2012

Feasibility of Using Cellular Telephone Data to Determine the Truckshed of Intermodal Facilities

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MID-AMERICA
TRANSPORTATION CENTER

Report # MATC-KU: 122

Final Report
25-1121-0001-122

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A Cooperative Research Project sponsored by the U.S. Department of Transportation Research and Innovative Technology Administration

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A Report on Research Sponsored by

Mid-America Transportation Center

University of Nebraska-Lincoln

December 2012

Technical Report Documentation Page

1. Report No. 25-1121-0001-122	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Feasibility of Using Cellular Telephone Data to Determine the Truckshed of Intermodal Facilities		5. Report Date March 2010 6. Performing Organization Code
7. Author(s) Ming-Heng Wang, Steven D. Schrock, Thomas Mulinazzi		8. Performing Organization Report No. 25-1121-0001-122
9. Performing Organization Name and Address The University of Kansas 1530 W. 15th Street Lawrence, KS 66045-7609		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Organization Name and Address Mid-America Transportation Center Nebraska Transportation Center University of Nebraska Lincoln 121.A NH, Lincoln, NE 68588-0530		13. Type of Report and Period Covered October 2006-December 2009 14. Sponsoring Agency Code MATC TRB RiP No. 17135
15. Supplementary Notes		

16. Abstract

In order to determine the feasibility of using cellular telephone location data in deriving the geographic extent (truckshed) from intermodal facilities, this study was conducted to determine the feasibility analysis in three aspects: technology, penetration analysis and truck tracking methodology. A preliminary test was also conducted to demonstrate the cell phone tracking and traveling characteristics identification process using Washington, D.C. metropolitan area data provided by AirSage, Inc.

The preliminary feasibility analysis found that cell phone locations could be located within an average of 100 meters or less of their actual position, which is feasible to use for a long haul truckshed tracking from the intermodal facilities. Cell phone penetration analysis showed that only partial cell phone data were available for the truckshed tracking system. Thus, a long time period of observations are needed in order to increase the number of cell phones tracked.

The research team developed a process and conducted a program for tracking cell phone trajectories and identifying the cell phone characteristics (truck or not). However, a database which covers possible truck traveling objectives, such as truck stops, rest area or warehouse, and land use categories, has to be established in order to identify the characteristics of the cell phones from the anonymous cell phone database.

The preliminary test illustrates several examples for tracking cell phones and identifying the characteristics of cell phones based on the proposed tracking and identification process. The results show that the vendor provided data can provide enough cell phone data points for tracking the trajectory of cell phones. It also demonstrates that the developed tracking and filtering process and computer program are able to track every individual cell phone data point and identify the traveling characteristicss based on the trajectory and destination of cell phones.

17. Key Words Cellular Phone Positioning Technology, Intermodal Facility, Truck Stops, Traffic Dispersion, Traffic Trajectory, Characteristics Identification		18. Distribution Statement No restrictions.	
19. Security Classification (of this report) Unclassified.	20. Security Classification (of this page) Unclassified.	21. No. of Pages 62	22. Price

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Acknowledgments

The authors would like to thank AirSage, Inc. for technical assistance and providing the raw data for this research. This study was funded by Mid-America Transportation Center at the University of Nebraska.

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the U.S. Department of Transportation's University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

Abstract

In order to determine the feasibility of using cellular telephone location data in deriving the geographic extent (truckshed) from intermodal facilities, this study was conducted to determine the feasibility analysis in three aspects: technology, penetration analysis and truck tracking methodology. A preliminary test was also conducted to demonstrate the cell phone tracking and traveling characteristics identification process using Washington, D.C. metropolitan area data provided by AirSage, Inc.

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point and identify the traveling characteristics based on the trajectory and destination of cell phones.

Chapter 1 Introduction

In today's world of global supply chains, the manufacturing of goods is increasingly spread throughout the world. The widening supply chain has increased the demand for freight movement across the United States. It has also created new opportunities for the railroad industry to compete with the trucking industry for long-haul operations through the development of rail-truck intermodal facilities. As intermodal facilities spread through the nation, it is unclear to what geographic extent (truckshed) that will impact the local and regional transportation network. There is a need to better understand the impacts of this truckshed on the transportation network. Thus, understanding the extent of the reach of a facility is an important first step to mitigate any negative consequences.

There are many methodologies which can be used to catch the geographic extent of trucks from intermodal facilities. Traditional origin-destination (OD) methods, such as roadside and truck driver surveys, may be performed but are time consuming. These methods are also increasingly unpopular due to resulting traffic disruption. Innovative technologies have become available that can reflect the traffic condition and also catch OD data by tracking vehicle trajectories and destinations. Among these new technologies, cellular phone tracking technology is one of the potential methods in tracking vehicle location and movement. It has received strong interest from the transportation community. A number of researchers (Lovell 2001, Smith 2006, Cayford and Yim 2006, Liu et al. 2008) have evaluated the application of cell phones in travel speed and travel time estimations as well as identifying congestion sections. Some researchers also used cell phone data to derive the OD matrix (Caceres et al. 2007, Sohn and Kim 2008). However, the application of a cell phone tracking system in determining the truckshed from an intermodal facility has not been addressed.

1.1 Research Objective

This research fits into the Mid-America Transportation Center's (MATC) theme of "improving safety and minimizing risk associated with increasing multi-modal freight movement on the U.S surface transportation system." The objective of this research was to determine the feasibility of using cellular phone tracking technology in determining the geographic extent of truckshed data from intermodal facilities and understanding the impact of intermodal facilities on the traffic network. The feasibility analysis pursued the following questions:

- Can cell phone tracking technology be used to track accurate locations to realize a long haul truckshed?
- Does the sample size of cell phone signals provide enough data to reflect the truck volume and impact on the network?
- How can it be determined if the cell phone is in a truck or not?
- How can truck's movement be tracked based on cell phone location data?

1.2 Research Approach and Methods

The feasibility analysis included three aspects: location tracking technology, data penetration analysis and a subject (truck) filtering and tracking methodology. First, the cell phone location tracking technologies and related research regarding its reliability were reviewed and analyzed. Cell phone penetrations, such as market penetration and cell phone signal coverage from cell phone carriers, were also investigated. Then, trucks tracking and filtering rules and procedures were developed to identify and track the trucks' movement from intermodal facilities.

A preliminary test and analysis was conducted using the cell phone data around the Washington, D.C. metropolitan area. One day's cell phone location data were used to test the

proposed process of cell phone location tracking, filtering and cell phone characteristics identification. The remaining challenges and perspectives of using cell phone data to determine the truckshed for future research are also discussed.

1.3 Research Tasks

To achieve the above objectives, six tasks were conducted. First, a literature review was completed. The review focused on literature discussing the use of cellular telephone data in transportation engineering.

The next task analyzed location technology. The concept and operation process of measuring cell phone location and the location accuracy test and evaluation were reviewed and analyzed. The capability of location technology for long haul traffic tracking was also discussed. Cell phone data provider systems and their location tracking technology were introduced.

Next, data penetration and structure were analyzed. The number of cell phone subscriptions and signal coverage were investigated. The cluster of possible types of cell phone data and portion of cell phones in use were also considered. The cell phone data structure provided by AirSage, Inc. and data coverage and transmission processes were introduced and analyzed. This task addressed the issues of data coverage, sample size, data transmission and storage process and the level of precision required in the data.

A cell phone tracking and truck identification process was then developed. The process, which can extract data from thousands of anonymous cell phone calls to estimate if the cell phones are in trucks or not, was proposed. Cell phone locations can be tracked by time and space. Criteria used to filter the data were based on the land use and traffic movement and stop characteristics.

The next task involved a preliminary test and analysis. A program was developed to

process the cell phone tracking and truck identification processes using one day of example cell phone location data. The preliminary test included cell phone network coverage analysis, a cell phone tracking and dispersion process from a target facility, and a cell phone traveling characteristics identification process demonstration.

For the final task a feasibility analysis was performed and remaining challenges were discussed. A feasibility analysis was conducted based on location technology analysis, data coverage and the preliminary test of cell phone location tracking and filtering results. Challenges for developing a more wide-ranging network and further research are discussed.

1.4 Organization

This report is organized into eight chapters, with this introduction being Chapter 1. Chapter 2 is a review of the literature that is pertinent to this study. It includes the application of cell phone location studies in transportation engineering, including traffic monitoring and OD matrix derivation.

Chapters 3 and 4 discuss the location tracking technology analysis, cell phone coverage and penetration analysis. Cell phone data provider's system and the cell phone data structure used for research purposes are also included. Chapter 5 presents the development of the procedure of cell phone and traveling characteristics identification.

Chapter 6 presents the cell phone location data structure including the data provider's operation system, data content, level of precision, and data transmission process. Chapter 6 illustrates the preliminary test using the Washington, D.C. metropolitan area and the proposed traffic tracking and characteristics filtering procedures. In addition to network coverage analysis, cell phone tracking processes and cell phone characteristics, the preliminary test also consisted of identification and filtration process testing.

Chapter 7 discusses the perspective and the remaining challenges of using cell phone location data for determining trucksheds. The research plan for the next phase is also proposed. The conclusions and recommendations are contained in the final chapter.

Chapter 2 Literature Review

To determine the use of cellular telephone data for transportation engineering, as well as the impacts of intermodal facilities, this section reviewed existing research and tests on the application of cell phone tracking data in transportation engineering. The application includes the measurement of travel speed, travel time estimation, OD data creation and travel pattern analysis.

2.1 Cellular Phones Location Technology in Traffic Monitoring

Cellular phone tracking technology was one of the new technologies for achieving traffic information after E911 technology was implemented. In 1996, the Federal Communications Commission's (FCC) E911 requirements mandated that cellular location should be provided when 911 emergency calls come in to emergency management authorities (FCC 2001).

The major application of cellular phone data is using the cell phone carried in vehicles as probes in the traffic stream. Real-time traffic information can be obtained based on the cell phone probe system. Several trials have been done in testing the feasibility and accuracy of cell phone tracking data for measuring travel speed and travel time in both the United States and abroad. Some research also tried to create OD data based on cellular phone mobility data.

There are two basic technologies that can be used to collect cellular phone position data. One measures signal strength from towers to triangulate the position. The other uses global position system (GPS) enabled cellular phones to provide traffic-related data. Most existing research on testing the cellular phone probe system was based on the first type of technology. However, as GPS enabled cellular phones become more popular, recent researchers are starting to apply such technology in the probe system.

In 2005, a research team from the Virginia Transportation Research Council at the University of Virginia investigated the feasibility of cellular phones as a probe system for traffic

monitoring. Researchers reviewed over 16 deployments of wireless location technology (WLT)-based monitoring systems both in the United States and abroad. They concluded that most systems did not produce data of sufficient quality or quantity to provide reliable traffic condition estimates. The other major findings were:

- There was not enough information to completely characterize the quality of the data.
- While performance of these systems has been demonstrated to a limited degree on freeways, there was very little experience monitoring arterials.
- The use of well-developed map matching and data screening methods are needed to enhance the accuracy of measures.

A similar task was completed by a research team from Florida International University (Wunnava et al. 2007). The study investigated the maturity of cell phone technologies for application as real-time traffic probes for travel time estimations along a highway. Results showed that the cell phone technology was feasible to determine the speed time under the normal conditions of free traffic flow, but it is not accurate in congested traffic conditions. The accuracy decreases rapidly as the congestion increased. They also pointed out remaining issues for application of cellular phone data as:

1. Privacy of cell phone users whose phone transmissions are being probed by the cell companies for location data.
2. Cell data for travel time and speed computations can be irregular and transient, especially during congested traffic and severe weather conditions.
3. The travel time providers' capabilities can become limited following changes by the cell companies in data formats and structures.

4. Incompatibility of data when switching from one travel time provider to another (with different affiliations with the cell phone companies)

The experiments of other major studies, along with their findings, are summarized in table 2.1.

Table 2.1 Research of Feasibility and Capability of Cellular Phones Probe-System

Authors (year)	Location (System)	Methodology and Major Findings
Ygance et al. (*2001*)	Vicinity of Lyon, France	The researchers found: - average speed according to loop detectors is about 10 percent higher than that obtained from cellular data (107.9 km/h southbound and 111.25 km/h northbound for loops compared with 100.5 km/h southbound and 99.4 km/h northbound for the cellular data), - Larger average differences of 24–32 percent were found on an urban freeway, - Lack of congestion is a major limitation for a study of this type since average speeds above 100 km/h prevailed along both the intercity freeway and the urban freeway at all times of the day.
Cayford & Johnson (*2003*)	Bay Area freeways, California (AirSage, Sprint)	Researchers investigated the parameters that could affect the effectiveness of cell phone-based traffic monitoring system including: - Accuracy of the locations, - Frequency with which location measurements are taken, - Number of locations available to support traffic monitoring in a given area. The study concluded: - Network-based location technology could provide measurements on 85 percent of the roads using approximately 5 percent of the location capacity of a single carrier, in every 5-minute interval, - With handset-based location technologies, using 5 percent of the location capacity of a single carrier can generate measurements for over 90 percent of the roads in every 5-minute interval.
Smith et al. (*2004*)	Southern suburban region of Washington, D.C. (Bell Atlantic NYNEX)	The study compared speeds measured by a point video sensor with cellular phone-based data for 39 intervals of 10 min each at different freeway locations, and for 35 intervals of 10 min each at different arterial locations. They concluded: - Early-generation WLT-based system produced link speed estimates of moderate quality. It was not able to meet the accuracy of 5 mph, as desirable, - The system was probably capable of determining whether congestion prevailed in a specific 10 minute interval, information that many travelers are likely to consider as fairly useful, - They recommended that a basic research program commence that addresses the complex sampling and map matching challenges that must be surmounted to make accurate, reliable WLT-based system monitoring a reality.

