COMPARISON OF CELL, GPS, AND BLUETOOTH DERIVED EXTERNAL O-D DATA – RESULTS FROM THE 2014 TYLER, TEXAS STUDY

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ABSTRACT

This paper documents a first-of-its-kind study conducted by the Texas A&M Transportation Institute (TTI) in coordination with the Texas Department of Transportation (TxDOT) in the spring 2014. The study’s scope was to collect, analyze, and compare external origin-destination (O-D) data for the Tyler Metropolitan Planning Organization (MPO) study area in Texas using Bluetooth technology provided by TTI, cellular data provided by Airsage, and GPS data provided by INRIX. The chief purpose of the study was to determine if cell and GPS data were viable for use in TxDOT’s external surveys so that TxDOT could resume collecting external data for Texas MPOs. The study focused on external-external (E-E) trips, but also provided some results related to external-internal/internal-external (E-I)/(I-E) trips.

The paper discusses study design, conduct, and the results in terms of the comparison of external trip data derived from Bluetooth, cellular, and GPS sources. The paper describes the TTI Bluetooth data collection, the acquisition of private sector cellular and GPS data, and the sampling and analysis of each data type. The study design included the aggregation of the Tyler MPOs traffic analysis zone system into larger zones and the development of large ‘travel shed’ zones around the periphery of the study area to better accommodate cell data capture. It also included an approximate 10-mile buffer around the study area for GPS data capture. One month of cellular data was acquired for the study that included data for average weekdays and weekends, AM and PM peak data, and 24-hour totals. Three months of pre-processed GPS data from INRIX was acquired for the study. INRIX provided separate data sets for GPS data sources from cars, freight/commercial fleet vehicles, and mobile applications. TTI collected Bluetooth data at 20 external stations for a two-week period and used data from Tuesdays, Wednesdays, and Thursdays to develop average weekday results.

Based on TTI’s extensive use and experience with Bluetooth technology and E-E data collection, Bluetooth data were used as a benchmark comparison to the cellular and GPS data. The study found that Bluetooth and GPS E-E results were most similar and that cell data under-estimated E-E trips. It also found that GPS O-D data (at the time) had a commercial vehicle bias and researchers suspect that cell data has a non-commercial vehicle bias. The paper provides results of O-D comparisons by technology with the key results summarized in the areas of 1) general findings, 2) E-E trips, and 3) E-I/I-E trips.

Keywords: Bluetooth, cellular, GPS, external, E-E, E-I, I-E, origin-destination, O-D, survey, technology
INTRODUCTION

This study was conducted by the Texas A&M Transportation Institute (TTI) in coordination with the Texas Department of Transportation (TxDOT) in the spring of 2014. The scope was to collect, analyze, and compare external origin-destination (O-D) data for the Tyler Metropolitan Planning Organization (MPO) study area using Bluetooth technology provided by TTI, cellular data provided by Airsage, and Global Positioning Satellite (GPS) data provided by INRIX. The chief purpose of the study was to determine if cell and GPS data were viable for use in TxDOT’s external surveys so that TxDOT could resume collecting external data for Texas MPOs. The key objectives of the study were to compare:

- External – External (E-E) trips between Bluetooth, cell, and GPS data;
- Commercial/freight E-E trips between Bluetooth and GPS;
- External-Internal/Internal-External (E-I/I-E) matrices and trip length frequency distributions between cell and GPS; and
- Where possible, compare study results to those of the Tyler 2004 External Survey (1).

To help improve the accuracy of cell data results, Airsage recommended that internal study area zones be a minimum of 500 meters x 500 meters in size (unpublished data, personal communication: TTI conference call with AirSage, discussion of cell data purchase on design of Tyler O-D study, March 28, 2014). Based on this criterion, the Tyler study area’s 420 traffic analysis zones (TAZs) were aggregated into 307 larger zones. Eighteen (18) large external zones were created around the periphery of the study area to capture cell data in these areas. The external capture zones were jointly developed by TTI and Airsage considering a 45-minute travel time buffer around the study area. The use of the buffer increased the likelihood of including vehicles where no cell phones were actively in use by capturing off-call handover cell sightings. Per the recommendation of INRIX, a 10-mile buffer was used around the study area to capture travel from GPS devices. Figure 1 shows the study area zones and capture areas used for the study.
FIGURE 1 Study Area Zones, Capture Areas, and External Stations

