# Analyzing Various Data Sources and Evaluating Effectiveness of Providing Travel Time for Non-Freeways – Phase 1


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16. Abstract

The Ohio Department of Transportation (ODOT) is placing an emphasis on Transportation System Management and Operations (TSMO) as ODOT strives to find innovative ways to fulfill the mission to enhance capacity and improve safety. The current critical success factors already reflect this emphasis by addressing Travel Time Performance. ODOT provides travel time information to the motoring public utilizing various technologies such as Dynamic Message Signs, Destination Dynamic Message Signs, and the OHGO platform. To date, these efforts have been focused on Ohio freeway routes. The overall goal of the project is to provide non-freeway motorists with accurate travel time information early enough that the driver has an opportunity to select the most efficient route. In Phase 1 of the project, the research team conducted an extensive literature search, state-of-the-practice review, agency interviews, and state traveler survey to understand the existing practice and corresponding effectiveness of providing travel time on non-freeway systems. Analysis of benefits and costs is applied to investigate the most cost-effective methods for data collection, travel time estimation and prediction, and information dissemination, to make recommendations to ODOT research and planning.

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# Analyzing Various Data Sources and Evaluating Effectiveness of Providing Travel Time for Non-Freeways

## (Phase 1 Interim Report)

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## Executive Summary

The Ohio Department of Transportation (ODOT) is placing an emphasis on Transportation System Management and Operations (TSMO) as ODOT strives to find innovative ways to fulfill the mission to enhance capacity and improve safety. The current critical success factors already reflect this emphasis by addressing Travel Time Performance. ODOT provides travel time information to the motoring public utilizing various technologies such as Dynamic Message Signs, Destination Dynamic Message Signs, and the OHGO platform. To date, these efforts have been focused on Ohio freeway routes.

The overall goal of the project is to provide non-freeway motorists with accurate travel time information early enough that the driver has an opportunity to select the most efficient route. In Phase 1 of the project, the research team conducted an extensive literature search, state-of-the-practice review, agency interviews, and state traveler survey to understand the existing practice and corresponding effectiveness of providing travel time on non-freeway systems. Analysis of benefits and costs is applied to investigate the most cost-effective methods for data collection, travel time estimation and prediction, and information dissemination, to make recommendations to ODOT research and planning. Findings from the literature and state-of-the-practice review and traveler survey include the following:

- **Alternatives of data sources**: Installation costs of the inductive loop, Bluetooth, Wi-Fi, and in-pavement magnetic detectors are relatively low. The installation of inductive loops and in-pavement magnetic detectors requires a lane closure. The maintenance costs of toll tag reader and automatic license reader, as well as other machine vision technologies, are relatively high. The vehicle re-identification methods have relatively high accuracy. The accuracy of inductive loops, radar, and microwave sensors depends on the density of detection stations and the estimation algorithm. Private sector data (e.g., INRIX and HERE) have become the main source of traveler information provision. However, its reliability and accuracy is often a critical concern. Therefore, evaluating and monitoring the validity of private sector data on the roadway of interests is quite necessary before using that data to provide to the public real-time travel time information.
- **Travel time estimation**: Before deploying traffic monitoring detectors, attention should be given to 1) calibrating and maintaining the technologies and 2) developing algorithms to better estimate travel times. The validation of the algorithm requires ground truth data. Estimating the realized travel times will require prediction of potential traffic state changes during a specific horizon. Machine learning and/or traffic models are usually applied. Instantaneous travel time cannot accurately capture travel time and may deviate substantially from the experienced travel time under transient states during which congestion is forming or dissipating during the trip. Estimating the realized travel times will require prediction of potential traffic state changes during a specific horizon.
- **Travel survey analysis**: Travelers have a positive attitude toward DMS and smartphone applications. Smartphone applications outperform DMS on routing and avoiding congestion, while DMSs do a slightly better job regarding raising awareness of downstream incidents and work zones. Both DMS and smartphone applications are useful and satisfactory to public travel and travelers use both information, if available, during their travel.
- **Travel time dissemination**: The DMS is thus far the only approach that can communicate real-time, en-route traveler information to ALL driving public while they are driving. Information disseminated at 511 or smartphone apps falls of pre-trip information. Providing traveler information through personal or in-vehicle devices (e.g., using an application like OHGO) has great future potential when the market penetration of the devices is high.

- **Potential system benefits according to the literature**:
    - Travel delay savings are the most commonly reported benefits. Agencies usually deploy detectors at both alternative routes to collect traffic volume, speeds and/or travel times to calculate the benefits. It has been reported at multiple sites that the travel speed enhancement varies from 5% to 20%.
    - Other direct traffic benefits: The literature and practice review report the potential benefits in reducing the number of crashes, energy consumption and emissions due to the enhancement in traffic flow.
    - User surveys were conducted in multiple deployment sites after the system was effective for months, and the reported results mostly show positive traveler experience of using the information.
    - Reported benefit-cost ratio: The benefits of the travel time provision vary from site to site, because of the network attributes, traffic patterns, and the existence of other ITS infrastructure. The literature reported overall favorable results with the B/C ratios varying from 4:1 to 27:1.
    - Also, accurate travel time information on non-freeways brings many other indirect benefits. This information is the foundation of many TSMO strategies and initiatives such as integrated corridor management, which will further reduce travel delay and crashes on the roadways. Some agencies (e.g., Georgia, Utah) rely on both freeway and arterial travel times to deploy the latest Active Traffic Management strategies.

Multiple gaps have been identified as potential obstacles for non-freeway travel time provision in Ohio. In order to fully develop the best practices and integrate them with existing TSMO/ATMS efforts, further work is proposed from the following four perspectives:

- **Data**
    - Investigate the appropriateness of using private sector data directly for travel time provision for non-freeways and scenarios where that would be possible and eliminate the need for infrastructure. The data should concern traditional TMC-based data or more detailed sources such as INRIX XD. Updated knowledge and understanding of these datasets need to be developed.
    - Develop algorithms and software for data fusion of multiple data sources and travel time estimation and prediction under recurring and non-recurring congestion (e.g., incidents, work zones, weather events).
- **Dissemination**
    - Disseminate the traveler information through DMSs and OHGO with information dissemination plan, including the selection of locations of the DMSs, detectors, and message characteristics, to test the non-freeway travel time technologies and collect corresponding data.
    - Investigate alternative modes of information dissemination, including using personal/in-vehicle devices and develop an overall framework to be included in the statewide non-freeway travel time recommendation/guide.
- **Evaluation**
    - Develop and execute methods for evaluating the effectiveness of deployed systems at multiple sites including examining travel time accuracy, performance evaluation of DMS influence on drivers, a quantified assessment of benefits and costs on the testing routes, and calculation of benefit-cost ratios.
    - Conduct post-deployment surveys with local travelers to understand the system effectiveness from the user perspective.

- **Statewide Guide**
    - Provide recommendations regarding the standard practice about providing travel times for non-freeways statewide in Ohio, regarding data sources, dissemination, evaluation, and integration of ATMS and other TSMO efforts.
    - Provide potential benefits (e.g., capacity enhancement factor) and costs when the systems are deployed at different types of locations (high v.s. low volume, rural v.s. urban)

# Chapter 1 Project Background

Travel time to a destination is a key piece of information that motorist's desire. It is vital for travelers to make good decisions about which route to take and whether to divert from their planned path. Technology now makes it feasible to provide drivers with real-time information about how long it will take to reach a given destination. While travel time information has traditionally been provided by transportation agencies only on major urban freeways, travel time messages are now being communicated on non-freeway systems in many agencies as well. Such a travel time information system is anticipated to bring benefit in the following aspects:

- Increase safety
- Reduce unexpected delay
- Reduce secondary crashes
- Enhance capacity
- Increase awareness of traffic conditions
- Reduce distracted driving

However, the collection of travel time data and proper dissemination remains a challenging problem that deserves a systematic review. This project is hence needed to identify, review, and synthesize information on current and potential future efforts in real-time travel time on non-freeway facilities.

Although non-freeway travel time data collection is a relatively new and rapidly evolving area, non-freeway travel times can be successfully implemented when a project is properly planned and executed. The importance of proper planning cannot be overstated. Successful implementers have carefully considered project objectives and have provided detailed implementation plans. Regardless of the latest specific data collection technologies released, asking the right questions is paramount, beginning with planning, continuing to the selection stage, and culminating with execution and evaluation. Practitioners who focus on asking the right questions and heed the lessons learned by colleagues will greatly increase the chances of a successful implementation. To further hone the opportunity of providing useful and accurate travel time information in arterial locations, it is important to ask the following questions:

- What insights and experiences have agencies developed with these technologies, and what are the best uses of these technologies?
- Given the challenges faced in calculating and providing travel time information on arterial highways, how feasible is deploying such technology?
- What are the potential benefits of providing additional traveler information, and how have they been quantified?

The Ohio Department of Transportation (ODOT) prioritizes several of the most congested corridors in the state of Ohio. Three of these corridors are in District 8: Colerain Avenue (US 27), Montgomery Road (US 22), and Beechmont Avenue (SR 125). These corridors are routinely heavily congested and have high crash rates. Each of these areas is also the location of a high amount of retail, resulting in large increases in congestion and traffic volumes during the holiday shopping season. These corridors, especially in the township (non-municipal) areas are the responsibility of ODOT. Providing accurate travel time studies along these corridors could potentially allow drivers to make more informed decisions during peak commute times and holiday shopping seasons.

ODOT is also placing an emphasis on transportation systems management and operations (TSMO) as researchers strive to find innovative ways to enhance capacity and improve safety. The current critical success factors already reflect this emphasis by addressing Travel Time Performance. ODOT provides travel time information to the motoring public utilizing various technologies such as Dynamic Message Signs, Destination Dynamic Message Signs, Highway Advisory Radios, and the OHGO platform. To date, these efforts have been focused on Ohio freeway routes.

There is a need by ODOT for a method to provide effective travel time information on the non-freeway systems. As part of this project, the research will evaluate current technologies which have been employed by ODOT and other States, processes, data sources, and traveler information systems in order to identify opportunities for improvement.

The research team conducted an extensive literature search, state-of-the-practice review, agency interviews, and state traveler survey to understand the existing practice and corresponding effectiveness of providing travel time on non-freeway systems. Analyses of benefits and costs are applied to investigate the most cost-effective methods for data collection, travel time estimation and prediction, and information dissemination, to make recommendations to ODOT research and planning.

The remainder of the report is organized as follows.

- **Chapter 2: Research Context** includes a discussion on the research objectives and the specific tasks that were accomplished.
- **Chapter 3: Research Approach** that gives a general description of the research activities.
- **Chapter 4: Research Findings and Conclusions** that a brief discussion of the research results.
- **Chapter 5: Recommendations** that include a section detailing how the research team recommends ODOT implement the findings.
- **Appendix I: Technology Review and Analysis**
- **Appendix II: Ohio Traveler Survey Results**
- **Appendix III: State-of-the-practice review**
- **Appendix IV: Agency Interview Results**
- **Appendix V: Proposed Phase 2 Work Plan**

# Chapter 2 Research Context

The primary purpose of this research is to conduct an in-depth analysis of ODOT's current process of providing travel time information and state-of-the-practice technologies for collecting or generating the travel time data, and provide recommendations on how to expand travel time information to the non-freeway systems. The overall goal of the project is to provide methods of producing and disseminating accurate travel time information early enough for non-freeway motorists so that the driver has an opportunity to select the most efficient route.

To achieve the above goal and objectives, the scope of work is divided into two phases, i.e., Phases 1 and 2. In Phase 1, a comprehensive literature review is undertaken to look at how ODOT currently provides travel time information and a review of nationwide practices for gathering and providing non-freeway travel times. An analysis of the historical data and past practices have been conducted, working closely with ODOT District 8. An Ohio traveler survey is conducted to understand the subject from the user perspective. The recommendations are developed by reviewing and documenting ODOT's current and past practices and then developing a matrix of choices and opportunities to enhance ODOT's travel time systems to cover non-freeways.

In the literature and state-of-the-practice review, the current ODOT processes for obtaining and disseminating travel time for freeways are evaluated, including evaluation of data sources related to speeds and travel times and identification of historical efforts to obtain and disseminate travel time for freeways and associated issues.

The review of existing practices covers multiple areas, such as existing processes, technologies being used and those are available now or soon, methods for information dissemination, existing infrastructure/hardware/software, existing data sources (e.g., StreetLight, INRIX and HERE), existing reports on travel time estimation and validation, past practices and lessons learned, ODOT's current ATMS platform and ongoing replacement study, and so forth. Additionally, an online survey of roadway users was conducted to understand how the users perceive and use current ODOT technologies related to travel time provision.

The state-of-the-practice review covers the past and existing practices of ODOT and other state DOTs across the nation. All resources identified in the literature review are assembled and organized in tabulate format that can facilitate the identification of the key trends and issues and also synthesize the findings. The review results in a summary of practices related to all applications of alternative methods for traffic data collection and travel time estimation. The review also documented the evaluation of effectiveness conducted by some agencies.

In the analysis of technologies, current products and technology available for obtaining and disseminating travel time information are analyzed. Then the analysis topics are referred to the following points of view:

- Different processes and mechanisms used by different state DOTs
- Pros and cons of data collection technologies available now or soon
- Advantages and disadvantages of different methods for information dissemination
- System functional requirements such as required infrastructure, hardware, and software
- Quality of travel time data from private vendors (e.g., INRIX, HERE)
- Various Information dissemination modes (e.g., Dynamic Message Signs/DMSs, smartphones, state traveler information websites and/or APP)

Also, three agencies which currently deploying non-freeway travel time information systems are interviewed to further understand the best practices and learns learned based on their experiences. The survey summary results and answers of agencies to the survey questions are detailed in **Appendix IV: Agency Interview Results**.

An Ohio traveler survey is also conducted to understand traveler information from the user's perspective. Particularly, the survey is designed to investigate travelers' attitude toward traditional traveler information mode (i.e., DMSs) and smartphone devices (both public channels and commercial products). Analysis of the survey results is detailed in **Appendix II: Ohio Traveler Survey Results**.

The key findings and issues identified in the literature and the state-of-the-practice review are summarized in two brief letter reports. More detailed contents of the synthesis report are included in **Appendix I: Literature Review and Analysis** and **Appendix III: State-of-the-practice review**. These results serve as the foundation for recommendations of ODOT future practices discussed in Chapter 5.

Based on the results of Phase 1, a work plan is recommended for Phase 2 that aims to address the identified gaps in knowledge using a select cost-effective way. The work plan also proposes a statewide plan and guidebook for non-freeway travel time provision under the umbrella of the Ohio statewide TSMO (Transportation System Management and Operations) plan. More details about the Phase 2 work plan are provided in **Appendix III: Phase 2 Work Plan**.

# Chapter 3 Research Approach & Key Findings

As mentioned in Chapter 2, Phase 1 work focuses on 1) literature review of technologies and methods for travel time data collection, travel time estimation, and information dissemination; 2) an online survey of roadway users on users' perceptions and use of current ODOT technologies related to travel time provision, and 3) analysis of the alternatives for providing travel times for non-freeways. *The research approach for analysis and key findings* are summarized below. More detailed analyses are included in **Appendix I: Literature Review and Analysis and Appendix II: Travel Time Survey Analysis.**

### 3.1 Detectors and Data Collection Technologies

Many travel time collection technologies are already relatively mature and commercial products are available to apply these technologies directly. In summary, Bluetooth Detection, Wi-Fi Detection, and In-pavement Magnetic Detectors are widely used technologies in recent years. Bluetooth Detection and Wi-Fi Detection share similar operating principles, and both of them are relatively inexpensive. Among these two, Wi-Fi detection has a higher detection rate (above 50%) and the match rate. Though the detection of MAC address might not be feasible due to potential MAC address randomization in the future, Bluetooth detection technologies are currently being widely used by state DOTs. Toll Tag Reader and Automatic License Plate Reader methods are mature technologies with a long history of application, though privacy issues also exist for a long time. The cost of these two technologies is relatively high compared to other methods. The cost of the In-pavement Magnetic Detector is relatively expensive, but it has several advantages. First, the detection rate (almost 100%) and match rate are pretty high. Since the detectors compare each vehicle's unique magnetic signature, there is no privacy issue. Moreover, vehicle spot speed, traffic volume information can be collected by the In-pavement Magnetic Detector.

While these technologies can be used to measure travel times directly, point detectors (e.g., radar, inductive loops), which can measure spot speeds, are usually deployed at multiple locations of a segment to collect data to infer the segment travel times. Some of the reviewed deployment sites have also achieved some success using the latter approach. Also, point detectors can be responsive traffic changes while the detectors such as Wi-Fi experience an unavoidable delay due to the nature of re-identification. Therefore, the literature recommends combining both methods for travel time estimation.

### 3.2 Private Sector Data

Private sector data have become the main source of traveler information provision, particularly at recent new deployment sites. This is mostly due to the fact that agencies are more willing to purchase the data, real-time and/or archived, as a service, instead of collecting raw data and maintaining the devices regularly. However, when the agency decides to use private sector data, the agency needs to caution against the data quality. This is because these data sources and their related algorithms are proprietary, and the reliability and accuracy of this private sector data is often a critical concern for transportation agencies. If inaccurate travel times are provided, the public may lose confidence and interests, and the travel times lose all the value.
Researchers have done many evaluation studies of data quality of INRIX and HERE on both freeways and arterials. They use relatively mature technologies, such as license plate recognition or validated Bluetooth product, as the ground truth. It is interesting that there are divided evaluation results at different sites, possibly due to factors such as variation of traffic and roadway conditions, changes of private sector data quality at different times (e.g., increase of probes and algorithmic improvement), and the quality of the ground truth data. Therefore,

evaluating and understanding the validity of private sector data on the roadway of interests is quite necessary before using that data to provide to the public real-time travel time information. Particularly, it is critical to understand the performance of the private sector data under different conditions, such as around bottleneck congestion, work zones, incidents, and signalized intersections. If the data perform unsatisfactorily under certain conditions, it may be necessary to incorporate additional data sources for better travel time estimation.

### 3.3 Travel Time Estimation and Prediction

Given the variety of sources of data for travel time provision, it is clear that each source of travel time data offers distinct advantages and disadvantages. It is highly unlikely that a single source of data will emerge as a clear winner that dominates all other approaches. Because of this, two aspects of the problem need to be discussed here. First, it is necessary to choose one or more travel time data services to best meet the needs. To do so effectively, there is a need for a standard test procedure to use in assessing the quality of different travel time data services. If an agency chooses to deploy traffic monitoring detectors, more attention should be given to 1) calibrating and maintaining the detector technologies and 2) developing algorithms to better estimate travel times. The validation of the algorithm requires a ground truth, which is usually collected by methods such as the floating car approach. If the private sector data are used, representative segments need to be identified and conventional, but mature, data sources are used to do an evaluation. The second aspect is to develop methods and algorithms to fuse multiple sources of the data and improve the accuracy of travel time estimation.

Another important issue is the definition of travel times. It can mean the instantaneous travel time of the road segment when drivers see the information on the DMS (i.e., at the beginning of the segment). The other is referred to as realized travel times– the travel times that the users actually experience when they complete traversing the segment. For a short roadway segment, the two may be similar to each other. For a relatively long segment, traffic conditions may change during the course of driver traversing the segment and therefore using instantaneous travel time cannot accurately capture travel time. Estimating the realized travel times will require prediction of potential traffic state changes during a specific horizon. Machine learning and/or traffic models are usually applied online for this purpose.

Travel time prediction is quite common in the literature, but not widely used in the existing deployed systems with a few exceptions. With the advancement of ubiquitous sensors and crowdsourcing data to provide real-time and archived data feeds, it is easier than before to make predictions of travel times, which may bring additional benefits, making the provided travel time more robust during severe traffic congestions, incidents, work zones, and other external events.

### 3.4 Travel Time Dissemination

Dynamic Message Signs (DMS) have been widely used to disseminate travel times to the public, and this applies to almost every deployment location in the country. The DMS is thus far the only approach that can communicate real-time, en-route traveler information to all driving public while they are driving. Some deployment sites also post the estimated travel times on the state or city 511 traveler information websites or smartphone apps. Note that these channels of information fall under the category of pre-trip information. Drivers are not supposed to check the information while driving unless the apps are specially designed for en-route purposes.

Only a limited number of studies looked into using personal devices to disseminate personalized information, such as information solely relevant to the drivers' routes. However, these methods cannot be implementable currently because in-vehicle devices are not yet prevalent. Also, while private traveler information apps, such as Google Maps, also provide O-D travel times, this is not public information, and drivers need to have a smartphone with the app installed to receive such information.

Multiple deployment sites conducted surveys or interviews after the public are provided with the information for a while. The public response, as reported by the agencies, are quite positive to the additional information in helping them making travel decisions. Agencies consider the provision of traveler information, on both freeways and arterials, as basic public service to the travelers.

### 3.5 Travel Time Survey Analysis

The survey was posted on qualtrics.com and disseminated through ODOT (@ODOT_Statewide) on Twitter. 367 respondents have participated in the survey. More detailed analysis is included in **Appendix II: Travel Time Survey Analysis**. A summary of the results is provided below.

In this survey, basic demographic information, travel-related information, and travelers' attitude toward DMS and smartphone applications are investigated. Compared to the situation across the United States, the respondents of this survey tend to have a higher education level and higher annual household income. This has an impact on the result that the respondents have a higher smartphone ownership rate than the national average.

For daily travel, the results imply that travelers have a great chance encountering congestion no matter if the trip purpose is work/school related or other family and personal errands. The congestion occurs on both freeways and non-freeways. For other family and personal errand trips, people tend to travel during the off-peak hours.

For respondents' view on travel time information dissemination methods, the survey results show that 99.73% of the respondents have ever seen a DMS (93.70% of the cases on the freeways). 94.25% of them have a smartphone and 93.96% of used smartphone applications to help with travel routing or pre-trip planning. Regarding the accuracy of the disseminated information, 84.97% of them think the DMS information is accurate, and 85.71% think smartphone application information is accurate. Respondents gave the reasons why they think the information is not accurate, including updating too slowly (both DMS and smartphones), actual travel times usually longer than DMS; smartphone applications do not place work zones at the right location.