Bar-Gera (2007)	Tel-Aviv, Israel (Declan)	The study compared the traffic speeds and travel times measured using cellular phone location data with those obtained by dual magnetic loop detectors, as well as 25 floating car measurements. The comparison uses data for a busy 14 km freeway with 10 interchanges, in both directions. Each measurement referring to a 5 min interval. The results showed that: - The average difference between the loop detectors computed travel time and the floating car measurement is 0.9 min, the average absolute difference is 0.93 min. - The equivalent values for computed travel times based on the cellular phones data were an average difference of 0.49 min and average absolute difference of 1.07 minutes - The study concluded that there was a good match between travel times obtained from the loop detector's data and the cellular phone data, as well as with travel times measured by floating cars. - The cellular phone-based system can be useful for various practical applications such as advanced traveler information systems and evaluating system performance for modeling and planning.
Liu et al. (*2008*)	Minneapolis, Minnesota (Sprint PCS network)	A research team at the University of Minneapolis evaluated the system travel times using cell phone tracking against ground truth conditions and then assessed the level of accuracy and reliability of the technology through statistical analysis. The preliminary result showed that the cell phone tracking technology produced results with varied accuracies. They also concluded that the error of speeds and travel times is dependent on the guidelines set forth by interested transportation agencies.

2.2 GPS-Enabled Cellular Phone in Traffic Monitor

As GPS-enabled cellular phones become more popular, some research teams have turned to applying this technology as probes in tracking traffic information. A research team from the University of California at Berkeley and Nokia tested the feasibility of using GPS-enabled mobile phones to monitor real-time traffic flow (UC Berkeley News 2008). One hundred vehicles were deployed onto a 10 mile test road for seven hours. The goal of this experiment was not only to test the efficiency of the traffic data collection and aggregation system, but also to

evaluate the trade-offs between traffic estimation accuracy, personal privacy and data collection. This project was ongoing at the time of this report and will include more than one thousand cars.

A previous study quantified position accuracy of multimodal data from GPS-enabled cell phones in the Tampa area of Florida (Aguilar et al. 2007). The results showed various accuracies as the cell phone was taken on different transportation modes in an urban environment. When the users were walking unobstructed with the cell phone, the highest percentage of GPS fixes (79.0 percent) was obtained; walking also produced valid GPS data (i.e., location data estimated to be accurate within 30 m of the true position) 66.2 percent of the time. For bus trips, GPS and valid fix percentages were 71.7 percent and 66.1 percent, respectively, when the phone was held near the window. When the phone was placed in the traveler’s lap these numbers fell to 51.3 percent and 27.8 percent, respectively. Car trips provided higher numbers: 77.7 percent and 71.6 percent, respectively. The findings indicated that location-based transportation applications are feasible using current technology, but predictive algorithms may be required to deliver highly accurate and timely location-aware services to cell phone users in highly obstructed environments.

2.3 Cellular Phone Location Technology in Origin-Destination Matrix Derivation

Cellular phone data were also tested for creating OD data. White and Wells (2002) proposed a pilot study, which investigated the feasibility of using billing data to obtain OD information in the Kent area of the United Kingdom. The OD matrix was developed by analyzing a sample of billing data from one morning. It demonstrated that it is possible to obtain OD information from mobile phone data. However, more and continuous data, phone calls or otherwise, were needed. The study also called for repeated analysis of billing data to create a matrix better resembling the original OD matrix.

Caceres et al. (2007) also assessed the feasibility of using mobile phone location databases to infer OD matrices via cellular phones that were switched on all the time. Instead of monitoring the flow of vehicles in a transportation network, the study used the flow of mobile phones in a cell-phone network to derive OD data. This methodology was based on the fact that a mobile phone moving on a specific route tends to change the base station at nearly the same position. For the pilot study, a global system for a mobile communications (GSM) network simulator was designed, where network data could be simulated, which was then extracted from the phone network, correlated, processed mathematically and converted into an OD matrix.

This study also introduced an adjustment factor, which could convert the cell phone data to vehicle traffic data. The simulation results showed that the method had great potential, and the results inferred were much more cost-effective than those generated with traditional techniques. This was because no change had to be made in the GSM network. The information could be directly extracted from the base station database, which was already in place for the entire infrastructure needed.

In addition to the application as a traffic monitoring system, the cell phone position tracking data were also applied in human and societal activity studies. Wiehe et al. (2008) assessed the feasibility of using GPS-enabled cell phones to track adolescent travel patterns based on 15 adolescent females. The result showed that GPS-enabled cell phones offer a feasible and, in many ways, ideal modality of monitoring the location and travel patterns of adolescents.

Gonzalez et al. (2008) studied the trajectory of 100,000 anonymous cell phone users outside of the United States and tracked them for a six-month period. They found that nearly three-quarters of those studied mainly stayed within a 20-mile-wide circle. Most individuals traveled short distances and only a few regularly moved over hundreds of miles. However, they

all followed a simple pattern, regardless of time or distance. The individuals studied also had a strong tendency to return to locations they had visited before. The study concluded that the inherent similarity in travel patterns of individuals could impact all phenomena driven by human mobility including epidemic prevention, emergency response, urban planning, traffic forecasting, and agent-based modeling.

According to the literature review, the application of cellular phones in tracking truckshed faces several factors and challenges.

2.3.1 Technical Factors

The efficiency of obtaining position data from cellular phones depends on various factors. One of these is the accuracy of the location data, which depends on the cell's range of coverage. Another factor is the renewal frequency of these location data, which depends on whether the terminal is merely switched on or the network is being used in some way that updating is instantaneous and continuous. These two factors depend on the data that is available from the cellular phone data provider.

In order to accurately measure the truck movement position, a well-developed map match and data screening methods are needed.

2.3.2 Privacy of Users Issues

The privacy of users is the legal issue of using mobile phone location data. One concern with the use of the cell phone location data is anonymity. With the introduction of the Human Rights Act, this is a key issue.

2.3.3 Tracking Methodology and Adjustment Factor

Determining the sampling truck identification and truck flow rate estimation is a critical issue. Since the cell phone position data do not show the vehicle types, a filter methodology is needed to identify the truck data based on the cell phone movement time period and frequency.

Chapter 3 Tracking Technology Analysis

Cell phone location tracking technologies can be generally divided into two categories: network-based and handset-based. Network-based systems utilize signal information from cell phones to derive their location. In network-based systems, one or several base stations (signal towers) are involved in locating a cell phone. All required measurements are conducted at the base stations and the measurement results are sent to a location center where the position is calculated. There is no requirement to make any changes to the current handsets for this system. However, the cell phone must be in active mode (i.e. in "talk" mode or sending a signal through the control channel) to enable a location measurement. Handset-based systems rely on GPS-enabled wireless phones. The GPS unit in the handset determines the location of a phone, and this information is relayed from the cell phone to a central processing system maintained by the wireless carrier.

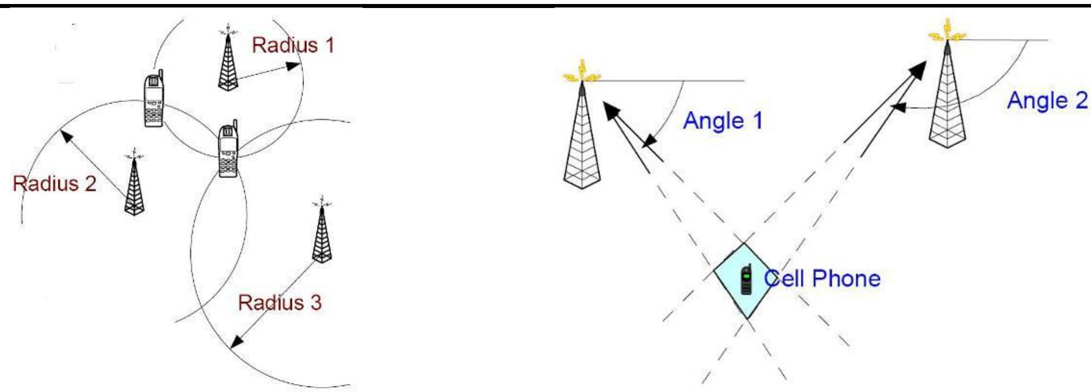
3.1 Cell Phone Location Calculation and Limitation

According to the requirement by the Federal Communications Commission (FCC 2001), location accuracy and reliability should be 100 meters for 67 percent of calls; and 300 meters for 95 percent of calls for network-based solutions; 50 meters for 67 percent of calls, 150 meters for 95 percent of calls for handset-based (GPS enabled) solutions. Depending on the technology, calculation methodology and signal path, the accuracy of cell phone location estimation vary.

For network-based systems, two major methods (as shown in fig. 3.1) are used to calculate the locations of cell phones. The first is a triangulation method. In ideal conditions, the cell phone location can be calculated exactly using the triangulation method with computed distances from three nearby stations. However, in reality, the computed distances are dependent on the reflections, diffraction, and multipath occurrences of the phone signal. The triangulation

method result is an area instead of a point. The accuracy of triangulation method is about 50-200 meters (Openwave Inc. 2002).

The other method is an Angle of Arrival method. In this method, special antenna arrays are installed at the base stations to calculate the direction the signal. Thus, two stations are enough to calculate from what direction the cell phone signal is coming. Considering the effects of multi-propagation, this method has an accuracy of about 50-300 meters.



(a) Triangulation Method (b) Angle of Arrival Method

Figure 3.1 Cell phone location calculation methods (Source: Openwave Inc. 2002)

For handset-based systems using the GPS satellite system to calculate the position of the cell phone, the accuracy is between 5-30 meters. The accuracy is affected by factors such as the ionosphere, troposphere, noise, clock drift, ephemeris data, multipath, etc. The use of GPS in cell phones as a positioning device also suffers from three main disadvantages (Zhao 2000). First, GPS signals are too weak to detect indoors and in urban canyons, especially with small cellular sized antennas. Second, the time required to obtain a GPS position is relatively long, ranging from 60 seconds to a few minutes due to the long acquisition of the satellite navigation message.

Finally, due to long signal acquisition time, GPS power dissipation is very high. These computations drain the battery of the phone.

The assisted-GPS method, where the wireless network uses a server to perform the calculations and transmit to the phones, can solve the delay and power consumption issues. Additionally, the wireless network can use the differential-GPS method to reduce errors. In this method, a tower with a known position is equipped with a GPS receiver to estimate the total error. The errors are roughly the same in nearby areas where the estimated error can be transmitted to the phone for compensation. Thus, the corrected location in a nearby area is the non corrected GPS location minus the estimated error. The accuracy is improved to 15 meters or less (Wunnava et al. 2007).

3.2 Cell Phone Location Technology Test

Several researchers have tested the accuracy of location tracking and the estimation of travel speed using cell phone tracking technology. The results showed that most cell phone location systems can provide reasonably accurate position data. The systems were unsuccessful in producing traffic flow information.

CAPITAL, deployed in the Washington, D.C. area in the mid-1990s, was the first major deployment of wireless location technology (WLT) in the US. The system was able to locate cellular phones within 100 meters of their actual position. The accuracy of the position estimates improved considerably as the number of cellular towers providing directional information increased. Speed information could not be calculated because at least four positions are needed to calculate speed. Less than four position estimates were collected 80 percent of the time (University of Maryland, 1997).

The other deployment using U.S. Wireless was conducted in the San Francisco Bay region in California (Yim and Cayford 2001). Researchers at the University of California - Berkeley obtained 44 hours of wireless location data. They were generally able to determine the location of the cell phone on the roadway network. The study found that the location estimates of cell phones were regularly accurate within 60 meters, although 66 percent of cell devices tracked had at least one outlier with an error of more than 200 meters (Smith et al. 2003).

A research team of the Virginia Transportation Research Council at the University of Virginia (2005) investigated and reviewed over 16 deployments of wireless location technology (WLT)-based monitoring systems both in the United States and abroad. The research concluded that most systems did not produce data of sufficient quality or quantity to provide reliable traffic condition estimates. A similar task was done by a research team at Florida International University (Wunnava et al. 2007). The study investigated the maturity of cell phone technologies for application as real-time traffic probes for travel time estimations along the highway and roadways. It found that cell phone technology was feasible to determine travel time estimations under the normal conditions of free traffic flow, but it was not accurate in congested traffic conditions. The accuracy decreased rapidly as congestion increases.

3.3 Cell Phone Location Provider

The research team collaborated with a cell phone location data vendor, AirSage, Inc., who provided location data for the field feasibility test. AirSage is one of several providers of location, movement and real-time traffic information based on cellular signaling data. The vendor has long-term cooperation terms with Sprint Wireless, and recently Verizon Wireless, to provide traffic condition and speed data (*AirSage New Release. 2009a*).

AirSage is an Atlanta, Georgia based company founded in 2000 to develop a system to derive traffic information through tracking cell phones (AirSage, 2009b). The AirSage product to extract traffic information is called Wireless Signal Extraction (WiSE™) technology, and its system architecture is illustrated in figure 3.2.