LITERATURE REVIEW

Texas external O-D studies were originally performed using intercept roadside surveys (2). However, this is a cumbersome data collection method associated with safety and feasibility concerns. Therefore, researchers considered other methods of capturing external travel for use in transportation models, including the possibility of synthesizing the data rather than collecting it (3). Recent advances in technology have led to additional options being available for external O-D data capture. Bluetooth technology was used to estimate E-E trips in a 2011 study that compared the Bluetooth E-E results to those of the area’s 2002 external survey that was conducted using a roadside intercept method. Results of this study showed a higher percentage of Bluetooth E-E trips than the E-E trips obtained using the intercept method. Researchers attributed this increase in the ability to collect Bluetooth data during non-daylight periods and an increase in growth of travel volumes between the two study periods (unpublished data, 2011 Bryan-College Station Bluetooth External Study, Technical Memorandum to the Texas Department of Transportation from Stephen Farnsworth of TTI) (4). However, Bluetooth’s usefulness in external studies is limited to the study of E-E trips. Cell and GPS technologies have emerged as possible options in capturing not only E-E trips, but also E-I/I-E trips. However, cell and GPS data are associated with questions of positional accuracy, sample size, sample penetration, and vehicle type biases.

Several studies have been performed to assess the use of cell data for external O-D studies with varying scopes and locations (5-13). The focus of these studies has largely been on comparing cell data to existing model outputs. Many of the results point to cell data being a useful tool in determining external O-D tables, though they are largely preliminary in nature and
highlight the need to further understand just what the cell data represent and how they compare
to data obtained using more traditional methods. Multiple studies stress the importance of
selecting the proper zone size to effectively capture external trips.

Though not as prevalent as cellular O-D studies, the literature points to a handful of
recent, and in some cases on-going, GPS O-D studies. TTI obtained and processed third-party
GPS data in both 2011 and 2013 from national data providers. These efforts used regional and/or
national GPS datasets to study the O-D patterns and the quality, granularity, and continuity of
trip data and traces. In both cases TTI found the GPS data sample penetration to be low, though
it was useable in developing and evaluating external trips (14). A study performed by the SRF
Consulting Group used INRIX GPS data to study congestion relief on IH-494/Highway 62 in the
Twin Cities area of Minnesota. Using data from 300,000 trips, they were able to develop O-D
tables and calibrate a travel model for the study corridor (unpublished data, INRIX Q&A
Session, Presentation to MnDOT Metropolitan Council by SRF, January 20, 2016). The
Maryland Freight Fluidity Study is an ongoing research effort where INRIX data are available
from 20 million trips and 5.5 million unique devices. One aspect of the study is to analyze O-D
data to help identify areas of congestion and provide suggestions of alternative routes that could
be used to reduce congestion (unpublished data, Freight Fluidity Framework, Calculation
Procedures and Analysis Findings, Technical Memorandum for the Maryland State Highway
Administration from Bill Eisele of TTI through University of Maryland, June 1, 2015).

While there are a large number of cell O-D studies and a handful of GPS O-D studies
cited in the literature, there have been very few studies focused on comparing the results
obtained from different new technologies. Fehr & Peers performed a NAPA County travel
behavior study comparing five data collection methods including vehicle classification counts,
winery regression analysis, license plate matching, surveys and mobile device data. The mobile
device data were INRIX and Streetlight data, which were found to provide a large sample size at
a relatively low cost. However, the fact that demographic information is not available from
cellular O-D data and the need to infer trip purpose are weaknesses of GPS data. Therefore, data
obtained from all methods were used in improving and assessing existing model results (15; 16).

The Tyler study presented within the present work represents a first-of-its-kind study to
compare cellular, GPS and Bluetooth external O-D data. Note that several of the cited studies
have been performed since the time of the Tyler Study discussed in this paper. TTI is currently
performing another comparative study of cell, GPS and Bluetooth external O-D data in the
Dallas-Fort Worth region of Texas. TxDOT is sponsoring the study and results from this effort
should be available by the fall of 2017.
BLUETOOTH DATA COLLECTION AND ANALYSIS

TTI’s Bluetooth technology and E-E data collection has been thoroughly tested and vetted (14). Agency researchers believe it is currently the best means of estimating E-E trips for urban areas and therefore used it as a benchmark comparison to the cellular and GPS data. Based on this premise, if the E-E estimates derived from the cellular and GPS data compared well to the Bluetooth E-E estimates, it could be assumed that the I-E/E-I estimates from those same sources could be considered reasonable.