A five-point Likert scale survey reveals that travelers have a positive attitude toward DMS and smartphone applications. Meanwhile, smartphone applications outperform DMS on routing and avoiding congestion, while DMSs do a slightly better job regarding raising awareness of downstream incidents and work zones. Survey results on usefulness and satisfaction indicate that respondents agree with the opinion that both DMS and smartphone applications are useful to their travel and they are satisfied with both technologies.

After analyzing the survey results, it is noted that the respondents are still using both information sources during their travel, possibly having them complement each other, and consider both sources of information provide useful assistance to their travel. However, for the remaining 23% of the travelers who do not own a smartphone (based on the data from Pew Research Center) will need to rely on DMS for accessing real-time traveler information, including travel times, incidents, and work zones. Fortunately, this survey also shows the effectiveness of DMSs for travelers in Ohio.

### 3.6 Benefits of Accurate Non-Freeway Travel Times

While many agencies have provided travel times on non-freeways for years, very few of them have conducted and reported a systematic evaluation of the benefits of travel time systems, mostly due to the difficulty to isolate the effects with other systems. This is considered a gap in the literature.

A summary of the benefits, quantitative or quantitative, is shown below:

- Travel delay savings are the most commonly reported benefits. Agencies usually deploy detectors at both alternative routes to collect traffic volume, speed and/or travel times to calculate the benefits. It has been reported at multiple sites that the travel speed enhancement varies from 5% to 20%.
- Additional direct benefits: The literature and practice review all report the potential benefits in reducing the number of crashes, energy consumption and emissions due to the enhancement in traffic flow.
- User surveys were conducted in multiple deployment sites after the system was effective for months, and the reported results mostly show positive traveler experience of using the information.
- Reported benefit-cost ratio: The benefits of the travel time provision vary from site to site, because of the network attributes, traffic patterns, and the existence of other ITS infrastructure. The literature reported overall favorable results with the B/C ratios varying from **4:1** to **27:1**.

Also, note that accurate travel time information on non-freeways brings many other indirect benefits. This information is the foundation of many TSMO strategies and initiatives such as integrated corridor management, which will further reduce travel delay and crashes on the roadways. Some agencies (e.g., Georgia, Utah) rely on both freeway and arterial travel times to deploy the latest Active Traffic Management strategies.

### 3.7 Analysis and Matrix of Alternatives for Data Sources

This task was conducted to compare each technology and data sources regarding cost, accuracy, and adoption rate. **Table 3-1** briefly summarizes the cost comparisons among major favorable data detection technologies, whereas **Appendix I: Literature Review and Analysis and Appendix III: State-of-the-practice review** provides a much detailed analysis of the cost estimations for each of the reviewed detection technologies. Among all the technologies, the installation (e.g., device, infrastructure) costs of the inductive loop, Bluetooth, Wi-Fi, and in-pavement magnetic detectors are relatively low. The costs of inductive loops are relatively high. Moreover, the installation of inductive loops and in-pavement magnetic detectors requires a lane closure. The installation cost of radar and microwave sensors are at a medium level. The costs of toll tag reader and automatic license reader are high. The maintenance costs of automatic license reader and other machine vision technologies are relatively high.

**Table 3-1. Cost Comparisons of Reviewed Detection Technologies**

| Detector | Cost |
|---|---|
| **Corridor Detector** | • Microwave: $9,000-$13,000 (operation/maintenance – O/M $100-$600/year)<br>• Acoustic: $3,700-$8,000 (O/M $200-$400/year)<br>• Passive/Active Infrared: $6,000-$12,000 (O/M $700/year)<br>• Ultrasonic: $600 (O/M $200/year) |
| **BlueTOAD** | • Hardware: BlueTOAD Base Unit $3,900; Solar/Battery $600; Cellular Modem $200; and Cellular Interconnect fees – 5GB $1,050<br>• Installation and Maintenance: data processing service/monthly: $130; maintenance agreement/annual $1,000; one-time activation fee $200; on-site consulting/day $1,000; and custom feed development fee $12,000 |
| **Wi-Fi** | • One system is roughly estimated at the cost of about $5,100. |

| | |
|---|---|
| **In-Pavement Magnetic** | • ODOT, 2011: $5,470.00<br>• Seattle.gov, 2011: $4,730.00 |

The analysis of data accuracy indicates that the vehicle re-identification methods are relatively accurate. The accuracy of inductive loops, radar and microwave sensors for calculating travel times depends on the density of detection stations and the estimation algorithm. Different agencies evaluated the quality of private sector data and the conclusions are divided. Generally, both INRIX and HERE provide acceptable accuracy for travel time estimation under certain conditions, but the accuracy level is not ideal under congested traffic, particularly during external conditions such as incidents or work zones. This raises the concern of using private sector data directly for travel time provision.

As a result of the comprehensive literature review, a matrix of alternatives of data sources is developed to compare and rank different data solutions, as illustrated in **Table 3-2**. Each of the solutions is evaluated based on four criteria: infrastructure cost, maintenance cost, accuracy, and adoption rate. The purpose of the table is comprehensively evaluating different technologies based on the costs and performance and then select the most cost-effective approach. The final weighted score is provided based on a ranking system in **Appendix I** and the score range from 1 to 5 with 5 as the best scenario.

Based on the table, Bluetooth and Wi-Fi detection are the most suitable technologies among vehicle re-identification methods. Radar/microwave detectors are the most cost-effective point detectors. The private sector data also stands out due to its “worry-free” nature of requiring no infrastructure, though the evaluation of the accuracy is divided in the literature.

Note that the selected three different technologies are not mutually exclusive. They can be combined to generate better travel time information. When the private sector data are not accurate enough, another source of information can be incorporated to correct the estimation/prediction. Also, the selection is also dependent on the location of the site and the availability of existing infrastructure.

**Table 3-2. Matrix of Alternatives of Data Technologies (Prices listed are per station installation cost and per year maintenance cost)**

| Alternative Methods | | | | Ranking Criteria | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | 10% | 30% | 50% | 10% | Weighted Score |
| Rank | | Data Collection Technology | Description | Infrastructure Cost | Maintenance Cost | Accuracy | Adoption Rate | |
| | Data Collection | **Bluetooth Detection** | Vehicle re-identification | 4k | 1k | Moderate to High | High | **4.2** |
| | | **Wi-Fi Detection** | Vehicle re-identification | 4k | 1k | Moderate to High | Moderate | **4.0** |
| | | **Toll Tag Reader** | Vehicle re-identification | 20 | 2k | Moderate to High | Moderate | **3.7** |
| | | **In-pavement Magnetic** | Vehicle re-identification | 0.5k * 20 | 0.1k | Moderate to High | Moderate | **4.1** |
| | | **Automatic License Plate Readers** | Vehicle re-identification | 25k | 3k | Moderate to High | Moderate | **3.7** |
| | | **Machine Vision** | Vehicle re-identification | 25k | 3k | Moderate to High | Low | **3.5** |
| | | **Radar, Microwave** | Spot speed method | 10k | 0.5k | High | High | **4.2** |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Inductive Loops** | Spot speed method | 1k | 1.5k | Moderate | High | **3.4** |
| **Private Sector** | **INRIX** | TMC data | Subscription cost (no infrastructure) | | Moderate | High | 4.3 |
| | **HERE** | TMC data | Subscription cost (no infrastructure) | | Moderate | High | **4.3** |

**Legend**

| Good | Medium | Bad |
|---|---|---|

# Chapter 4 Conclusions

This section summarizes basic findings from the literature and state-of-the-practice review, while Chapter 5 discusses identified gaps and recommendations.

- Detectors and Data Collection

- Bluetooth Detection, Wi-Fi Detection, and In-pavement Magnetic Detectors are widely used technologies. Wi-Fi detection and In-pavement Magnetic Detector have a higher detection rate and match rate, and the latter has no privacy issue.
- Private sector data (e.g., INRIX and HERE) have become the main source of traveler information provision. However, its reliability and accuracy is often a critical concern. Therefore, evaluating and monitoring the validity of private sector data on the roadway of interests is quite necessary before using that data to provide to the public real-time travel time information.

- Travel Time Estimation

- Before deploying traffic monitoring detectors, more attention should be given to 1) calibrating and maintaining the technologies and 2) developing algorithms to better estimate travel times. The validation of the algorithm requires ground truth data.
- Estimating the realized travel times will require prediction of potential traffic state changes during a specific horizon. Machine learning and/or traffic models are usually applied.
- Instantaneous travel time cannot accurately capture travel time and may deviate substantially from the experienced travel time under transient states during which congestion is forming or dissipating during the trip. Estimating the realized travel times will require prediction of potential traffic state changes during a specific horizon

- Traveler Survey Analysis

- Travelers have a positive attitude toward DMS and smartphone applications. Smartphone applications outperform DMS on routing and avoiding congestion, while DMSs do a slightly better job regarding raising awareness of downstream incidents and work zones.
- Both DMS and smartphone applications are useful and satisfactory for public travel.

- Analysis and Matrix of Alternatives

- Installation costs of the inductive loop, Bluetooth, Wi-Fi, and in-pavement magnetic detectors are relatively low. The installation of inductive loops and in-pavement magnetic detectors requires a lane closure. The maintenance costs of toll tag reader and automatic license reader, as well as other machine vision technologies, are relatively high.
- The vehicle re-identification methods have relatively high accuracy. The accuracy of inductive loops, radar, and microwave sensors depends on the density of detection stations and the estimation algorithm. The quality of private sector data varies and need to be carefully evaluated.

- Travel Time Dissemination

- The DMS is thus far the only approach that can communicate real-time, en-route traveler information to ALL driving public while they are driving. Information disseminated at 511 or smartphone apps falls of pre-trip information.
- Providing traveler information through personal or in-vehicle devices (e.g., using an application like OHGO) has great future potential when the market penetration of the devices is high.

# Chapter 5 Recommendations

Providing travel times on non-freeway systems has the potential to increase traveler safety perception via the timely received travel information on non-freeways; help decision making more efficiently during congestion or incidents by using alternate routes; increase driver awareness of construction areas and temporal traffic control; and help provide advanced warning of congestion to harmonize speed to reduce crash potential.

On the basis of extensive literature and state-of-the-practice review, this research has identified the benefits for providing travel times on non-freeways, including a significant reduction in delay (5% - 20%) and a potential decrease in crashes and environmental impacts, generating a benefit-cost ratio of **4:1 – 27:1**.

Additionally, estimating or predicting travel time information is an indispensable part of the statewide Transportation Systems Management and Operations (TSMO) plan and initiatives such as integrated corridor management. Accurate information of travel times or speeds can serve as input to other traffic management strategies, such as variable speed limit and traffic signal control. ODOT’s current ATMS efforts focus on traffic surveillance and management strategies on freeways. The results of this project can serve as an extension to the existing capability by:

1) Providing an additional layer of information for the travelers to make more informed route and departure time decisions, and

2) Enabling advanced traffic management that simultaneously consider freeway and adjacent arterial traffic conditions.

Multiple gaps have been identified as potential obstacles or risks for non-freeway travel time provision in Ohio. In order to fully develop the best practices and integrate them with existing TSMO/ATMS efforts, these gaps need to be addressed:

1) Ohio and other states have deployed a very limited number of traffic detectors along non-freeways systems, and most of the traffic management systems focus on freeways due to institutional issues. The lack of data on arterials and other non-freeway systems make agencies less confident in providing travel times to the public and make other traffic management decisions for non-freeways.

2) Based on the literature review and agency interview, travel time information quality becomes unreliable during severe congestion and external conditions, such as weather, incidents, and work zones. The Ohio user survey also shows that around 20% of the travelers consider the provided travel times underestimated and inaccurate during congestion. These all conclude with the need to develop an enhanced methodology for travel time estimation and prediction. Prediction is particularly important during external events because it is necessary to capture the potential flow evolution after an event occurs.

3) The use of private sector data has become increasingly popular because it relies on infrastructure and incurs no maintenance costs, but the evaluation results of private sector data are divided in the literature into different states. The appropriateness of using them directly for travel time provision for non-freeways and scenarios where that would be possible and eliminate the need for infrastructure investment and maintenance is yet to be determined.

4) The benefit-cost ratio of non-freeway travel time provision has only been reported at limited locations elsewhere. An effective statewide TSMO planning will require the actual B/C ratio for non-freeway travel time provision in Ohio. This ratio may also vary depending on the deployment location and other traffic and geometric characteristics.

The recommendation for implementation aims to address the identified gaps. The proposed work for Phase 2 is proposed and more details are included in **Appendix V: Phase 2 Work Plan**. The proposed work includes the following:

- Data
  - Investigate the appropriateness of using private sector data directly for travel time provision for non-freeways and scenarios where that would be possible and eliminate the need for infrastructure. The data should concern traditional TMC-based data or more detailed sources such as *INRIX XD*. Updated knowledge and understanding of these datasets need to be developed.
  - Recommend data fusion approach and strategies to improve travel time provision, including the selection of detectors and private data sources for collecting and providing travel times.
  - Develop algorithms and software for travel time estimation and prediction under recurring and non-recurring congestion (e.g., incidents, work zones, weather events).
- Dissemination
  - Disseminate the traveler information through DMSs and OHGO with information dissemination plan, including the selection of locations of the DMSs, detectors, and message characteristics.
  - Investigate alternative modes of information dissemination, including using personal/in-vehicle devices and develop an overall framework to be included in the final recommendation/guide.
- Evaluation
  - Develop and execute methods for evaluating the effectiveness of deployed systems at multiple sites including examining travel time accuracy and performance evaluation of DMS influence on drivers, as well as a quantified assessment of benefits and costs on the testing routes, and benefit-cost ratio calculation.
  - Conduct post-deployment surveys with local travelers to understand the system effectiveness from the user perspective.
- Statewide Guide
  - Provide recommendations regarding the standard practice about providing travel times for non-freeways statewide in Ohio, regarding data sources, dissemination, evaluation, and integration of ATMS and other TSMO efforts.
  - Provide potential benefits and costs when the systems are deployed at different types of locations (high v.s. low volume, rural v.s. urban) based on the data collected from the test sites

Overall, the goal of Phase 2 is to develop a statewide guide for the recommendation of best practices for providing travel times on non-freeways though the deployment of the system on multiple test sites. A proposed Phase 2 schedule and budget are included in **Appendix V: Phase 2 Work Plan**.

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# Appendix I: Literature Review and Analysis

## I.1 Detector Technology

Detector technologies refer to the products and technologies used by transportation agencies to collect travel time information. To estimate travel time from any origin "O" to any destination "D" or on any specific link, there are two types of methods:

1. Collect traffic information such as spot speed at fixed locations with detectors using point detectors such as Radar, Microwave, and Inductive Loops.
2. Probe vehicles/devices that are identified at the start and end of the segment, using technologies such as Bluetooth detection, Wi-Fi detection, Automatic License Plate Reader, In-pavement Magnetic Detectors, Machine Vision and Toll Tag Reader.

These technologies will be further discussed in this report. Emerging technologies like Connected Vehicle (CV) method is also discussed in this report, though it is not ready for implementation and therefore out of the scope of this study. We use the following terms throughout the report, defined here for clarity:

**Detection rate**: the proportion of vehicles detected by any selected detection device.

**Match rate**: among all the detected vehicles, the proportion of vehicles re-identified between two detection points.

In this section, we will talk about the **fundamentals, validation, application, the pros and cons, and the cost** of each data collection technology.

### *I.1.1 Bluetooth Detection*

- <u>Fundamental</u>

Bluetooth technology exchanges data over short distances using 2.4 GHz radio frequencies. Detectors recognize the unique Media Access Control (MAC) address (for example 00:24:9F:DD:FB:08) of devices carried by vehicles and store in the system with a time stamp. The paring of the same MAC address with different time stamps can give the accurate travel time of the vehicle between the two locations while the distance between the two locations is known. The communication range of Bluetooth is from 1 meter to 100 meters among different products and systems. The inquiry time of Bluetooth is 10.24 seconds which means it takes 10.24s to recognize the MAC address. Sometimes fast-moving vehicles cannot be detected due to 10.24s inquiry time. Other factors also have an impact on the detection rate, for example, vehicle speed and the number of Bluetooth active devices within the travel route.

- <u>Validation</u>

After Bluetooth technology emerged, several studies were conducted to verify its accuracy for travel time uses. In 2009 and 2010, researchers installed Bluetooth detectors developed by the authors on a three-mile corridor and a six-intersection arterial grid (Puckett & Vickich, 2010). The results showed that the Bluetooth detector was an effective and accurate method to collect arterial travel time data. Previous research showed that the detection rate ranged from 4.4% to 8.3% and the match rate was 1.8% (Vo, 2011). The author found that the height of the Bluetooth device had a significant impact on the detection rate and among all heights (7 feet, 10 feet, and 14.5 feet), Bluetooth detectors at 10 feet and 14.5 feet had the highest detection rate at two different locations. In this research, the Bluetooth detection system was deployed by the author. Researchers tested Bluetooth devices on signalized arterial. The study corridor was Verree Road, with 13 signalized intersections along the corridor. The total length of the corridor was 3.9 miles, and the posted speed limit was 35 MPH (KMJ Consulting Inc. 2011). Travel time from a floating car was set as ground truth. The results showed that Bluetooth devices had some advantages such as offering a more realistic approach to measure travel time.

- Application

Bluetooth detection is a mature technology with several kinds of products available on the market, such as Bluetooth Travel-time Origin And Destination (BlueTOAD) (shown in **Figure I-*1***) and BlipTrack-BT. BlueTOAD is developed by TrafficCast International (TCI) and BlipTrack-BT is a product of BlipTrack.

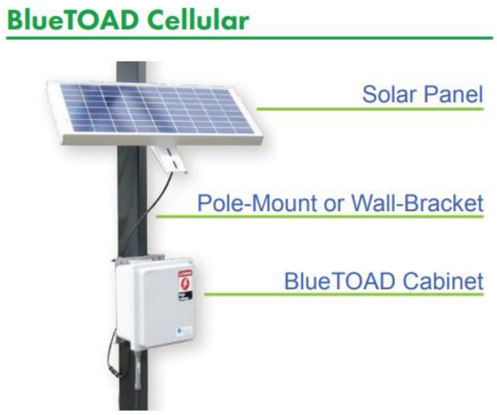



**Figure I-1. BlueTOAD Cellular**

Source: trafficcast.com

Regarding the percentage of pairs matched among all detected devices, researchers found there is no significant difference between rural road and urban road (Effinger 2011). Researchers from the University of Washington tested the devices on two corridors (Wang et al. 2014). One of the corridors was an urban arterial with frequent intersections and the other was a freeway. Travel time data collected based on Automatic License Plate Readers (ALPR) was considered as the ground truth. The authors compared BlueTOAD data with other sensor data such as BlipTrack-wifi, BlipTrack-Bluetooth, Sensys and probe data (i.e., INRIX). It was found that all of the sensors provided more accurate travel time estimates than INRIX. For Bluetooth data, the results showed that for travel time estimation, the accuracy deteriorates during peak hours as compared to non-peak hours.

The City of Chandler, AZ implemented Bluetooth detection to collect travel times in 2011 (Singer et al. 2013). This project aimed to provide the travel time approaching certain destinations covering both arterial and freeway travel times. Seven fixed Bluetooth detectors were placed along the road, and two “floating” detectors could be placed at locations according to the demand. The Bluetooth detectors were placed in traffic signal cabinets or on light poles for power and communication. Bluetooth data was housed by the vendor so the vendor could refine the algorithm. The data from Bluetooth detectors merged with two other data sources and was processed by the Intelligent Roadway Information System (IRIS), a traffic management system software package developed by the Minnesota Department of Transportation. IRIS calculated the travel time which combines the arterial travel time and freeway travel time. It then generated the travel time message and sent the messages to DMSs. When traffic was light, DMSs displayed default free-flow travel time.

From 2011, Bluetooth detectors started to be implemented because Bluetooth detectors could provide detection and match rates comparable to toll tag readers with half of the original costs.

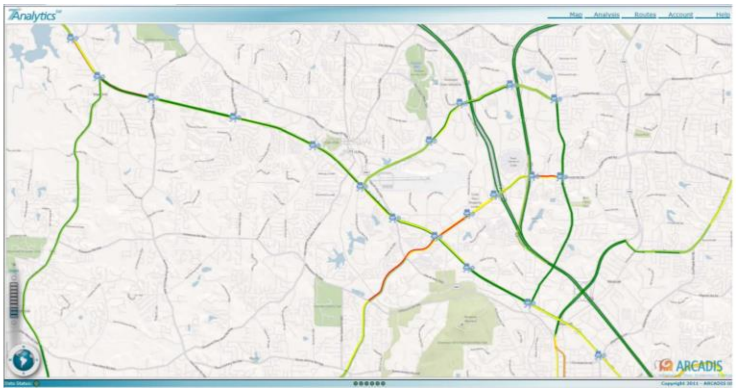


**Figure I-2. BlueTOAD Locations in Cobb County**

Source: gis2.arcdis-us.com

In 2012, Georgia DOT expanded the travel time system to provide travel times for arterial routes around I-75, near Atlanta. I-75 is a major interstate and often experiences congestion as a result of commuter traffic going to and from the Atlanta area. When I-75 experiences heavy congestion, surrounding arterials often experience congestion as drivers seek alternate routes. There are also four arterial DMS showing I-75 travel times on approaches to I-75 to allow drivers to determine whether to take I-75 or an arterial route. Bluetooth detection was implemented on select routes in Cobb County and Fulton County. 19 BlueTOAD units were deployed on arterials in Cobb County, see **Figure I-2**; 12 BlueTOAD units were deployed on arterials in Fulton County, and an additional 4 units were deployed in the City of Alpharetta. Arterial travel time data were used to monitor the roadway network for incidents and to determine the effects of heavy I-75 congestion on surrounding arterials. The arterial travel conditions are shown on a color-coded map on GDOT's website.

In 2014, City of Houston started the Houston Intelligent Transportation Systems (HITS) Project. HITS planned to deploy 91 DMSs, 650 Bluetooth Automatic Vehicle Identification (AVI) sites and other intelligent transportation hardware and software in the Houston area (supported by TIGER 2014 Discretionary Grant).

