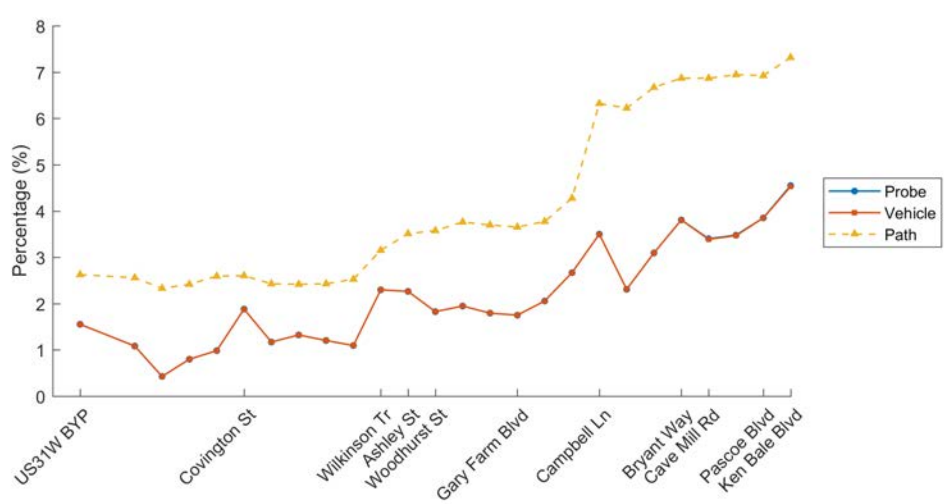



(d) PM period

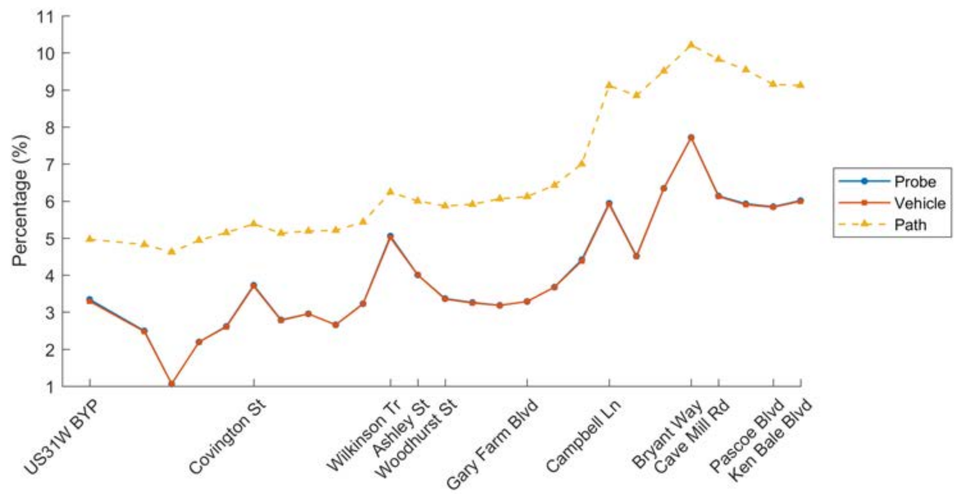
**Figure C-23 US-231 southbound vehicle data sample coverage between car and truck**



