Understanding Travel Time and Origin-Destination Characteristics at Airports Using Bluetooth Technology

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ABSTRACT

Bluetooth Technology has become increasingly popular in recent years for conducting travel time and Origin-Destination (OD) data collection. The application of this technology is however still fairly new at airports where the roadway networks and ground traffic characteristics are unique. This paper summarizes a recently-completed study in which eleven Bluetooth detectors are deployed and used to estimate travel time and OD information at two airports in the Phoenix, Arizona region.

This study demonstrates the suitability of Bluetooth technology for the collection of traffic data at atypical locations like airports. Some important findings are that the Bluetooth penetration rate (sample rate) at these airports is favorably higher than on local arterial streets, and that the distribution of these samples closely matches the distribution of concurrent traffic volumes. Travel time, OD information, and terminal dwell time have been analyzed to infer important characteristics of vehicle traffic at these airports such as the percentage of non-airport cut-through traffic and the distribution of other trip purposes.

Advantages of Bluetooth technology include flexibility and mobility of deployment, relative low-cost of long duration collection, and simple data processing. Planning and design of the data collection efforts must however be performed according to the specific conditions at each airport. Results from this study are being used in development and calibration of the airport model as a special generator sub-model of the regional travel demand model in the Phoenix region. Results also serve as reference to ground traffic management and operations at these airports.

1. INTRODUCTION AND LITERATURE REVIEW

The Maricopa Association of Governments (MAG) is the designated metropolitan planning organization (MPO) for transportation planning in the metropolitan Phoenix area. To facilitate the update, development and calibration of an airport ground travel model, as a special generator sub-model in the current MAG regional travel demand model, travel time and Origin-Destination (OD) data are needed from two airports in the Phoenix metropolitan region (Phoenix Sky Harbor [PHX] and Phoenix-Mesa Gateway [AZA]). As the nation's 6th busiest passenger airport, the PHX airport attracts 60,000 vehicles per day and has a complex roadway network that provides airport access from the East and West sides via multiple freeway and arterial connections. Since the budget-constrained data collection effort requires a long duration at a sufficient number of locations, Anonymous Wireless Automatic Matching (AWAM) or Bluetooth® Re-Identification technology is selected instead of traditional OD survey methods. By deploying the Bluetooth readers at major access points such as at entrance, exit, terminal, and road segments between terminals, it is possible to investigate airport ground traffic's travel time and OD characteristics.

The use of remote sensing technology, or vehicle re-identification methods, has quickly emerged as a useful and viable means of obtaining accurate and reliable traffic data. In particular, Bluetooth signals emitted from vehicles (and/or their occupants) have been at the forefront of the short-range communication protocol technology used to obtain travel characteristics such as travel time, speed, and routing (OD). This paper focuses on further experimentation with Bluetooth technology in a travel time and OD study at airports where unique roadway configurations and ground traffic characteristics exist. After review of literature on Bluetooth technology applications in travel time and external survey studies, this paper summarizes a specific implementation of data collection and data processing at airports. This paper then presents primary findings of airport

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traffic problems such as Bluetooth penetration rates, representativeness of Bluetooth samples to actual ground traffic, airport traffic OD, travel time patterns by trip purposes, and terminal dwell time. Lessons learned and conclusions formulated from this study are then discussed.