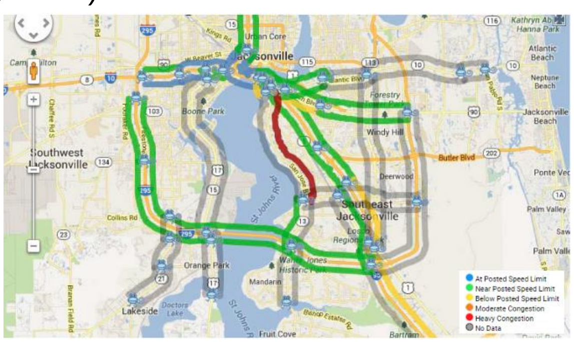



**Figure I-3. Traffic Condition from BlueTOAD data in Jacksonville, FL**

Source: (Elefteriadou et al. 2014)

BlueTOAD is widely used in the Florida area for arterial travel time data collection. **Figure I-3** displays the traffic condition in Jacksonville based on BlueTOAD data. FDOT District Four launched its Arterial Management Program (AMP) in 2017 (Crist et al. 2017). Forty-three BlueTOAD devices were deployed in Palm Beach County and 73 BlueTOAD devices were deployed in Broward County and are utilized as part of the AMP.

- Pros and cons

The pros and cons of Bluetooth devices are listed below:

**Pros:**

- Less expensive compared to many traditional data collection methods
- Installation does not impact traffic or the road surface (non-intrusive)
- The impact of inclement weather is small
- Acceptable accuracy

**Cons:**

- Low detection rate
- The matching rate is even lower than the detection rate
- Short lifespan compared to loop detectors
- Privacy issues
- Travel time data lag

### *I.1.2 Wi-Fi Detection*

- <u>Fundamental</u>

Wi-Fi detection technology has similar principles with Bluetooth detection. Wi-Fi detection detects the devices embedded in or carried by vehicles with a unique MAC address. Wi-Fi detection uses 2.4 or 5 GHz radio frequencies to transmit data. Higher radio frequencies mean high power requirements and faster transmission speed. The detection range of the Wi-Fi detection system is about 50 meters. The inquiry time of Wi-Fi is only 8 ms which is significantly shorter than the inquiry time of Bluetooth. This allows the devices to be detected by Wi-Fi detection quicker, providing for a larger collection sample. Researchers found that for a single device, BlipTrack-WiFi had more matched pairs than BlipTrack-BT and it was possible to capture twice as many matched vehicles if combining Bluetooth and Wi-Fi devices (Wang et al. 2014). The researcher also found that the detection rate decreases as the free flow speed increases and the detection rate increases with the intersection movement delay raised (Goodall 2016). The latter research also indicated that on the same road segment, Wi-Fi devices provide more matched pairs, almost twice as many Bluetooth devices provided.

- <u>Application</u>

Acyclica, in partnership with the City of Seattle, installed Skywave antennas along the street corridor of Seattle in 2015 (David 2015). The antennas created a Wi-Fi signal and read the signal from the wireless device. Acyclica gathers timestamps for all the detected devices and uses them to measure travel times along given routes. While Bluetooth readers capture 5-7 percent of cars passing intersections, the Wi-Fi readers capture nearly 50 percent from cars with smartphones or tablets with Wi-Fi turned on. The price of each Wi-Fi reader is approximately $2,000. The project started along Mercer Street and expanded to the whole downtown area. **Figure I-4** displays the location of Acylica Devices in the Central Business District (CBD) area of Seattle (Siemens Industry, 2017).

- <u>Pros and Cons</u>

Compared to the traditional traffic data collection method, Wi-Fi technology has almost the same pros and cons. However, compared to Bluetooth technology, there are two pros Wi-Fi technology:

- Fast detection
- Higher detection rate

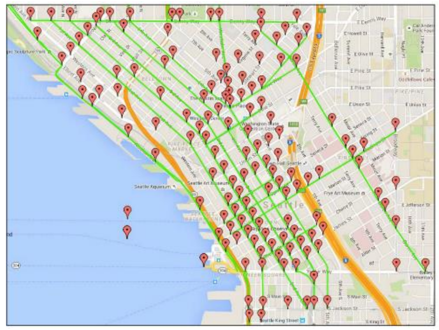


**Figure I-4. Location of all the Acyclica Devices in the Seattle CBD Area**

Source: (Siemens Industry, 2017)

*I.1.3 In-Pavement Magnetic Detection*

- <u>Fundamental</u>

In-pavement magnetic detection uses arrays of magnetometers installed in the pavement at a specific location to detect vehicles. Vehicles' unique magnetic signatures are captured by in-pavement magnetic sensors at different locations with a timestamp. The system matches the magnetic signatures of vehicles. Coupled with the distance between the locations, travel time can be calculated. In-pavement magnetic system has a high detection rate of over 97%.

The size of the magnetometers is much smaller than inductive loops, and it is easy to install. Since the magnetometers are installed in the pavement, when installed, it requires a lane closure. One magnetometer only can cover one lane. So, for each detection spot, multiple magnetometers are required to guarantee the detection rate.

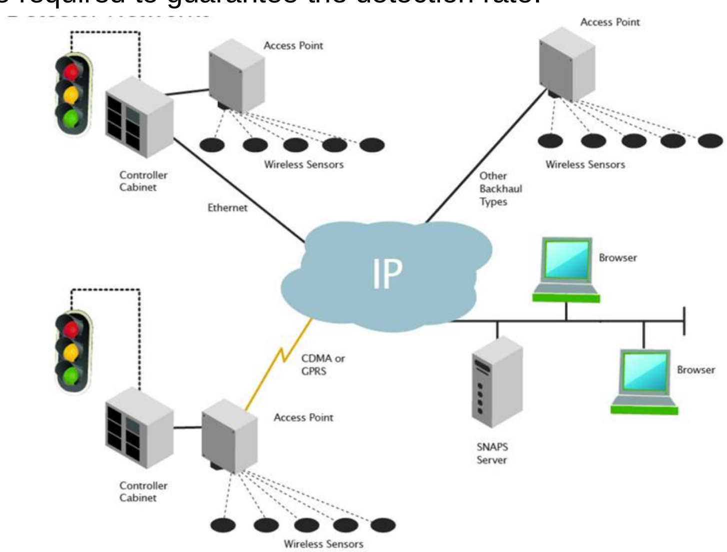



**Figure I-5. SNAPS Topology**

Source: sensysnetworks.com

Sensys Network developed mature wireless sensors for traffic detection based on magnetic detection. Apart from the sensors, Sensys Network also developed software – SNAPS to assist data collection, network management, and communication. SNAPS is the abbreviation of

Sensys Networks Archive, Proxy, and Statistics (SNAPS). Figure I-5 displays how the SNAPS works

.

- Application

In the City of St. Louis, 15 arterial corridors, over 180 intersections including side streets and left-hand turn pocket along Skinker, Hampton, Jefferson, Grand, and the Kings Highway north/south corridors were outfitted with Sensys network detectors (Sensys Network, 2008). The detectors were installed approximately every 1 to 1.25 miles over more than 130 miles of the roadway (An array of five detectors can be installed in 30 minutes). I-64 is a vital traffic corridor in the city of St. Louis, but it was not built to the interstate standard. When Missouri DOT decided to rebuild it, it was urgent for the city to have a rapid, effective and economical solution to mitigate potential traffic congestion. In 2009, Sensys Network detectors were deployed along the arterials of St. Louis, Missouri to provide travel time information to the roadway users and collect data for internal purposes (Singer et al., 2013).

The arterial data from Sensys Network detectors were integrated with Bluetooth and freeway sidefire radar data through MoDOT's advanced traffic management system (ATMS). Since MoDOT is responsible for most of the arterials in the St. Louis area, there was no institutional barrier to integrate the data. Travel time information for the outfitted corridors was disseminated via DMSs from 5 am to 10 pm.

For the Utah County I-15 Corridor Expansion Project, TransCore used Sensys Network detectors to collect travel time data. The in-pavement magnetic detectors were placed on State Street. Sensys Network updated travel time every two minutes and sent this information to TransCore. TransCore analyzed the data and updated the travel time every six minutes. The travel time data was disseminated through two ways: Utah Commuter Link website and Trailblazer Signs. During the construction, eight Trailblazer signs were placed on westbound approaches to State Street.

- Pros and Cons

To summarize, the advantages and disadvantages are listed below:

**Advantages:**

- High accuracy
- High detection rate
- Long lifespan
- Fewer privacy issues

**Disadvantages:**

- Installation requires a lane closure
- Higher cost compared to Bluetooth and Wi-Fi technology

*I.1.4 Automatic License Plate Reader and Machine Vision*

- Fundamental

For the Automatic License Plate Readers (ALPR) technology, optical cameras are installed along the roadside or above the roadway. The cameras capture images of license plates and image processing software is applied to identify the license plate numbers.

Similar to ALPR, machine vision installs video cameras on the roadside or above the roadway. The software is used to identify vehicle presence, lane occupancy, and speed. "Virtual loops" are used to measure vehicle speeds. Advanced machine vision can identify license plate numbers at different locations, match them, and provide travel time of road segment between the two locations.

- Validation

ALRP is a mature technology with high accuracy and has been widely deployed. In 2004, a study on a two-lane rural highway in Arizona found that ALPR achieved a 60% detection rate and a segment license plate match rate of 11% (FHWA, 2004). In some research, ALPR data is used as ground truth data (Wang et al., 2014) because of the high accuracy.  Other than travel time and origin-destination information, ALPR can provide other traffic information such as vehicle presence, lane occupancy, speed, and vehicle classification.

Machine vision is a mature technology and has been widely used in recent years. A study proposed a vehicle re-identification algorithm for computer vision, and the re-identification F-score is 68% and 57% for two cases (Yin et al., 2015)，(Yin et al., 2015), which indicate that the vehicle re-identification algorithm is reliable.

- Pros and Cons

ALPR has a high requirement for the line of sight. Inclement weather such as fog, thunderstorm, and snow can have a serious impact on ALPR detection. For installation, depending on where the system is placed, it may or may not require a lane closure. Machine vision technology has similar advantages and disadvantages to ALPR. The pros and cons of ALPR and Machine Vision are listed below:

**Pros:**

- High accuracy
- One camera can cover multiple lanes (compared to loop detectors)

**Cons:**

- Expensive for installation
- Heavy maintenance work (frequent lens cleaning)
- The high requirement of line of sight (large impact of inclement weather)
- Privacy issues – some agencies have specific laws against such technology

*I.1.5 Toll Tag Reader*

- Fundamental

The travel time of a vehicle is estimated by matching the tag numbers identified by a toll tag reader at both start and end points of a road segment with time stamps. Average speed and origin-destination information are also available. However, the market penetration of the toll road is pretty low. In 2015 January, there were only 241.2 miles of interstate toll roads in Ohio. Therefore, this method is only preferred on tolled roads. The privacy issue is another concern.

- Application

The City of Houston has a long history of collecting travel time information. Toll tag reader was a method used to collect freeway travel time data for Houston TranStar, which provides real-time travel time information to travelers: speed range on freeways and congestion level on non-freeways. Travel time information on Houston TranStar is updated every one minute.

The website Travel Midwest  (http://www.gcmtravel.com/lmiga/home.jsp ) provides freeway and arterial travel time to roadway users for the Chicago area. Travel Midwest uses data from a variety of sources, including loop detectors, toll tag readers, microwave radar, infrared, ultrasonic, acoustic, video image processing, and movement of transit.

- Pros and Cons

The pros and cons of Toll Tag Reader are listed below:

**Pros:**

- Small impact of inclement weather

- High accuracy

**Cons:**

- High cost to build Toll Tag reader stations
- Privacy issue
- Low market penetration, only applicable to toll roads

*I.1.6 Connected Vehicle*

- Fundamental

Vehicle-to-infrastructure communication technology in a Connected Vehicle (CV) environment gives the possibility to collect detailed traffic data. The speed of vehicles can be used to estimate travel times. The re-identification of vehicles offers the potential to calculate the travel time between two detection locations. Compared to other vehicle re-identification method, CV has fewer privacy problems because privacy protocols are already established in the system. Roadside Equipment (RSE) is required, and the installation does not disrupt the flow of traffic.

- Validation

For now, the technology is in the early stage. Studies show traffic density, CV market penetration, and transmission range are the factors that influence the accuracy of travel time estimation. Olia et al. (Olia et al., 2017) focused on optimizing the number of locations of RSE on the freeway to get a more reliable travel time estimation.

Researchers recently completed a study about utilizing CV data to collect traffic information and support traffic management decisions (Hadi et al., 2018). In this project, service patrol vehicles of Florida DOT District 5 Road Ranger were installed with Onboard Units (OBU). The cost of updating the vehicles is around $3,300 per vehicle. Existing Roadside Units (RSU) were used. The research states that CV data can be used to measure point speed data and to verify the accuracy of spot detector data. Additionally, the researchers also used CV data to detect incident information and estimate queue lengths on the urban road network. For travel time estimation on the freeway, the results showed that 1% market penetration of CV could produce results with errors of less than 10%. For travel time estimation on the urban network, 3% to 4% of CV market penetration can produce data for planning usage. For errors less than 10% on the urban network, it is better to have the CV market penetration rate of at least 10% to 15%. For queue length estimation, 3% to 6% CV market penetration rate can meet the requirement. The research also identified the trend of CV with mandate regulation on a CV. The researchers found that after four years of applying mandate regulation on CV, CV data can be used to estimate traffic volume on urban streets in combination with current detectors. After five to eight years, people can start to remove the detectors. Around 10 to 15 years later, it will be possible to remove all the detectors.

- Pros and Cons

The pros and cons of CV are listed below:

**Pros:**

- Less expensive once the infrastructure is in place
- The impact of inclement weather is small
- High accuracy
- Fewer privacy issues as compared to Bluetooth or Wi-Fi technology

**Cons:**

- Low detection rate due to a low current market penetration rate of CVs
- Cost of initial infrastructure installations

*I.1.7 Radar/Microwave Sensor*

- Fundamental

The device emits different waves (depends on the sensor type) and receives the reflected waves from a vehicle. With the observed frequency shift, the speed of the vehicle is determined. This type of technology is normally used to detect vehicle presence and calculate vehicle spot speed. On the road segments where travel speed variability is minimal, the technology can be used to calculate travel time. However, for the road segments where travel speeds vary spatially, these technologies are less useful and may need to be spaced closely in order to provide reliable data.

- Application

In Missouri State, the arterial data from Sensys Networks were integrated with Bluetooth and freeway sidefire radar data through MoDOT's advanced traffic management system (ATMS). The website Travel Midwest provides freeway and arterial travel time to roadway users for the Chicago area with data from a variety of sources, including loop detectors, toll tag readers, microwave radar, infrared, ultrasonic, acoustic, video image processing, and movement of transit. As a statewide application, Washington State DOT (WSDOT) provides travel time of freeways and non-freeways to roadway users through their website. Radar data is used as a supplementary data source.

- Pros and Cons

These technologies are mature, and there is no privacy issue. Inclement weather conditions do not significantly impact affect device performance.

**Pros:**

- No privacy issue
- Mature technology and many products available

**Cons:**

- High cost
- For travel time calculation, only works for road segments with small speed variability

*I.1.8 Inductive Loops*

- Fundamental

Magnetic loops are placed in the pavement and can detect vehicle presence and provide related traffic information such as lane occupancy, speed (a pair of loops), headway, and traffic volume. This is a mature technology and has been widely used. The most common use of inductive loops is for detecting vehicle presence and traffic volume. Similar to radar and microwave detectors, inductive loops are point detectors, which measures travel speed at a specific location. This data, however, can be used to enhance the travel time estimation accuracy in combination with other travel time estimation processes and data sources, particularly when the other sources cannot provide a reliable estimation.

- Validation

Researchers used the Dempster–Shafer data fusion method to improve travel time estimation quality with inductive loop data and toll collection data (El Faouzi et al., 2009). Other research combined inductive loop data and GPS data from cellphone to compute travel time (Mazaré et al., 2012).

- Application

Loop detectors data is widely used to provide travel time data. For example, The website Travel Midwest provides freeway and arterial travel time to roadway users for the Chicago area. The

Travel Midwest uses data from a variety of sources, including loop detectors, toll tag readers, microwave radar, infrared, ultrasonic, acoustic, video image processing, and movement of transit.

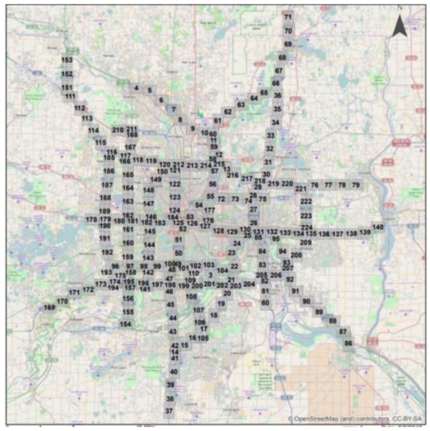


**Figure I-6. All Detectors on Freeway in Twin Cities Metropolitan Area**

Source: (Minnesota Department of Transportation, 2015)

Twin Cities network has 3,780 freeway inductive loop detectors (Minnesota Department of Transportation, 2015). **Figure I-6** displays the detectors locations on the freeway in the Twin Cities Metropolitan Area. Loop detectors and virtual (Wavetronix) detector were installed on the freeways. These loop detectors were used for traffic estimation and control purposes. Researchers tried to adopt the experience to arterials (Davis et al., 2010) and found freeway loop detector data had limited value for directly updating arterial volumes and travel times. More sophisticated approaches were suggested.

Washington State DOT (WSDOT) provides travel time on freeways and non-freeways to roadway users statewide through their website (Washington State Department of Transportation, n.d.). Vehicle speed is calculated based on the loop detector data from data stations located along the roads. Based on vehicle speed and the distance between two stations, travel time is calculated. Other detectors such as infrared, radar, sound or video imaging and Bluetooth are also used by WSDOT. But compared to loop detectors, the coverage of these data collection methods is much smaller.

- <u>Pros and Cons</u>

Inclement weather conditions have limited impact. And there is disruption to traffic while installing and maintaining the device.

**Advantages:**

- High detection rate
- No impact by bad weather
- Low cost
- No privacy issue

**Disadvantages:**

- Installation requires a lane closure
- Destructive to road pavement
- High maintenance cost

*I.1.9 Summary of Data Collection Technologies*

The highlights of each technology are summarized below:

- **Bluetooth Detection**: wireless technology detects devices such as cell phones or laptops in a vehicle with its unique MAC address; less expensive than many other options; mature product (BlueTOAD, Bliptrack-BT), low detection rate (requiring medium traffic volume for accurate travel time estimation).
- **Wi-Fi Detection**: wireless technology detects devices such as cell phones or laptops in a vehicle with its unique MAC address; less expensive than many other options; mature product (Acyclica, Bliptrack-WiFi), medium detection rate.
- The detection and re-identification of MAC address methods raise a privacy issue. The study of MAC address randomization in mobile devices emerges recently. If MAC address randomization is applied on electronic device successfully, the devices will not have unique MAC addresses, the detection and re-identification methods will be not applicable.
- **In-pavement Magnetic Detectors**: magnetic detectors detect vehicle's unique magnetic signatures; invasive installation; mature product (i.e., Sensys); high detection rate; other traffic information such as the traffic volume and vehicle type; high initial cost, low maintenance cost.
- **Toll Tag Reader**: Detect radio frequency ID of automated toll tags, mature technology; works with adequate toll tag fleet penetration rate at tolled roads; privacy issue.
- **Automatic License Plate Readers**: cameras capture an image of the license plate, which are then processed by software; mature technology; sensitive to optical condition; privacy issue.
- **Machine Vision:** video cameras monitor traffic flow, read license plate; bandwidth for data transmission; privacy issue.
- **Connected Vehicle**: Short range radio communications; Vehicle to Vehicle (V2V) and Vehicle to infrastructure (V2I); early state technology; penetration rate is low now; some privacy issues which have been partially addressed.
- **Radar/Microwave:** mature and widely used; less use in travel time collection; no privacy issue.
- **Inductive Loops**: vehicle presence detection; travel time calculation on road segment that speed variability is minimal; normally not used in travel time estimation.
- The state-of-the-practice review indicates that most of the agencies provide travel time information derived from not only a single source of data but also a combination of multiple sources. **Table I-3** summarizes part of the practice of different states or cities.

**Table I-3. Summary of Part of the Practice of Providing Non-Freeway Travel Times to the Public**

| City/State | Range | Data source |
|---|---|---|
| **Chandler** | An arterial | Bluetooth |
| **St. Louis** | Citywide | In-pavement magnetic detector, Bluetooth, Sidefire radar |
| **Twin Cities** | Citywide | Loop detector, License plate reader |
| **Houston** | Citywide | Toll tag reader, Bluetooth |
| **Seattle** | Citywide | Wi-Fi |
| **Washington** | Statewide | Loop detector, Infrared, Radar, Sound or video imaging, Bluetooth, License plate reader |
| **I-15, Utah** | An interstate | In-pavement magnetic detector |
| **Florida** | Statewide | Bluetooth, Microwave sensors, Camera |

| | | |
|---|---|---|
| **Chicago** | Citywide | Loop detectors, Toll tag readers, Microwave radar, Infrared, Ultrasonic, Acoustic… |
| **Atlanta** | Arterial routes around I-75 | Bluetooth |
| **I-95 Corridor** | Multi-State | INRIX, HERE, and TomTom, Bluetooth |

**In summary**, Toll Tag Reader and Automatic License Plate Reader methods are mature technologies which have a long history of usage, though privacy issues exist for a long time. The cost of these two technologies is relatively high compared to other methods. Bluetooth Detection, Wi-Fi Detection, and In-pavement Magnetic Detectors are emerging technologies. Bluetooth Detection and Wi-Fi Detection have similar operating principles, and both of them are relatively inexpensive. Among these two, Wi-Fi detection has a higher detection rate and match rate. Though the detection of MAC address might not be feasible due to potential MAC address randomization in the future, Bluetooth detection technologies are currently being widely used by state DOTs. The cost of the In-pavement Magnetic Detector is relatively expensive but it has several advantages.  First, the detection rate (almost 100%) and match rate are pretty high. Since the detectors compare each vehicle's unique magnetic signature, there is no privacy issue. The lifespan of the device is about ten years with relatively low maintenance cost. Moreover, vehicle spot speed, traffic volume information can be collected by the In-pavement Magnetic Detector.