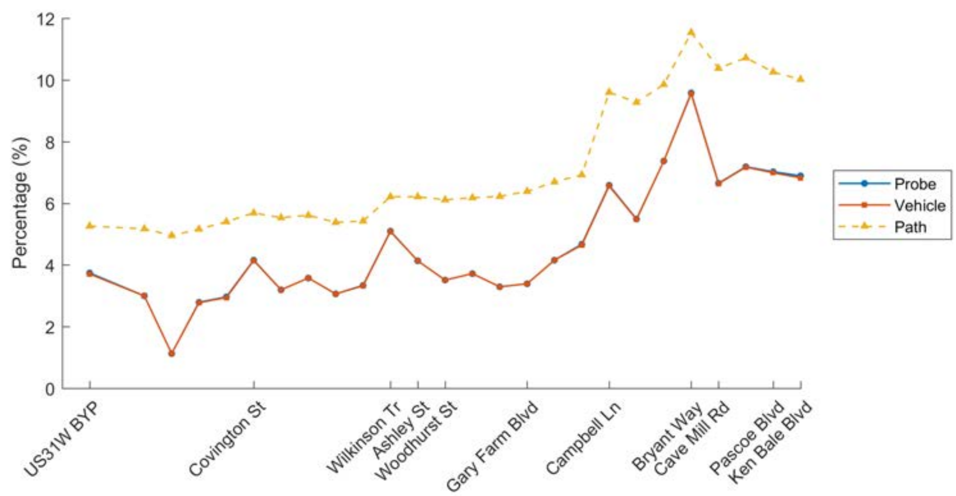

Car All Year




(a) AM period

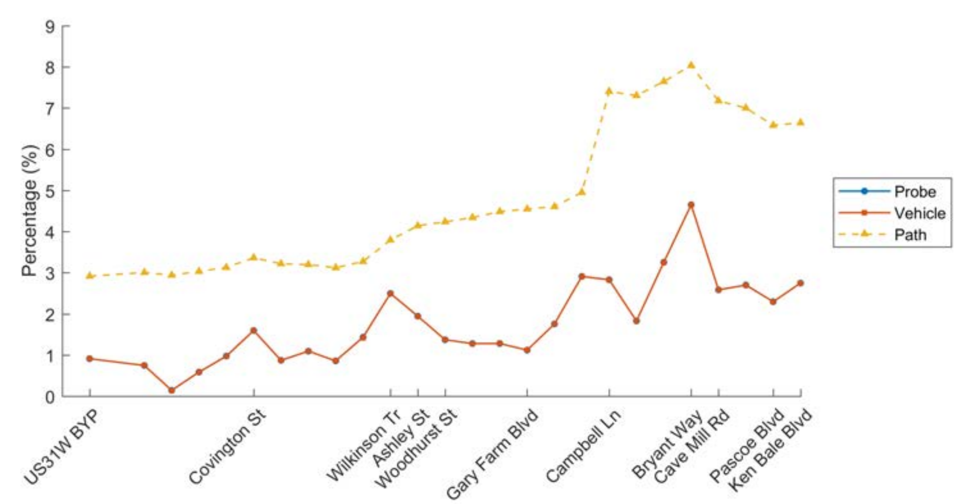



(b) Midday period

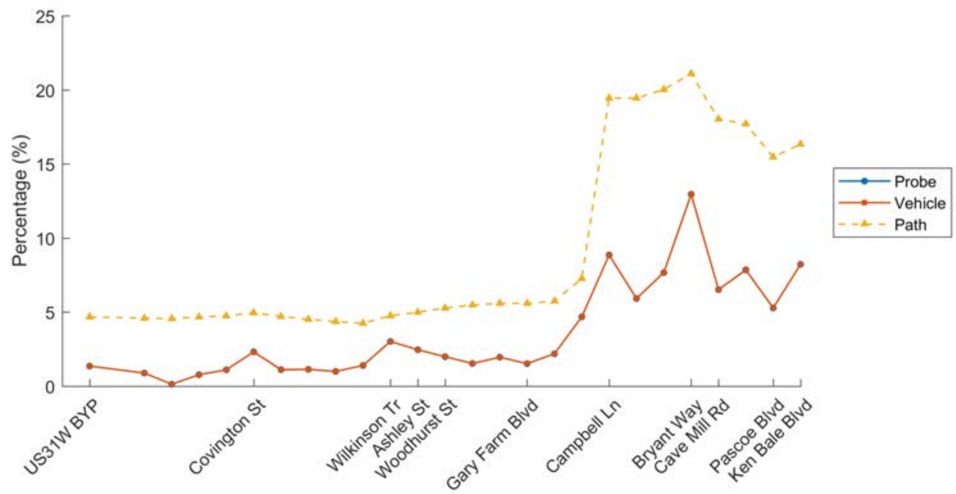



(c) PM period

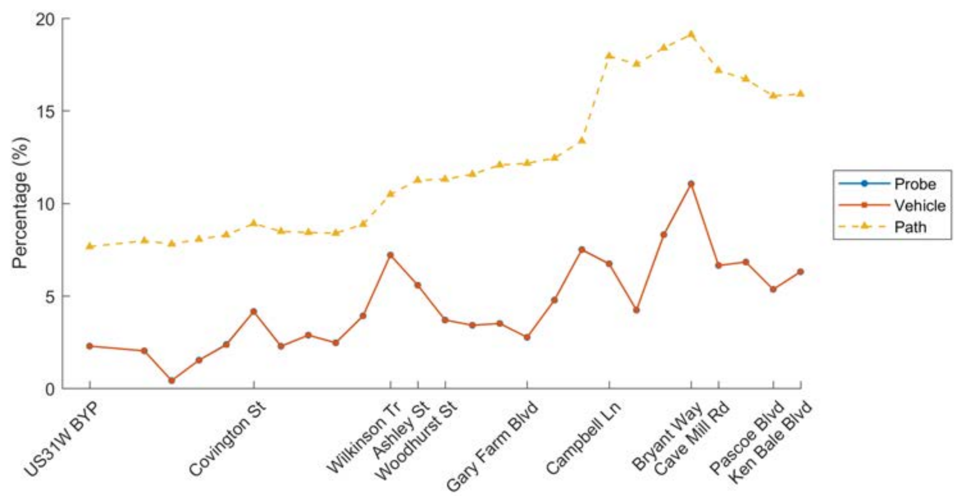
**Figure C-24 US-231 southbound car sample coverage among probe, vehicle and path**