TTI collected Bluetooth data for a two week period and used data from Tuesdays, Wednesdays, and Thursdays to develop average weekdays results. Two weeks was the longest time period Bluetooth data could be collected due to the battery life of the mobile Bluetooth devices. Cellular data were harvested for a one-month period at the recommendation of Airsage. GPS data were acquired for a three-month period due to its lower sample penetration rate. Data collection between the three technologies were coordinated such that the data collection time periods of the cell and GPS data centered around the first two weeks of April 2014 when the Bluetooth and traffic counts data were collected.

Bluetooth data and vehicle classification counts were collected at 20 external stations, which were the same stations used in the 2004 Tyler External Survey (unpublished data, 2004 Tyler External Survey, prepared for TxDOT by Stephen Farnsworth, April 2005). While deployed, the mobile Bluetooth units transmitted data in real-time to the TTI host software. Bluetooth data were also saved/retained in the portable devices in case of spotty or interrupted cell service so that the “raw” Media Access Control (MAC) address values were not lost. Since the Bluetooth results represent only a sample of traffic travelling through the area, the counts served as a basis for expanding the Bluetooth data (unpublished data, 2014 Tyler Bluetooth External Study, Technical Memorandum to TxDOT from Stephen Farnsworth and Darrell Borchardt, November 11, 2014).

Over 170,000 Bluetooth observations were captured during the survey period. Across all external stations, Bluetooth detection ranged from about 4-to-11 percent. The Bluetooth detections were processed to determine the number of daily matches between each external location and all other locations. All matches that had an observed travel time that exceeded the time skim value were assumed to have stopped at some point between the Bluetooth locations and therefore were removed from the analysis of through (E-E) trips. Such matches were removed because if a vehicle stopped in the study area it would be classified as an E-I or I-E trip.

There were nearly 4,100 weekday matches and over 1,800 weekend matches. Using the expansion factors developed for each Bluetooth location, the raw data were expanded and balanced to produce final O-D matrices for the external locations. Additionally, the distribution of commercial and non-commercial vehicles by location was used to proportion the matrix results by vehicle type.

CELL DATA ACQUISITION AND ANALYSIS

One month of cellular data was acquired for the study. It included data for average weekdays and weekends, AM and PM peak data, and 24-hour totals. It also included resident class attributes for two categories; residents and visitors. The cell data acquired included 198,344 unique devices, which represented a 17.1 percent sampling rate of the study area population (unpublished data, email from AirSage’s Vijay Sivaraman to TTI’s Ed Hard, Subject: Tyler Data, August 25, 2015). Airsage reported an average of 180 device sightings per day for the study area. The data were expanded by Airsage to the census tract of the device home location to
account for different penetration rates. Estimated trips from device movement data were provided for each device by longitude/latitude. Within the data set, each device is identified as a resident of visitor based on the nighttime resting place of the device (unpublished data, email from AirSage’s Vijay Sivaraman to TTI’s Ed Hard, Subject: Tyler Study Comments/Questions, October 9, 2014).

Upon review, the initial cell data submission included erroneous trips between the large external capture areas and defined devices with home locations in the external capture areas as residents (when they should have been visitors). Airsage reprocessed and resent the cell data to correct these items. TTI analyzed the data in relation to the internal zone structure and the external capture areas to identify and analyze E-I, I-E, and E-E trips as well as resident versus non-resident trips by external station. The key products resulting from the analysis of E-E cell data included an expanded trip matrix and related matrices by time periods and resident classes; traffic counts by station; and the percent splits of residents versus non-residents by station. The key products from the analysis of E-I/I-E data included an expanded trip matrix and related matrices by time periods and resident classes and trip length frequency results for the study area and by station.

GPS DATA ACQUISITION AND SAMPLE

Three months of pre-processed GPS data from INRIX was acquired for the Tyler Study in the spring of 2014. INRIX used GPS data collected within the Tyler MPO study area (Smith County, TX) and within an area that was roughly a 10-mile buffer around the study area (see Figure 1). This buffer served as a means to detect and capture trips that began or ended outside of the study area. INRIX provided separate data sets for GPS data sources from non-commercial passenger cars/vehicles, commercial/freight vehicles (including trucks), and mobile applications. They also provided a fourth total data set, which included GPS data from all sources combined. (It should be noted that due to the new manner in which INRIX’s Trips products captures trips, a buffer around a study area is no longer needed).