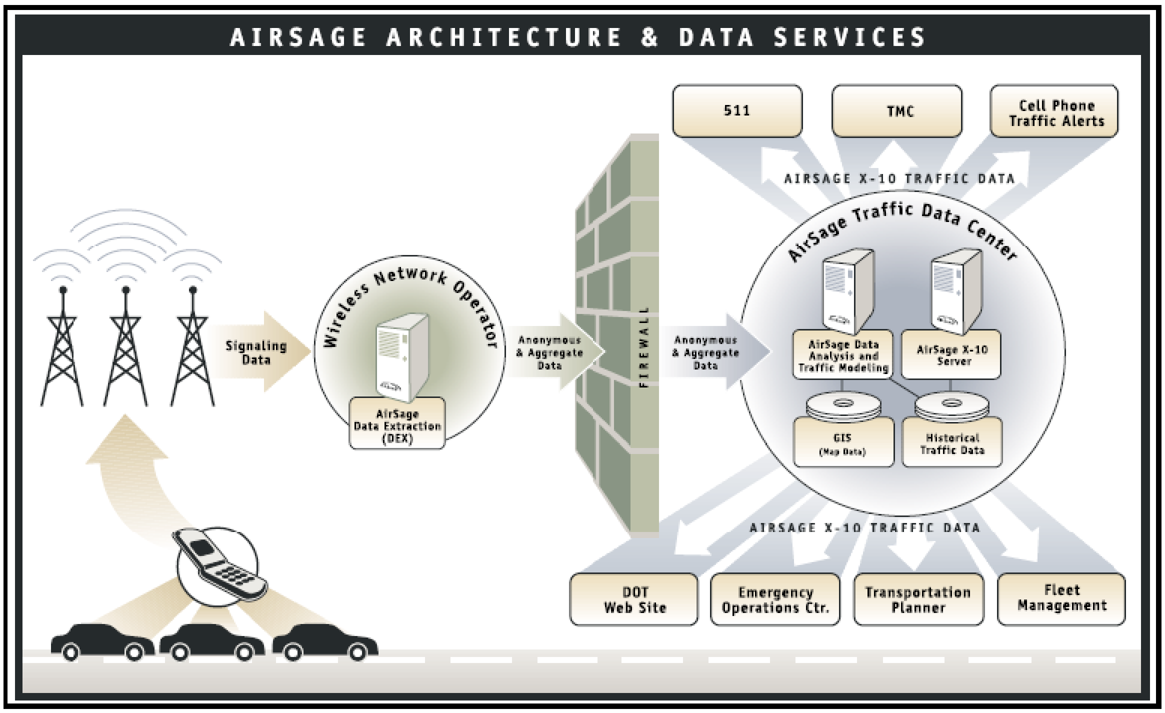


Figure 3.2 AirSage X-10 system architecture (Source: AirSage's WiSE Technology)

The WiSE technology aggregates, anonymizes and analyzes signaling data from individual handsets using the cellular network. It also determines accurate location information and converts it into real-time anonymous location data. In essence, each individual handset becomes a mobile location sensor, allowing AirSage to identify how phones move over time.

WiSE™ Technology is the key to AirSage's providing location information from the most extensive coverage available. Proprietary algorithms convert anonymous wireless signals

into accurate, complete, and relevant information. Extensive coverage is assured as a result of the inherently widespread footprint of wireless signal carriers.

Several subsystems work together to create the WiSE™ system architecture and data services. The AirSage Data Extraction Subsystem (DEX) resides within the wireless carrier environment, and is responsible for aggregating and anonymizing network data. Patented technology and multiple layers of privacy protection ensure that no proprietary, customer-identifying data is accessed or released from the secure environment of the wireless carrier.

Inside the AirSage Data Center, the AirSage Data Analysis Subsystem receives data from the DEX(s) and uses proprietary algorithms to convert it into location and movement information. The AirSage Content Delivery Platform packages the information and delivers it to the customer. The AirSage system has been tested in several metropolitan areas. In 2003, AirSage was awarded a contract by the Virginia Department of Transportation to estimate location, speed, travel time, and other performance measures on the basis of cell-phone probes. The test was conducted in one region of Virginia in 2005. It was concluded that AirSage system could not provide the quality of data desired by the Virginia Department of Transportation (Smith 2006).

A research team at the University of Minnesota evaluated the AirSage system's travel times against measured conditions and assessed the level of accuracy and reliability of the technology through statistical analysis (Liu et al. 2008). The study investigated travel speed and travel time from the field and compared to the AirSage's reported performance on two different type roadways in the Minneapolis–St. Paul metropolitan area. The results found that the accuracy of the cell phone tracking system varied on travel speed and speed time estimation. On segments with very congested and uncongested conditions, AirSage system can estimate the speed within 10 mph of the observed speeds. On segments with moderate congestion, the accuracy was varied

compared to the observed speeds. Some consistency for underestimating or overestimating travel times were found at one observed location during the peak hours.

In April 2009, AirSage release a third-party test result on their web site (AirSage, Inc., 2009d). The study conducted by GeoStats Inc., was a month-long independent quality test, and included traffic verification tests on highways and arterials in Detroit, New York and San Diego to measure the overall quality of AirSage's Real-Time Traffic (ART) data. GeoStats drove more than 11,800 miles during the comprehensive testing to collect GPS data points, which then served as ground truth data for the comparison to AirSage data. In Detroit, New York and San Diego, AirSage performed very well on highways, reporting accurate congestion levels 91percent of the time. On arterials, AirSage reported congestion correctly 93 percent of the time, proving that real-time data on arterials is possible.

Chapter 4 Data Penetration and Data Structure

Generally, cell phone data penetration analysis includes the number of cell phone subscribers, the cell phone signal service area, and the portion of cell phone in calling situations that can be tracked. The cellular phone data structure and coverage and data transmission process provided by the cell phone vendors are also introduced in this section.

4.1 Cellular Phone Penetration

4.1.1 Cell Phone Subscription

By the end of 2008, there were more than 270 million cell phone subscriptions in the USA, which is about 87 percent of total U.S. population (CTIA, 2009). About 17.5 percent of U.S households are wireless-only. The cell phone market penetration covers nearly all ranges of vehicle users, especially truck drivers. Thus, using cell phones to develop a truckshed would cover almost all truck drivers, if all cell phone signals were available.

However, there is no integrated system today which could provide all cell phone signals. The USA is the most competitive in the cell phone market in the world. The top four carries represent only 86 percent of the market. The cell phone signal data belong to different cell phone carriers. The top four cell phone carriers cover 28.5 percent, 26.7 percent, 18.2 percent, and 12.1 percent, respectively, of the cell phone market at the end of 2008 (*CTIA, 2009*).

4.1.2 Cluster of Cell Phone Data

Since the location data are available only when the cell phone is being actively used to make a call, only a partial number of drivers can be detected. Considering the truckshed tracking process makes use of cell phone location data, the cluster and relationship of the number of truck drivers and available cell phone location data in the facility area are illustrated in figure 4.1.

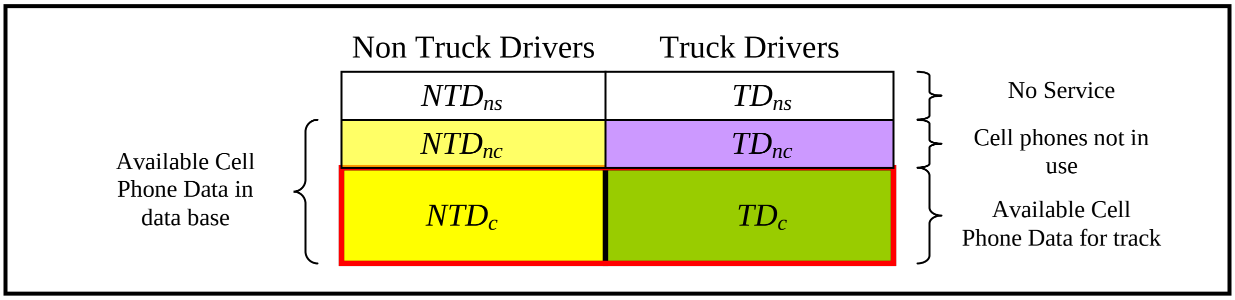


Figure 4.1 The cluster and relationship of truck drivers and available cell phone data

NOTE: Total people within the intermodal facility = {NT_{ns}, NT_{nc}, NT_c, T_{ns}, T_{nc}, T_c}, where

NTD_{ns} : Non-truck driver who does not have cell phone in provider data base,

NTD_{nc} : Non-truck driver who did not use cell phone during data collection period,

NTD_c : Non-truck driver who have used cell phone during data collection period,

TD_{ns} : Truck driver who does not have cell phone in provider data base,

TD_{nc} : Truck driver who did not use cell phone during data collection period,

TD_c : Truck driver who have used cell phone during data collection period.

Non-truck drivers include employees, workers, customers, train drivers and possible residential passing-by drivers. No Service data consist of the drivers who do not have a cell phone or the cell phone data are not available in the provider's database. Cell phones not in use represent those drivers who do not use their cell phone when they are in the facility during the data collection period. The portion of this cluster would decrease over a long time period of observation. Available cell phone data are the location data when the cell phones carriers make a call or send a message. These data include truck and non truck drivers' cell phone data and are the only known data for the cell phone tracking system during the data collection period.

Based on the cluster distribution above, only partial cell phone data are available for the truckshed tracking system. One of difficulties of using cell data to track a truckshed is determining the relationship between the characteristics of sample size and the entire volume of trucks from the intermodal facility. Fortunately, as the cell phone becomes the basic

communication tool and more cell phone signal data will be integrated, more cell phone data will be available in the provider database. For a long time period of observation, the available cell phone data for tracking will increase since the probability of cell phone carriers making calls will increase. Therefore, the sample size of cell phone data would be enough for long haul truck tracking from the intermodal facility.

<u>4.2 Location Data Coverage in Data Provider's System</u>

The major purpose of the AirSage system is to provide the live traffic condition based on sampled cell phone movement data. Figure 4.2 shows the coverage of cell phone location and traffic condition information provided by the AirSage system. The system provides real-time, historical and predictive traffic information for 127 U.S. cities. Most data concentrate on the major metropolitan area (*AirSage, Inc. 2009c*).

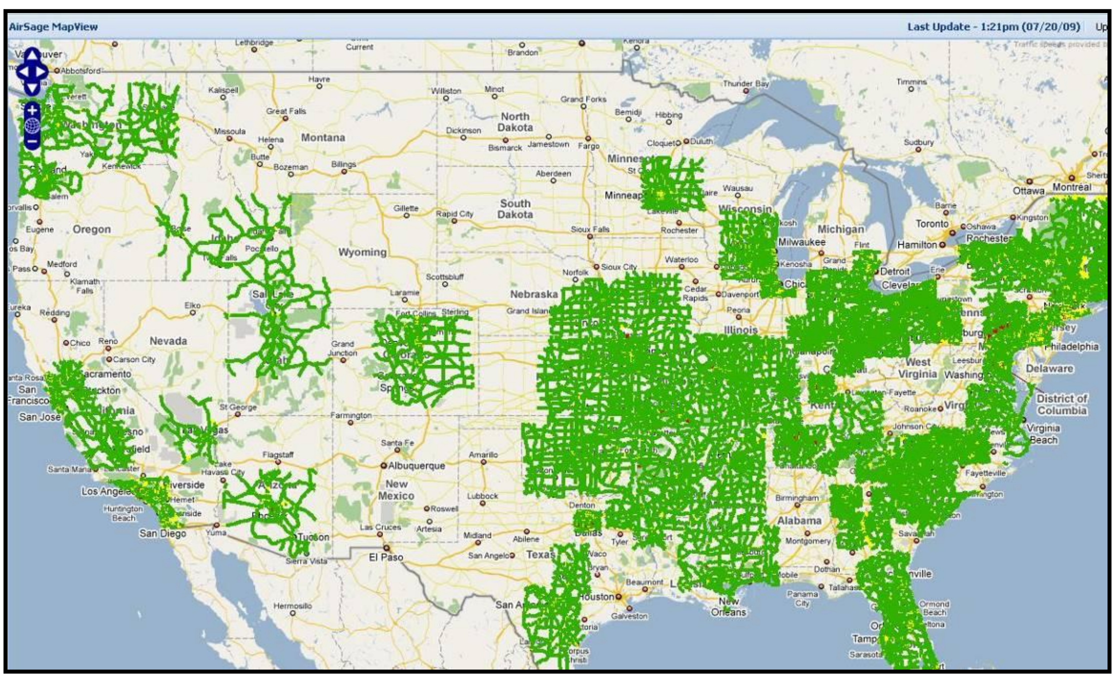


Figure 4.2 AirSage Live Traffic Service Area (Source: AirSage, Inc. 2009c)

Although AirSage's live traffic system covers most metropolitan areas in the USA, the system does not have data storage function to store the location data due to the enormous file storage space that would be required. Thus, the data file storage function needed to first be accomplished by the research team for the long time traffic tracking purpose in this study.

4.3 Location Data for Research

The research team has held two official meetings with the CEO and technicians of AirSage, Inc. and they consented to provide access to the data coverage and transmission procedure based on the research scope of work. Since the cell phone location data in AirSage system did not store the location data for a record in their traffic surveillance system, the technician has developed a new function which enabled the system to save the location data and transmit the data to the research team's computer server at the University of Kansas.

The target area for this study was set to cover seven states in the Midwest in the USA. However, due to technology issues, such data were not ready to transmit to the research team's server to date. An alternative data collection area around the Washington, D.C. metropolitan area was ready and the data already have been transmitted to the research team's server starting on September 1, 2009. To test the feasibility of tracking traffic using cell phone location data and recognizing the coverage of cell phone location data, the research team decided to use these alternative data for a preliminary test and to develop the analysis program to process the data analysis and test.

The location data are provided on a 30-second basis. For every 30 seconds, all the locations of the cell phones in actively being using for calls or typing messages in the network were recorded. For every two minutes, these 30-second data sets were save as a CSV file in

AirSage's local server and then transmitted to a computer server in the University of Kansas, simultaneously. The sizes of every 2-minute zipped data file range from about 600 KB to 4MB.

4.3.1 Washington, D.C. Metropolitan Data

The data cover Washington, D.C., and the states of Maryland and Virginia. The location data were transmitted to the research team's server starting from September 1, 2009 and continuing to December 31, 2009. Figure 4.3 shows the metropolitan area around Washington, D.C. used for the preliminary test.