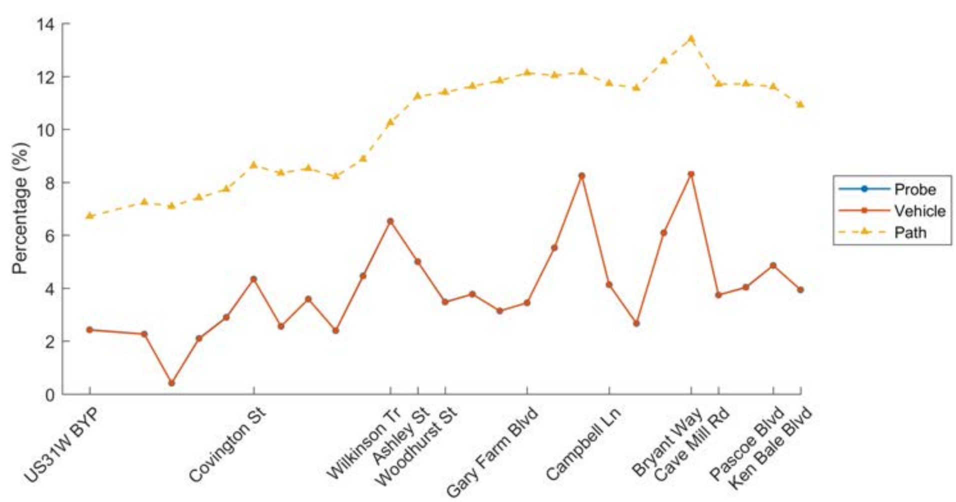

(a) All year




(b) AM period

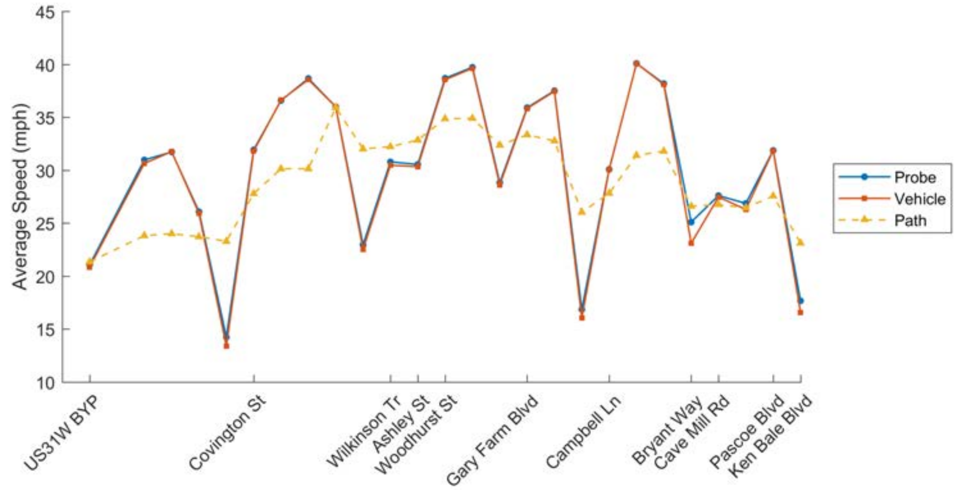



(c) Midday period

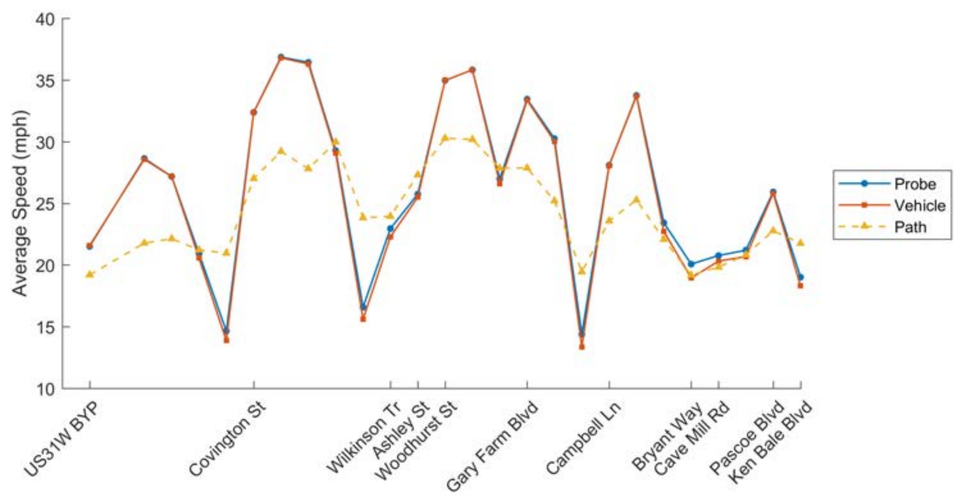



(d) PM period

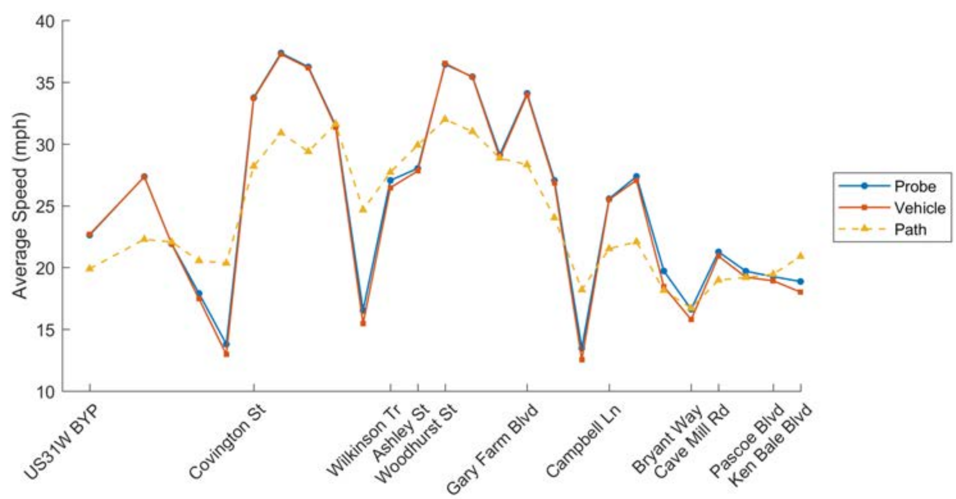
**Figure C-25 US-231 southbound truck sample coverage among probe, vehicle and path**