### I.2. Private Sector Data

Private sectors integrate data from multiple sources provided by a large number of road users. Typically, location-aware (GPS or cellular network-based) devices running an application that sends location information to a central server of the vendors and then raw data are processed using customized algorithms to generate travel time/speed data products. In this section, three private sector data providers and their products will be discussed.

*I.2.1 INRIX*

- <u>Fundamental</u>

INRIX provides many road speed information such as reference speed, measured speed, historical average speed, and time required to travel across a segment to help understand traffic condition. The primary source of the INRIX data is the Global Positioning System (GPS) data from GPS equipped on vehicles and cellphone data. The GPS data is supplemented by DOT sensor and detector data and historical traffic flow data from state DOTs. INRIX data can provide both real-time and historical speed and travel time data. **Figure I-7. INRIX Data** Source: (Elefteriadou et al., 2014) **Error! Reference source not found.**illustrates INRIX data along I-95 southbound in Florida.

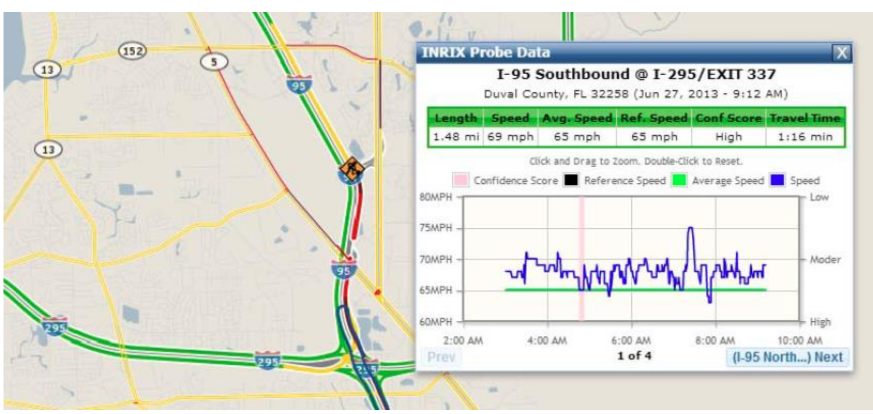


**Figure I-7. INRIX Data**

Source: (Elefteriadou et al., 2014)

Right now, INRIX data reports speed and incident data with two types of segments as the basis to define road sections—TMC Segments and XD Segments. The Traffic Message Channel (TMC) Segment was defined, owned, maintained, and expanded by the North American Location Code Alliance. The XD Segments are defined in 2013 and maintained by INRIX. With XD Segments, INRIX covers the road segments which is not defined by TMC location codes. Based on INRIX (INRIX, 2018), INRIX XD Segments has more queue details and road coverages as well were interchanges (**Figure I-8**). Sub-segment data provide real-time/archived information with a much greater resolution.

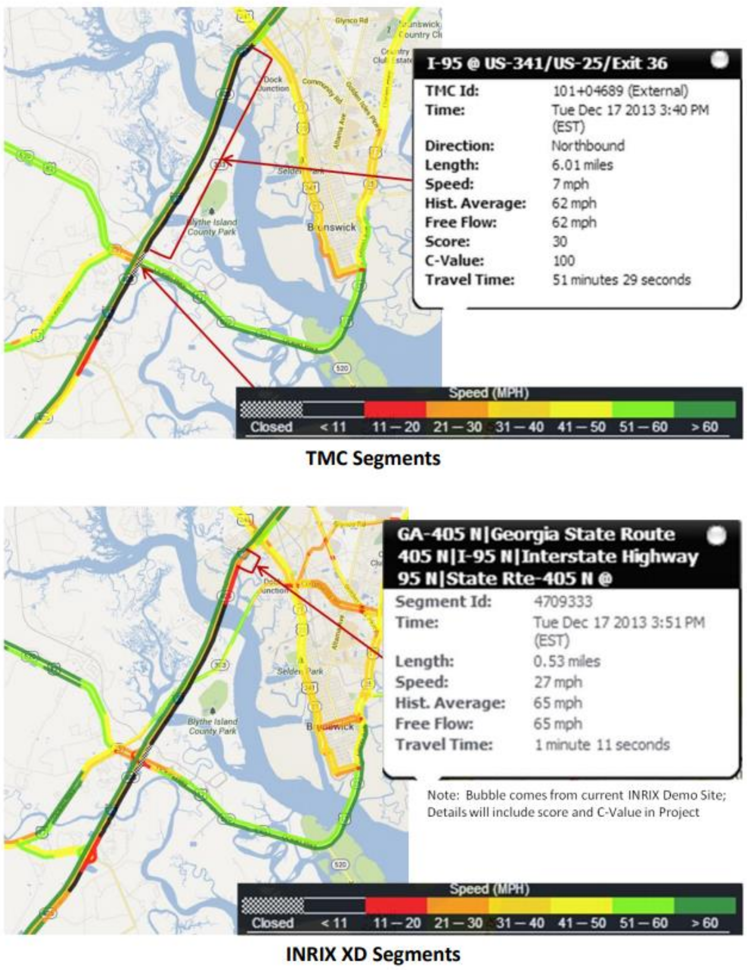



**Figure I-8. Different Segments used by INRIX data**

Source: (INRIX, 2018)

Right now, INRIX data is purchased by many state DOTs (e.g., Michigan DOT, Iowa DOT, New Jersey DOT, North Carolina DOT, and Virginia DOT) and widely used to provide travel time information.

- <u>Validation</u>

Researchers from the University of Maryland, College Park, conducted a study to assess INRIX data quality (Haghani et al., 2009). The study area was I-95 Corridor Coalition with about 1,500 miles of freeways and 1,000 miles of arterials. Data from the Bluetooth device was set as ground truth data. Also, they used floating car data to verify Bluetooth data. Other than evaluating INRIX data with Bluetooth data, the researchers also used Standard Error of the Mean to represent the uncertainty of INRIX data. The research found most of the time INRIX data were satisfactory for speed and travel time information provision. But some issues were identified such as mapping and geospatial accuracy (in the nature of GPS data), temporal distribution and penetration rate of INRIX data, and INRIX data tend to be least responsive to traffic changes. It was also found that INRIX data tend to overestimate speeds below 45 mph and underestimate speeds over 60 mph.

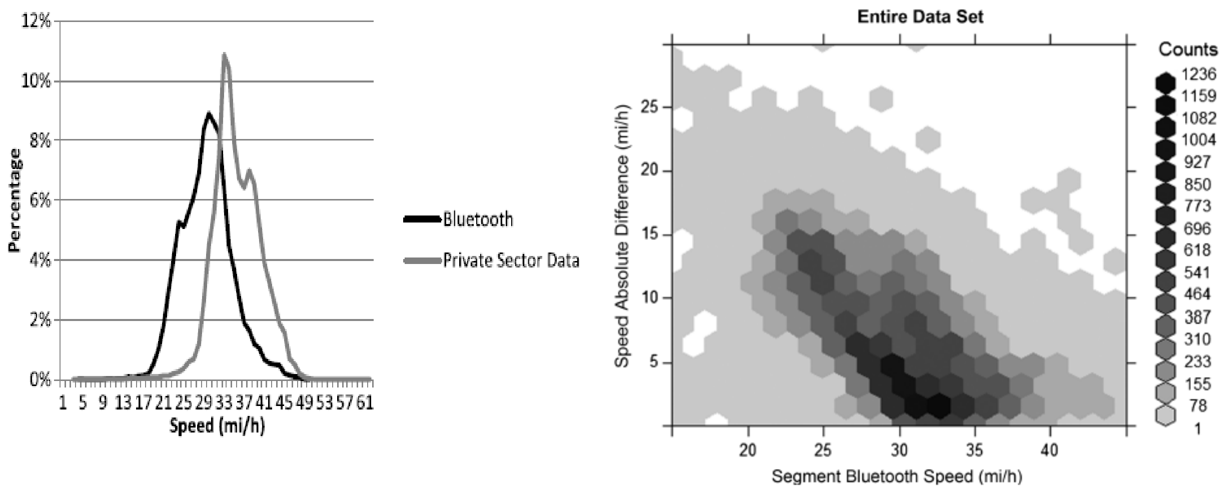
The University of Washington did research on evaluating various traffic data collection devices which includes INRIX data (Wang et al., 2014). The study areas were two corridors: part of State Route 522 (SR 522) part of I-90. Data from ALPR was set as ground truth data in this research. The research found that for certain road segment, INRIX could not provide satisfactory results while other data sources such as Bluetooth detection, Sensys could provide satisfactory results. INRIX data tends to over or underestimate the travel time systematically. When the sample size was small (like overnight), INRIX would be less reliable. And they found that for travel time estimation, INRIX data had lower accuracy compared to data from other sources such as Blip and Sensys systems. They used the Mean Absolute Percent Error (MAPE) to measure the relative magnitude of the error.

Another research project assessing the data quality of STEWARD, INRIX, BlueTOAD, and HERE data on measuring the travel time of freeways and arterials was done in Florida (Elefteriadou et al., 2014; Kondyli et al.,). The results suggest that the HERE traffic data provide better freeway travel time estimates compared to the remaining methods. In oversaturated conditions, STEWARD, INRIX and BlueTOAD data seem to underestimate travel times, while HERE data were found to be more accurate. For under saturated freeways, STEWARD, INRIX, and BlueTOAD were found to perform better than HERE. At the arterial sites, BlueTOAD and HERE travel time data were analyzed, and the analysis suggests that none of the methods is accurate, possibly due to the small sample size. ,

Compared to freeway travel times, the travel times on arterial have more variation due to intersection and traffic signal interferences. To validate GPS probe data, i.e.,INRIX HERE, and Bluetooth, a  study (Zhanget al., 2015) created a validation methodology based on the coefficient of variation. For weekdays from 5:00 PM to 8:00 PM, INRIX data showed a larger deviation from base data. For weekends, the deviation is relatively high during the daytime and low during the evening peak when comparing to the deviation on weekdays. To work with Bluetooth data, the authors introduced a context-dependent travel time fusion framework and it was proved that data from multiple sources could help improve the reliability of the travel time information.

A research team from the University of Maryland, College Park validated INRIX arterial data against Bluetooth device generated data based on the coefficient of variation (Zhang et al., 2015). They presented a validation method for a corridor in which there were more traffic signals on arterials compared to freeways. Pure INRIX arterial data was found not satisfactory, and therefore a fusion method was proposed to blend INRIX data and Bluetooth data for arterial travel time estimation.

Our research team also conducted one of the earliest studies in validating non-freeway and arterial travel times (Hu, Fontaine, & Ma, 2016). Arterials represent a fundamentally more challenging environment for probe vehicle data given the larger variance in travel times created by traffic signals and other intermediate access points. In that research, the quality of private sector data (INRIX) on arterials was evaluated by utilizing the Bluetooth travel-time data as the ground truth. The evaluation was conducted from two perspectives: the ability to track real-time conditions and the ability to identify long-term traffic state changes. The study sites are three signalized arterials in the State of Virginia. The results indicate that the private sector data evaluated are not suitable for real-time applications but could be used to measure long-term traffic state changes for performance measurement programs. **Figure I-9** (a) and (b) demonstrate the substandard performance of the private sector data as compared with the Bluetooth data (used as ground truth in the study). However, recent technology advancements by private vendors may have improved their data quality. Companies like INRIX have started to provide high-definition data (INRIX XD Traffic, 2016) aiming to provide data with better granularity and to better capture traffic dynamics. These data sets should be understood better before using them directly for arterial travel time provision.




**(a) Probability density function plot of the two data sources**

**(b) Speed absolute error density hexbin plot**

**Figure I-9. Results of the PI's Previous Study**

Source: (Hu, Fontaine, & Ma, 2016)

A study analyzed the coverage and penetration of INRIX data in Iowa on both interstates and non-interstates (Ahsani et al., 2018). INRIX provides a higher percentage of coverage on interstates than on non-interstates. For the reliability of INRIX data during different times of the day, the conclusion was similar to other studies—the reliability was higher during the day than the night. They also compared INRIX speed data with speed data from Wavetronix smart sensors. INRIX speeds are space mean speeds while speeds detected by Wavetronix are time mean speeds. The researchers divided the INRIX speed data into five groups (0–25, 25–45, 45–55, 55–65, and greater than 65mph). It was found that for INRIX data under 45 mph, the magnitude and variation of speed bias were greater than others. There was a lower speed bias during day time compared to the night time, and the speed bias is less during morning and afternoon peak traffic hours. To examine the impact of traffic volume on the speed bias, AADT and truck-AADT were examined and truck-AADT had a more significant impact on the data and it was concluded that the speed bias was less in the busy hours of the day. This research also explored the accuracy and reliability of INRIX data when used in congestion detection with modified congestion detection algorithms and it was found that INRIX data has a higher accuracy for recurring congestion than non-recurring congestion.

*I.2.2 HERE*

- <u>Fundamental</u>

Similar to INRIX, HERE provides real-time and arrived 5-minute speed data for the Traffic Message Channel (TMC) segments. Origin-destination information, volumes, travel times, incidents of data are also provided (Turner et al., 2011).

- Validation

Research evaluating the performance of probe data (which is sourced from HERE) on road network performance was performed. This research considered congestion mapping, access time analysis and other road network performance (Espada and Bennett, 2014). In this study, HERE provided 5-minute speed data and OD data (at that time, 0.2% of the traffic were captured). For travel speed data, data from Toll Tag Reader was used as the reference data. They found HERE travel speed data is relatively accurate. For the accuracy of OD data, Automatic Number Plate Recognition (ANPR) was set to be ground truth, and in this case, ANPR could capture roughly 50% of the total traffic. The research found HERE data was a viable source for OD data as well.

Research on HERE data showed that HERE data provided better freeway travel time estimates, especially on oversaturated conditions(Elefteriadou et al., 2014). In this research, they evaluated the travel time measurements obtained by STEWARD, INRIX, BlueTOAD, and HERE. Floating cars were used to collect data as a reference. For uncongested situation, STEWARD, INRIX, BlueTOAD outperformed HERE data. Analysis of arterials suggested that neither method is accurate.

## I.3 Analysis of Alternatives

### *I.3.1 Cost*

- Inductive Loops

Inductive loops are widely used in freeway and intersection management. For a project in Phoenix, Arizona, the bid price for a single loop detector ranges from $485 to $1,200. The bid price for a loop detector card ranges from $80 to $200. The bid price for a loop detector AC isolator unit ranges from $44 to $100.89. Relatively recent data showed the installation cost per unit of the inductive loop detector was $1,500 to $2,000 (this price is highly variable given maintenance of traffic considerations, i.e. arterial vs. freeway) and the operation and maintenance cost per year ranged from $580 to $1,900. Compared to microwave radar and other non-intrusive technologies, inductive loops require high maintenance cost. The installation of inductive loops is intrusive, damaging the pavement and disrupting the traffic, and therefore it is not recommended for the Phase 2 study.

- Radar, Microwave, Acoustic, Infrared, and Ultrasonic

Installation costs per radar site are estimated at $8,000 according to Cambridge Systematics (2012), but the costs may vary depending upon the type of installation. North Carolina DOT reported that using microwave sensors cost approximately $48,600 per mile of roadway on a major freeway, based on the typical sensor spacing used. A study listed the costs for a different detector used on corridors in **Table I-4** (Walton et al., 2009).

**Table I-4. Cost of Detection Technologies for Corridor**

| Technology | Installation Cost | Operation and Maintenance Cost/Year |
|---|---|---|
| **Microwave** | $8,000-$16,000 | $100-$600 |
| **Acoustic** | $3,700-$8,000 | $200-$400 |
| **Passive/Active Infrared** | $6,000-$12,000 | $700 |
| **Ultrasonic** | $600 | $200 |

- Bluetooth Detection

Bluetooth detection costs were reported to be approximately $4, 000 for potable battery-power cases, and the deployment costs vary by equipment and location. The cost of a permanent station cost between $100 and $1,000, depending on the available infrastructure at the location (Day et al. 2012). In another study, the capital cost of the Bluetooth detection equipment was about $4, 000. Installation was estimated at $500 per person sensor (Young 2012). The study estimated the cost for recurring data were $40 per month for 200MB data. In a proposal of the City of Houston, the cost for single Bluetooth AVI is estimated to be $2,500 (the City of Houston, 2014). The cost of the BlueTOAD equipment, including the pole, but excluding power, communication, data formatting, and system integration, is approximately $9,700 to $12,200 per device, nearly one third the cost of EZPass (Toll Tag Reader technology) (KMJ Consulting, 2010). BlueTooth devices can be purchased for as low as $500 for equipment, however, in these instances, the processing of the data may need to be completed by the installing agency, whereas devices such as BlueToad and Acyclica provide processed data. The pricing is listed in **Table I-5** (KMJ Consulting, 2010).

**Table I-5. BlueTOAD Cost**

| Item | Description | Price |
|---|---|---|
| **Hardware** | | |
| 1 | BlueTOAD Base Unit | $3,900 |
| 2 | Solar/Battery | $600 |
| 3 | Cellular Modem | $200 |
| 4 | Cellular Interconnect fees – 5GB | $1,050 |
| **Installation and Maintenance** | | |
| 5 | Data Processing Service/Monthly | $130 |
| 6 | Maintenance Agreement/Annual | $1,000 |
| 7 | One-time Activation Fee | $200 |
| 8 | On-Site Consulting/Day | $1,000 |
| 9 | Custom feed development fee (2 staff weeks; plus travel expenses) | $12,000 |

- Wi-Fi Detection

The cost of each Wi-Fi detector was reported to be $2,000 per detector (David Kroman, 2015). One of the vendors of Wi-Fi detectors for traffic detection is Acyclica. The price of Acyclica from ODOT's is listed in **Table I-6** WiFi devices can be purchased for as low as $800 for equipment, however, in these instances, the processing of the data may need to be completed by the installing agency, whereas devices such as BlueToad and Acyclica provide processed data.

**Table I-6. Price of Wi-Fi Traffic Detection System**

| ITEM | DESCRIPTION | UNIT PRICE |
|---|---|---|
| 1 | Acyclica Roadtrend Unit | $4,000.00 |
| 2 | Acyclcia Antenna | $50.00 |
| 3 | Acyclica Antenna Cable | $250.00 |
| 4 | Acyclica Modem | $800.00 |
| 5 | Acyclica 12db Omnidirectional Antenna | $145.00 |
| 6 | Acyclica 5 port Cloudgate Modem | $800.00 |

| | | |
|---|---|---|
| 7 | Acyclica 5-Band MIMO Antenna | $250.00 |
| 8 | Acyclica 50Ft LMR 400 RP-SMA to N-Type | $149.00 |
| 9 | Acyclica 9db Omnidirectional Antenna | $90.00 |
| 10 | Acyclica Cellular Data Service | $400.00 |
| | **GRAND TOTAL** | **$5,100.00 (*)** |
| ***It is noticed that the sum of the unit price does not equal to the grand total.** | | |

- In-Pavement Magnetic Detectors

The cost of In-Pavement Magnetic Detector varies depending on several factors such as the number of sensors per array and number of lanes, as well as the required maintenance of traffic. The cost also varies depending on the service provided by the technology vendor. In 2013, Sensys Networks of Berkeley, California bided for an intersection detection in the City of Grand Island. The bid price was $22,539 (City of Grand Island, 2013). Data from ODOT and Seattle.gov are listed in **Table I-8**

**Table I-7. Cost of In-Pavement Magnetic Detectors**

| Description | Price | |
|---|---|---|
| | ODOT, 2011 | Seattle.gov, 2011 |
| **In-Pavement sensor** | $485.00 | $460.00 |
| **Receiver** | $2,940.00 | $2,590.00 |
| **Repeater** | $1,275.00 | $880.00 |
| **Control Interface** | $635.00 | $650.00 |
| **Ethernet Trans receiver** | $135.00 | $123.00 |
| **Total** | **$5,470.00** | **$4,730.00** |

- Automatic License Plate Reader

A study considered the cost of each ALPR camera to be $20,000. Supporting costs such as installation and fiber optics costs are estimated at $4,000 (Eberline, 2008). The report also pointed out the cost of cameras for law enforcement for license plate readers can range from $10,000 to $25,000.

- Connected Vehicle (CV)

Florida DOT used CV data to collect traffic information and support traffic management decisions (Hadi et al., 2018). They modified service patrol vehicles of Florida DOT District 5 Road Ranger to collect data. The cost for updating the vehicles is around $3,300 per vehicle (3,000 for the RSU plus $300 for the Ethernet-to-cell 3G modem, $11.60 for a Bluetooth adapter, and $7.00 for the DC-DC converter for the cell modem). This information is provided as a reference. The CV is not recommended for Phase 2 in this project due to its current low market penetration and prohibitive costs to increase the market penetration to an acceptable level for travel time estimation.

- Private Sector Data

The cost of private sector data, such as INRIX and HERE, are contractual prices negotiated between the vendors and agencies. Therefore, no reference prices were reported. ODOT currently has access to HERE real-time/archived data for freeways and real-time/archived INRIX data for non-freeways. One feasible approach is to negotiate with HERE or INRIX to conduct a pilot study, during which ODOT will have access to the real-time data on selected routes.

Note that, although real-time HERE or INRIX data is most useful for this project or can be used directly for providing travel time (though quality to be investigated), archived INRIX data can still be useful in understanding traffic patterns and be used in travel time estimation and prediction.

- Summary of the Cost of Detection Technologies

Among all the technologies, the installation (e.g., device, infrastructure) costs of the inductive loop, Bluetooth, Wi-Fi, and in-pavement magnetic detectors are relatively low. The costs of inductive loops are relatively high. Moreover, the installation of inductive loops and in-pavement magnetic detectors requires a lane closure. The installation cost of radar and microwave sensors are at a medium level. The costs of toll tag reader and automatic license reader are high. The maintenance costs of automatic license reader and other machine vision technologies are relatively high.