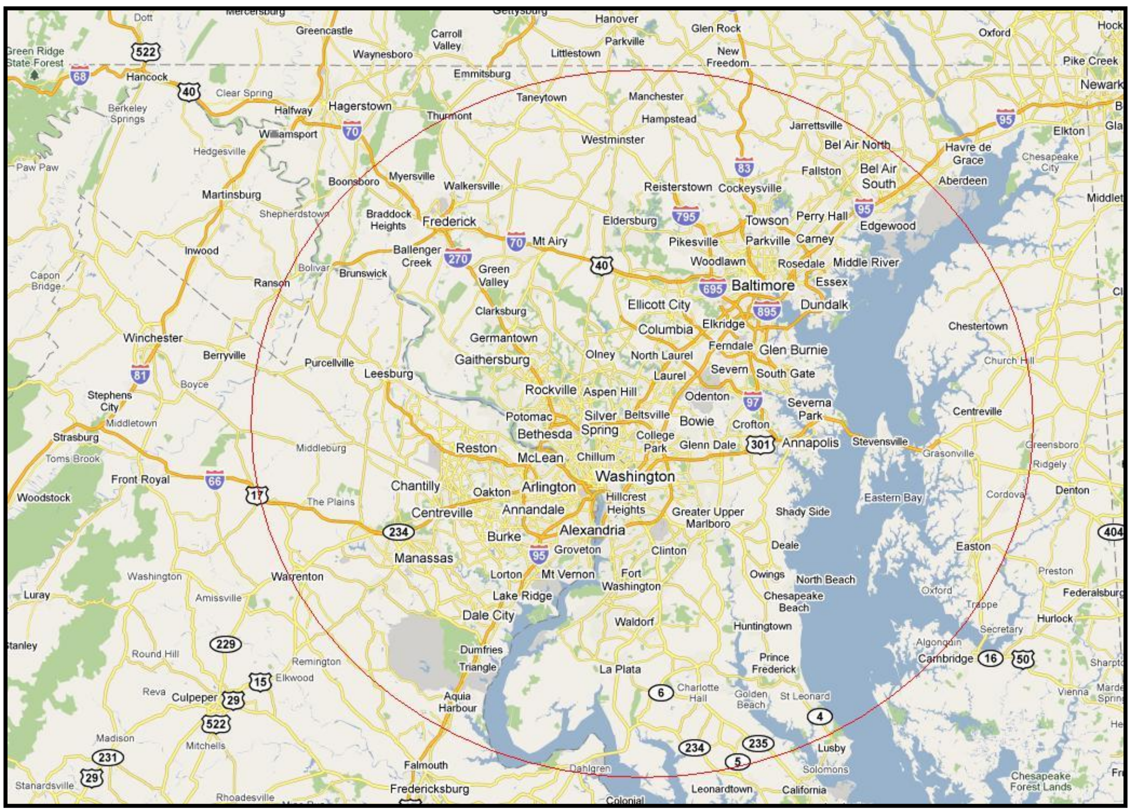


Figure 4.3 Cell phone locations coverage around Washington, D.C. metropolitan area

The research team developed an interactive program which converts the cell phone location data into a Google™ Earth maps. During the first month of the data transmission period, the research team found some data files were missed and some cell phones where positioned

outside the territory of the continental USA, which were considered to be unreasonable data. The transmission program was updated at the end of October and those miscalculations were corrected.

4.3.2 Seven States of Midwest Data

Cell phone location data needed for future phases of the research are expected to cover seven states in the Midwest, centered around Kansas City. Figure 4.4 shows the desired coverage area in the Midwest. The data are expected to cover major cities, such as St. Louis MO, Des Moines, IA, Omaha, NE, and Tulsa, OK. These data will be used to evaluate the accuracy of the cell phone location data and truck volume identification by comparing the cell phone derived data to the field observation data from selected intermodal facilities.

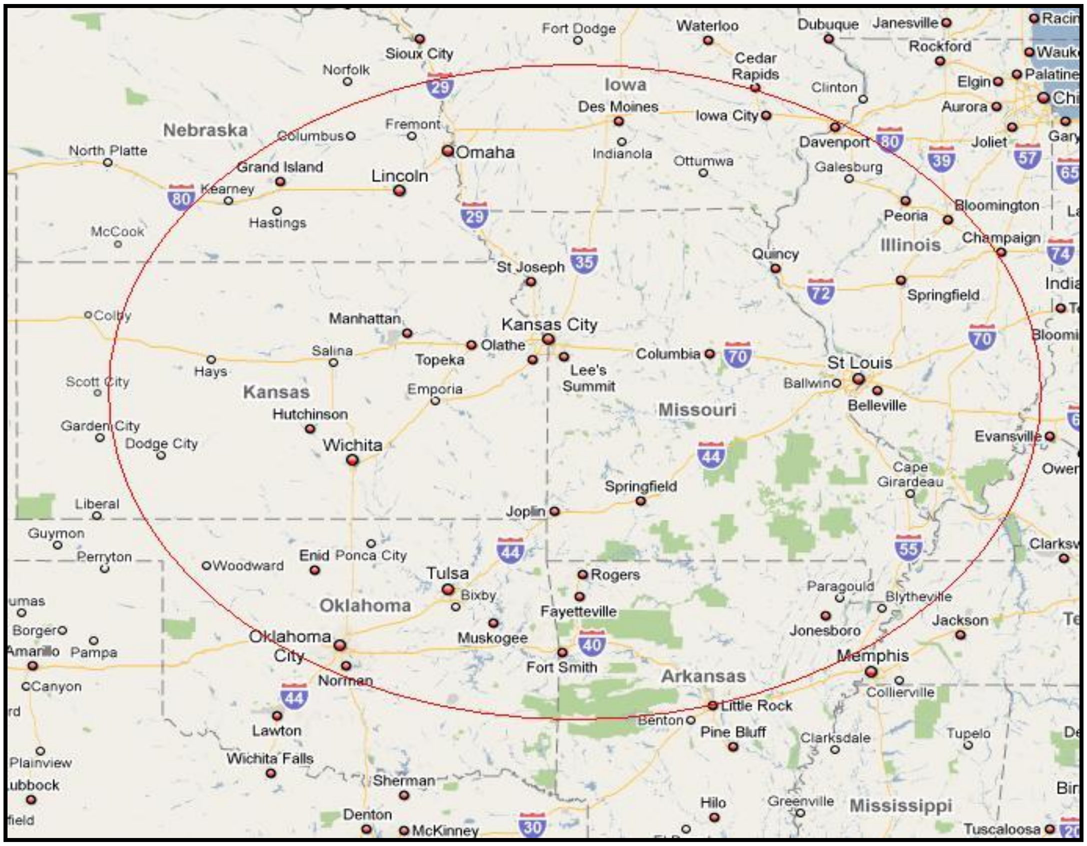


Figure 4.4 Desired cell phone locations coverage of the Midwest

4.4 Data Structure

The cellular phone data structure shown in table 4.1 mainly includes a unique identification number (encrypted ID), location information and the time when the cell phones are actively being used for calls. The location information was shown as longitude and latitude.

Table 4.1 Cell Phone Location Data Structure from AirSage, Inc.

No	Field name	Data type	Explanation
1	encrypted_id	character varying	Encrypted unique ID to identify a subscriber
2	first_dialed_digits	character varying	3 first digits of the call event
3	longitude	double precision	
4	latitude	double precision	
5	distance_to_tower	integer	distance between the estimated location and the closest tower (in meters)
6	uncertainty	integer	estimated uncertainty (alpha version) (in meters)
7	method	integer	number of pilots used
8	Psmm event	integer	1 = first event of a call or 2 = last event of a call
9	epoch_time	integer	UTC timestamp (it can't be null)

The encrypted ID number is more than 30 digits and a unique string for every individual cellular phone. The epoch time is presented in the UNIX timestamp format. The epoch time was transferred to a readable data/time by using the following equations using SAS.

$$East\_time = Sas\_time - 3600 * k \text{, and} \tag{4.1}$$

$$Sas\_time = Time + 86400 \times (365 \bullet 10 + 3)$$

Where:

East_time = timestamp in the eastern time zone of the USA,

Sas_time = timestamp for GMT time zone in the SAS program system, the SAS timestamp starts at 0 on January 1st, 1970,

k = Adjustment factor for timestamp from GMT time zone to the eastern time zone of the USA, k = 3 during daylight saving time; k=4 during standard time.

An example of the raw data is shown in figure 4.5. The location of the cell phone is presented as longitude and latitude, which can be converted directly to Google™ Earth maps.

	A	B	C	D	E	F	G	H	I
1	544d6909253606662af9d41128bca8ce	#77	-77.3309	39.70633	2894	336	1	2	1258610282
2	98f7a88b35d1f08140d6e64afd7d1fda	301	-77.3186	39.69515	3011	77	2	2	1258610305
3	66897a35f91c09fc4c0c9f318073fdf8	#77	-77.3057	39.72071	447	94	1	2	1258610325
4	244830179c71e0534b592a23877a12de	#77	-77.3473	39.71882	3954	345	1	2	1258610354
5	66897a35f91c09fc4c0c9f318073fdf8	#77	-77.3056	39.72048	426	62	1	2	1258610355
6	9143cda41e0e9b85d34e4c0c29c760d1	#77	-77.3336	39.70992	2946	394	1	2	1258610307
7	161b0167880bac2319ba847d76fd29ed	#77	-77.2847	39.73296	2124	333	1	2	1258610381
8	544d6909253606662af9d41128bca8ce	#77	-77.3315	39.70705	2903	346	1	2	1258610363
9	544d6909253606662af9d41128bca8ce	#77	-77.3321	39.70779	2913	358	1	2	1258610309
10	c2c7e327bd7048f3e4e130254a0333b2	0	-77.3099	39.70191	2008	425	2	2	1258610383
11	66897a35f91c09fc4c0c9f318073fdf8	#77	-77.3057	39.72071	447	94	1	2	1258610340
12	234071b3c73761f1bbc2255981be727d	#77	-77.365	39.70878	5585	258	1	2	1258610353
13	244830179c71e0534b592a23877a12de	#77	-77.3477	39.71861	3992	344	1	2	1258610286
14	9143cda41e0e9b85d34e4c0c29c760d1	#77	-77.3343	39.71095	2967	414	1	2	1258610364
15	544d6909253606662af9d41128bca8ce	#77	-77.3261	39.70238	2801	282	1	2	1258610333
16	c2c7e327bd7048f3e4e130254a0333b2	0	-77.3097	39.70201	1990	415	2	2	1258610327
17	d72f9c4bb61294abb3b76c910349345b	#77	-77.3513	39.67987	587	113	1	2	1258610319
18	7abd9e0dd81207bb2b02a7097af721c4	0	-77.4136	39.64154	2457	382	1	2	1258610390
19	e57f6dd74fe2ada333a4ca20608f05d3	0	-77.4091	39.62745	1702	316	1	2	1258610286
20	91d4a1e260ef5ca27f3448ed356d036f	#77	-77.4213	39.61921	315	224	1	2	1258610313
21	91d4a1e260ef5ca27f3448ed356d036f	#77	-77.422	39.6194	274	194	1	2	1258610340
22	91d4a1e260ef5ca27f3448ed356d036f	#77	-77.4213	39.61921	315	224	1	2	1258610280
23	91d4a1e260ef5ca27f3448ed356d036f	#77	-77.4213	39.61921	315	224	1	2	1258610367
24	a7b0854c41e351873603aac03041066f	#77	-77.4047	39.43934	1776	119	2	2	1258610396
25	154f0cc6715c323f1ca35c38e5d1fbeb	0	-77.4112	39.42121	538	330	1	2	1258610364

Figure 4.5 Raw data of cell phone location data from AirSage, Inc.

Chapter 5 Location Tracking and Characteristics Identification

5.1 Location Tracking Component

One of the major challenges of tracking a truckshed using cell phone data is how to isolate the truck cell phone data from the available cell phone data. All available cell phone data includes truck and non-truck location data in the intermodal facility. The first step in tracking trucks is to catch all available cell phone data within and from the targeted intermodal facility. This step can be done directly by matching the cell phone location data to the facility. Every cell phone signal located within the facility area during the data collection period would be an initial data point and used for tracking.

The second step is to identify which cell phone user is a truck. Since the cell phone data are anonymous, the vehicle type can only be identified by tracking its moving path and destination. The characteristics of truck movement and traveling pattern and destination are different from passenger cars. The big difference is that most trucks travel for longer distances and frequently stop at truck stops, rest areas, and logistic warehouses. Thus, those popular and possible truck stop locations should be established during the truckshed process. In principle, the analysis network can be categorized into several types of regions based on the land use and truck movement characteristics. Possible types of regions include intermodal facilities, truck stops, rest areas, supermarket and logistic warehouses, business region and residential regions. Interstate highway network and city land use information could be referenced to create the database. Truck stops information available on the Internet also can be embedded into the database.

5.2 Truck Filtering and Tracking Process

Conversely, passenger car trips from an intermodal facility most likely are local and short distance. Those passenger cars can be filtered based on their destination. For example, if the cell

phone data from an intermodal facility is found in the residential or commercial area most of time, this point will be considered as a non-truck driver.

Depending on the size and the divided regions in the network, the truck filtering rules are varied. However, the principle of the filtering rules should be based on the results of a long tracking period. Figure 5.1 illustrates the procedure of isolating trucks and tracking a truckshed. During the analysis process, only and all those cell phone signals, which have ever appeared within the facility area, are isolated and tracked along the entire network data. Those tracked cell phones frequently located around truck stops with a certain traveling pattern and following the filtering rules could be consider as trucks. All the isolated truck cell phones are then embedded into the network map to derive the truckshed and present the impact of an intermodal facility on the entire network.