The collection period for GPS data spanned 74 days. The original total data set had 500,019 records. After removing the data collected on a holiday (Good Friday), there were 492,023 records remaining. Each record contained a unique device identification (ID) and the trip ID with time-stamped trip end locations. Trip ends were pre-processed by INRIX using a 10-minute dwell time threshold and the time stamps for trip ends were rounded to the nearest hour. The actual trip end locations were anonymized by offsetting the first five minutes for the trip origins and the last five minutes for the trip destinations. For the purpose of E-E trip comparison with Bluetooth data, if the GPS traces passed a Bluetooth reader location, the station number and time stamp rounded to the nearest 10 minutes were recorded.

The distribution of GPS data by sources for commercial/freight vehicles, non-commercial passenger vehicles, and mobile applications were 57 percent, 16 percent, and 27 percent, respectively. Using the frequency of the GPS passes and the traffic counts collected at the external stations, TTI calculated the sampling rate of the GPS data to be about 1.6 percent for the study area. As expected, the GPS saturation rate was lower than the cellular data, but it is expected to increase over time. Since the Tyler study was conducted in early 2014, TTI researchers believe that the saturation of car/non-freight GPS data has improved relative to the truck/freight data.

TTI and INRIX coordinated on the GPS data elements that were delivered in the data set. These elements were as follows.
Vehicle ID. An anonymous unique identifier for each vehicle.

2. Trip ID. A unique identifier for each trip.

3. Day type of trip: An identifier where 1=Weekday, 2 = Weekend.

4. Start time of trip. The time when the trip began, rounded to the nearest hour.

5. Start location. The latitude/longitude coordinates where the trip began.

6. First external station crossed. The external station number where the trip first entered and/or exited the study area boundary. Note that I-E and E-I trips will only cross the study area boundary one time.

7. First crossing time of trip. The time, rounded to the nearest 15-minute time period within the hour, when the trip crossed the external station identified in item 6.

8. Second external station crossed. The external station number where the trip entered and/or exited the study area boundary for the second time. This field was only populated for E-E trips.

9. Second crossing time of trip. The time, rounded to the nearest 15-minute time period within the hour, when the trip crossed the external station identified in item 8. This field was only populated for E-E trips.

10. End time of trip. The time when the trip ended, rounded to the nearest hour.

11. End location. The latitude/longitude coordinates where the trip ended.

12. Vehicle type. An integer estimating the type of vehicle, which completed the trip, where 1 = freight, 2 = non freight.

13. First buffer sighting. The time, rounded to the nearest hour, when the vehicle was first sighted in the buffer area.

14. Last buffer sighting. The time, rounded to the nearest hour, when the vehicle was last sighted in the buffer area.

DEVELOPMENT OF O-D MATRICES FROM INRIX DATA

The GPS trip ends provided by INRIX were processed and analyzed by TTI in relation to E-E, E-I, I-E, Internal-Internal (I-I) trip types and the 20 external stations, the 320-zone TAZ structure, the study area boundary, and the buffer area surrounding the study area. Data on trips where both trip ends occurred within the 10-mile buffer area were excluded from the study (since they were not an E-E, I-E, or E-I trip). Classification count data collected at each external station were used to expand the GPS data.

A TAZ polygon layer was overlaid on the trip end coordinates to identify the corresponding TAZ for each trip end. Since the trip ends provided were offset from the actual trip ends due to the anonymization process, an assumption had to be made in some cases to reclassify the trip end based on whether it should be inside or outside the study area. INRIX’s anonymization process offset the true origin and destinations by five minutes, which caused some trips to be misclassified relative to their being an I-E/E-I or an E-E trip. To account for this, a reclassification process was used that assumed a fixed distance threshold of three miles and reclassified the internal TAZs as external if the distance between the reported trip ends and the nearest external stations was less than the fixed threshold and the other trip ends are inside the study area. The trip type classification was based on the following.

- E-E trips must have both two external stations (Ext1 and Ext2) recorded and no internal TAZs.
- E-I trips must have TAZ1 as external and TAZ2 as internal. Either Ext1 or Ext2 is recorded. If both Ext1 and Ext2 are recorded, use Ext1.
- I-E trips must have TAZ1 as internal and TAZ2 as external. Either Ext1 or Ext2 is recorded. If both Ext1 and Ext2 are recorded, use Ext2.
- I-I trips must have both TAZ1 and TAZ2 as internal.