Several studies have examined the validity of Bluetooth-based travel time data using empirical experiments that have relied on comparisons with GPS tracking, automatic license plate recognition (ALPR) technology, or Automated Vehicle Identification (AVI). The method of using Bluetooth technology for measuring travel time was first developed and utilized for the Indiana DOT by Wasson, et al. *(1),* who noted that errors in sampled travel times were negligible at 2- to 3-mile spacing of data collection devices. Quayle et al. *(2)* found the percentage differences in travel time between Bluetooth- and GPS-based probe data ranged from 1.3 to 7.2%. In another 2010 study, for PennDOT *(3)*, KMJ Consulting, Inc. found the average travel time difference of 16 seconds or 7% when comparing Bluetooth travel times with travel time data obtained through an established electronic toll/AVI system. Malinovskiy et al. *(4)* found that the Bluetooth-based travel time samples overestimated travel times by 8% on average when compared with travel times obtained from ALPR equipment. Kim et al. *(5)* conducted a series of research studies where the accuracy of Bluetooth-based travel times were tested against "ground truth" data from a vehicle probe carrying two known Bluetooth-enabled cell phones, and the results were mixed (significant or no differences). The Texas Transportation Institute has been involved in demonstrations of Bluetooth technology in Texas and elsewhere *(6, 7)*, and findings indicate that travel times calculated from Bluetooth address matching are comparable in accuracy to ALPR and Toll tag technology but at many times lower the cost. One of the most exhaustive uses of Bluetooth speed data has been in the evaluations of private sector speed data quality for the I-95 Corridor Coalition Vehicle Probe Project *(8, 9).* At higher speeds when greater variance exists in the travel times between individual vehicles, Bluetooth travel times were suggested as being even more accurate than probe data, and this is because of the increased sample size. Sadabadi et al. *(10)* have determined that the overall maximum error in distance for a matched Bluetooth device would be double the typical detection zone radius (or about 600 feet). Assuming this maximum error, Haghani et al. *(8)* developed a relationship to estimate error based on segment length and travel speed where long segments and high speeds yield the best travel time estimation.

Bluetooth technology has also been applied to external OD travel studies. Farnsworth et al. *(11)* evaluated the capability of Bluetooth technology to provide an alternative to traditional methods of collecting external related travel data in urban areas based on a week-long data collection. They concluded that external-through trip tables can be developed and expanded with associated traffic counts, but that there is an inability to differentiate between commercial and non-commercial vehicles. As such, an "external station-only" implementation cannot be used to develop reasonable external-local estimates without the assumption that vehicles without Bluetooth devices exhibit the same travel characteristics as vehicles with Bluetooth enabled devices. Lee et al. *(12)* compared OD survey data collection between Bluetooth and traditional ALPR cameras, and concluded that travel time analysis using Bluetooth in external survey is useful and that ALPR is considered more reliable only with a higher capture rate. A 2010 study by Blogg et al. *(13)* in Australia concluded that Bluetooth-based data collection for the purpose of OD determinations was cost-effective for small controlled study areas. Sun et al. *(14)* has more recently discussed a method of using video in manually validating OD trips and travel time distributions, and has additionally used Bluetooth addresses in distinguishing between inter- vs. intra-city travel.

Bluetooth technology has been applied locally in the Phoenix region collecting traffic data in an evaluation of non-recurring congestion *(15)* and in permanent installations for real-time arterial travel time displayed on arterial dynamic message signs *(16)*. Bluetooth technology has been utilized in airports in Indianapolis *(17)* and Houston *(18)* to measure wait times between airport roads, parking lots, security check point, and concourses. This technology has not, however, been applied previously in analyzing OD travel patterns at airport locations, making the collection of traffic data discussed in this paper new and innovative.

2. DESIGN OF DATA COLLECTION, PILOT STUDY AND DATA PROCESSING

2.1 Data Collection Design

At PHX airport, Bluetooth readers are installed at designated roadway locations to collect Bluetooth signals to be later re-identified and matched between two or more readers. This formal data collection effort takes place for seven continuous days in April, 2012. Bluetooth signal matching allows for calculation of individual vehicle travel time, speed, and OD. Adapting to airport's infrastructure and roadway layouts, the Bluetooth reader locations are strategically chosen to allow only the targeted traffic to be picked up. Concurrent traffic volume data is collected for determining the Bluetooth sample rate and expanding and cross-referencing the results.

The seven deployment locations at PHX along Sky Harbor Boulevard (labeled A through H, excluding F) are shown in Figure 1. Bluetooth reader units are self-contained with long-life batteries (sufficient to 7 days) in rugged all-weather suitcase enclosures to allow customized temporary placements that comply with airport safety protocols while targeting the desired traffic only. Readers are, where possible, located to collect directional one-way traffic while omitting other possible traffic. All deployment locations and attachment poles or landscape objects for the pilot and formal studies were vetted to airport and FAA requirements.