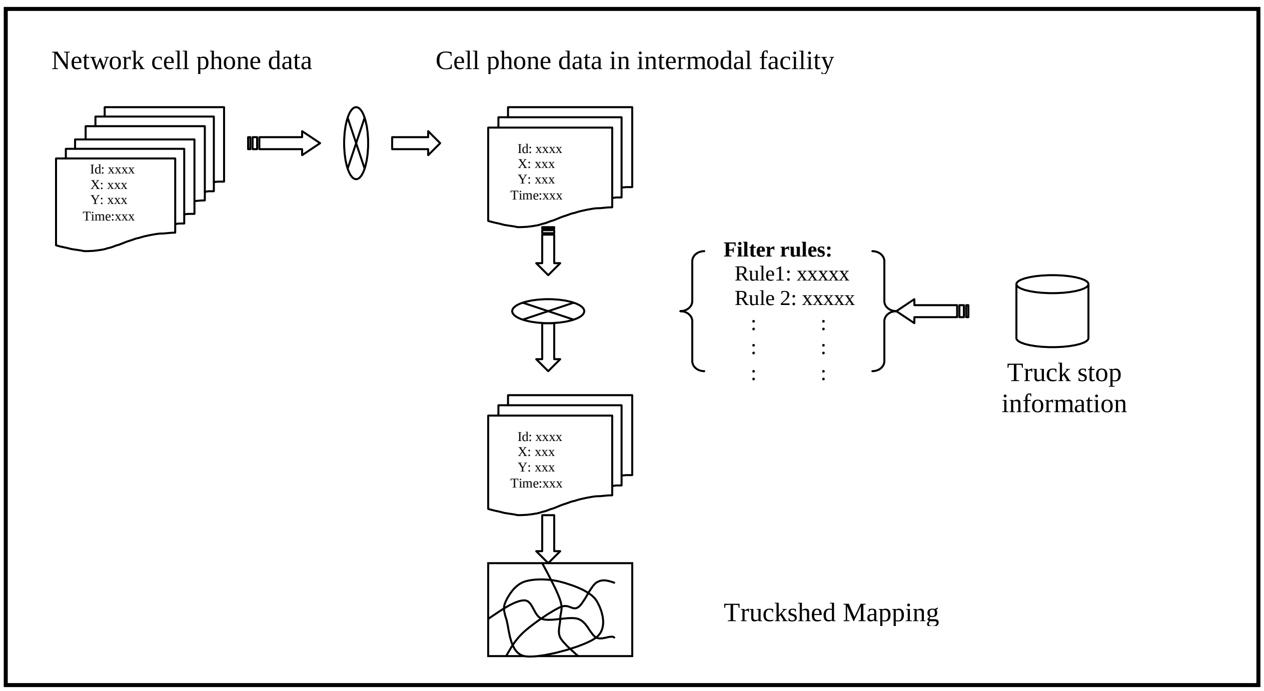


Figure 5.1 Procedure of filtering truck and tracking the truckshed

Every cell phone signal point includes a unique identification number, location data in both the X and Y axis, and operation time. An electronic map is also needed to embed all the cell phone locations into the designed region of the network. Data are sorted and tracked in the following format in table 5.1.

Table 5.1 Process of Cell Phone Tracking and Truck Filtering

Point ID	**t1**	**t2**	**t2**	**t2**	**…**	Filter Result
1	**n1(0,0)**	**n1(x,y)**	**n1(x,y)**	**n1(x,y)**	**…**	**Truck or Non-Truck**
2	**n2(0,0)**	**n2(x,y)**	**n2(x,y)**	**n2(x,y)**	**…(Location)**	**Truck or Non-Truck**
3	*******	**n3(0,0)**	**n3(x,y)**	**n3(x,y)**	**…**	**Truck or Non-Truck**
⋮	⋮	⋮	⋮	⋮	**…**	⋮

Where:

ID : cell phone initial ID as the new point appears in the intermodal facility,

T : time interval, system is scanned based on a set time interval (30 sec, 5 min), and

n(x,y) : cell phone location, the region where the cell phone location is determined.

Chapter 6 Preliminary Test Analysis

To determine the feasibility of using cellular phone location data to track the truckshed, a preliminary test was conducted to analyze the coverage of cell phone location data provided by the vendor's system and to test whether the cell phone location is of use in tracking traffic movement and dispersion and identifying cell phone travelers' characteristics, and to isolate heavy trucks from the traffic stream.

6.1 Preliminary Test and Analysis Plan

Since the cell phone location data in the Midwest were not ready from data provider's system, the cell phone location data around the Washington, D.C. metropolitan area were used for the preliminary test. A computer program was developed using SAS software (*SAS 9.1.3, 2007*) to process the cell phone location data analysis. The tracked and filtered data were then converted into Google™ Earth to illustrate the cell phone location data coverage, trajectory and dispersion from the target facility.

In addition to the cell phone location data coverage analysis, the major concept of the preliminary test is to lock those cell phones which have ever appeared within the target facility, then track their dispersion and trajectory, so as to identify their travel characteristics. Since there is no typical rail-truck intermodal facility around the Washington, D.C. metropolitan area, a significant travel dispersion pattern facility, Ronald Reagan International Airport (DCA), was selected as the target facility for the test and analysis. The basic information of cell phone location data and time period for the preliminary test are listed in table 6.1.

Table 6.1 Preliminary Test Area and Facility and Data Range

Test Network :	Washington DC Metropolitan Area
Target Facility :	Ronald Reagan International Ariport
Longitude:	From 38.8415 to 38.86
Latitude:	From -77.048 to -77.035
Data Date:	Nov 19th, 2009
Time Period:	0:00AM-0:00AM
Number of Files:	720
Data Files:	Locations_1258610532 to Locatinos_1258696815

The preliminary test and analysis consisted of three major parts, including cell phone network coverage analysis, cell phone tracking and dispersion process from the target facility and cell phone traveling characteristics identification. The content and process of the preliminary test are listed as figure 6.1 and discussed below.

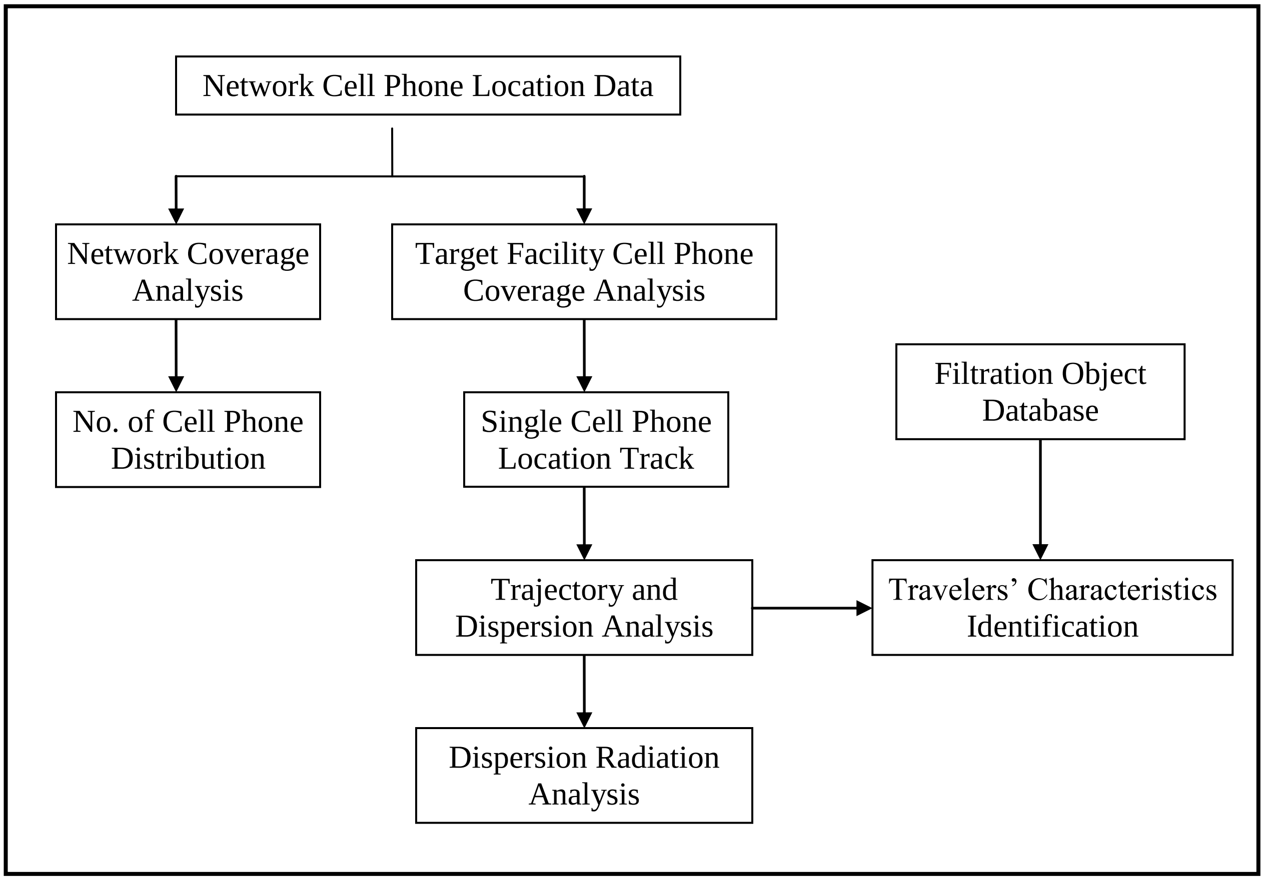


Figure 6.1 Process of preliminary test and analysis for cell phone location tracking

6.1.1 Cell Phone Network Coverage Analysis

The purpose of the cell phone network coverage analysis is to recognize the cover range of the available cell phone location data provided by the vendor's system and the distribution of cell phone calls in the research network. The coverage area and its boundary of cell phone location data were obtained by looking for the farthest points in all directions. The distribution of cell phone calls was conducted by counting the number of calls made in a certain interval.

6.1.2 Dispersion Tracking Analysis from a Target Facility

To realize the cell phone dispersed from DCA, all the cell phones, which appeared within DCA, were tracked and recorded. First, the coverage/service area of cell phones dispersed from

DCA was conducted. Then, the tracking process of sampled cell phones and their trajectories were illustrated. The dispersion distribution of cell phones on the network, including distance and travel time distribution, were also analyzed.

6.1.3 Cell Phone Characteristics Identification Analysis

The travelers' characteristics of cell phones can be identified based on the trajectory of the cell phones over time. To estimate whether the cell phone holder travels by a passenger car or a truck, an example set of truck stops was used as the identification criteria. Those cell phones, which appeared in DCA and then appeared or stayed at those truck stops, are considered as traveling by trucks.

6.2 Data Coverage Analysis

The coverage analysis consists of two major parts: 1) the boundary of the cell phone data coverage for the research, and 2) tracking the cell phone distribution. The boundary analysis is to recognize the service and coverage area of the cell phone data provided by AirSage, Inc. The cell phone distribution analysis attempted to investigate the total number of cell phones and their variation in the network over the course of the test day.

6.2.1 Coverage Boundary Analysis

To obtain the boundary of the cell phone location data coverage area, the data points with the farthest east and west latitude and the farthest north and south longitude, and the data points with the largest sum of latitude and longitude and sum of absolute value of latitude and longitude were picked from one day's (24 hours) data files. Figure 6.2 shows the boundary of the data coverage and all cell phone data points in a four-minute interval (two data files) during the peak afternoon.

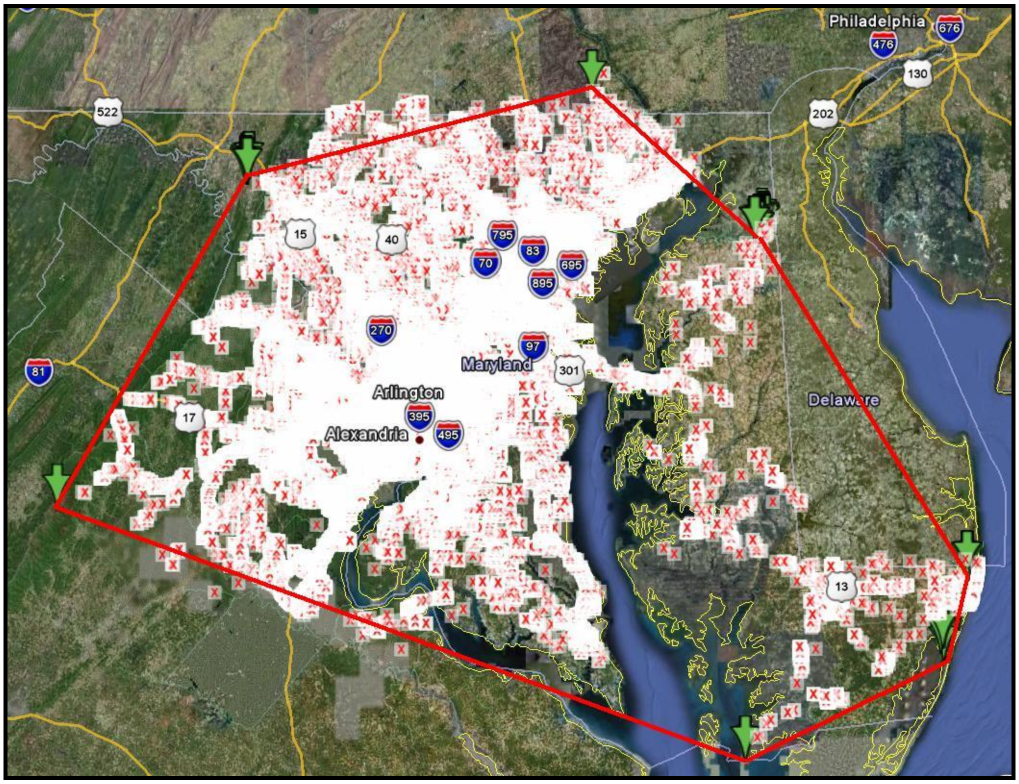


Figure 6.2 Boundary of entire cell phone data coverage

The cell phone data cover the Washington, D.C. metropolitan area and the vicinity cities, such as Baltimore, MD and Alexandria, VA, and cities crossing Chesapeake Bay in the state of Maryland. The northern boundary is at the geographic boundary of Pennsylvania and Maryland. The western boundary ends east of Interstate 81. Most cell phone signals were located at the Washington, D.C. metropolitan area, the City of Baltimore, and along the major corridors and interstate highways.