(a) AM period

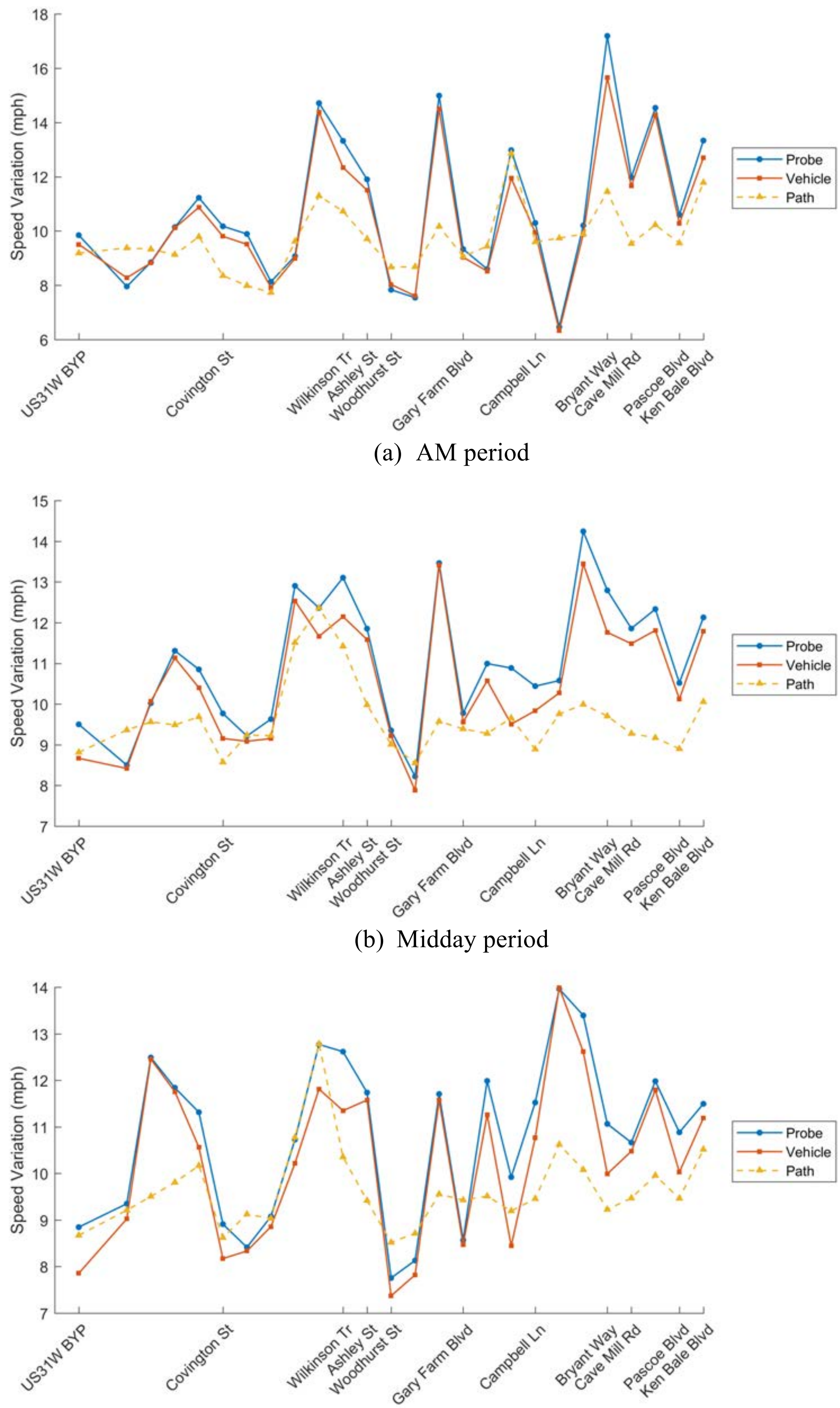



(b) Midday period




(c) PM period

**Figure C-26 US-231 southbound average speed from probe, vehicle and path**

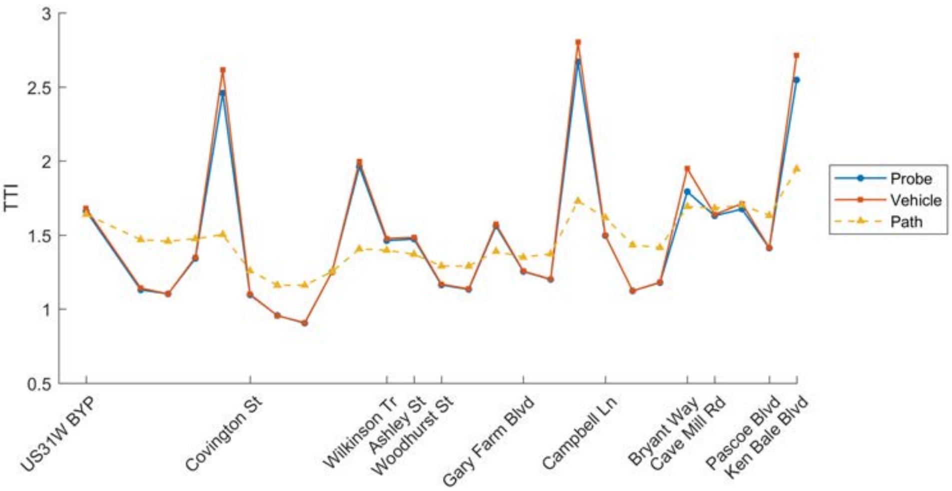



(a) AM period

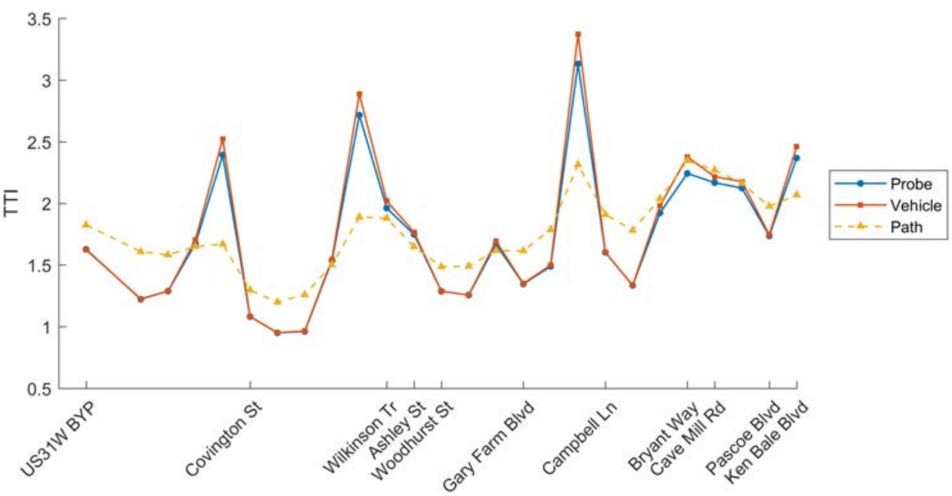
(b) Midday period

(c) PM period

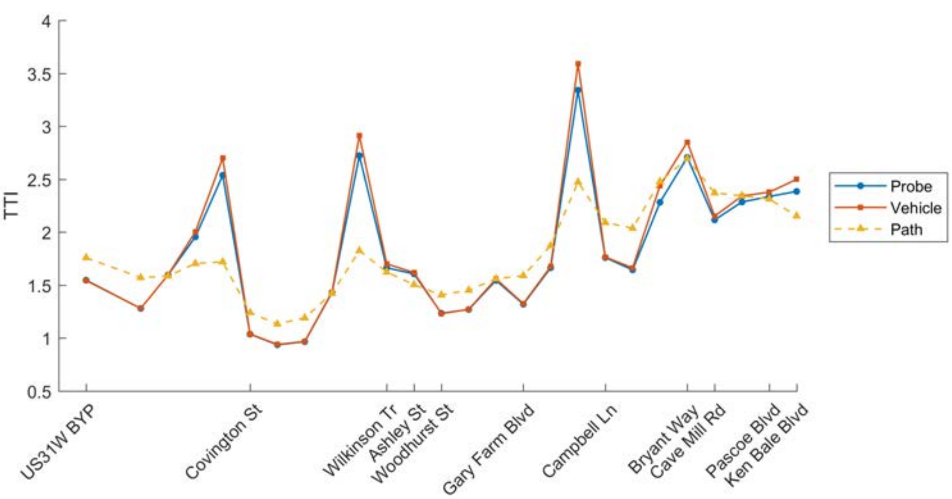
**Figure C-27 US-231 southbound speed variation from probe, vehicle and path**