The trip records were used to build E-E O-D matrices for all vehicle types, commercial/freight vehicles, and non-freight (passenger vehicles plus mobile applications). TTI used the Tyler models skim travel times plus 10 minutes as the threshold for extracting out trips that may have stopped inside the study area. The 10-minute buffer was added to account for 10-minute rounding in GPS time stamps recorded at the external stations. The skim times were considered to be generally conservative and therefore no extra buffers were needed. In addition, this threshold was consistent with the values used for Bluetooth E-E analysis (except for the 10-minute buffer addition since the Bluetooth time stamps were reported as-is). Note that due to their coarser granularity, travel time constraints cannot be applied with cell data. The E-E trips totals produced from cell data are based on the time period of the cell dataset analyzed such as 24-hour, peak period, etc.

The GPS O-D matrices were balanced and then expanded since the GPS trips for the O-D pairs represented just samples of the population. A Fratar method was used to factor up the GPS sample O-D matrices.

**COMPARISON OF E-E RESULTS BY TECHNOLOGY**

The E-E results from Bluetooth, GPS, and cellular data were compared to those from the Tyler 2004 external survey that was conducted using roadside intercept and a license match surveys. For all external stations combined, the total traffic count increased by about 12 percent from 156,635 vehicles in 2004 to 175,345 vehicles in 2014. The 2004 and 2014 counts are based on automatic vehicle classification counts taken as part of these studies. The 2014 vehicle count based on cell data was estimated to be 187,860.

Key items related to the development of E-E estimates that should be kept in mind when assessing the results between each source include the following:
- The total E-E trips for the 2004 survey, Bluetooth, and GPS are based on the expansion of raw E-E trips to vehicle traffic counts taken at each external station.
- The total E-E trips for cell data are based on the expansion of a 24-hour traffic count estimated using cell data. This count is developed based on device movements and census tract population data.
- The 2014 higher vehicle count estimate from cells seems logical since this total essentially represents counts from all roadways that cross the study area boundary, while the 2014 class counts for Bluetooth and GPS only represent counts from the 20 external stations.
- The total E-E trips for Bluetooth and GPS data were developed using the travel time limitations between external pairs. The travel time skims for the Tyler model, plus 10 percent were applied as the time constraint.
- The total E-E trips for cell data were based on a 24-hour period with no travel time constraint imposed between external pairs. Cell data cannot be disaggregated into small enough time durations (e.g., hourly) to allow use of time constraints.

Table 1 shows a summary comparison of the total and percentage E-E trips between the 2004 survey data and the 2014 Bluetooth, GPS, and cell data. The table also shows E-E results
for Bluetooth and cell data broken down by non-commercial and freight/commercial categories. Results for cell data in these categories are not provided since cell data cannot distinguish between vehicle classes. Vehicle class cannot be identified with Bluetooth either, but it can be estimated based on the vehicle class count taken at each external station when the Bluetooth units were deployed. The percentage of E-E trips reflects the percent of trips in relation to I-I/E trips for the entire study area.

**TABLE 1** Comparison of E-E Trips between 2004 Survey and 2014 Bluetooth, GPS, and Cell Data

<table>
<thead>
<tr>
<th>Vehicle Category</th>
<th>2004 Survey</th>
<th>Bluetooth</th>
<th>GPS</th>
<th>Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EE Trips</td>
<td>% EE</td>
<td>EE Trips</td>
<td>% EE</td>
</tr>
<tr>
<td>Non-Commercial</td>
<td>18,714</td>
<td>15.5%</td>
<td>29,925</td>
<td>25.9%</td>
</tr>
<tr>
<td>Commercial/Freight</td>
<td>8,907</td>
<td>25.0%</td>
<td>18,626</td>
<td>31.2%</td>
</tr>
<tr>
<td>Total</td>
<td>27,620</td>
<td>17.6%</td>
<td>48,551</td>
<td>27.7%</td>
</tr>
</tbody>
</table>

The 2004 survey found 27,620 E-E trips, which comprised 17.6 percent of the study area’s external travel. The results show that the 2004 survey and 2014 cell E-E results are similar with lower percentages of 17.6 and 18.8, while the 2014 Bluetooth and GPS results are similar with higher percentages of E-Es at 27.7 and 33.7. Just considering the 2014 study, the total cell E-E results at 18.3 percent are clearly lower than the total GPS and Bluetooth E-E results at 27.7 and 33.7 percent, respectively. A possible reason for the lower cell E-E results may a non-commercial bias in cell data; in other words, a disproportionate representation of non-commercial vehicles to commercial vehicles in the cell sample. The cell E-E results are especially low considering they were developed based on a 24-hour period, unlike the Bluetooth and GPS results where travel time constraints were applied to develop the E-E trips.