6.2.2 Number of Cell Phone Distribution

The number of people using cell phones may depend on the frequency of social activity, including transportation activity. To realize the relationship between the number of cell phone data points and social activity, the number of cell phone holders making at least one call during a certain time interval was obtained to conduct the distribution of the cell phone activities. Figure

6.3 shows the distribution of cell phones, which have at least one data point by a five-minute interval in 24 hours. During the five-minute interval, only one cell phone data point was counted even if the same cell phone had more than one location point.

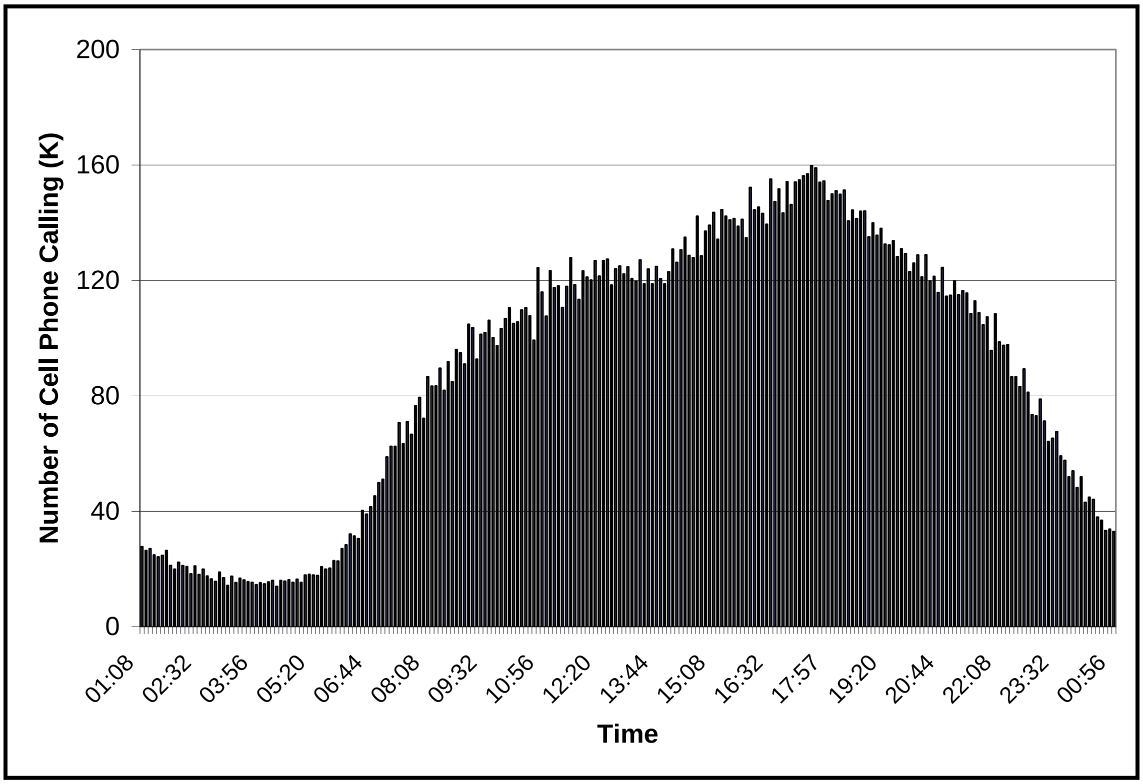


Figure 6.3 Number distribution of cell phone call in five-minute intervals

Obviously, the cell phone location point count shows the peak volume between 3 p.m. and 7 p.m., and has the lower volume from midnight to the early morning before 6 a.m. Table 6.2 summarizes the cell phone distribution on the test day.

Table 6.2 Statistics of Number (in Thousand) of Cell Phone in Five-Minute Intervals

Time Period	Mean	Stdev	Maximum	Minimum
All Day	89.2	47.4	159.7	14.0
3 p.m. to 7 p.m.	146.8	6.9	159.7	134.2

The average cell phone volume in a five-minute interval was 146.8 thousand (K) during the 3 p.m. to 7 p.m. time period. The peak volume was 159.7 K cell phones at 5:32 p.m. The peak cell phone volume occurred in the evening presumably because more social activity outside the home or office was expected in a metropolitan area.

6.3 Cell Phone Dispersion Analysis

In addition to time and location information of the cell phones, the travel time and distance from DCA were also computed. The distance to DCA is the straight-line distance between the location of the cell phone and DCA. The straight-line distance was calculated using the equation 5.1 as presented below:

$$Dist_{i,j} = 39.49.99 \times \text{arccosine}\begin{bmatrix} \sin\left(\frac{\mathrm{Lat}_o}{57.2958}\right) \times \sin\left(\frac{Lat_{i,j}}{57.2958}\right) + \\ \cos\left(\frac{Lat_o}{57.2958}\right) \times \cos\left(\frac{Lat_{i,j}}{57.2958}\right) \times \cos\left(\frac{Long_o}{57.2958} - \frac{Long_{i,j}}{57.2958}\right) \end{bmatrix} \tag{5.1}$$

Where:

$Dist_{i,j}$ = straight-line distance of cell phone *i* from location *j* to the center of facility (miles),

Lat_o = Latitude of the center of the target facility,

$Lat_{i,j}$ = Latitude of the center of cell phone *i* in location *j*,

$Long_o$ = Longitude of the center of the target facility, and

$Long_{i,j}$ = Longitude of the center of cell phone *i* in location *j*.

The dispersion analysis was illustrated as (1) the service area/impact area from the facility; (2) the single point trajectory; (3) the overall trajectory; and (4) the radiation distribution by percentile of cell phones and travel times.

6.3.1 Service/Impact Area from Target Facility

Transmissions from 7122 cell phones were collected within DCA during the test day. Table 6.3 presents the statistic of the farthest straight-line distance of all cell phone traveling from DCA. The dispersion (6453) represents that number of cell phones which made at least one call outside DCA. Thus, a total of 669 (7122 – 6453) cell phone holders appeared in DCA, but did not make a call after leaving DCA within the network.

Table 6.3 Statistics of Farthest Space Distance for All Cell Phones Traveling

Type	N	Mean (Miles)	Standard Deviation (Miles)	Minimum (Miles)	Maximum (Miles)
All	7122	8.6	10.1	0.0	75.1
Dispersion	6453	9.5	10.3	0.3	75.1

The cell phone data points were converted into Google™ Earth to compare the corresponding location of the cell phone to the geographic information. Figure 6.4 shows the cell phone data points, which have appeared within DCA and then appeared elsewhere during the observation period. This figure also illustrates the service area and possible traffic impact area from DCA. Note the figure was plotted with a ten-minute interval, which means the same cell phone call shows only one point within ten minutes.

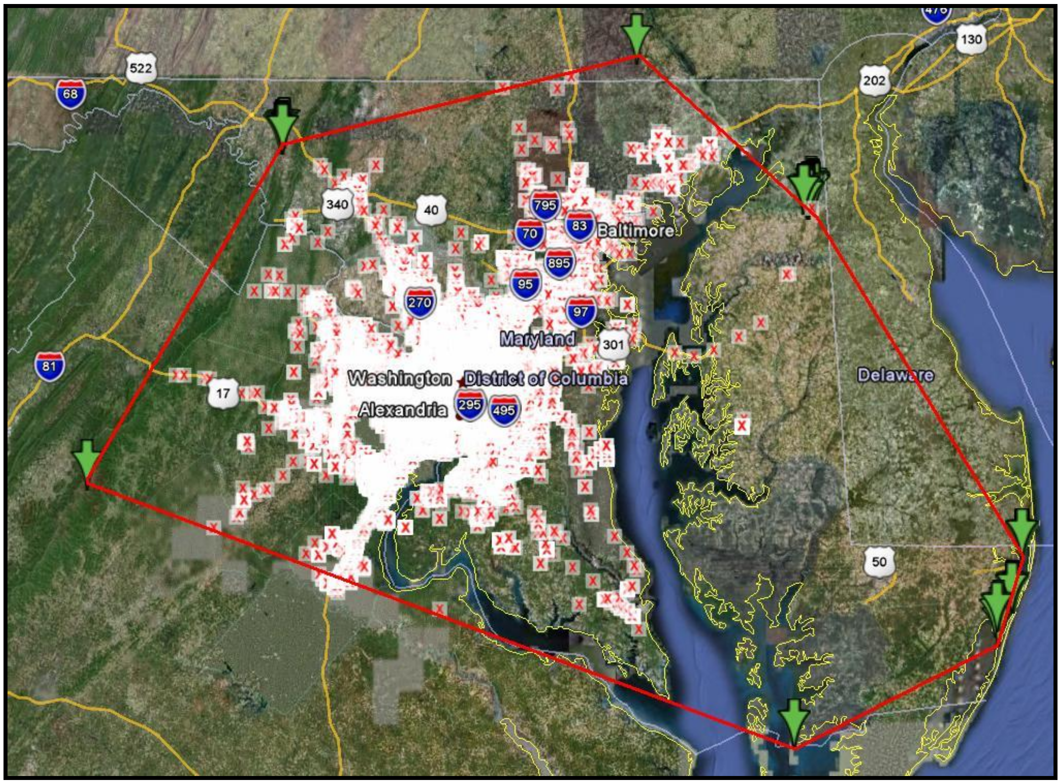


Figure 6.4 Location distributions of cell phones which have ever appeared within and dispersed from the Regan International Airport (over a one day period)

Comparing the boundary of the entire cell phone network, most cell phones from DCA were later observed around the Washington, D.C. and Baltimore area and dispersed along corridors and major roads. Only a few location points show up at eastern shore of Maryland crossing the Chesapeake Bay.

Figure 6.5 shows the number of cell phones that first appeared in DCA and the number of cell phone calls after leaving by a 30-minute interval. Note only the first data point was counted for the same cell phone even if more calls were made in DCA. Only one call was counted for the same cell phone outside DCA in a thirty-minute interval even if more than one location points were observed in the interval.

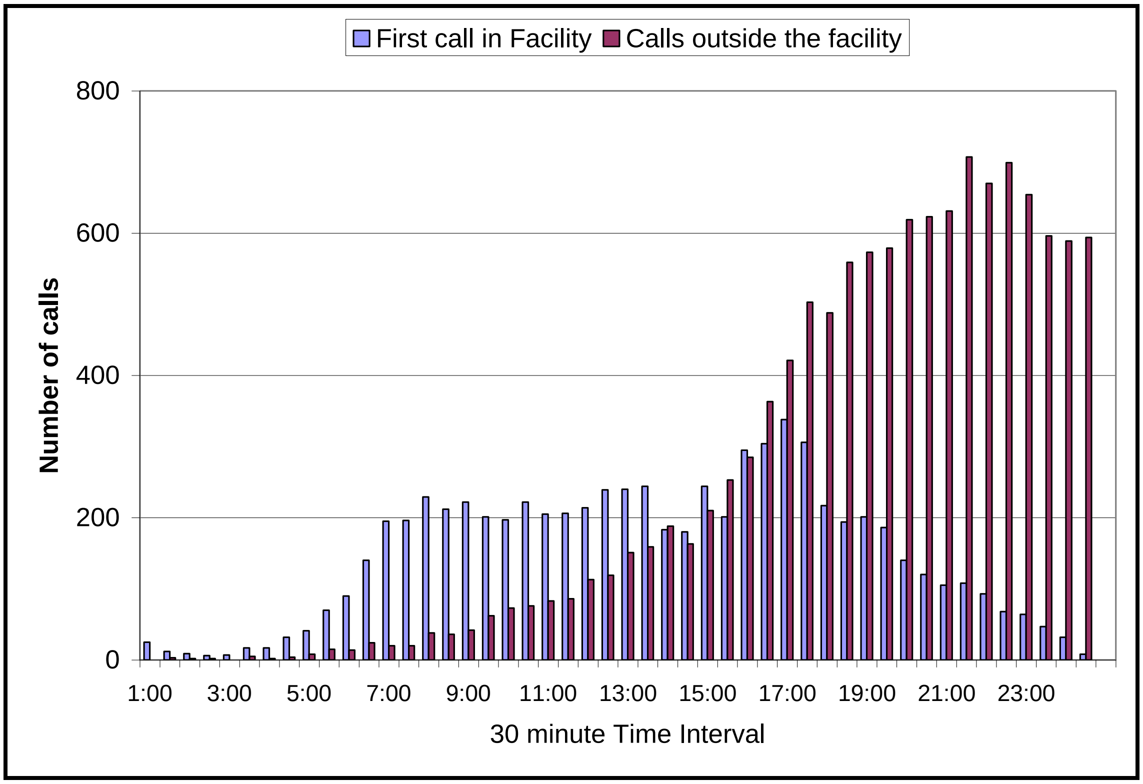


Figure 6.5 Distribution of number of cell phones in then outside the facility

The number of cell phone holders, who made the first call in DCA, can be treated as the cell phone volume generated from the DCA. The cell phone volume generated from DCA increased starting from about 5 a.m., then remained constant from 7 a.m. to 2 p.m., and increased to the peak from 4 p.m. to 6 p.m. The number of calls made outside DCA increased as time passed throughout the day since more cell phone calls were generated. The calls outside DCA increased rapidly during the evening and remained nearly constant at night.