(a) AM period

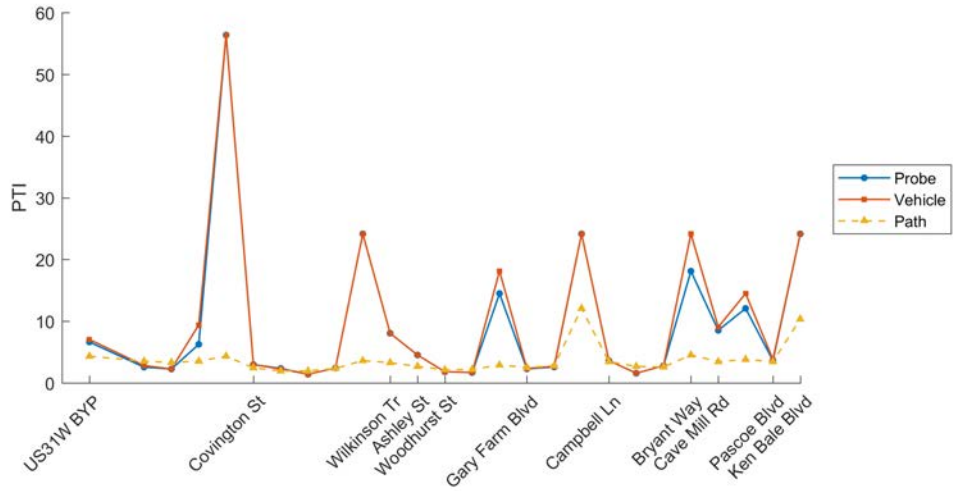



(b) Midday period

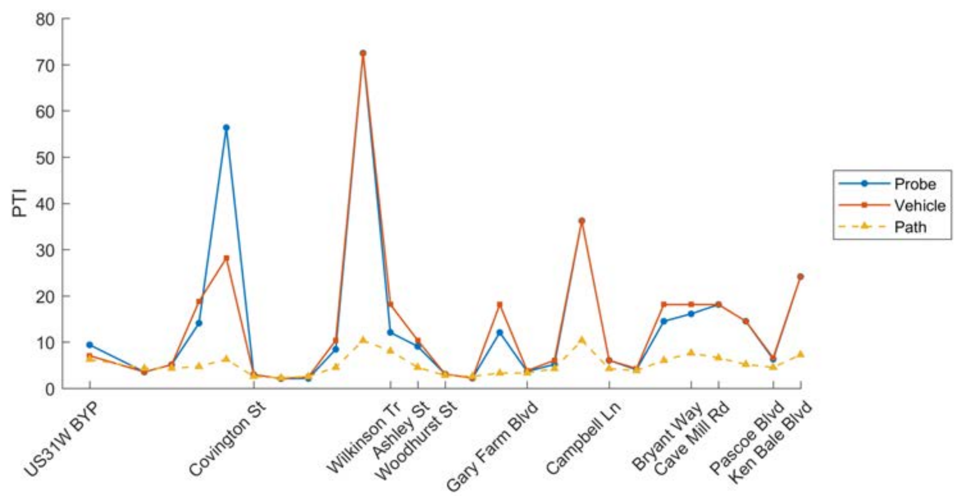



(c) PM period

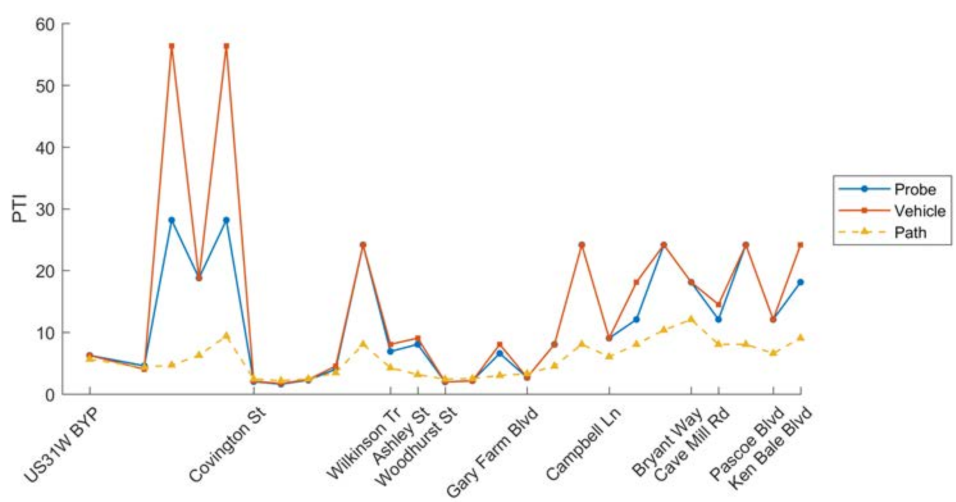
**Figure C-28 US-231 southbound travel time index from probe, vehicle and path**