Figure 2 shows the percent of E-E trips to total traffic by external station for the 2004 survey and the 2014 Bluetooth, GPS, and cell data. The chart shows predominantly low levels of E-Es for the 2004 survey (shown in dark blue) and mostly higher levels of E-E for GPS (shown in red), which are consistent with the E-E totals shown in Table 1.

Cell results notwithstanding, the Bluetooth and GPS results show a considerable increase in E-E trips through the Tyler study area from 2004 to 2014. Reasons and factors that may explain the increase include:

- An increase in traffic volumes, population and growth/development in the study area, combined with roadway improvements from 2004 to 2014 would tend to favor an increase in E-E trips;
- The 2004 results may have been low due to the low sampling rates experienced with intercept surveys;
- The 2004 data were collected on one weekday during daylight hours only (approximately 10-12 hours) while the 2014 Bluetooth and GPS data are collected for 72-hour and 3 month periods, respectively; and
- Bluetooth and GPS data represent averages for multiple weekdays that smooth daily variances; the 2004 data represented a one-day snapshot of traffic.
The higher number and percent of E-Es for GPS is due in large part to a bias toward commercial vehicles. With few exceptions, commercial vehicles make a higher percentage of E-E trips than non-commercial vehicles. The GPS data for the Tyler study was comprised of 70 percent freight/commercial vehicles, 20 percent mobile applications, and 10 percent passenger vehicles. The high percentage of the freight/commercial vehicles combined with the fact that these vehicles make a higher percentage of E-E trips substantiates a commercial bias in the GPS data.

The E-E results for cell data compare better to the other E-E sources when they are compared to the non-commercial categories. Figure 3 shows the non-commercial E-E results for the 2004 survey, and the 2014 Bluetooth and GPS vehicles along with the total (all vehicle category) E-E results for the 2014 cell data. The percent of total cell E-E’s at 18.3 percent compares better to the non-commercial E-E trips of the 2004 survey, Bluetooth and GPS data at 15.5, 25.9, and 25.0 percent, respectively. Researchers believe this chart may represent a more accurate comparison, since the commercial bias in the GPS data is mitigated and since cell data may have a bias toward non-commercial vehicles.

In light of the commercial bias in the GPS data the probable non-commercial bias in cellular data, the non-commercial E-E results are considered to be the most reliable. The non-commercial results for Bluetooth and GPS were very close at 25.0 and 25.9 percent, respectively. Based on these results, the percentage of E-E trips through the Tyler study area has increased from about 18 percent in 2004 to about 25 percent in 2014.
The percentage of commercial E-I/I-E trips for the study area from the 2004 survey, 2014 Bluetooth, and GPS data was 25.0, 31.2, and 50.7 percent, respectively. The 2014 Bluetooth and 2004 results are most similar, while the 50.7 percent figure reflects the commercial bias in the GPS data. While this bias in GPS data may not make it the best source for the all-vehicle category, it does make it the best source for studying commercial/freight O-D patterns. Since the Tyler study was conducted in 2014, INRIX data scientists have indicated that they have additional sources of GPS data, the saturation/granularity of their data has improved, and the commercial bias in their data has been reduced.

**COMPARISON OF E-I/I-E RESULTS BY TECHNOLOGY**

The E-I/I-E trips for the Tyler study area were compared between the 2004 survey data and the 2014 Cell and GPS data. This comparison used data for all vehicles and included both commercial and non-commercial vehicles. Bluetooth data is not included since it cannot be used to develop E-I/I-E trips on an area wide basis. The data were assessed by comparing the distribution of total trips ends (origins and destination points) for each source across the Tyler area’s aggregated internal TAZ structure. Figure 4 shows the distribution of E-I/I-E trip ends across the internal TAZ structure based on the expanded data for each option.