6.3.2 Cell Phone Tracking and Trajectory Plot

In the tracking process, every individual cell phone was tracked as it dispersed from DCA. Figure 6.6 shows the overall trajectories of all cell phones which appeared in DCA. Note the trajectory plot is the straight line between two adjacent points in sequence of time for the same cell phone and may not be the real traveled routes.

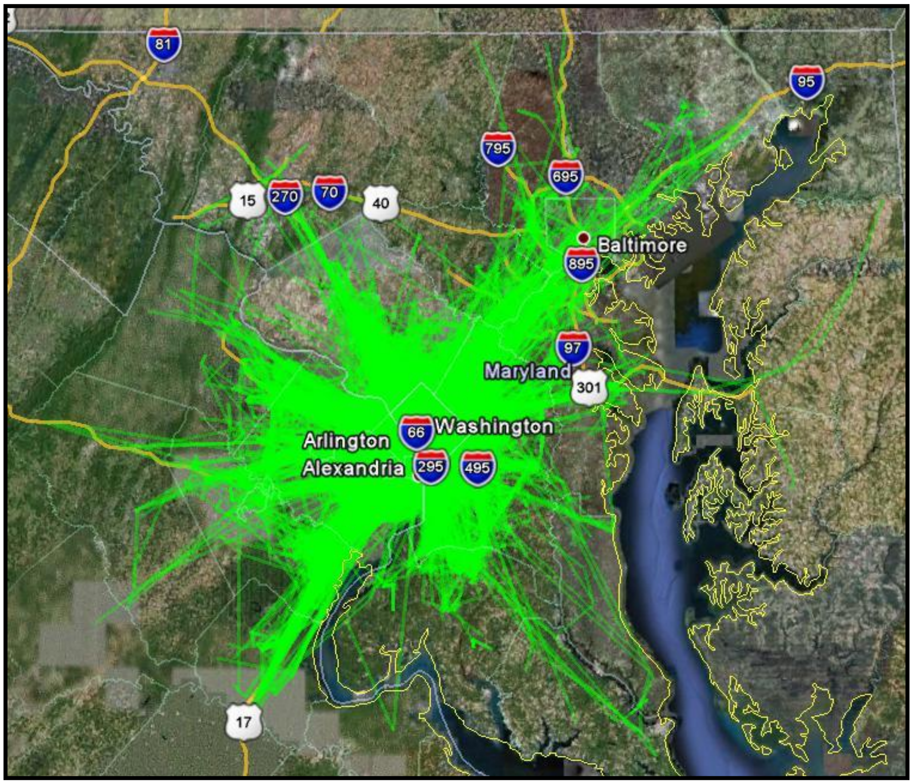


Figure 6.6 Trajectory of all cell phones originating in DCA and later appearing elsewhere in the Washington, D.C. metropolitan area

Figure 6.7 illustrates the trajectories of five different cell phones dispersing from DCA in different directions. Some cell phone location points are located the interstate highway systems.

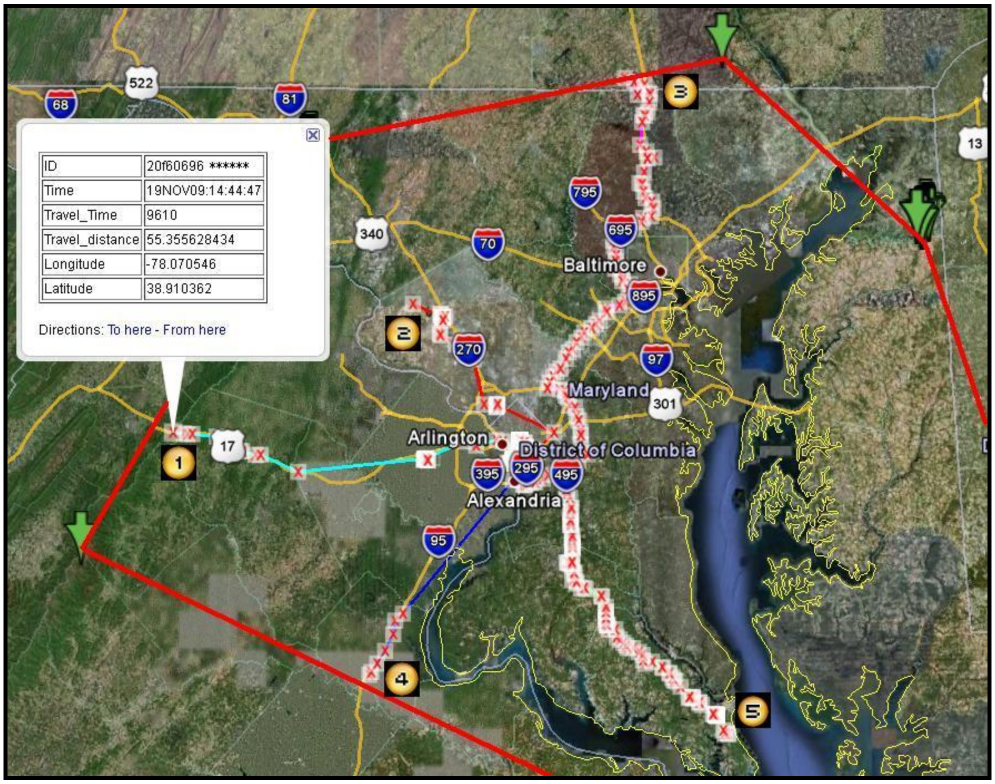


Figure 6.7 Cell phone trajectory tracking process for five individual cell phones

The profile of each location point was also converted into Google™ Earth and can be showed by clicking the location point on the map. The profile of each cell phone included the cryptic unique identification number, time, and time elapsed since the first call within DCA, the straight-line distance from the facility, and its location, longitude and latitude. The trajectory data were also converted onto Google™ Maps as shown in figure 6.8 with various colors.

Four of the sampled cell phones traveled toward the boundary of the cell phone network. Some of them show the continuous points along the highways; some of them show more points at their destination and may continue traveling out of the network. Table 6.4 lists the start tracking time, the farthest and final location of these sampled cell phones. The travel time is the

difference of the times between the current call and the first call in DCA. The straight-line distance is the distance from the current location to the center of DCA.

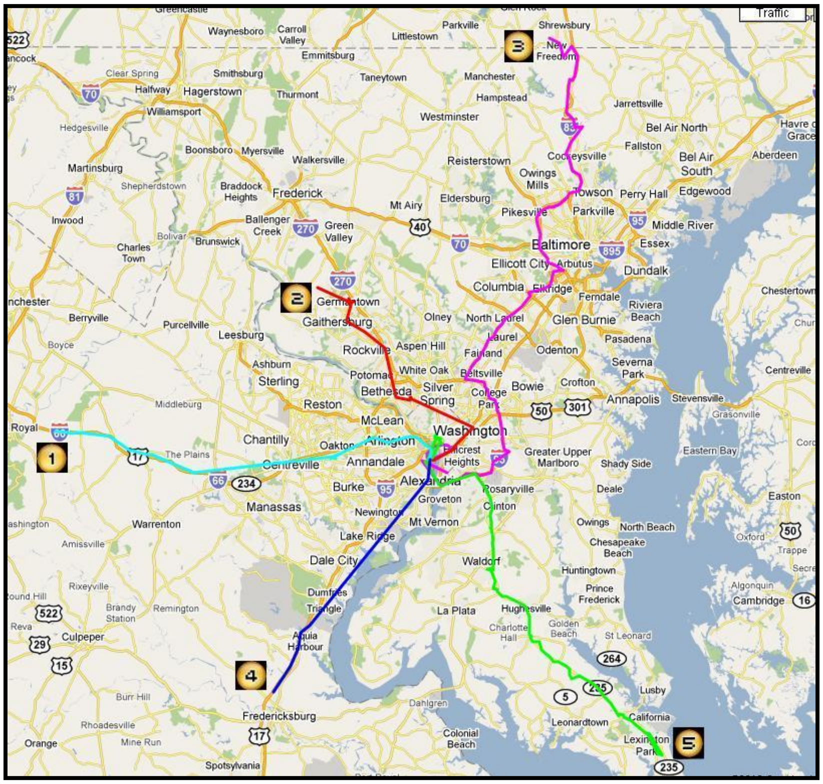


Figure 6.8 Sampled cell phone trajectories shown in Google™ Maps

Table 6.4 Start Time and Farthest and Final Locations of Example Cell Phones

No	Start Time	Farthest Location			Final Location		
		Straight-line distance (miles)	Time	Travel Time (sec)	Straight-line distance (Miles)	Time	Travel Time (sec)
1	12:04:37 p.m.	55.4	02:44:47 p.m.	9610	55.4	02:44:47 p.m.	9610
2	04:36:16 p.m.	30.2	07:30:42 p.m.	25795	30.2	11:46:11 p.m.	25795
3	03:22:32 a.m.	63.7	06:50:19 a.m.	12467	63.7	06:50:19 a.m.	12467
4	02:13:06 p.m.	41.4	04:19:44 p.m.	7598	41.4	04:19:44 p.m.	7598
5	10:35:52 a.m.	55.2	05:58:41 p.m.	26569	51.7	07:50:18 p.m.	33266

The characteristics of each cell phone could be judged according to the cell phone traveling path, the farthest location and destination in the network. For instance, cell phone No. 1 started the first call in DCA at 12:04 p.m. and end at 2:44 p.m. with the farthest distance which is the same with the final distance. Similarly for No. 3, the first data point showed up at 3:22 a.m. in DCA and continued moving toward Pennsylvania and ended at 6:50 a.m.; it indicates these two cell phones are the long-distance travelers who traveled all the way out of the cell phone data network. The No. 4 could be the similar characteristics with No. 1 and 3.

The cell phone No. 2 stayed at the same location 30.2 miles away from DCA from 7:30 p.m. to 11:46 p.m. It is believed that this cell phone holder is a resident due to this pattern or behavior. Similarly for No. 5, the cell phone stayed around a region from 5:58 p.m. to 7:50 p.m., and could be considered as a resident.

Note the determination of cell phone characteristics needs more information for some cell phones to make a definitive identification. For example, if a cell phone goes along an interstate corridor, the cell phone can be assumed to be inside a vehicle. If a cell phone stays at or goes out of a defining boundary, the cell phone user could be a worker or otherwise associated with the facility.

Thus, a database of the land use categories and special objects should be established in order to identify the characteristics of the cell phone accurately. However, since the cell phone coverage in this preliminary study is only limited to the Washington, D.C. metropolitan area, for long-haul truck traffic tracking, may not be detected and determined.

6.3.3 Traffic Dispersion Distribution

The movement of cell phone holders can reflect one kind of traveling activity and the impact of the target facility on the transportation network. To estimate the radial dispersion

distribution of cell phones from DCA, two types of radial distribution data were derived from the cell phone location data. The first one is the travel distance distribution by the percentage of cell phones; the second one is the traffic dispersion distribution by travel time.

For the travel distance distribution, the farthest straight-line distances from DCA for all cell phones was computed then were sorted to derive the dispersion radial area of the percentage of cell phones.

Figure 6.9 shows the radial dispersion distribution of cell phones spreading out from DCA for 25, 50, 75 and 100 percent shown in sky blue, pink, blue and bright green, respectively. Note that only two data points were used to plot the straight-line for each cell phone, one is the first point in DCA; the other one is the farthest point from DCA.

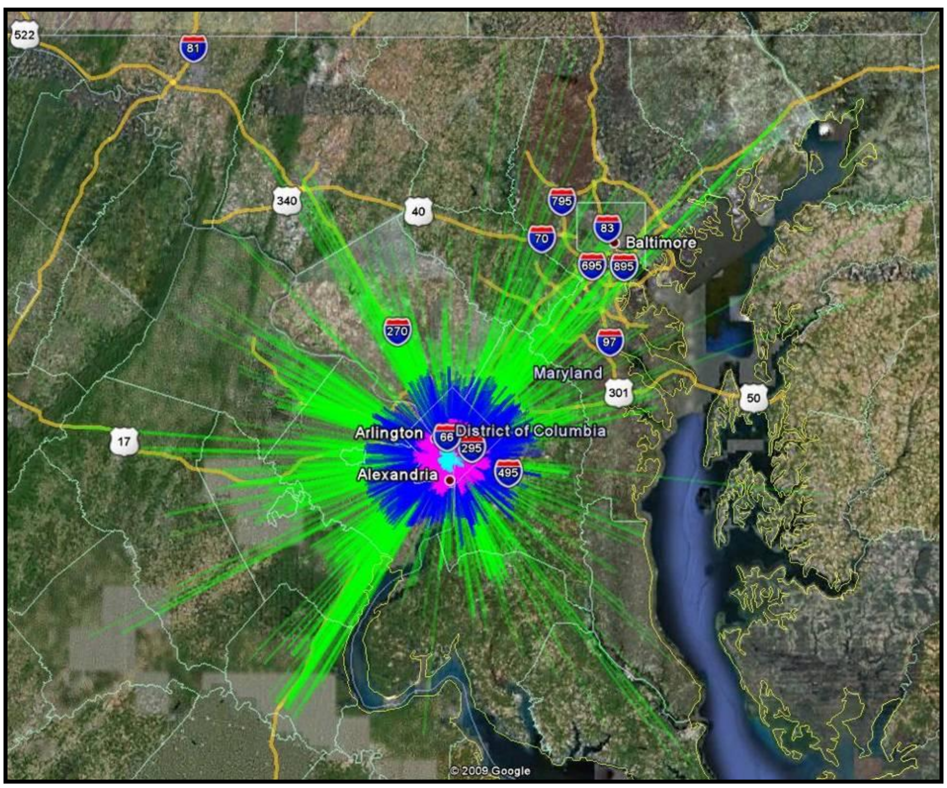


Figure 6.9 Cell phone radial distance distributions by percentage of cell phones

Figure 6.8 shows that about 75 percent (in sky blue, pink and blue colors) of cell phones from the airport traveled within the metropolitan area and only around 25 percent (in bright green) of cell phone holders traveled farther than the corridor of the Washington, D.C. area.