*I.3.2 Accuracy*

- Inductive Loops and Radar, Microwave

Inductive loops are accurate in vehicle counts, classification, and spot speeds. Radar and Microwave detectors have similar capabilities for measuring counts, classification, and spot speed. Before the vehicle re-identification technologies were widely used, actually even today, these spot speed traffic detectors, or point detectors, are widely used to provide spot speed data for the traffic management system to provide travel times to roadway users. Under these circumstances, the accuracy of the travel time estimation relies on certain algorithms and methods. Compared to travel times from vehicle re-identification method, travel times estimated by point detectors respond quickly to changes in travel times that may occur (Haas et al., 2009) because the travel times/speeds can be reported instantly without the need to wait for vehicle trips to complete. Please see the state-of-the-practice review for details.

- Bluetooth

Previous research showed that the detection rate of the Bluetooth and WI-FI ranges from 3% to 11.4% (ITERIS 2011; Vo 2011). Bluetooth and Wi-Fi-based systems reported satisfactory results, staying below the 25 percent error threshold except during nights and sometimes the peak periods. Specifically, the BlueTOAD system can be less reliable overnight when the sampling rate is low (Wang et al. 2014). The study found that Bluetooth travel times were accurate except during congestion, which is the most important period of time for travel time provision. During congestion, the Bluetooth travel times were shorter than the GPS travel times (Vo 2011), indicating a conservative estimation of congestion. Some other studies suggest that with calibration and verification, Bluetooth readers can provide accurate travel time information for corridors with ADT greater than 15,000 ADT(ITERIS, 2011). A study found the travel times produced by the BlueTOAD were comparable to those produced by the E-ZPass tag readers (KMJ Consulting, 2010). For travel time estimation, the accuracy is between 80% and 90% during different times of the day. That is because during off-peak hours, especially during the night, the sample size is not large enough (Turner, Sadabadi, Haghani, & Hamedi, 2011a; Vo, 2011; Wang et al., 2014).

- Wi-Fi Detection

With the increase of market penetration of in-vehicle and personal Wi-Fi devices, Wi-Fi detections capture nearly 50% of the cars with smartphones or tablets with Wi-Fi turned on (David, 2015). Researchers found that for a single device, Bliptrack-WiFi had more matched pairs than Bliptrack-BT and it was possible to capture twice as many matched vehicles if combining Bluetooth and Wi-Fi devices (Wang et al., 2014). The researcher also found that the detection rate decreases as the free flow speed increases and the detection rate increases with the intersection movement delay raised (Goodall, 2016). The latter research also indicated that on the same road segment, Wi-Fi devices provide more matched pairs, almost twice as many Bluetooth devices provided.

A previous study showed that, when combining Bluetooth and Wi-Fi (from BlipTrack) detection in travel time estimation, the hourly travel time had an average of 40% MAPE (Mean Absolute Percentage Error) and during the peak hours, the estimated travel time had higher errors (Wang et al., 2014). A study found that the absolute percentage error compared to ground truth data is less than 10% for a Bluetooth and Wi-Fi combination detection (Shiravi, Hossain, Fu, & Ghods, 2016).

- In-Pavement Magnetic Detectors

In-pavement magnetic detectors have an almost 100% detection rate and a high match rate. Based on previous studies, the match rate ranges from 30% to 70%. Researchers found the accuracy of the data varied by a segment on arterial roadways and the Sensys system posted acceptable accuracy in most cases (Wang et al. 2014).

- Automatic License Plate Reader

A study on a two-lane rural highway in Arizona found that ALPR achieved a 60% detection rate and a segment license plate match rate of 11% (FHWA, 2004). In many studies, ALPR data is used as ground truth data because of the high accuracy (Shiravi et al., 2016; Wang et al., 2014). ALPR, however, does not apply for this project.

- Private Sector Data

Previous studies accessed the accuracy of the INRIX data. A study evaluated the data quality for freeways along a corridor (Haghani et al. 2009). It was found the average absolute speed error was less than 10 mph and speed error bias was less than 5 mph. For travel times and speeds, the data quality improves as speed increases. For the congestion situation, the results indicated INRIX could provide an accurate overall picture of traffic conditions for limited access roadways within the Corridor.

The University of Washington did research on evaluating various traffic data collection devices which includes INRIX data (Wang et al., 2014). Data from ALPR was set as ground truth data. The research found that for certain road segment, INRIX could not provide satisfactory results while other data sources, such as Bluetooth detection and Sensys, could provide satisfactory results. INRIX data tends to over or underestimate the travel time systematically. When the sample size was small (like overnight), INRIX would be less reliable.

HERE data provided better freeway travel time estimates than non-freeways, especially during oversaturated conditions (Elefteriadouet al. 2014). In this research, they evaluated the travel time measurements obtained by STEWARD, INRIX, BlueTOAD, and HERE. Floating cars were used as the ground truth. For uncongested conditions, STEWARD, INRIX, and BlueTOAD outperformed HERE data. Another study validates INRIX and HERE data in the I-95 Corridor Coalition Vehicle Probe Project on the interstate of North Carolina (Hamedi & Aliari, 2017). Both INRIX and HERE showed to have better performance when the speed is high.

The quality of private sector data is related to several factors such as sample size and the algorithm the private sector is using. As time goes, the vendors will update the algorithms and it is likely the data quality can be improved. Currently, based on the evaluation studies across the states, the data quality varies across different locations (e.g., cities, states) on different types of roadway facilities.

- Summary of the Accuracy of Detection Technologies

There are three major categories of methods to collect travel time information: Vehicle re-identification, spot speed, and private sector data. Bluetooth, Wi-Fi, ALPR, and other machine vision methods belong to the first category. Inductive loop, radar, and microwave methods belong to the spot speed method. In-pavement magnetic detectors locate between them.

Detection rate and match rate impact the accuracy of the vehicle re-identification methods. Road segments, traffic condition, and sensor location also impact the accuracy of the methods.

Generally, the accuracy of the travel time data collection methods, vehicle re-identification method, in particular, is not ideal when the traffic is congested, or the traffic volume is low. With low traffic volume, the number of detected vehicles for matching and calculating travel time is not sufficient. During congested traffic, if the distance between the two detection points is long, it is impossible to predict the travel time since the vehicle re-identification methods report the travel times the vehicles just experienced. In summary, vehicle re-identification methods have relatively high accuracy. Inductive loops, radar, and microwave sensors are also used to provide travel times and the accuracy depends on the density of detection stations and the estimation algorithm. The quality of private sector data is related to several factors such as sample size and the algorithm the vendors are using. Based on previous studies, both INRIX and HERE provide acceptable accuracy results for travel time estimation, but the accuracy level is not ideal. Every method needs to be verified before putting into use. In the validation, researchers usually use data from ALPR, or Floating car as the ground truth due to their high accuracy. Research should be continued to consider the possibility of using several data sources together to increase the accuracy of the calculated travel time

#### *I.3.3 Adoption Rate*

Among all the detection technologies, inductive loops were invented in the 1960s. Because of its high accuracy in spot speed measurement, vehicle count and classification, inductive loop detectors were widely used in the U.S. Minnesota State Department of Transportation installed loop detectors at intersections /ramps on the Interstates around Minneapolis (Minnesota Department of Transportation, 2015). In total, there are 5500 loop detectors in Minnesota. Accompanied by CCTV, these inductive loop detectors provide spot speed data for travel time estimation.

There are about 800 detectors/microwave radars in the St. Louis and Kansas City region. Michigan has 428 microwave sensors for travel time estimation. Iowa is using 394 side-fire radar traffic sensors to help with travel time calculation. Indiana has hundreds of detectors including side-fire radar, micro loops, and loops for the travel time calculation.

Automatic License Plate Reader (ALPR) and Toll Tag Reader (TTR) are mature technologies widely used in some states such as Washington, Texas, and the Bay Area in California. Both technologies could provide accurate travel times to the public. Recently, people started to use Bluetooth to replace ALPR and TTR for reducing costs.

Bluetooth and Wi-Fi detections share similar operating principles: re-identifying vehicles with unique MAC addresses. Right now, Bluetooth detection is widely used in many states. Recently, Bluetooth started to replace some technologies because Bluetooth devices are relatively inexpensive. The adoption rate of Wi-Fi is relatively low compared to Bluetooth technologies. This is likely because commercial Wi-Fi technologies matured later than Bluetooth. But recent market trends see many new Wi-Fi products and their performance were evaluated as at least as good as Bluetooth.

In-Pavement Magnetic Detectors are used in several states. Missouri and Utah used Sensys (product of In-Pave Magnetic Detector) to provide arterial travel times. Illinois and Washington tested Sensys on several urban streets. The adoption rate of the In-Pavement Magnetic Detector is relatively low compared to the detections discussed above.

The INRIX datasets are widely used by state DOTs in the United States, for example, Michigan DOT, New Jersey DOT, North Carolina DOT, Virginia DOT, Indiana DOT, and Iowa DOT. HERE data is getting more and more attention and used by states including Missouri DOT, Michigan DOT, North Carolina DOT, and Utah DOT. StreetLight focuses more on OD matrices, through which traffic volumes and travel times between origin and destination can be obtained. StreetLight data is working with several partners to provide mobility data. Minnesota DOT, City of Sacramento, Southeast Region of Florida, and Virginia DOT use StreetLight data to provide intelligent traffic management systems and traveler information to the public.

The state-of-the-practice review indicates that most of the agencies provide travel time information derived from not only a single source of data but also a combination of multiple sources. **Table I-8** summarizes part the practice of different states or cities.

**Table I-8. Summary of Part of the Practice of Providing Travel Time to the Public**

| City/State | Range | Data source |
|---|---|---|
| **Chandler** | An arterial | Bluetooth |
| **St. Louis** | Citywide | In-pavement magnetic detector, Bluetooth, Sidefire radar |
| **Twin Cities** | Citywide | Loop detector |
| **Houston** | Citywide | Toll tag reader, Bluetooth |
| **Seattle** | Citywide | Wi-Fi |
| **Washington** | Statewide | Loop detector |
| **I-15, Utah** | An interstate | In-pavement magnetic detector |
| **Florida** | Statewide | Bluetooth, Microwave sensors, Camera |
| **Chicago** | Citywide | Loop detectors, Toll tag readers, Microwave radar, Infrared, Ultrasonic, Acoustic… |
| **Atlanta** | Arterial routes around I-75 | Bluetooth |
| **I-95 Corridor** | Multi-State | INRIX, HERE, and TomTom, Bluetooth |

*I.3.4 Summary*

To weight each alternative method, each ranking criterion is given a score of 1 to 5. Moreover, the weights of each criterion are listed in **Table I-9**.

**Table I-9. Weights and Scores for Alternative Methods**

| | Infrastructure Cost | Maintenance Cost | Accuracy | Adoption Rate |
|---|---|---|---|---|
| **Weight** | **10%** | **30%** | **50%** | **10%** |
| **Low** | 5 | 5 | 1 | 1 |
| **Low to Moderate** | 4 | 4 | 2 | 2 |
| **Moderate** | 3 | 3 | 3 | 3 |
| **Moderate to High** | 2 | 2 | 4 | 4 |
| **High** | 1 | 1 | 5 | 5 |

**Table I-10** shows the completed Matrix of Alternative for different data sources. It is noticed that in **Table I-10** all the emerging and trending technologies such as Bluetooth detection, Wi-Fi detection, and radar detectors receives relatively high scores. The private sector data are not rated because of the above-mentioned reasons, such as the uncertainty in the costs. But the "worry-free" nature of this type of data makes it widely used among state DOTs.

Based on the discussion above, multiple data sources are preferred in this study for the purpose of data quality comparison and enhancement of the travel time accuracy. The ranking indicates the following options can be adopted in the study:

- Bluetooth or Wi-Fi (re-identification)

- Radar detector (spot speed measurement)
- HERE or INRIX (depending on the availability of archived data and/or real-time feeds)

**Table I-10. Alternative of Matrix**

| Alternative Methods | | | | Ranking Criteria | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | 10% | 30% | 50% | 10% | |
| Rank | | Data Collection Technology | Description | Infrastructure Cost | Maintenance Cost | Accuracy | Adoption Rate | Weighted Score |
| | Data Collection | **Bluetooth Detection** | Vehicle re-identification | 4k | 1k | Moderate to High | High | **4.2** |
| | | **Wi-Fi Detection** | Vehicle re-identification | 4k | 1k | Moderate to High | Moderate | **4.0** |
| | | **Toll Tag Reader** | Vehicle re-identification | 20 | 2k | Moderate to High | Moderate | **3.7** |
| | | **In-pavement Magnetic** | Vehicle re-identification | 0.5k * 20 | 0.1k | Moderate to High | Moderate | **4.1** |
| | | **Automatic License Plate Readers** | Vehicle re-identification | 25k | 3k | Moderate to High | Moderate | **3.7** |
| | | **Machine Vision** | Vehicle re-identification | 25k | 3k | Moderate to High | Low | **3.5** |
| | | **Radar, Microwave** | Spot speed method | 10k | 0.5k | High | High | **4.2** |
| | | **Inductive Loops** | Spot speed method | 1k | 1.5k | Moderate | High | **3.4** |
| | Private Sector | **INRIX** | TMC data | Subscription cost (no infrastructure) | | Moderate | High | 4.3 |
| | | **HERE** | TMC data | Subscription cost (no infrastructure) | | Moderate | High | **4.3** |

**Legend**

| Good | Medium | Bad |
|---|---|---|

### I.4 Travel Time Dissemination Method

The Phase 1 research found out that Dynamic Message Signs (DMS), Variable Message Signs (VMS), Changeable Message Signs (CMS), Destination Dynamic Message Signs (DDMS), Highway Advisory Radios, and 511 websites (e.g., OHGO platform) are among the different technologies that have been traditionally applied to disseminate route information in the State of Ohio. Fixed or portable DMSs have been widely used to provide real-time en-route traveler information on freeways and arterials. Because of the DMS's capability of displaying limited information and a possible distraction to drivers due to reading the message on driving, localized speed reduction may occur due to drivers braking when reading DMS messages. Nevertheless, DMSs are still thus far the most widely used traveler information dissemination mode. DMSs are installed above the roadway and the message can be accessed by all the passing drivers. On the contrary, other emerging modes such as smartphone or 511 websites, may not be accessible to some of the driving population. It is worth noticing that DMSs have been extensively studied in the past decades, and the community has had a clear understanding of the effectiveness and best practices, such as font size, information amount, and design of messages. Additionally, many studies indicated that DMS is a safe tool to disseminate traffic information to roadway users with no significant adverse effect on traffic safety.

On the other hand, Phase 1 research also suggested that the emerging apps, both public and private, may be currently suitable for pre-trip planning or when the vehicle is not in motion. While some innovative concepts such as the Virtual Dynamic Message Signs (VDMS) (Ma and Zhou, 2016) that uses smartphones, personal devices, or any connected vehicle in-vehicle devices to provide auditory travel time information, these new technologies can be a good option for travel time provision in the future, rather than for the near future.

The results in terms of “Travelers’ Attitude,” the survey conducted during Phase 1 revealed that travelers have a positive attitude toward DMS and smartphone applications. General results indicated that smartphone applications outperform DMS on routing and avoiding congestion, while DMSs do a slightly better job regarding raising awareness of downstream incidents and work zones. Results from the survey respondents show that both DMS and smartphone applications are useful to their travel and they are satisfied with both technologies.

The survey results also indicate that the respondents are still using both information sources during their travel, possibly having them complement each other, and consider both sources of information provide useful assistance to their travel. However, for the remaining 23% of the travelers who do not own a smartphone (based on the data from Pew Research Center) will need to rely on DMS for accessing real-time traveler information, including travel times, incidents, and work zones. Overall, this survey shows the effectiveness of DMSs for travelers in Ohio. The fixed or portable DMSs are still considered as the most practical, cost-effective way to provide traveler information as of today, and are expected to continue to be used in the near future.

Since portable DMSs could be deployed flexibly in the field, portable DMSs will be primarily used to facilitate field testing trials to be conducted in Phase 2, whereas Smartphone app with OHGO and OHGO website will be used as a supplementary tool for information dissemination. The portable DMS is usually a trailer-mounted DMS and can be equipped with radar, cameras, and other sensing devices, which are particularly needed for places in proximity to work zones.

The estimated unit cost is $10,000 to $15,000 for a single DMS and about $1,000 for one-year maintenance (Office of the Assistant Secretary for Research and Technology, 2018; the City of Houston, 2014). The costs of portable DMSs vary depending on the manufacturer, size and support structure. For example, for Illinois State Toll Highway Authority project, the bid price for single trailer mounted full matrix portable DMS ranged from $2,500 to $11,070.15 (Illinois Tollway, 2016). The rental price for portable DMS ranged from $787.50 per month to $870 per month. For traveler information websites such as OHGO, depending on the size of the website, the cost of creation and maintainence of a website vary but still relatively inexpensive. For this project, there may be only marginal costs to display the travel time information on the existing OHGO website.

The cost of each dissemination methods is summarized in **Table I-11**.

**Table I-11. Travel Time Dissemination Method**

| Alternative Methods | Infrastructure Cost | Maintenance Costs | Adoption Rate |
|---|---|---|---|
| **DMS** | High | High | High |
| **Portable DMS** | Moderate | High | Moderate |
| **DMS + OHGO** | High | High | High |

# Appendix II: Travel Time Survey

To understand roadway users' view on travel time-related information provided by dynamic message signs (DMS) and private smartphone applications, a survey was conducted to evaluate traveler' preferences and attitudes. The survey was posted on qualtrics.com and disseminated through the Ohio Department of Transportation (@ODOT_Statewide) on Twitter. 367 respondents have participated in the survey.

### II.1 Basic Information

This section of the survey collected the basic socio-economic information of the respondents, such as gender, age, annual household income, and education level.

Of all the respondents, 47.14% are male, 52.04% are female, and 0.82% refuse to provide gender information. The age distribution is presented in **Figure II-10. Distribution of Age**

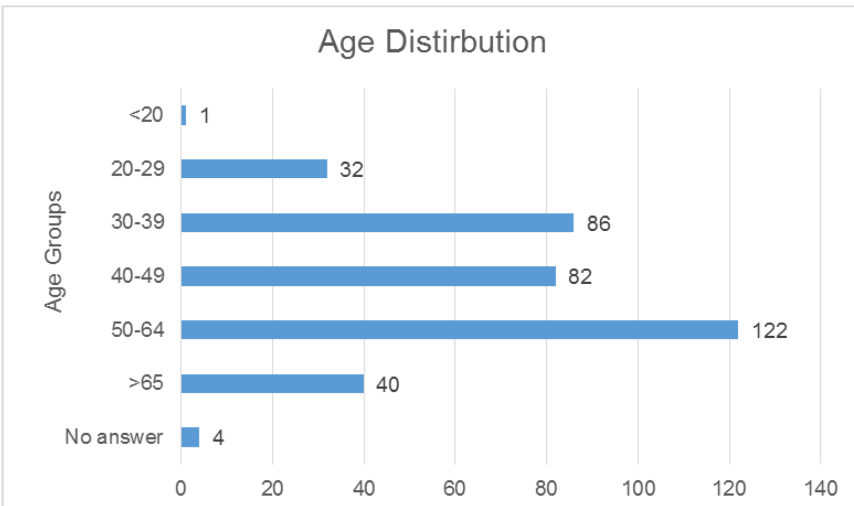
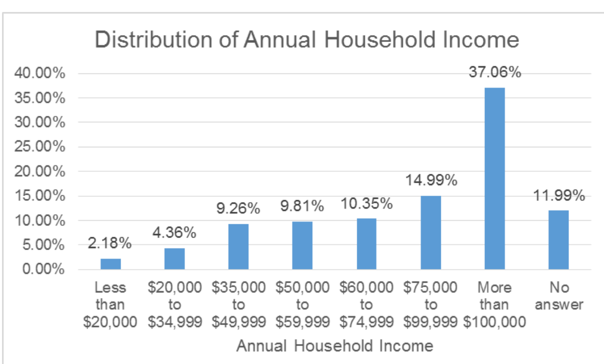
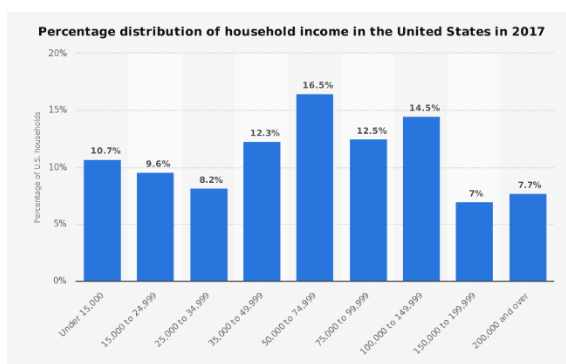



**Figure II-10. Distribution of Age**

Regarding the question about the speed of adopting new technologies (1 means "very slow," 5 means "very quick"), the mean value is 3.91 with a standard deviation of 0.87. Over 70% of the respondents think they adopt new technologies pretty quickly or very quickly. The distribution of annual household income is in **Figure II-11**.



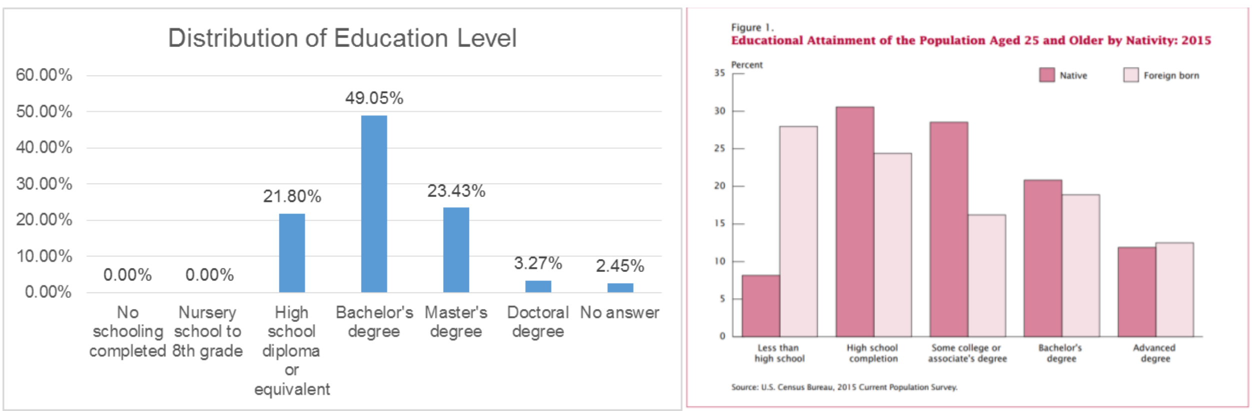

(a) Survey respondent (b) Population of the United States

**Figure II-11. Annual Household Income Distribution**

Compared to the results of the US Census Bureau in 2017 (in **Figure II-11** (b)), the results of this survey skews to the right. The proportion of high-income people is relatively high in our survey. This can explain why many respondents think they adopt new technology quickly. This is also directly related to a later result that 94.25% of the respondents own a smartphone, higher than the national average.