Figure 4 shows that the external trip ends for the 2014 cell and GPS data are clearly better distributed than those in the 2004 survey. The 2004 graphic shows more trip end concentration in the urban core probably reflecting the prevailing development pattern at the time and potentially the small sample size afforded by the roadside intercept survey method. The charts for the cell and GPS data show more widespread trip distribution than 2004 probably due to increased traffic volumes, substantially more suburban development, and better sampling rates.

Compared to the GPS graphic, the cell graphic shows unusually high trip ends in some of the rural periphery zones near the study area boundary. These results could be due to poor cell coverage and/or a lack of positional accuracy of cell data. The numerous high spikes in trip ends near the top of the GPS graphic are probably a result of the commercial bias in this data. These spikes are located along a major interstate that runs through the area and likely represent trip ends at truck stops.
The E-I/I-E trips and the Tyler model skims were used to develop trip length frequency distributions (TLFDs) for the 2004 survey and 2014 cell and GPS data for the Tyler study area (based on all survey stations combined). When charted, the TLFD’s appear to be similar for all options, especially between cell and GPS data, but statistically they are not. A Kolmogorov-Smirnov (K-S) test was used to test the statistical similarity of the TLFDs. A K-S test is a nonparametric statistical method commonly used to test whether the empirical distributions from two samples are the same. The p-value of the test indicates the probability that the statistic will be larger than the observed value, assuming that the null hypothesis is true. A threshold of 0.01 or 0.05 is often used for p-value comparison. A small p-value (< 0.05) indicates that there is strong evidence against the hypothesis that the two distributions are the same.

The K-S test performed on the TLFDs from the 2004 survey, GPS, and cell data resulted in a p-value of << .01, indicating that the chance that the three TLFD distributions being the same are very remote. Figure 5 shows the variations in TLFD’s for all sites combined. Further study should be conducted to examine the TLFD’s at each individual station because the variations at each location would likely be greater than that for the study area as a whole.

Summary findings, conclusions lessons learned from the Tyler Study are provided in the sections.

**General Findings:**
- Cell data has a large sample size but poor positional accuracy, while GPS data has a small sample size with good positional accuracy.
- The 500 x 500 meter minimum size of zones to capture cell data was too small. Future studies should use larger zones.
- The sample rate/penetration of GPS O-D data is low, especially when compared to cell data sample penetration.
GPS data had a significant commercial vehicle bias. Fifty-seven percent of the GPS sample was from commercial/fleet vehicles. (As previously noted, since this study was conducted in 2014, INRIX has indicated that the commercial bias in its data has been reduced).

- Cell data may have a non-commercial vehicle bias. Researchers suspect that commercial vehicles are under-represented in cell data.
- Based on TTI’s extensive use, experience and testing of Bluetooth data for travel times, speeds, and O-Ds, agency researchers believe it is a good source for collecting E-E O-D data. In light of this, the E-E results for cell and GPS data from this study were benchmarked against Bluetooth E-E results.

Findings Related to E-E Trips:
- When the study was conducted in 2014, TTI researchers concluded that Bluetooth estimates for total (all vehicles) E-E trips were superior to those derived from cell and GPS data.
- In developing estimates of E-E trips, travel time constraints between external zone pairs can be applied using Bluetooth and GPS data, but not for cell data.
- The percentages of total E-E trips for Bluetooth, GPS, and cell were 27.7, 33.7, and 18.3, respectively.
- The estimates of total cell E-E trips were thought to be low, especially since they were developed based on a 24-hour period, unlike the Bluetooth and GPS results where travel time constraints were applied. The time constraint used was the time it takes to travel between each external station, plus about a 20 percent cushion.
- Travel time constraints for cell data cannot be applied since this data cannot be provided in minutes or hourly increments.
- Bluetooth and GPS E-E trips compared well when only non-commercial vehicles are considered.
- Bluetooth, cell, and GPS E-E trips are most similar when only non-commercial vehicles are considered.
- The GPS data over-estimated commercial E-E trips due to its commercial bias.

Findings Related to E-I/I-E Trips:
- Cell and GPS derived O-D data provide a better sample and distribution of E-I/I-E trips than those of prior traditional methods (e.g., intercept, license mail out, or postcard surveys).
- The commercial bias in GPS data was evident in areas and corridors with high commercial/ truck activity.
- It appeared that cell data provided questionable trip ends in rural areas with poor cell coverage where estimated device locations are less accurate.
- The similarities of the cell and GPS TLFDs for E-I/I-E trips were not statistically similar, despite their appearing to be when charted.
REFERENCES