(a) AM period

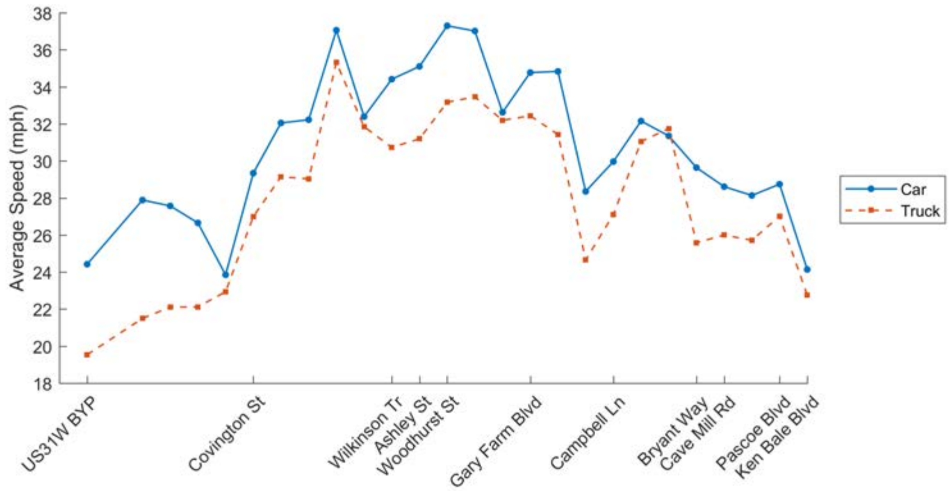



(b) Midday period

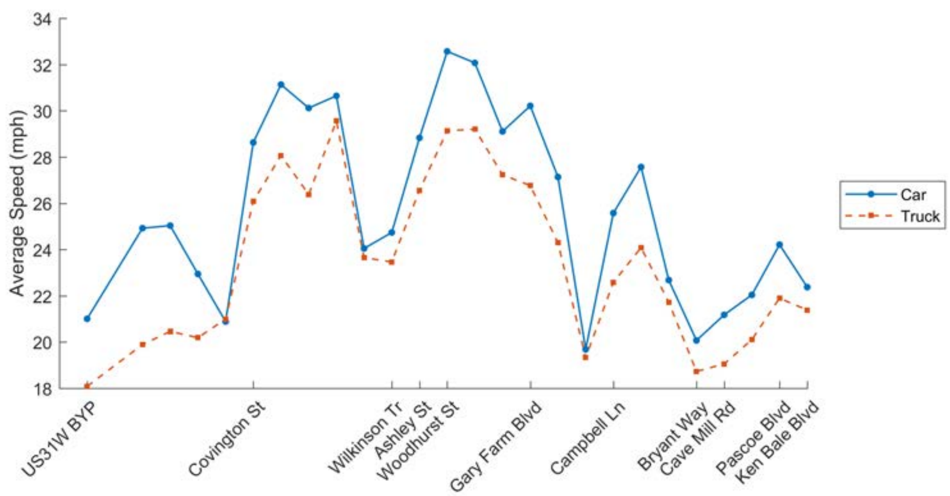



(c) PM period

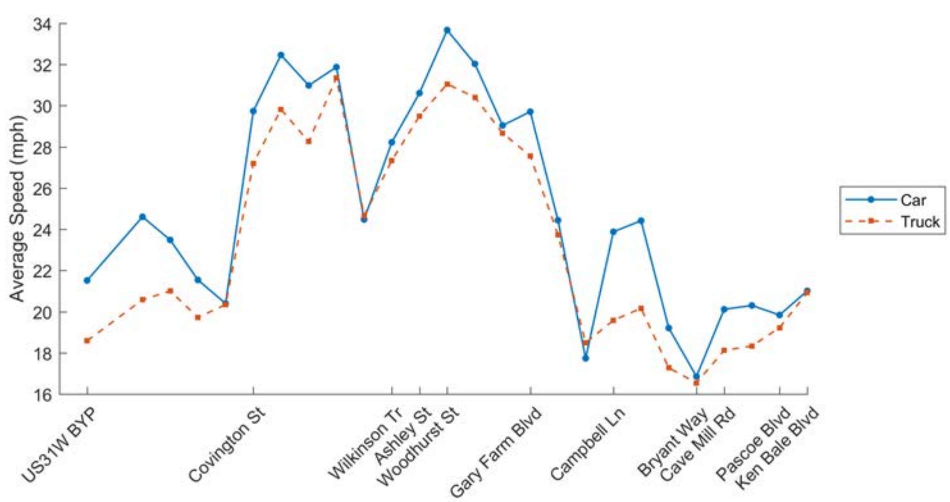
**Figure C-29 US-231 southbound planning time index from probe, vehicle and path**