Among the 367 participants, 80 of them (21.08%) have a high school diploma or equivalent. Half of them have a bachelor's degree. 26.70% of them have a graduate degree. Detailed distribution is presented in Figure **II-12.** Distribution of Education Level

(a). All the respondents have at least a high school diploma or equivalent. The population survey conducted by the US Census Bureau in 2017 (**Figure II-12** (b)) identifies about 7% of people who have less than a high school diploma. Again, the education level of our survey participant also skews to the right.




(a) Travel Time Survey (B) National Survey

**Figure II-12. Distribution of Education Level**

In summary, compared to the situation of the US, the respondents of this travel time information survey have higher education levels and annual household income. This is due to the way we distribute the survey (i.e., social media). After the discussion with ODOT, we decided to stay with this pool of respondents and use this survey to focus on understanding the attitudes and experience of the respondents to DMSs and smartphone apps.

## II.2 Travel Related Information

This part collected daily travel related information, including commute trips and other family and personal errands related trips. Information such as trip duration, travel distance, the chance of encountering congestion was collected.

The average number of trips related to work/school every week is 11.18, with a standard deviation of 11.46. Based on the results, 88. 35% of the work/school related trips are made by private vehicles. Data from the 2017 National Household Travel Survey shows that 88.2% of To/From work and 80.1% of Work-Related Business trips are done by private vehicles. The proportions of people who choose to carpool, public transit, and other method are 3.69%, 4.26%, and 3.69%, respectively. For the trips for other family and personal errand, 92.06% of the travelers choose private vehicles.

For work-related trips, the chance of encountering congestion is pretty high for the respondents (see **Figure II-13**). Only 7.85% chose "no congestion." 18.73% of them has a low probability of encountering congestion, 23.56% of them have a median probability of encountering congestion, 21.15% of them have a high probability of encountering congestion, and 28.70% of them encounter congestion almost every day. In comparison, for trips about other family and personal errands, only 6.37% of travelers encounter congestion almost every day. The reason is that, compared to work and school or related trips, people can arrange the trips for other family and personal errands more flexible. For the travelers who encounter en-route congestion, 30.40% of the congestion occur on the freeways, 30.40% on the non-freeways, and 31.61% on both freeways and non-freeways. For the trips related to other family and personal errands, 52.22% of the travelers encounter the congestion on non-freeways.

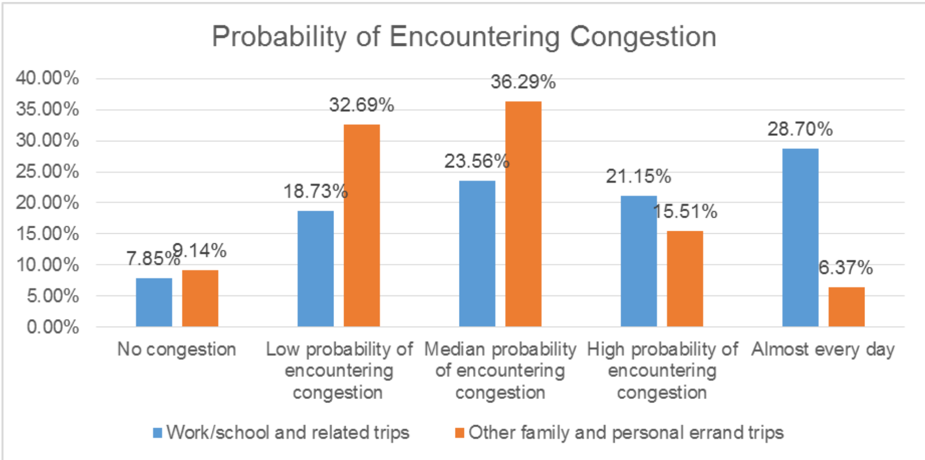



**Figure II-13. The Probability of Encountering Congestion**

After cleaning the data, only 318 of the respondents finished the question about trip duration and travel distance. The average trip duration for work/school related trips during peak hour is 38.61 minutes with a standard deviation of 28.79. The average travel time for work/school related trips during off-peak hours is 26.22 minutes with a standard deviation of 20.61. By comparing the distance in pairs for each of the respondents, it turns out for work/school or related trips, most of the travelers do not change the route or there is no alternative route for them. For other family and personal errand trips, the average trip duration during peak hour is 24.13 minutes with a standard deviation of 20.15, the average trip duration during an off-peak hour is 21.73 minutes with the standard deviation of 22.84. Sixteen of the respondents mentioned they do not travel during peak hours.

### II.3 Travelers' Attitude

This section collected respondents' attitudes and references toward travel time information disseminated through DMSs and smartphone apps.

Among the 367 respondents, 99.73% of them have seen a DMS and, in 93.70% of the cases, the DMS is on the freeway. 84.97% of the respondents think the information provided by DMS is accurate. For the respondents who think the information is inaccurate, some respondents listed the reasons. 12 travelers mentioned that the posted travel time on DMS is too low compared to actual travel times (non-responsive). 20 of the travelers considered the DMS updating too slowly. This is probably because most of the DMSs provide instantaneous travel times – the segment travel times at the moment when the drivers pass the DMSs. When the drivers traverse the segment, particularly when the segment is long, traffic states may have already changed significantly.

Among the respondents, 94.25% (344) of them have a smartphone and 93.96% used a smartphone app to provide them with routing or pre-trip planning information. Based on the data from Pew Research Center, on Feb 2018, 77% of Americans own smartphones, again, lower than our results due to the unique respondent pool.

Among all the smartphone apps, Google Maps is the most popular and 56.33% of the respondents use it, 22.05% use WAZE, and 10.04% use OHGO, and 7.64% use Apple Map. It turns out that 79.50% of the respondents check traffic information on the app before the start of the trip and 72.58% of the respondents check traffic information during the trip. Regarding the accuracy of the information provided by smartphone apps, 85.71% of the respondents think the information is accurate. The respondents listed several reasons for that: updates are too slow, work zones are not shown at the right location, and the app does not always give the most effective routes. This is due to the nature that private smartphone apps mostly reply on probe data and passenger reports, and the information, including the digital map, cannot be updated timely. Information latency has always been a problem with these smartphone apps.

For the usefulness of DMS, a Likert scale rating system was used to collect the information. On the scale, 1 means useless and 5 means very helpful. For the results, the mean is 3.60, and the standard deviation is 1.23, indicating that respondents generally consider the DMS is helpful for their travels.

To understand what aspects the DMSs help the travelers, the research team requested feedback on four particular aspects: routing, avoiding congestion, aware of upcoming incidents and aware of the upcoming work zones. Respondents were asked to rate each aspect from 1 to 5 (1 means not helpful and 5 means very helpful). The result is shown in **Table II-12** "Aware of upcoming incidents and upcoming work zones" were rated with higher means and smaller standard deviations than "routing and avoiding congestion." This result is in line with the team's expectation that DMSs focus on providing traveler information to assist drivers to make decisions, instead of providing specific routing options. Also, agencies have access to almost real-time incident and work zone information, and this accurate information is posted on the DMSs directly and timely.

**Table II-12. Helpfulness of DMS**

| Aspect | Mean | Standard Deviation |
|---|---|---|
| **Routing** | 3.13 | 1.42 |
| **Avoiding congestion** | 3.20 | 1.37 |
| **Aware of upcoming incidents** | 4.00 | 1.19 |
| **Aware of upcoming work zones** | 3.66 | 1.29 |

**Table II-13** displays the respondents' attitude toward the four aspects of smartphone apps. Routing and avoiding congestion are rated with higher means as compared to awareness of upcoming incidents or work zones. It is expected that the smartphone apps are rated higher than DMS regarding routing and avoiding congestion because the former is designed for routing purposes, and the latter is not. It is interesting to note that DMSs are rated slightly higher than smartphone apps on awareness of upcoming incidents or work zones. The standard deviation of DMSs is smaller, indicating that the respondents agreed upon the usefulness of DMSs for raising the awareness of incidents or work zones.

**Table II-13. Helpfulness of Smart Phone Applications**

| Aspect | Mean | Standard Deviation |
|---|---|---|
| **Routing** | 4.46 | 1.00 |
| **Avoiding congestion** | 4.09 | 1.17 |
| **Aware of upcoming incidents** | 3.94 | 1.26 |
| **Aware of the upcoming work zone** | 3.62 | 1.33 |

To understand the acceptance (from various perspectives) of DMS and smartphone applications, five-point Likert scale questions were included. The answer options were designed to evaluate usefulness and satisfaction to assess the drivers' acceptance of this new application of transportation telematics1. Questions rated qualities like usefulness and pleasantness, safety, informational value, convenience and ease of receipt, comprehension of messages, and annoyance.

**Table II-14** displays the aggregate results of nine-item questions on DMS. **Table II-15** shows the results of smartphone applications. The number in each cell lists the number of participants who checked that cell during the survey.

**Table II-14. Results of Nine-item Questions on DMS**

| Answer Options | Scores | | | | | Answer Options | Mean | Standard Deviation |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | | |
| **Useful** | 133 | 101 | 56 | 35 | 26 | Useless | 2.20 | 1.25 |
| **Pleasant** | 90 | 99 | 139 | 17 | 6 | Unpleasant | 2.29 | 0.96 |
| **Good** | 117 | 115 | 97 | 16 | 6 | Bad | 2.08 | 0.97 |
| **Nice** | 95 | 11 | 116 | 22 | 7 | Annoying | 2.25 | 0.99 |
| **Effective** | 115 | 105 | 77 | 37 | 17 | Superfluous | 2.2.25 | 1.16 |
| **Likeable** | 96 | 97 | 134 | 19 | 5 | Irritating | 2.26 | 0.97 |
| **Assisting** | 122 | 110 | 72 | 34 | 13 | Worthless | 2.16 | 1.12 |
| **Desirable** | 115 | 99 | 105 | 18 | 14 | Undesirable | 2.19 | 1.08 |
| **Raising alertness** | 151 | 112 | 67 | 11 | 10 | Sleep-inducing | 1.91 | 1.00 |

**Table II-15. Results of Nine-item Questions on Smart Phone Applications**

| Answer Options | Scores | | | | | Answer Options | Mean | Standard Deviation |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | | |
| **Useful** | 246 | 60 | 15 | 5 | 9 | Useless | 1.42 | 0.86 |
| **Pleasant** | 145 | 105 | 72 | 7 | 6 | Unpleasant | 1.88 | 0.94 |
| **Good** | 184 | 96 | 42 | 7 | 6 | Bad | 1.67 | 0.90 |
| **Nice** | 146 | 100 | 72 | 11 | 6 | Annoying | 1.90 | 0.97 |
| **Effective** | 210 | 91 | 21 | 7 | 6 | Superfluous | 1.53 | 0.85 |
| **Likeable** | 145 | 100 | 73 | 13 | 4 | Irritating | 1.90 | 0.95 |
| **Assisting** | 207 | 95 | 20 | 6 | 7 | Worthless | 1.54 | 0.85 |
| **Desirable** | 182 | 95 | 43 | 8 | 7 | Undesirable | 1.70 | 0.93 |
| **Raising alertness** | 167 | 90 | 61 | 9 | 8 | Sleep-inducing | 1.81 | 0.98 |

Reliability analysis was conducted with the Nine-item Questions on both DMS and smartphone applications, Cronbach's α and average scores for usefulness and satisfaction for each technology are displayed in **Table II-16**. In the analysis, item 1, 3, 5, 7, and 9 are used for the usefulness scale, and item 2, 4, 6, and 8 are used for the satisfying scale. The reliability (Cronbach's α) is sufficiently high (above 0.65). On a scale of 1 to 5, the average scores imply that the respondents agree with the opinion that both DMS and smartphone applications are useful to their travel and satisfy with both technologies. Note that most of the respondents use

[1] Van Der Laan, J. D., Heino, A., and De Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. Transportation Research Part C: Emerging Technologies, 5(1), 1-10.

both DMSs and smartphones during their travel in our survey. This indicates that travelers are still using both information sources during their travel, possibly having them complement each other, and consider both sources of information provide useful assistance to their travel.

**Table II-16. Reliability Coefficients (Cronbach's α) and Average Scores for the Usefulness and Satisfying Subscales for Each Technology**

| Technology | Cronbach's α | | Average Score | |
|---|---|---|---|---|
| | Usefulness | Satisfaction | Usefulness | Satisfaction |
| **DMS** | 0.942 | 0.872 | 2.08 | 2.45 |
| **Smart phone applications** | 0.936 | 0.873 | 1.59 | 1.84 |

### II.4 Summary

In this survey, basic demographic information, travel-related information, and travelers' attitude toward DMS and smartphone applications are investigated. Compared to the situation across the United States, the respondents of this survey tend to have a higher education level and higher annual household income. This has an impact on the result that the respondents have a higher smartphone ownership rate than the national average.

For daily travel, the results imply that travelers have a great chance encountering congestion no matter if the trip purpose is work/school related or other family and personal errands. The congestion occurs on both freeways and non-freeways. For other family and personal errand trips, people tend to travel during the off-peak hours.

For respondents' view on travel time information dissemination methods, the survey results show that 99.73% of the respondents have ever seen a DMS (93.70% of the cases on the freeways). 94.25% of them have a smartphone and 93.96% of used smartphone applications to help with travel routing or pre-trip planning. Regarding the accuracy of the disseminated information, 84.97% of them think the DMS information is accurate, and 85.71% think smartphone application information is accurate. Respondents gave the reasons why they think the information is not accurate, including updating too slowly (both DMS and smartphones), actual travel times usually longer than DMS; smartphone applications do not place work zones at the right location.

A five-point Likert scale survey reveals that travelers have a positive attitude toward DMS and smartphone applications. Meanwhile, smartphone applications outperform DMS on routing and avoiding congestion, while DMSs do a slightly better job regarding raising awareness of downstream incidents and work zones. Survey results on usefulness and satisfaction indicate that respondents agree with the opinion that both DMS and smartphone applications are useful to their travel and they are satisfied with both technologies.

After analyzing the survey results, we consider that the respondents are still using both information sources during their travel, possibly having them complement each other, and consider both sources of information provide useful assistance to their travel. However, for the remaining 23% of the travelers who do not own a smartphone (based on the data from Pew Research Center) will need to rely on DMS for accessing real-time traveler information, including travel times, incidents, and work zones. Fortunately, this survey also shows the effectiveness of DMSs for travelers in Ohio.

## Appendix III: State-of-the-Practice Review

A survey conducted by Office of the Assistant Secretary for Research and Technology, over 95% of the agencies provide traveler information on freeways and arterials with Dynamic Message Signs (DMSs) in 2017. Other than DMSs, social media like Twitter and Facebook are also widely used by the agencies. 511 Traffic System, Email or Alert, Website, and Highway Advisory Radio are other widely used methods for disseminating traveler information on the freeway. Currently, 76 Traffic Management Centers (TMCs) in the United States display travel time information on DMSs. In this chapter, we review the selected agency practices of providing non-freeway travel time information.

### III.1 ODOT Existing Practice

Researchers and the Ohio Department of Transportation conducted several projects on traffic data collection or providing traffic information on the Ohio public roads. There have not been practices of estimating or providing travel time on non-freeway systems, many studies have been done related to freeway travel times. For example, researchers from the University of Akron estimated freeway travel times based on fixed single loop detector data (Yi et al., 2007). Another study accessed the travel time data quality provided by a private sector against floating vehicle data, Bluetooth data, and fixed traffic sensor data (Schneider IV et al., 2010). In the study, six road segments over 100 miles of freeways and arterials were chosen as the study sites. The authors also compared the travel times derived using data point detectors (i.e., side-fire radar) and probes (i.e., Bluetooth and floating car methods), and the Bluetooth data was shown to be more accurate than the point detector data.

Regarding the Bluetooth technology, researchers conducted a study to apply the Bluetooth technology to the rural freeways to collect speed data (Schneider et al., 2012). The research team fabricated a Bluetooth device with a computer processing unit, 3G cellular communication capability, and a power supply unit. The device was placed roadside and used to collect travel speed information. With the travel speed information, incidents and congestion caused by incidents were identified.

In Ohio, researchers assessed the data quality of SpeedInfo (**Figure III-14**) and INRIX using loop detector data as the ground truth (Coifman and Kim, 2013). SpeedInfo uses a Doppler radar to measure aggregate traffic speed. Based on the aggregate traffic speed, traffic management agencies could evaluate the traffic condition and estimate travel times for the roadway segment. Apart from traffic speed information, SpeedInfo can also provide traffic counts. I-71 was chosen to be the study area, and the deviations between SpeedInfo and loop detector data were investigated. It was found that SpeedInfo tends to report higher speeds during congestion possibly because the radar system tends to catch faster moving targets. At 5 min level, the SpeedInfo data were comparable to the loop detector data and the results are generally satisfactory. However, at 1 min level, there were two problems of SpeedInfo data. First, the SpeedInfo system tends to have a lower speed compared to a loop detector system. Second, there was a latency of about 1 minute for the SpeedInfo system to report the data. Also, several issues appeared after the evaluation of INRIX data. First, generally, there is a 6-minute latency. Second, INRIX data reported repeated measurements. After excluding repeated values, the actual effective reporting period was more like 3-5 min, with occasional periods of repeated measurements lasting in excess of 10 minutes. Third, although INRIX provides two measures of confidence their data, none of them considered the impact of the repeated measurements.

**Figure III-14. SpeedInfo Doppler Vehicle Speed Sensor**

Source: speedinfo.com

### III.2 Chandler, Arizona

The City of Chandler, AZ implemented Bluetooth detection to collect travel times in 2011 (Singer et al., 2013). This project aimed to provide the travel times to certain destinations with routes covering both arterial and freeway travel times. As shown in **Figure III-15**, Notation 1, 2, and 3 indicate the locations of DMSs. Default travel time messages are also shown. The green line, black line, and blue line indicate the route each DMS covers. Every route combines a segment of an arterial and a freeway. These three routes are the major commute route in Chandler.


**Figure III-15. Location of DMS in Chandler, AZ**

Source: City of Chandler & Oz Engineering, 2011

All the three travel times of the three routes were collected by Bluetooth, and it is chosen because of the low-cost. Also, two of the freeway segments are also installed with loop detectors. The freeway travel time data were provided by Arizona DOT while Chandler City was responsible for the arterial data collection. Seven fixed Bluetooth detectors were placed along the road, and two “floating” detectors could be placed at locations according to the demand. The

Bluetooth detectors were placed in traffic signal cabinets or on light poles for power and communication. Bluetooth data were housed by the vendor so the vendor could refine the algorithm.

The data from Bluetooth detectors were merged with two other data sources and then processed by the Intelligent Roadway Information System (IRIS), a traffic management system software package developed by the Minnesota Department of Transportation. IRIS calculated the travel time which combines the arterial travel times and freeway travel times and then generated the travel time messages before sending the messages to DMSs. When traffic was light, DMSs displayed the default free-flow travel times. The City of Chandler & Oz Engineering also conducted a survey to understand the public reaction to the DMSs. Based on the survey, most of the travelers thought the travel time information displayed by DMS were easy to understand, accurate and helpful.

### III.3 St. Louis, Missouri

I-64 is a vital traffic corridor in the city of St. Louis, but it was not built to the interstate standard. The city decided to rebuild the corridor and the traffic needed to be diverted to city streets. This action might cause traffic congestion on those streets. It was urgent for the city to have a rapid, effective and economical solution to mitigate potential traffic congestion.

In 2009, Sensys Networks were deployed along the arterials of St. Louis, Missouri to provide travel time information to the roadway users and collect data for internal purposes (Singer et al., 2013). Fifteen arterial corridors, over 180 intersections including side streets and left-hand turn pockets along Skinker, Hampton, Jefferson, Grand, and the Kings Highway north/south corridors were installed with Sensys networks detectors (Sensys Network, 2008). The detectors were installed approximately every 1 to 1.25 miles over more than 130 miles of the roadway (an array of five detectors can be installed in 30 minutes).

Compared to Bluetooth detectors, the cost of in-pavement magnetic detectors was much more expensive. But, in-pavement magnetic detectors have almost 100% detection rate and high match rate. Based on previous studies, the match rate ranges from 30% to 70%. Moreover, in-pavement magnetic detectors have a battery life of up to 10 years, during which limited maintenance is required. Sensys networks could provide a full range of data such as the volume and spot speed, occupancy, and vehicle classification.

The arterial data from Sensys Networks were integrated with Bluetooth and freeway sidefire radar data through MoDOT’s advanced traffic management system (ATMS). Since MoDOT is responsible for most of the arterials in the St. Louis area, there is no institutional barrier to integrate the data. After the process, travel time information was disseminated via DMSs from 5 am to 10 pm. DMSs were placed on arterials before the diversion point to help travelers make route choice decisions. To avoid traffic safety problem and disseminate clear travel time information to drivers, DMSs were placed at least 500 feet away from signalized intersections. For most of the DMSs, only arterial travel times were displayed, but for the rest of the DMSs, the combined arterial and freeway travel times were presented. Travel time information was updated every 1 minute during peak hours and, and the update frequency was lower during off-peak periods.

### III.4 Houston, Texas

The City of Houston has a long history of collecting travel time information. At first, toll tag reader was used to collect freeway travel time data for Houston TranStar, which provides real-time travel time information to travelers: speed range on freeways and congestion level on non-freeways (**Figure III-16** and **Figure III-17**). Travel time information on Houston TranStar is updated every one minute. From 2011, Bluetooth detectors started to be implemented because Bluetooth detectors could provide detection and match rates comparable to toll tag readers with half of the original costs.