FIGURE 1 Bluetooth Reader Locations at PHX Airport

2.2 Pilot Study and Data Processing

A one-day pilot study or pretest is conducted at a subset of locations at the PHX airport to test the data collection plan validity and to identify potential issues. Test runs are conducted with a probe vehicle containing several known Wireless IDs from Bluetooth devices within the vehicle. Bluetooth reader locations are assessed for signal coverage, nearby land use/activities, and for the usefulness of the specific location in determining the different trip routes/types that might comprise the airport-related traffic. This pretest shows that the bridge infrastructure between G and H locations at the east end of the PHX airport successfully prevent Bluetooth signals from one location being picked up at the other location, making traffic data collected at these locations exclusively directional. The pretest also found that locations at the west access to the PHX airport continuously pick up the same Bluetooth signals, at a steady frequency of 1 second, from parked taxis in an adjacent parking lot. Treatment of the data is therefore required such that redundant signals from parked vehicles are filtered out. Experience from this pilot study has led to sound revisions in the formal data collection plan that significantly improves the quality of data collected. In processing the raw Bluetooth data, the following steps are followed:

1-Data collected from all locations for the whole week are compiled into a single database file. Data fields include masked Anonymous Wireless ID, Time stamp, and Location ID.

2-Wireless IDs continuously identified at a single location (with time difference less than 2 seconds) are identified as idling records, and all but the first and the last reads are filtered out.

3-The appearance of each Wireless ID is registered at all possible locations chronologically, to obtain trip chaining of each vehicle or person.

4-Individual trip's origin and destination are identified, and travel time between any pair of locations within this trip is calculated.

The following results are obtained (summarized by end time) based on the analysis steps just described:

-Trip OD (routing) and trip chaining;

-Trip travel time between any pair of locations within a trip chain, and;

-Trip dwell time at selected terminal locations.

3. RESULTS AND DISCUSSION

3.1 **Bluetooth Penetration Rate at Airport**

To understand how Bluetooth sample data represents total traffic at the PHX airport, the Bluetooth penetration rate (or travel time sample rate), as defined below, is investigated.

$$\frac{\text{Number of Matched Travel Time Record}}{\text{Traffic Volume}} \times 100\%$$

The average penetration rate at the PHX airport is 4.83% of the total traffic entering the airport from either side. With this sample rate, estimations developed from this dataset have ±3% margin of errors at a 95% confidence level. This penetration rate is nearly double the average penetration rate of 2.56% identified along 36 arterial segments in the Phoenix area during the same period of time and using the same equipment. This higher penetration rate is an indication of the increased likelihood of Bluetooth devices being carried by the demographic of travelers in the airport. The increased rates may also be attributed to a higher number of shuttle busses carrying multiple occupants. Table 1 shows the travel time sample rates by weekday for the PHX airport and Phoenix region arterial streets from both 2012 and a similar 2010 arterial data collection effort with similar technology. The increased arterial Bluetooth penetration rate from 1.67% in 2010 to 2.56% in 2012 is a clear indication of increasing in-vehicle use of Bluetooth devices. Higher penetration rates at airport locations, and this general increase on arterial segments, leads to increasing confidence in data collected via Bluetooth technology, particularly at airports. It is also worth noting that there is no significant fluctuation of the rates found across days of the week.

TABLE 1 Bluetooth Travel Time Sample Rate by Weekday

	Mon	Tue	Wed	Thu	Fri	Sat	Sun	**Week**
Airport 2012	-	4.8%	4.8%	4.8%	4.7%	5.0%	4.2%	**4.83%**
Arterial 2012	2.2%	2.6%	2.7%	2.6%	2.6%	2.6%	3.3%	**2.56%**
Arterial 2010	1.7%	1.9%	1.8%	1.8%	1.9%	1.3%	1.3%	**1.67%**

Understanding that Bluetooth devices are more frequently integrated into high-end vehicles and are more popular among high income people, an effort to find a relationship to income is attempted. An airport passenger survey, conducted by MAG concurrently with this study, shows that airport interviewee's average household income is 46% higher than the average household income obtained from the 2008 National Household Travel Survey (NHTS) *(19)* in the same region. Table 2 shows that the percentage of respondents in income categories of $80,000 and higher is significantly higher at the airport than from NHTS results reflecting overall local populations. This supports that travel data collection from Bluetooth technology is especially favorable for use at airports or other locations where these devices are most prevalent.