(a) AM period

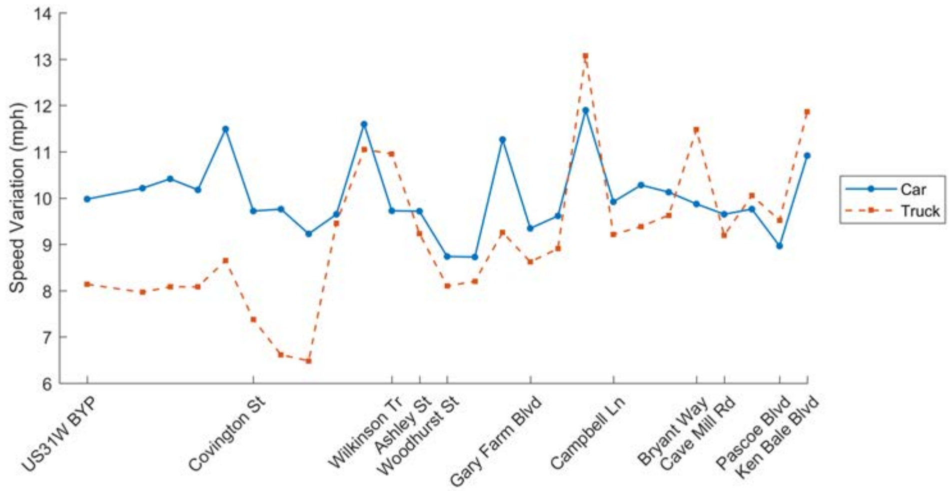



(b) Midday period

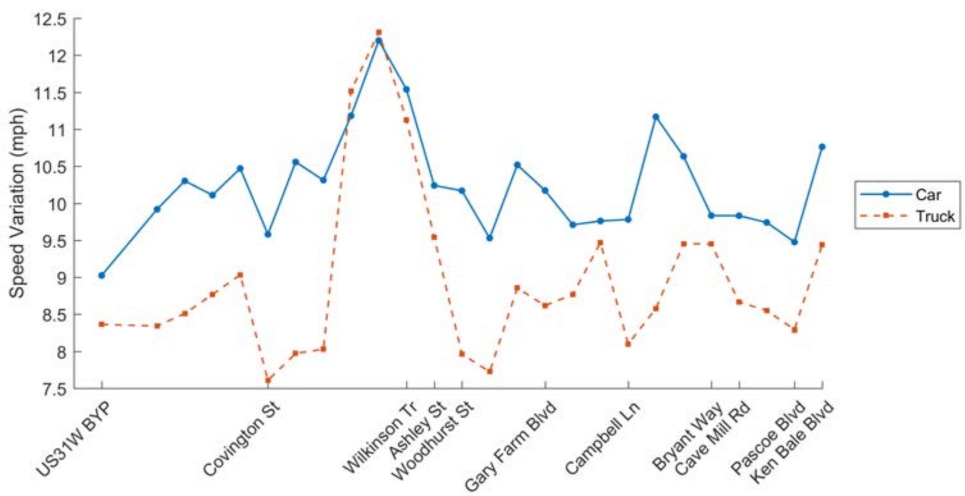



(c) PM period

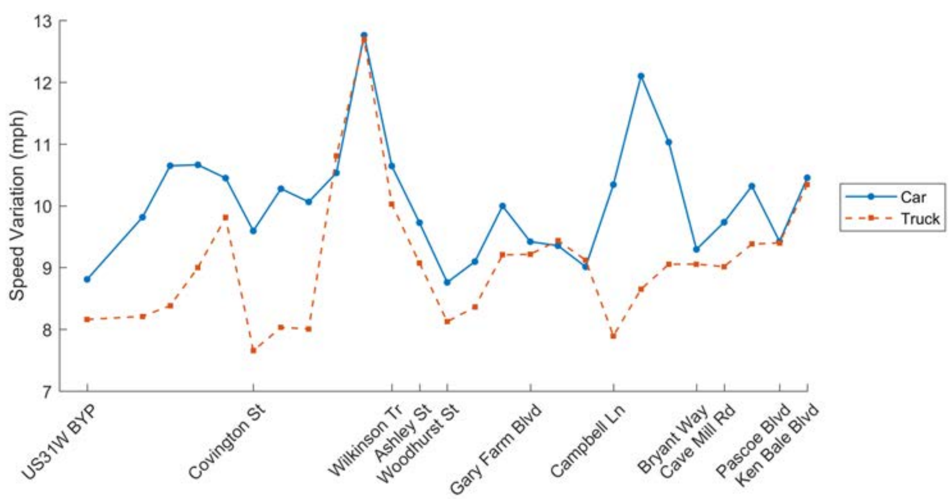
**Figure C-30 US-231 southbound average speed comparison between car and truck**