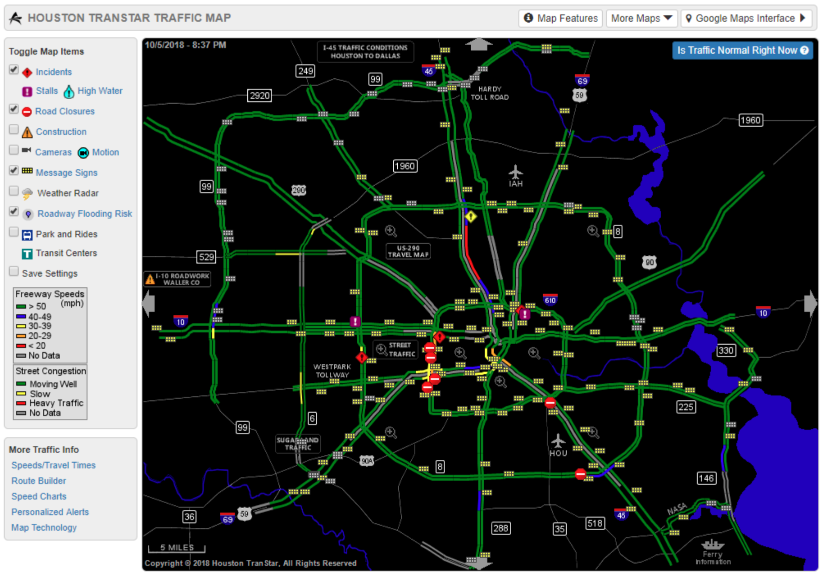



**Figure III-16. Houston TranStar**

Source: Houston TranStar

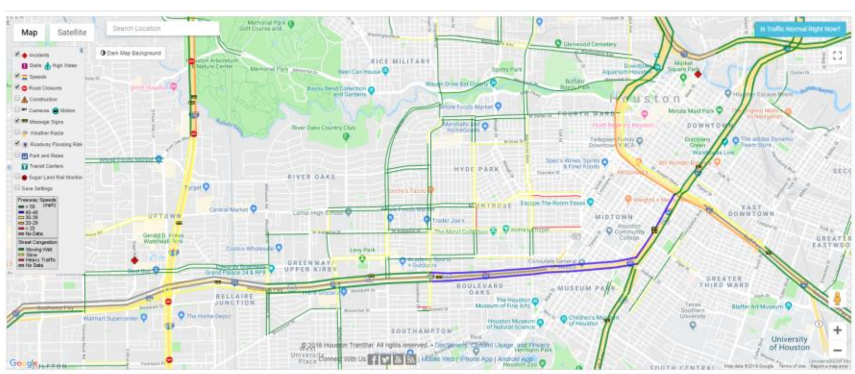
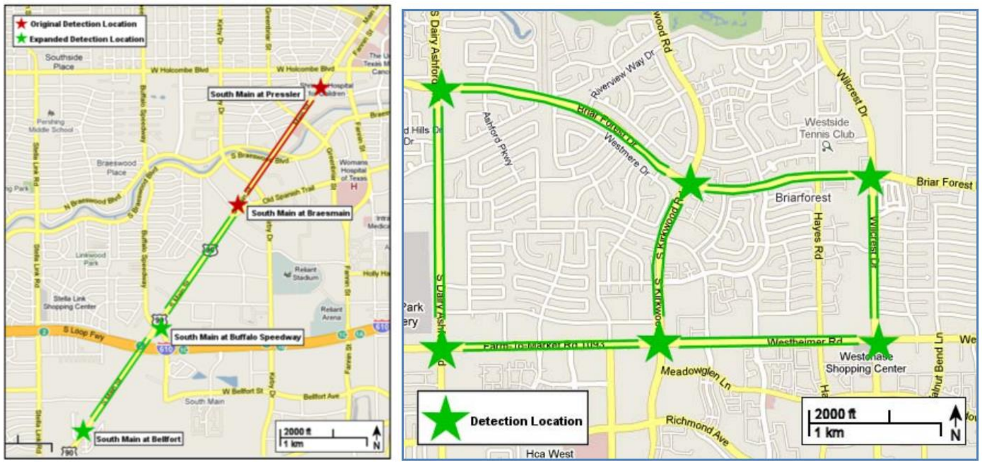



**Figure III-17. Houston TranStar with details of non-freeway**

Source: Houston TranStar

Arterial travel time data are collected using Bluetooth detectors. In 2009 and 2010, researchers installed Bluetooth detectors on a three-mile corridor and a six-intersection arterial grid (Puckett and Vickich, 2010). **Figure III-18** displays the location of Bluetooth detectors in this project. The results showed that the Bluetooth detector was an effective and accurate method to collect arterial travel time data. Following this deployment, Bluetooth detectors were widely installed in Houston. Detectors were placed at major intersections, and the distance between detectors was 0.5 miles to 1 mile.

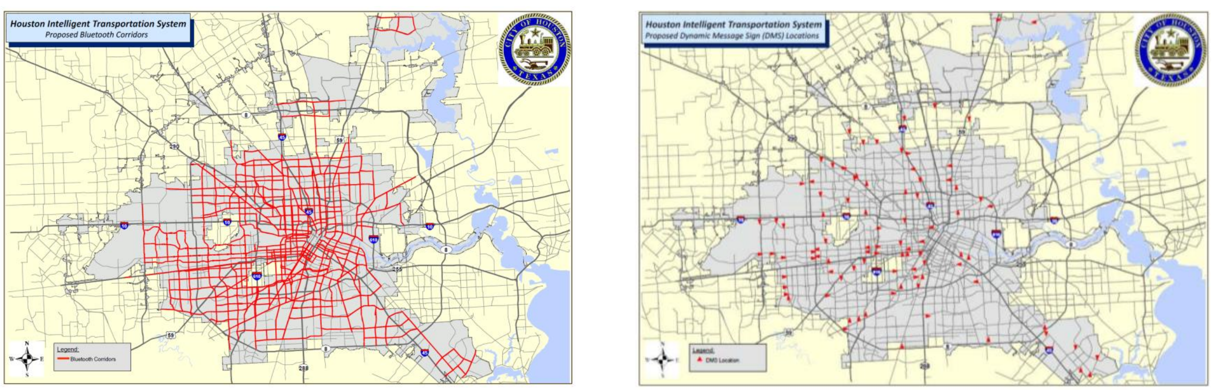



(a) Corridor (b) Grid Network

**Figure III-18. Bluetooth Detector Locations**

Source: (Puckett and Vickich, 2010)

In 2014, City of Houston started the Houston Intelligent Transportation Systems (HITS) Project. HITS planned to deploy 91 DMSs, 650 Bluetooth Automatic Vehicle Identification (AVI) sites and other intelligent transportation hardware and software in Houston area (supported by TIGER 2014 Discretionary Grant). Bluetooth AVI is used to collect real-time traffic information, as shown in **Figure III-19** (a). The estimated cost is $2,500 for a single Bluetooth AVI and $10,000 for a single DMS. Travel time and incident information were disseminated to the travelers through DMSs. The locations of DMS are shown in **Figure III-19** (b) (the City of Houston, 2014). There were some proposed locations on non-freeways. But until now, all the deployed DMSs are on freeways, as shown in **Figure III-16.**




(a) Bluetooth Travel Time Corridor (b) Dynamic Message Sign Locations

**Figure III-19. Bluetooth Detector and DMS Deployment**

Source: (the City of Houston, 2014)

A benefit-cost analysis was performed with the ITS Deployment Analysis System (IDAS) software using a 20-year system lifecycle. IDAS analyzed that the benefit-cost ratio for the baseline system ranges from 4 to 7.1 depending on the discount rates. By deploying DMSs and CCTV cameras, results showed that the benefit-cost ratio ranged from 14.7 to 27.0.

### III.5 I-15 and Parallel Arterials, Utah

I-15 is a major corridor in Utah, passing through Salt Lake City and Provo. Utah DOT started the Utah County I-15 Corridor Expansion project in 2010 and finished it in 2012. This project expanded the freeway by two more lanes in each direction. Although the I-15 CORE project kept traffic moving throughout construction, a lot of traffic needed to be diverted to arterials in parallel to I-15 and it was important to find solutions that could ease the congestion as a result of the project. The construction contractor partnered with TransCore and developed a system to provide travel times for the parallel arterial, the State Street.

TransCore used the Sensys Network to collect travel time data. The in-pavement magnetic detectors were placed along State Street. Sensys Network updated travel time data every two minutes and sent this information to TransCore, which then analyzed the data and updated the disseminated travel times every six minutes. The travel time data was disseminated through two ways: Utah Commuter Link website and Trailblazer Signs (**Figure III-20**). During the construction, eight Trailblazer signs were placed on westbound approaches of the State Street.


(a) Utah Commuter Link (b) Trailblazer Signs

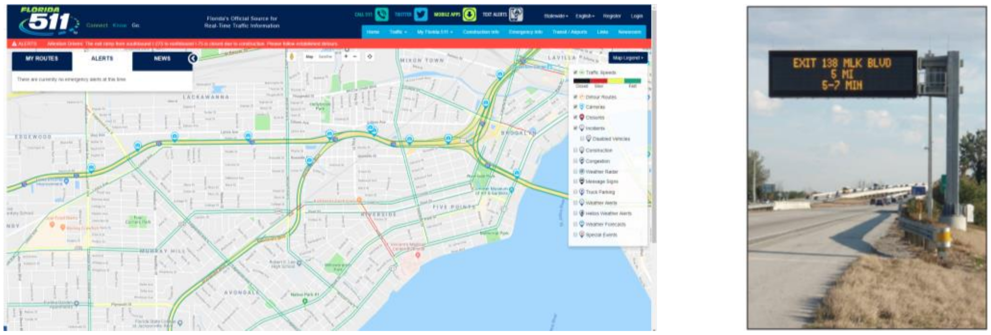
**Figure III-20. Travel Time Information Dissemination**

Source: utahcommuterlink.com and itsinternational.com

The Trailblazer signs are hybrid message signs with both static and dynamic information. The static information is the destination and unit of time. As **Figure III-20** (b) shows, the destination is Lehi, a city in the northbound direction, and the unit of the travel time is minute. The dynamic part contains two types of information: direction and time. The Trailblazer signs compare local road travel times versus freeway travel times: if stay on this route (freeway, arrow points up), it takes 21 minutes to the destination; if make a left turn (to arterial, arrow points left) and follow the Trailblazer signs, it takes 15 minutes to the destination. Each phase of the sign is shown for 3 seconds. Based on the report of Sensys, this implementation led to a significant reduction in delays, congestion, confusion, and collisions.

### III.6 Florida

Florida's Regional Transportation Management Centers (RTMC) are the nerve centers for disseminating information to the traveling public. Each district has an RTMC, and they are using SunGuide software for collecting, storing, and disseminating information about events on the arterial and freeway networks. SunGuide system disseminates information to the public through CCTV, Arterial Dynamic Message Sign (ADMS), and Florida 511 website (https://fl511.com/).




(a) fl511 website (b) ADMS

**Figure III-21. FL 511|Florida Traffic and ADMS**

Source: fl511.com and (FDOT, 2010)

Florida's 511 website provides traffic information, including travel times, to roadway users on both freeways and non-freeways (**Figure III-21**). The data source of 511 includes sensors (for example, BlueTOAD, microwave vehicle detection sensors) and cameras along roadways, road rangers, highway patrol, Waze and so on. For arterial travel times, BlueTOAD is the major data source. ADMS displays traffic information such as incident messages, travel time information, and general public service announcements, and the travel time information is the default message. Figure I-3 displays the traffic condition in Jacksonville and the data source is BlueTOAD.

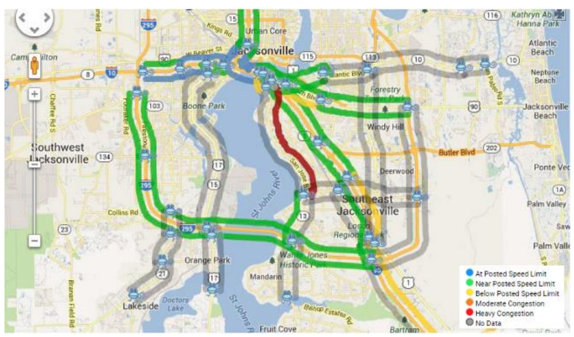



**Figure III-22. Traffic Condition from BlueTOAD data in Jacksonville, FL**

Source: (Elefteriadou et al., 2014)

Researchers also compared various methods for measuring travel times in Florida (Elefteriadou et al., 2014), **Figure III-22**. The research team obtained travel times from STEWARD, INRIX, BlueTOAD, and HERE, compared with field-measured travel times, which are collected using a vehicle instrumented with a portable GPS receiver. Maximum Relative Error and Absolute Percent Error were used to compare field-measured data with data from sensors and the private sector. Based on the results, BlueTOAD did not provide accurate travel time at either congested or uncongested traffic conditions while the sample size was relatively small.

FDOT District 4 launched the Arterial Management Program (AMP) in 2017 (Crist et al., 2017). AMP helps create efficiencies in improving traffic flows through the use of technologies and the professionalism of its staff and partnering agencies. Based on the Standard Operating Guidelines of APM, there was Travel Time Subsystems (TTS) under the AMP. TTS was responsible for collecting real-time traffic information, including speed and travel time. BlueTOAD was used to collect traffic information. ADMS was used to disseminate travel time information. **Table III-17** shows the deployed ADMS in the Palm Beach area. There are 23 ADMS in the Broward area.

**Table III-17. ADMS in the Palm Beach Area**

| ID Number | IP Address | Roadway | Cross Street |
|---|---|---|---|
| **#01** | 10.6.11.37 | SR 80/Southern Blvd (EB) | West of Lamstein Lane |
| **#02** | 10.6.15.87 | SR 80/Southern Blvd (WB) | West of Avocado Ave |
| **#03** | 10.6.15.117 | SR 80/Southern Blvd (EB) | East of Kirk Road |
| **#04** | 10.5.121.27 | SR 80/Southern Blvd (WB) | East of Paseo Alcala |

### III.7 Illinois

Researchers in Illinois attempted to use real-time bus tracking data to estimate urban street travel times (Pu and Lin, 2008). The study area is shown in **Figure III-23Error! Reference source not found.**. Real-time bus tracking Automatic Vehicle Location (AVL) data were acquired from the Chicago Transit Authority (CTA). A GPS equipped passenger car was used as the test vehicle. The GPS device recorded the test vehicle's speeds, acceleration and deceleration rates, positions, and other information at every 0.1 seconds. To modeling the relationships between bus and general vehicle travel times/speeds, multivariate time series state-space modeling techniques were applied. The case study concludes that buses can be used as probes for travel information on signalized urban streets, especially under medium to heavy traffic conditions.

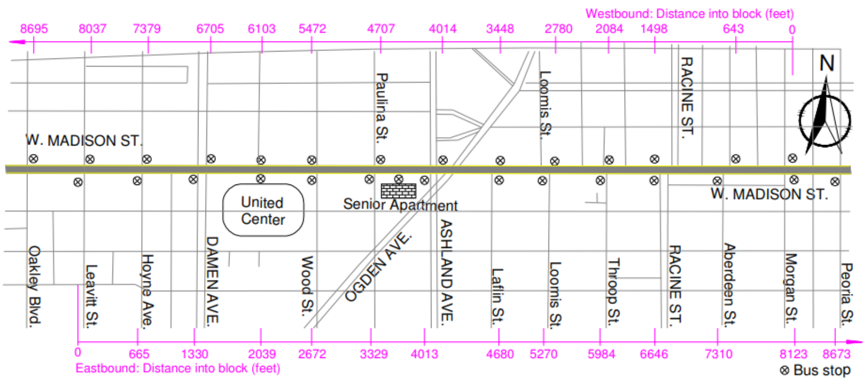



**Figure III-23. Study Street Segment in Chicago**

Source: (Pu and Lin, 2008)

In 2010, Illinois has over 2400 pavement loop sensors on freeways and non-freeways (Galas, 2010), and traffic information such as vehicle counts, occupancy, and speed was collected. Travel time information was provided to the public. At that time, there were 42 freeway DMS and 14 ADMS (Arterial DMS; see **Figure III-24**).


**Figure III-24. ADMS in Chicago**

Source: (Galas, 2010)

The website Travel Midwest (http://www.gcmtravel.com/lmiga/home.jsp ) provides freeway and arterial travel times to roadway users in the Chicago area. The Travel Midwest uses data from a variety of sources, including loop detectors, toll tag readers, microwave radar, infrared, ultrasonic, acoustic, video image processing, and movement of transit. **Figure III-25** displays the traffic condition of part of the City of Chicago. By clicking the bubble in the red circle, multiple detailed traffic reports displayed on the left side.

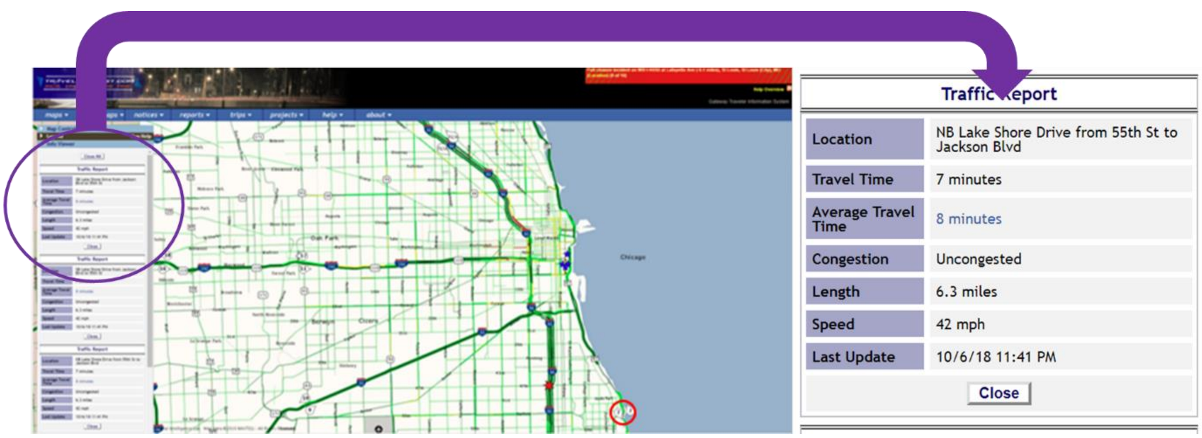



**Figure III-25. Traffic Condition of Chicago Area on TravelMidewest.com**

Source: TravelMidewest.com

In 2009, City of Chicago installed the Sensys Network on Cicero Ave and BlueTOAD on Archer Ave as a pilot study (Zavattero, 2009). The results showed that BlueTOAD displayed as an accurate travel time data collection method. In 2010, when resurfacing I-290, BlueTOAD was chosen as the temporary vehicle detection system. In this project, BlueTOAD was used to determine the average speeds of road segments, provide accurate travel time information to the Advanced Traffic Management System (ATMS), and disseminate travel time through ATMS DMSs.

**III.8 Twin Cities, Minnesota**

In 2009, led by the Minnesota Department of Transportation (MnDOT), the researchers created a Minnesota Arterial Travel Time (MATT) algorithm to predict travel time information based on 15-minute traffic volume data from loop detectors (Athey Creek Consultants LLC, 2009). The project location is along Highway 55 from I-494 to Theodore Wirth Parkway, and the total length is about 7 miles. The algorithm targets the regular data-poor environment, where only spot speed data are available. A typical travel time calculated by travel distance and effective speed was used in the MATT algorithm. Based on the Volume/Capacity (V/C) ratio, additional waiting time was added to the typical travel time. The waiting time is based on the cycle wait time and the V/C ratio. The MATT algorithm compares the current Volume/Capacity (V/C) ratio to the historic V/C ratio to classify the performance of the arterial route. Based on a statistical analysis comparing the I-70 EB travel time runs conducted over the four days of testing against MATT predicted travel time values, 80 - 90% of MATT predicted times fall within 2.6 minutes of the actual travel times. **Figure III-26.** displays the location of all loop detectors on the freeway in the Twin Cities Metropolitan Area.

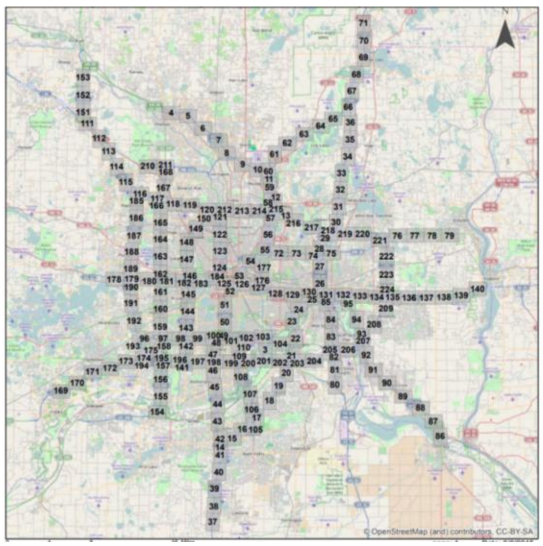


**Figure III-26. All Detectors on Freeway in Twin Cities Metropolitan Area**

Source: (Minnesota Department of Transportation, 2015)

Bluetooth devices were tested for providing accurate arterial travel time information in Hennepin County, MN along the CSAH 81 corridor (ITERIS, 2011). **Figure III-27** displays the location of Bluetooth devices on the CSAH 81 corridor. Eight Bluetooth devices were placed at six intersections, and the Bluetooth devices were from STREETWAVE. Two Bluetooth devices were placed at the intersections on both ends of the corridor to ensure that the installed Bluetooth readers could provide sufficient coverage for monitoring and tracking devices at the corridor endpoints. Directional tube counts were also placed in selected locations along CSAH 81 at the same time the travel time data were being collected to determine traffic volumes at each node. Compared to traffic volume data, it was found the detection rate of Bluetooth devices ranged from 3% to 11.4%. The “Average floating car” technique was used to determine the ground truth average travel times of a vehicle passing through the corridor. This project did not conduct a systematic evaluation but aimed to serve as a prototype, based on which the researchers suggested that, because the range of operating speeds varies greatly along arterial corridors, additional study will be needed to better relate Bluetooth data to the current traditional travel time methodologies. The study also reported the cost of the project, as listed in **Table III-18**.