TABLE 2 Household Income: 2012 Airport Passenger Survey VS. 2008 NHTS

	2012 Airport Survey	2008 NHTS
Under $20,000	4.9%	13.3%
$20,000 to $40,000	7.9%	21.3%
Over $40,000 to $60,000	14.0%	19.8%
Over $60,000 to $80,000	11.9%	12.9%
Over $80,000 to $100,000	16.3%	8.7%
Over $100,000 to $150,000	21.3%	11.4%
Over $150,000 to $200,000	9.5%	5.1%
Over $200,000	14.1%	7.5%

To investigate the potential temporal variation in Bluetooth samples as well as samples' correlation to concurrent ground traffic, the distribution of hourly Bluetooth reads and hourly traffic volume at individual location is compared. Figure 2 visually confirms that, while the distributions vary through the week, Bluetooth samples closely track the traffic volume.

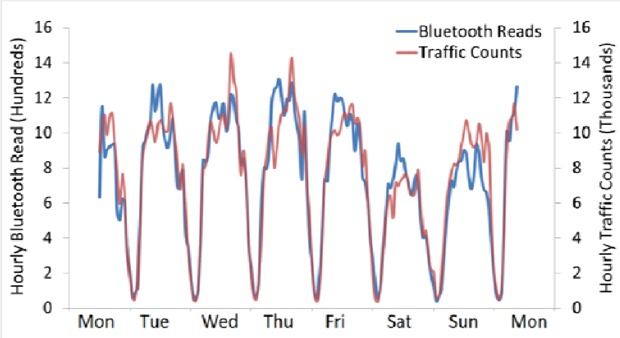

FIGURE 2 Distribution of Airport Bluetooth Reads and Traffic Counts.

To substantiate whether or not Bluetooth sampling correlates with all ground traffic, a statistical analysis based on PHX airport data is conducted with results presented in Table 3. Between variables of hourly Bluetooth sample and traffic volume, the correlation coefficients are high (over 0.85) in all locations and are not significantly different across days of the week. This indicates again that Bluetooth samples correlate highly with the actual ground traffic, and that it is reasonable to treat this Bluetooth data sample as representative of ground truth traffic.

TABLE 3: Correlation Coefficients between Bluetooth Reads and Traffic, by Location and by Weekday

	Location						
	A(S)	A(N)	C	D	E	G	H
	West Entrance (EB)	West Exit (WB)	Terminal 3 (EB)	Upstream of Terminal 3 (WB)	Upstream of Terminal 4 (EB)	East Exit (EB)	East Entrance (WB)
Mon	0.852	0.807	0.902	0.928	0.895	0.572	0.862
Tue	0.900	0.636	0.863	0.954	0.974	0.931	0.911
Wed	0.872	0.821	0.886	0.954	0.959	0.915	0.946
Thu	0.816	0.703	0.856	0.922	0.975	0.910	0.935
Fri	0.915	0.746	0.918	0.961	0.949	0.929	0.915
Sat	0.796	0.628	0.944	0.953	0.901	0.918	0.822
Sun	0.936	0.634	0.928	0.966	0.922	0.918	0.915
Whole Week	0.857	0.729	0.889	0.933	0.946	0.849	0.893

3.2 PHX Airport Access Problem, OD and Travel Time Characteristics

Since the PHX airport can be accessed from both the East and West sides, under certain circumstances the connectivity of the main corridor through this airport (Sky Harbor Blvd) offers an alternative to commuters in rush hours. It is known that some commuters would choose to cut through the airport, instead of using parallel (and often congested) freeway paths such as I-10 and Loop 202, because the airport offers shorter or more reliable travel time. However, the extent to which this takes place is not known. To quantitatively examine and evaluate cut-through traffic characteristics and the impact of this traffic to airport-relevant ground traffic, OD and travel times obtained from three Bluetooth readers installed at the boundaries (or external stations) of the airport are analyzed. Figure 3 illustrates that the ground traffic accessing the airport from East side (6,635 records in one week) is 33% greater than from the West side (4,930 records in one week). Figure 3 also shows that 73% of trips entering the airport from East side would leave from the East side, while 64% of trips entering the airport from West side would leave from the West side. Most importantly, a total of 31% of ground traffic travels through the airport from one side to another. The day-by-day distribution pattern shows that the through traffic is more frequently seen during weekdays than on weekends with the peak on Wednesday.