(a) AM period

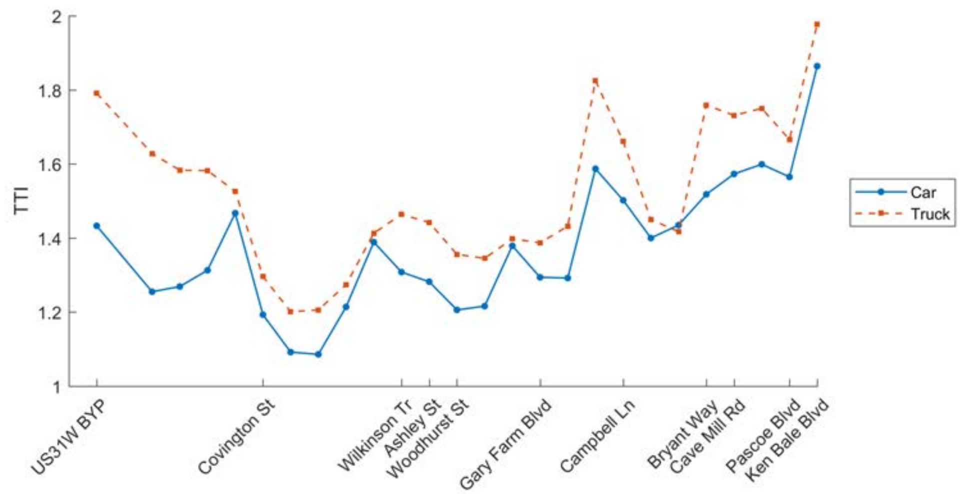


(b) Midday period

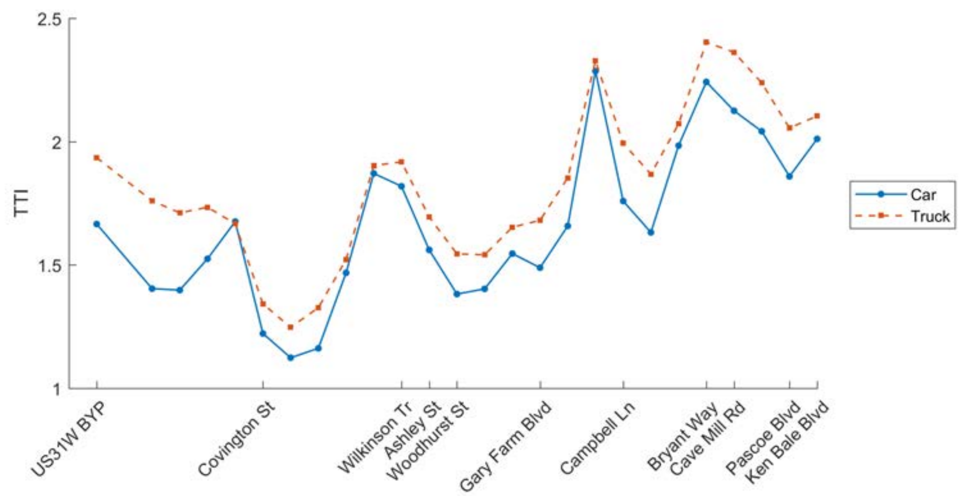


(c) PM period

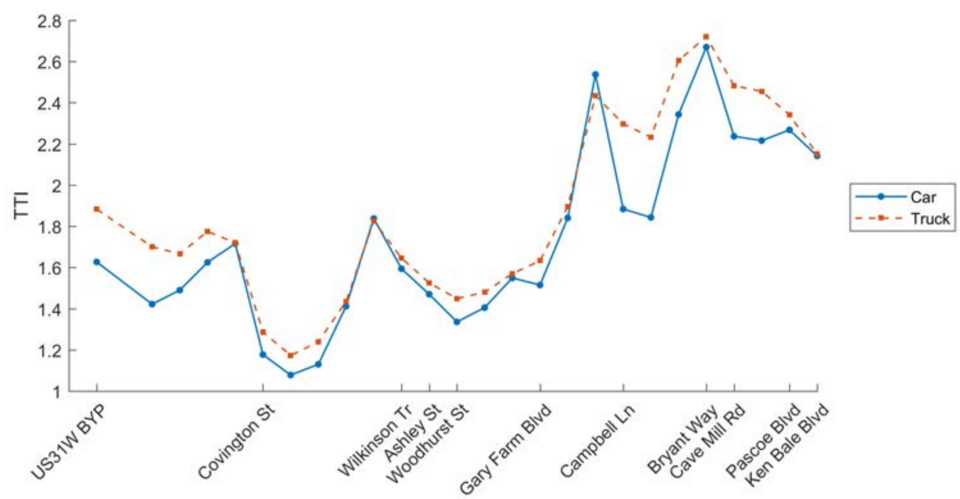
**Figure C-31 US-231 southbound speed variation comparison between car and truck**




(a) AM period

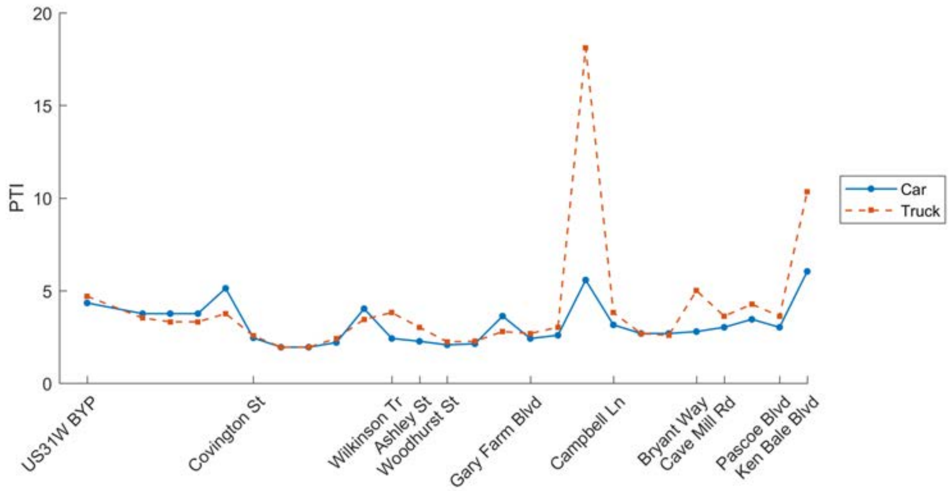



(b) Midday period

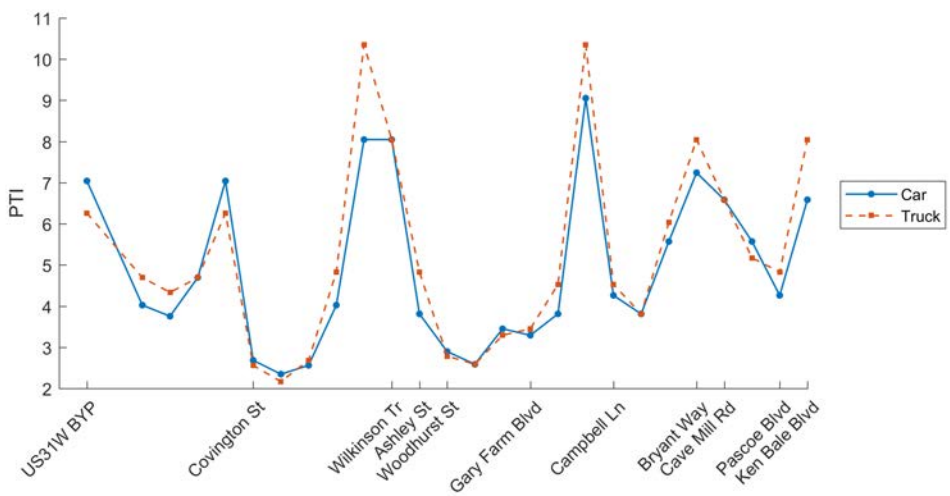



(c) PM period

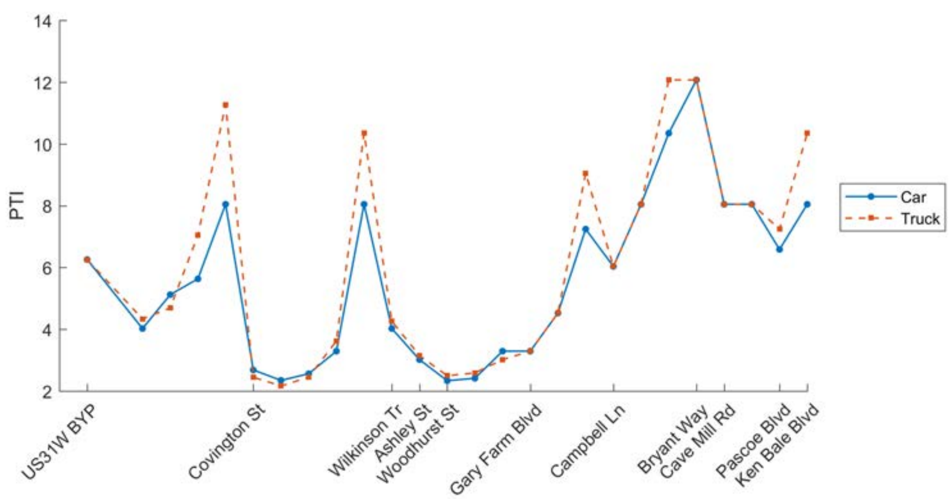
**Figure C-32 US-231 southbound travel time index comparison between car and truck**




(a) AM period




(b) Midday period




(c) PM period

**Figure C-33 US-231 southbound planning time index comparison between car and truck**