For the travel time dispersion distribution, the straight-line distance was obtained for every cell phone after a certain time leaving DCA. The dispersion distribution was plotted based on the farthest point within the time interval. Figure 6.10 shows the radial dispersion distribution after an hour, two and three hours after leaving DCA in sky blue, red and blue colors, respectively.

The dispersion radial distribution shows most cell phones around the metropolitan area within an hour after each call was first recorded in DCA. However, some of them went toward the boundary of the cell phone network. The dispersion after two hours and three hours does not show a big difference although some data points after three hours were found farther from DCA.

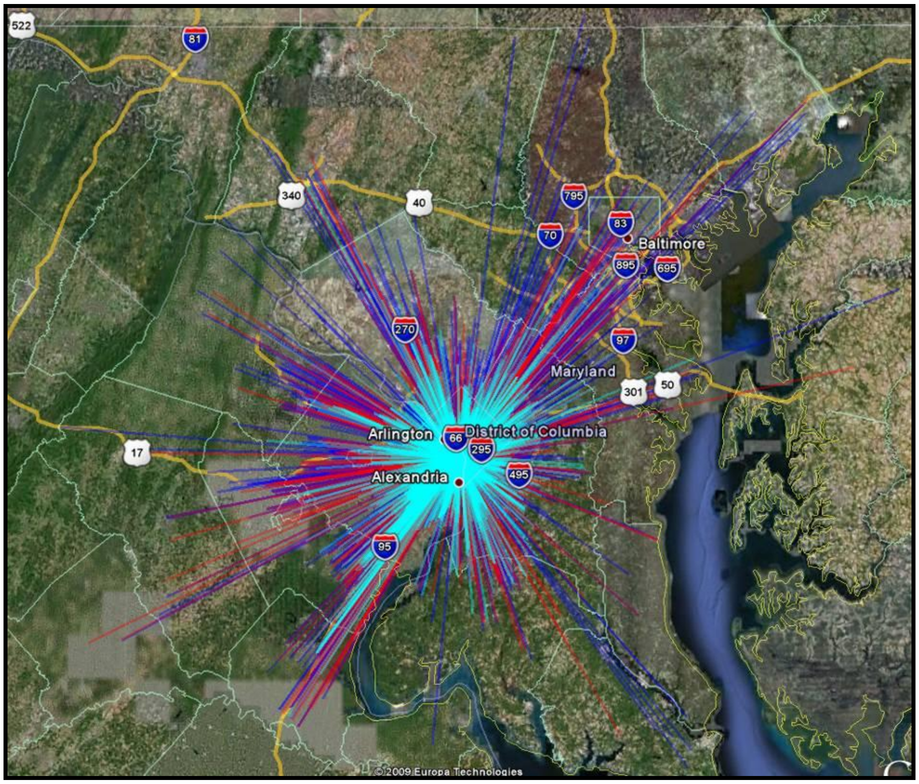


Figure 6.10 Cell phone radial dispersion by travel time

The dispersion radial distribution shows most cell phones around the metropolitan area within an hour after each call was first recorded in DCA. However, some of them went toward the boundary of the cell phone network. The dispersion after two hours and three hours does not show a big difference although some data points after three hours were found farther from DCA. However, all the farthest locations were near the boundary area of the cell phone network. That is because most of cell phone coverage network can be reached within two hours after leaving DCA.

6.4 Traveler Characteristics Identification

Travelers' characteristics identification analysis is to test whether the cell phone location data are feasible to identify and track truck traffic from a target facility. For test purposes, several potential truck stops were obtained through the Google™ Maps research engine. The location

and address and name of these truck stops are list in table 6.5. The truck stop area was set as 0.015 degree of longitude and latitude from its center position.

Those cell phones, which made calls within the truck stop areas, were isolated and considered as potential trucks. The trajectory points of these isolated cell phones are shown in figure 6.11. The red color truck symbols represent those potential truck stops.

Table 6.5 Location of Potential Truck Stops around Washington, D.C.

Latitude	Longitude	Address	City	State	Zip	Name
38.9380	-77.5415	3673 John Mosby Hwy	Chantilly	VA	20152	Chantilly Truck Stop
38.6306	-77.8005	9719 James Madison Hwy	Warrenton	VA	20187	Quarles Truck Stop
39.1028	-76.6274	8400 Veterans Hwy	Millersville	MD	21108	New Transit Truck Stop
39.2724	-76.5689	1701 S Clinton St	Baltimore	MD	21224	Port Truck Stop
38.5470	-77.3380	154 IH 95	Triangle	VA	22172	Dole city triangle rest area
39.1491	-76.7913	7541 Assateague Drive	Jessup	MD	20794	Baltimore South

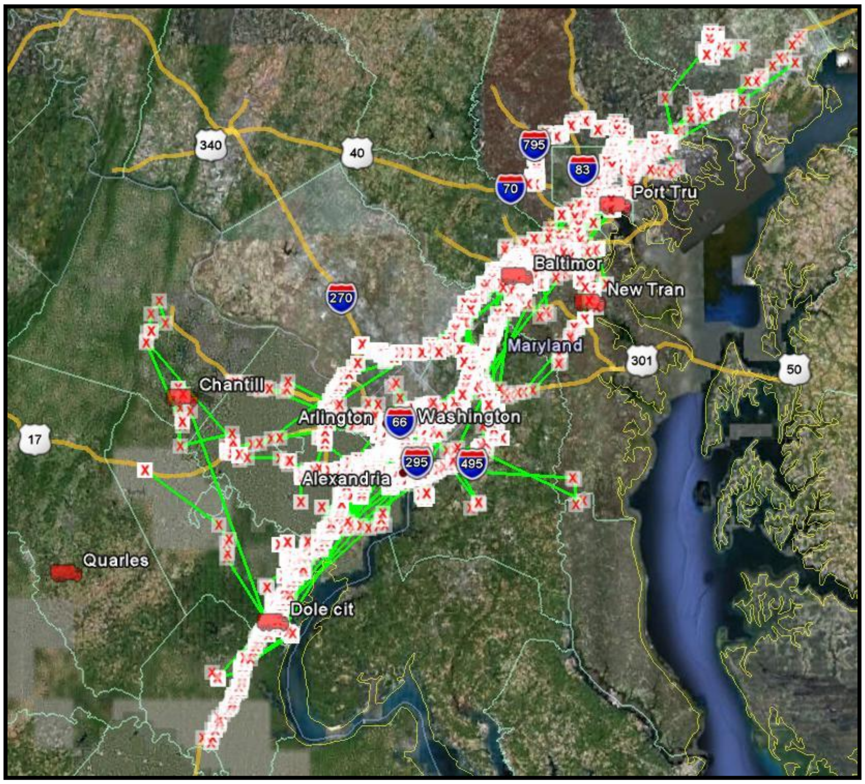


Figure 6.11 Trajectory points of potential trucks from the test facility

A total of 50 cell phone holders were filtered for those, who had appeared around DCA and then traveled through or stayed at the potential truck stops. Clearly, most cell phones traveled along the major highways indicating that those cell holders are drivers traveling in

vehicles. However, since most truck stops are located along the highway systems, some vehicles that stopped at the truck stops may not be trucks. Other criteria, such as the time the cell phone stayed at the truck stops, or the final destination, should be deployed in the filtering rule to determine whether the cell phone is a truck or not.

Chapter 7 Feasibility Analysis and Remaining Challenges

Based on the technology analysis and preliminary test results, the feasibility analysis of using cell phones for tracking traffic and identifying travelers' characteristics and the remaining challenges for more wide-ranging potential applications are discussed in this section.

7.1 Feasibility Analysis

The general results for the feasibility analysis of using cellular phone location data to determine truckshed includes:

7.1.1 Technical Analysis

According to previous research and tests, location estimates using cell phones were able to provide reasonably accurate location data. Cell phones could be located within an average of 100 meters or less of their actual position. The cell phone location technology is feasible for use in long haul truckshed tracking from intermodal facilities.

7.1.2 Data Coverage of Penetration Analysis

The cell phone data coverage and penetration analysis showed that only partial cell phone data were available for the truckshed tracking system. Prospectively, more cell phone data will be integrated into vendors' databases, which will increase the sample size and coverage of the cell phone location data. For long time periods of observation, the available cell phone data for tracking will also increase since the probability of cell phone users making calls will increase.

7.1.3 Privacy Protection Issues

The cellular phone data structure shows that the cell phone data were presented as anonymous. The cell phone identification number was shown as an encrypted number. There is no way to identify who the cell phone holder is or know any individual information from the cell

phone data. Thus, the privacy of cell phone holders should be protected using these cell phone location data.

According to the preliminary test results, the cell phone location data provided by AirSage, Inc. were able to be used to track the cell phone trajectory and estimate cell phone users' vehicle characteristics using the proposed tracking and filtering process and the developed computer program.

7.1.4 Data Structure Analysis

The location data were provided on a 30-second basis. For every 30 seconds, the locations of all cell phones actively in use in the network were recorded. All the data were then transmitted to a server in the University of Kansas. Thus, these continuous data should have enough location data points to track the movement and trajectory of the cell phones as long as the cell phone is in calling condition.

7.1.5 Cell Phone Trajectory Analysis

The preliminary test illustrated the process of tracking individual cell phone and deriving the traffic dispersion distribution from the target facility, Ronald Reagan Airport (DCA). It also showed the capability of the developed computer program in cell phone tracking and the vehicle filtering process. Although the preliminary test was only conducted in a limited area of metropolitan, Washington, D.C., the cell phone tracking and filtering process would also be applied to a more wide-ranging area of cell phone data.

7.1.6 Travelers' Characteristics Identification

The cell phone users' characteristics could be estimated according to their trajectory and destination. The preliminary test illustrated the characteristics identification process by using an example set of truck stops. The results shows that the cell phone users' characteristics can be

roughly identified but more exact determination are needed. Development of a more refined algorithm, including improved land use detail, would help in this area.

7.2 Challenge and Perspective

The remaining challenges for determining the feasibility of using cell phone location data to determine truckshed from an intermodal facility include:

7.2.1 Sample Size Issues

The cell phone location can only be detected when the cell phone is actively being used to make a phone call or send a text message. If the cell phone owners did not make any calls when they were in the intermodal facility, the location data cannot be located and tracked. Fortunately, long-term observations may conquer this issue if the trucks routinely return to the facility.

7.2.2 Database Storage and Computer Process

Since the cell phone location data for the entire network are recorded every 30 seconds, especially for long-term and wide-ranging network tracking, the storage size needed to record these data is expected to be huge and the time for processing the data tracking and analysis are expected to be much longer than the preliminary test. For a one-day data test in the Washington, D.C. area, a total of 720 data files with total of 4.8 GB size were required. The processing time of reading data, locating, sorting and tracking cell phones required about 15 hours, which did not include the time for running the Google™ Earth software.

7.2.3 Truck Stops and Land Use Categorization

Since the cell phone data are anonymous, the vehicle type can only be estimated by tracking its moving path and destination. Although trucks stop information is available, to embed this information into a truck tracking system is still a big challenge. Since the program designed

for filtering truck will affect the accuracy of truck estimation, how to divide the network into several appropriate regions would be a difficult task. Also, land use categories, such as commercial, residential, or entertainment areas, should be carefully categorized and embedded into the filtration database.

7.2.4 Truck Volume Calibration and Verification

Since only partial truck locations can be tracked, field trip data collection is needed to verify the portion of trucks which has been tracked using cell phones. Even though it is possible to estimate trucks through cellular phone movements, there are still sampling challenges to estimate the truckshed since not every truck driver carries a cell phone and not all cell phone data are covered by the same data provider. Thus, a calibration factor is also needed for estimating the truck trips from the intermodal facility. That is an adjustment factor that can transfer cellular phone data to vehicle (truck) traffic data (volume), for example, cell phones per vehicle (truck) equivalents.

Chapter 8 Conclusions and Recommendations

Understanding the extent of the reach of an intermodal facility is an important and first step to mitigate any negative consequences. In order to determine the feasibility of using cellular telephone location data in deriving the geographic extent (truckshed) from intermodal facilities, this study conducted a feasibility analysis in three aspects: technology, penetration analysis and truck tracking methodology. A preliminary test was also conducted to demonstrate the cell phone tracking and traveler's characteristics identification process using Washington, D.C. metropolitan area data.

The general feasibility analysis and preliminary test concluded:

- Cell phones could be located within an average of 100 meters or less of their actual position, which makes them feasible to use in long-haul truckshed tracking from an intermodal facility.
- Only partial cell phone data are available for the truckshed tracking system, but a long time-period of observation will increase the sample cell phones that are tracked.
- The cell phone data provided by the vendor system can provide enough cell phone data points for tracking the trajectory of cell phones.
- The developed tracking and filtering process and computer program are able to track every individual cell phone data point and preliminarily estimate the travelers' characteristics based on the trajectory and destination of sampled cell phones.

To continue the feasibility analysis of using cellular phone location data in determining the truckshed from intermodal facilities, research tasks and procedures are recommended for future testing:

- Establishing a detailed database of truck traveling objects and land use categories, which can serve as criteria to estimate the cell phone travelers' characteristics and determine the truck volume and trajectory from selected intermodal facilities.
- Long-term observations are needed to increase the sample size in the intermodal facility.
- Field data collection is also needed to verify the accuracy of the truck identification and to derive a calibration factor for generating truck trips from intermodal facilities.

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