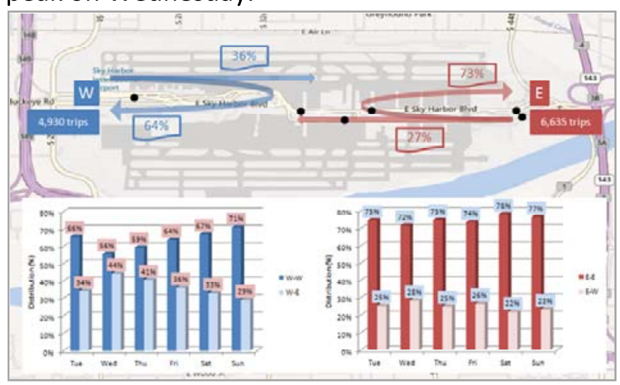

FIGURE 3 Distribution of Ground Traffic Accessing PHX Airport

The travel time of the typical through trip is analyzed further. First, probe car runs show that a cut-through trip (without making a stop in the airport) takes less than 4.5 minutes from one side to another. If a curb-side drop-off or pick-up visit is made, the trip through the airport would take at least 2-min longer due to the additional time spent on accessing inner lane and making a stop at a terminal. A travel time of 4.5-min is therefore used as the threshold to benchmark cut-through traffic from the total through traffic. Figure 4 shows the distribution of travel times from East to West (toward the city center) for selected weekdays. The highest number of nearly 4.5 minute travel times, representing cut-through traffic, are most often observed during 7:00-8:30 a.m. and 3:30-6:00 p.m. on weekdays, which exactly corresponds with the rush hours in the Phoenix region.

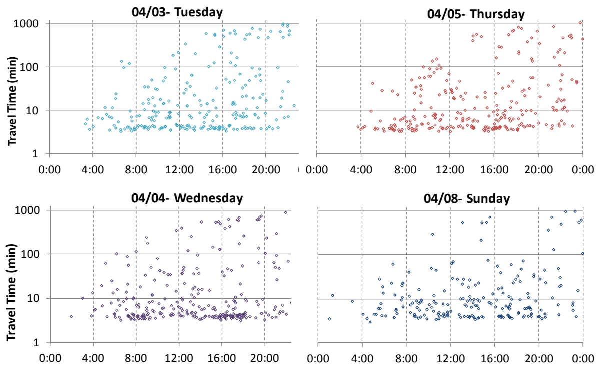

FIGURE 4 Travel Time of Cut-through Traffic (from West to East) for Selected Days.

Table 4 summarizes travel time distributions of all through traffic. Cut-through traffic (travel time less than 4.5 minutes) are identified from East to West at a rate of 32% to 39%, which is higher than expected, for each weekday; from West to East, the cut-through rate varies from 21% to 34% during weekday and is only 4% to 9% during weekend. Non-airport commuter traffic is therefore found to be significantly higher during weekdays on both directions of Sky Harbor Blvd.

TABLE 4 Travel Time Distribution by Weekdays for Cut-Through Traffic

	Travel Time (min)	3-Apr Tuesday	4-Apr Wednesday	5-Apr Thursday	6-Apr Friday	7-Apr Saturday	8-Apr Sunday
Westbound	<4.5min	32%	38%	32%	39%	34%	26%
	15min	33%	33%	31%	31%	35%	46%
	60min	17%	14%	21%	18%	18%	18%
	>60min	19%	15%	16%	11%	13%	10%
Eastbound	<4.5min	25%	34%	26%	22%	9%	6%
	15min	36%	32%	30%	35%	33%	53%
	60min	20%	18%	23%	30%	34%	24%
	>60min	19%	16%	21%	13%	24%	16%

In Figure 5 the duration of time spent in the PHX airport for all records is shown. Such a distribution may be used to qualitatively attribute trips to reasonable activity patterns or trip purposes. The majority of trips (55% of all travel time records obtained) spend on average less than 20 minutes in the airport, and such trips may be characterized mainly as pick-up/drop-off traffic which only involve curb-side visit at the terminals. About 25% of trips spend 20 minutes to 1 hour in the airport and may be characterized as meeter/greeter trips which would use cell-phone lots or parking facilities in the airport. The other travel time bins are progressively smaller except for 8-16 hour bin, which is assumed to represent airport employment trips.

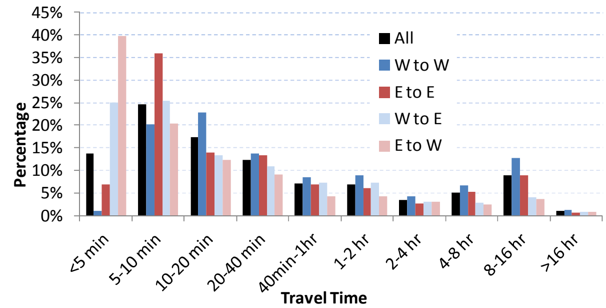

FIGURE 5 Time Spent in the Airport Based on Matched Travel Time.

4. SUMMARY AND LESSONS LEARNED

In this study, Bluetooth technology is applied at airports to collect travel time and OD data for investigating unique airport traffic characteristics. A literature review and a pilot study are performed to help develop the week-long data collection plan and data analysis method. The Bluetooth data sample rates and their relationship to ground traffic at several airport locations are assessed; access patterns to PHX Airport from different directions are examined; and travel time patterns for certain airport trips are evaluated.

The following is a summary of the key results found in this study:

1) **Bluetooth penetration rate is found to be higher (nearly double) at airports than on normal arterial streets.** It is assumed that this is caused by higher composition at airports of above-average income people and high-end vehicles more likely equipped with Bluetooth devices. Information developed from this close to 5% sample rate (matched travel time records/total traffic) should produce results with 95% confidence level and ±3% margin of errors.
2) **Bluetooth penetration rate is highly correlated with simultaneous ground traffic volume**. The overall correlation coefficient for all days and locations together is above 0.9.
3) **The use of Bluetooth readers to monitor airport ground traffic is proven feasible by the previous two findings**. Airport ground trip's OD and travel time can be successfully tracked, and the trip chaining within airports can be effectively obtained.

4) **This study specifically explores characteristics of cut-through traffic** using PHX airport's Sky Harbor Blvd as a commute alternative during rush hours. It is found that close to 30% of PHX airport through traffic make no stop for airport related business and are most often identified during the 2-hour AM and 2-hour PM peak periods during weekdays.

The following is a summary of lessons learned from this study:

1) Given the complexity of airport roadway network and its ground traffic composition, a specific plan and design should be deliberated for conducting Bluetooth data collection at an airport and its vicinity areas. A successful data collection plan for one airport, though beneficial, may not effectively apply to another airport.
2) A pilot study pretest is necessary and all possible major concerns of the draft data collection plan should be tested. Travel time probe runs (with known Bluetooth devices) are recommended during both the pilot and formal study in order to provide essential information in validating and fine-tuning the data collection plan and results.
3) Analysts should be mindful of data noise introduced by stationary vehicle fleets such as the parked airport shuttle and taxis encountered in this study. Software and data processing algorithm should be customizable to successfully identify a variety of non-representative data.
4) The range of travel times collected at the airports can be vast when compared to travel times collected from freeway and arterial streets. Outlier identification must be performed with great care and the specific conditions and characteristics of the airport locations in mind.
5) Bluetooth sample rates are found to highly correlate with concurrent traffic volume, but this does not prove that OD results developed from the sample are 100% unbiased.

Bluetooth technology has advantages of flexibility and mobility of deployment, low-cost, affordability of long duration collection, and simple data processing and is well suited for an airport study such as is discussed in this paper. Information collected via Bluetooth technology has great potential to help organizations understand the characteristics of ground traffic at airports, and can be informative to airport management in the operation of airport roadway, terminal, and parking facility. Results of this study are also being used in development and calibration of a special generator airport sub-model within the regional travel demand model for the Phoenix region.

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