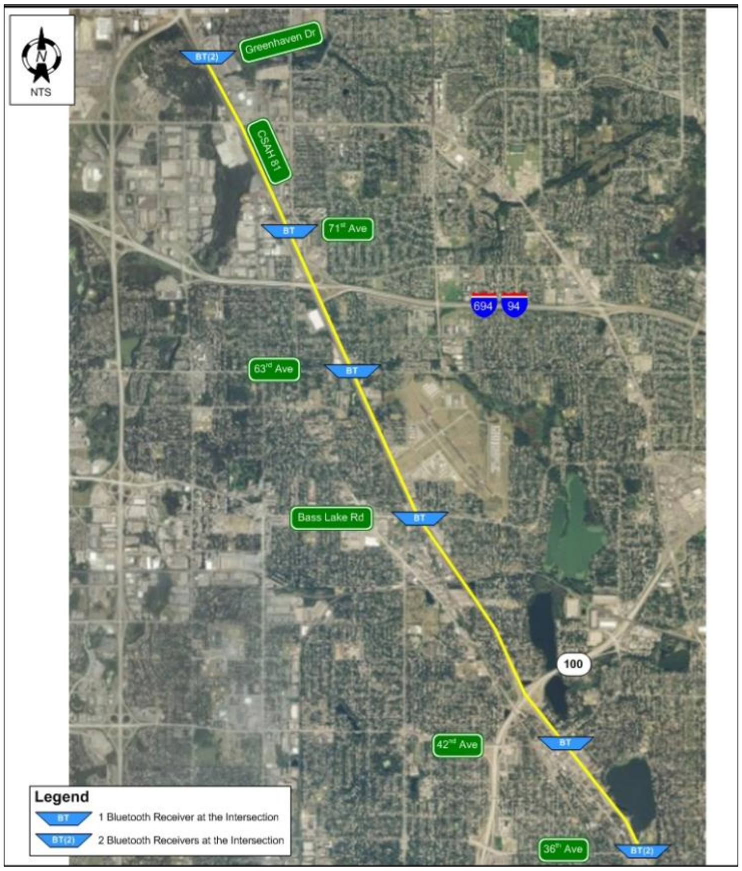



**Figure III-27. Bluetooth Locations on CSAH 81 Corridor**

Source: (ITERIS, 2011)

**Table III-18. Cost of Arterial Bluetooth Project Hardware/Software**

| Hardware Type | Unit Cost | Number of Units | Total Cost |
|---|---|---|---|
| **3G+5Ghz+BT enabled AP** | $6,000 | 2 | $12,000 |
| **5Ghz+BT enabled AP** | $5,000 | 2 | $10,000 |
| **3G+BT enabled AP** | $5,000 | 4 | $20,000 |
| **Server (purchased)** | $3,000 | 1 | $3,000 |
| **Miscellaneous installation hardware (strapping, etc.)** | N/A | N/A | $3,000 |
| | | | Total: $48,000 |

### III.9 Washington State

The City of Seattle provides travel time information through the Seattle Department of Transportation website (https://web6.seattle.gov/travelers/ ). By clicking the sign on the interactive map, travel times to several destinations show up on the right side of the screen. The travel times are also displayed on the arterial DMSs if any (**Figure III-28**). Currently, Seattle DOT manages 31 DMSs on urban streets in the City of Seattle.

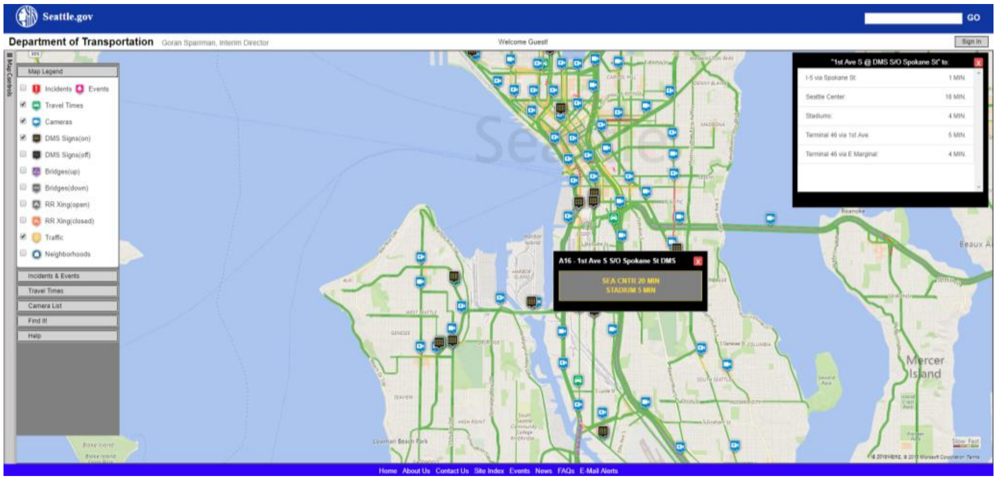



**Figure III-28. Seattle Traveler Map**

Source: https://web6.seattle.gov/travelers/

Travel times were calculated using a combination of License Plate Reader and Acyclica (Wi-Fi) data. The practice of using License Plate Reader to calculate travel time can trace back to 1990s. Researchers compared average travel time from license plate matching to the average travel time from the floating car method (Rickman et al., 1990). The comparison results showed no statistically significant difference in average travel times between the results.

Acyclica installed Skywave antennas along the street corridor in 2015 (David, 2015). The antennas created a Wi-Fi signal and read the signal from passing wireless devices. Acyclica gathers timestamps for all the detected devices and uses them to measure travel times along given routes. While Bluetooth readers capture 5-7 percent of cars passing intersections, the Wi-Fi readers capture nearly 50 percent from cars with smartphones or tablets with Wi-Fi turned on. The price of each Wi-Fi reader is approximately $2,000. The project started along Mercer Street and was extended to the whole downtown area. **Figure III-29.** displays the location of Acylica Devices in the Central Business District (CBD) area (Siemens Industry, 2017).

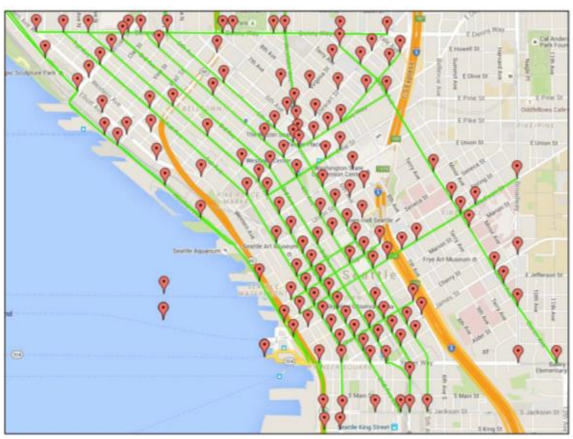


**Figure III-29. Location of all the Acyclica Devices in the CBD Area**

Source: (Siemens Industry, 2017)

Statewide, Washington State DOT (WSDOT) provides travel times of freeways and non-freeways to roadway users through their website (Washington State Department of Transportation, n.d.). Vehicle speeds were calculated based on the loop detector data from the stations along the road. Based on vehicle speed and the distance between two stations, travel times are calculated. Other detectors such as infrared, radar, video imaging, and Bluetooth are also used by WSDOT. But compared to loop detectors, the coverage of these data collection methods is much smaller.

In 2014, a study evaluated the effectiveness of various travel time data collection technologies side-by-side (Wang et al., 2014). Two corridors were chosen: State Route 522 (an urban arterial with frequent intersections) and I-90 (a rural freeway). Data from Automatic License Plate Reader (ALPR) was considered as the ground truth, and data from Sensys, BlueTOAD, BlipTrack-BT, BlipTrack-WiFi, and INRIX were evaluated. Mean Absolute Deviation (MAD), Mean Percent Error (MPE), Mean Absolute Percent Error (MAPE) and Root Mean Square Error (RMSE) were used. Researchers found the accuracy of the data varied segment by segment (particularly on arterial roadways) and the Sensys system provides acceptable accuracy in most cases. BlueTOAD was less reliable overnight when the traffic volume was relatively low. INRIX data was least responsive to traffic changes.

### III.10 Philadelphia, Pennsylvania

Researchers conducted a study to evaluate Bluetooth devices for travel time data collection along with a signalized arterial corridor in Philadelphia. The study corridor was Verree Road, with 13 signalized intersections along the corridor and the total length of the corridor is 3.9 miles with the posted speed limit of 35 MPH (KMJ Consulting Inc., 2011). In the study, two BlueTOAD units were installed at the intersection on both ends of the road segment, and a third BlueTOAD unit was installed near the mid-point of the segment, as shown in **Figure III-30**. The researchers used data from the test probe cars as the ground truth. The test car is installed with GPS devices, and runs were conducted for the entire corridor during two peak periods on a typical weekday. PC-Travel™ software[2] (a commercial traffic data processor for calculating travel times and delay) were used to report the final travel time results.

A simplified cost assessment was performed to establish the relative cost difference and a breakeven point between BlueTOAD and PC-Travel (with probe cars), as shown in **Table III-19** (KMJ Consulting Inc., 2011). The Bluetooth method collected more data points in the same period, therefore offering a substantially reduced "cost per data point" rate.  The researchers compared the cost of the PC-Travel with the Bluetooth method based on a typical three-mile segment. It turned out that the Bluetooth method becomes more cost effective than the manual test probe car method, the cost of which increases quickly as the number of segments increases.

The analysis showed that Bluetooth is advantageous in terms of offering a more realistic approach to measure travel times, the ease of installation and operation, and limited inclination for human error. However, they pointed out some disadvantages as well, such as the requirement for a certain technology awareness/knowledge to operate the device. Nonetheless, the Bluetooth technology, particularly the BlueTOAD device, was found to be a cost-effective alternative to traditional approaches.

[2] https://www.pc-travel.net/PCT_Suite/PC-Travel/pc-travel.html

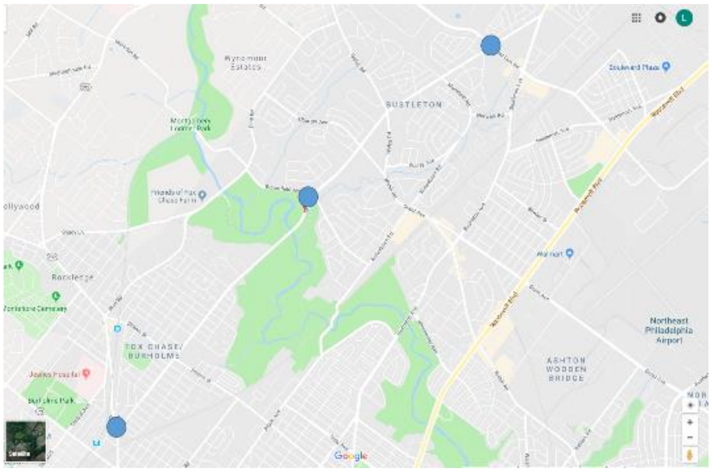



**Figure III-30. BlueTOAD Location on Verree Road**

**Table III-19. Summary of Cost**

| | BlueTOAD | | PC Travel | | |
|---|---|---|---|---|---|
| | Standard | Mini | | | |
| | Data Period Independent | Data Period Independent | PC Travel 3 days | PC Travel 5 days | PC Travel 7 days |
| **Equipment Cost** | $14,265.00 | $11,240.00 | $1,766.48 | $1,766.48 | $1,766.48 |
| **Labor Cost** | S400.00 | S400.00 | $1,200.00 | $2,000.00 | $2,800.00 |
| **Mileage Cost** | - | - | $179.82 | $299.70 | $419.58 |
| **Total Cost** | **$14,665.00** | **$11,640.00** | **$3,146.30** | **$4,066.18** | **$4,986.06** |

### III.11 Atlanta, Georgia

A Bluetooth travel time test was performed in Atlanta in 2011. Bluetooth stations were set up at two sites along Spring Street, a one-way street in Atlanta, GA (**Figure III-31.**), with four Bluetooth readers at each site (Vo, 2011). The length of the road segment is approximately 0.9 miles. Two probe vehicles containing Bluetooth devices and GPS units continuously drove past the stations throughout the study period. The researcher conducted 3.5 hours of data collection, including both peak and off-peak hours. Video camera data were collected for post-processing, allowing for the determination of traffic volumes during the study period. The detection rates at two ends were 4.44% and 8.27%. Bluetooth travel time was accurate except during congestion, during which the Bluetooth travel times were shorter than the GPS travel times.

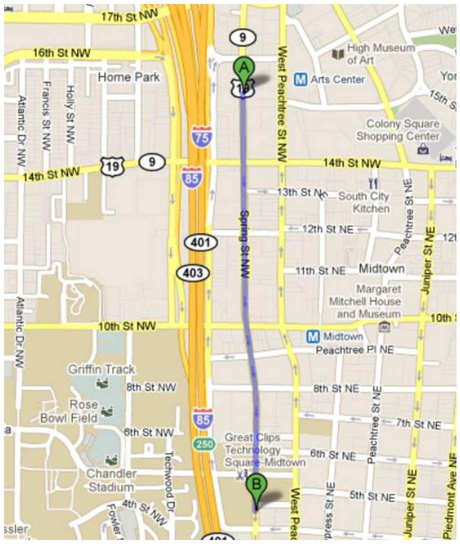



**Figure III-31. Study Road Segment on Spring Street**

Source: (Vo, 2011)

In 2012, Georgia DOT expanded the travel time system to provide travel times for arterial routes around I-75, Atlanta. I-75 is a major Interstate that often experiences congestion as a result of commuting traffic going to and from the Atlanta area. When I-75 experiences heavy congestion, surrounding arterials also suffer congestion as drivers seek alternate routes. There are four arterial DMSs showing I-75 travel times on approaches to I-75 to allow drivers to determine whether to take I-75 or an arterial alternative route. Bluetooth detection was implemented on selected routes in Cobb County and Fulton County. Nineteen BlueTOAD units were deployed on arterials in Cobb County (**Figure III-32**), twelve BlueTOAD units were deployed on arterials in Fulton County, and an additional four units were deployed in the City of Alpharetta. Arterial travel time data were used to monitor the roadway network for incidents and to determine the effects of heavy I-75 congestion on surrounding arterials. The arterial travel conditions are shown on a color-coded map on GDOT's website.

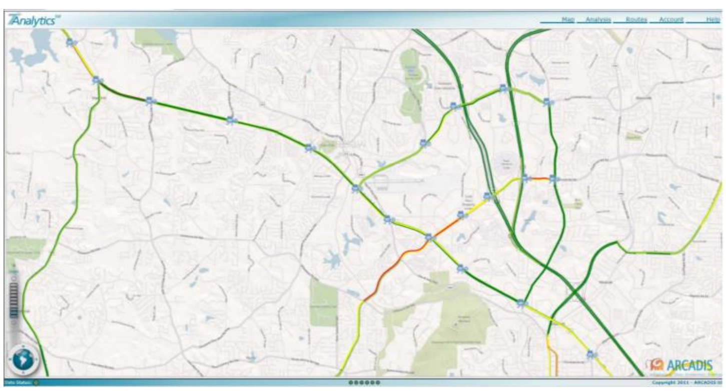



**Figure III-32. BlueTOAD Location in Cobb County**

Source: gis2.arcdis-us.com

### III.12 I-95 Corridor Coalition

The I-95 Corridor Coalition is a multi-State and multi-jurisdictional organization that aims at improving transportation system performance. In 2008, a Vehicle Probe Project (VPP) was launched and it collected and evaluated real-time travel time and speed data for approximately 1,500 miles of freeways and 1,000 miles of arterials, from New Jersey to North Carolina. The purpose of VPP was to create a traffic monitoring system and provide traffic information including travel time to motorists. Note that VPP is the same concept as private sector data discussed earlier in this report. INRIX data was evaluated and validated with field collected Bluetooth data. These data have been used for the dissemination of travel information on 511 phone lines and websites, as well as on DMSs (in Maryland, Virginia, and South Carolina only).

**Table III-20. Case Study Locations of VPPII**

| Case Study Number | Data Set (State-ID#) | Road Number | Road Name | Validation Date Span | # of Segments | # of Through Lanes | AADT Min-Max / Weighted Average[1] (in 1000s) | Length[2] (mile) | # Signals / Density[3] | # of Access Points | Median Barrier | Speed Limit (mph) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | NC-06 | NC-55 | Williams St, Apex Hwy. | Apr 30-May 13, 2013 | 18 | 1-3 | 15-43/25 | 30.3 | 62 / 2.05 | 231 | Partial | 35-50 |
| 2 | MD-07 | MD-355 | Wisconsin Ave, Rockville Pike, Hungerford Dr, Frederick Rd | July 6-20, 2013 | 10 | 2-4 | 32-67/44 | 17.1 | 67 / 3.9 | 221 | Partial | 30-45 |
| | | MD-586 | Veirs Mill Rd | | 6 | 2-3 | 21-43/34 | 6.2 | 19 / 3.1 | 56 | Yes | 30-45 |
| 3 | NJ-11 | US-1 | Trenton Fwy, Brunswick Pike | Sep 10 - 24, 2013 | 10 | 2-4 | 33 – 90/70 | 14.2 | 10 / 0.7 | 112 | Yes | 55 |
| | | NJ-42 | Black Horse Pike | | 8 | 2 | 25-54/48 | 12.5 | 23 / 1.8 | 260 | Yes | 45-50 |
| | | US-130 | Burlington Pike | | 10 | 3 | 42-42/42 | 14.3 | 28 / 2.0 | 229 | Yes | 50 |
| 4 | NJ-12 | NJ-38 | Kaighn Ave. | Nov 5-19, 2013 | 16 | 2-4 | 32-80/46 | 24.5 | 44 / 1.8 | 235 | Yes | 50 |
| | | NJ-73 | Palmyra Bridge Rd. | | 18 | 2-4 | 33-74/52 | 23.9 | 41 / 1.7 | 236 | Yes | 45-55 |
| 5 | PA-05 | US-1 | Lincoln Highway | Dec 3 - 14, 2013 | 28 | 2 - 3+3 | 21 – 100/45 | 30.6 | 107 / 3.5 | 178 | Yes | 40 - 50 |
| | | US-322 | Conchester Highway | | 6 | 1-2 | 22 – 34/25 | 14.3 | 7 / 0.5 | 48 | No | 35 - 45 |
| 6 | PA-06 | PA-611 | Easton Rd<br>Old York Rd | Jan 9 - 22, 2014 | 14 | 1-4 | 18-32/27 | 20.5 | 68/ 3.3 | 227 | Partial | 15-45 |
| | | PA-611 | N Broad St | | 12 | 2-4 | 16-30/21 | 12.5 | 144/ 11.5 | 251 | Partial | 25-40 |
| 7 | VA-07 | VA-7 | Leesburg Pike and Harry Byrd Hwy | April 5-16, 2014 | 30 | 2-4 | 45-60/56 | 30.5 | 57 / 1.9 | 203 | Yes | 35-55 |
| | | US-29 | Lee Hwy (S Washington St) | | 4 | 2 | 14-25/21 | 4.4 | 22 / 5.0 | 114 | Partial | 30 |
| 8 | VA-08 | US-29 | Lee Hwy | May 8-19, 2014 | 26 | 2-4 | 15-45/33 | 31.9 | 115/3.6 | 287 | Partial | 35-50 |
| 9 | MD-08 | MD-140 | Reistertown Rd | Jun 5-17, 2014 | 20 | 1 - 3 | 19-44/31 | 17.4 | 68 / 3.9 | 221 | No | 30-40 |
| | | | Baltimore Blvd | | 8 | 2 - 3 | 40-53/42 | 15.5 | 18/ 1.2 | 52 | Partial | 50-55 |

[1]AADT weighted average is weighted by length of the segments

[2]Uni-directional mileage, a 2 mile roadway in which both direction of travel are analyzed will result in 4 total miles of tested roadway.

[3]Signal density is number of signals per mile

Source: (Young et al., 2015)

**Table III-21. Arterial Probe Data Usability**

| ✓ RECOMMENDED | SHOULD BE TESTED | ✖ NOT RECOMMENDED |
|---|---|---|
| ● <= 1 signal per mile | ● 1 to 2 signals per mile | ● >= 2 signals per mile |
| ● AADT > 40,000 vpd (2-way) | ● AADT 20K to 40K vpd (2-way) | ● AADT < 20K (2-way) - low volume |
| ● Limited curb cuts | ● Moderate number of curb cuts | ● Substantial number of curb cuts |
| Principal Arterials | Minor Arterials | Major Collectors |
| Likely to be accurate… | Possibly accurate, test … | Unlikely to be accurate… |

Source: (Young et al., 2015)

In 2013, the I-95 Corridor Coalition shifted focus to arterials and started Vehicle Probe Project II (VPPII): Validation of Arterial Probe Data (Young et al., 2015). VPPII emphasizes on arterial roadways, and the coalition evaluated data from three private sector data providers: INRIX, HERE, and TomTom (Young, 2015). Field Bluetooth data were used as the ground truth. Case study locations were chosen by Coalition members to cover different traffic conditions and the locations are listed in **Table III-20**. The results indicated that signal density (signal per mile) would impact the accuracy of private sector data. Increased volume will improve accuracy if all the other factors stay the same. Recommendations for vehicle probe data used for signalized arterial were listed in **Table III-21**.

In this study, the authors revealed some fundamental issues of the VPP data. The issues were related to traffic characterization on signalized roadways. The issues include:

- VPP data consistently errored toward faster speeds during congested periods.
- Whenever traffic progresses at two distinct travel times or speeds as a result of the signal operation, VPP data invariably report the faster of the two modes.
- Complex flow patterns common on signalized roadways cannot be observed in VPP data.

## III.13 Summary of Arterial Travel Time Practice

Each state and city has its own pace of collecting and providing arterial travel times to the public. **Table III-22** summarizes the practices mentioned in this chapter. Some of them are just pilot studies on collecting travel time of an arterial segment while some others are collecting travel times on certain arterial corridors and disseminating travel times to the motorists. In some cases, cities are collecting travel time of road network citywide on all major roadway facilities. Note that some information in **Table III-22** are left blank because this information is not available or does not apply for the study.

**Table III-22. Summary of Arterial Travel Time Practice**

| # | Year | Location | | | Detection | | | | Other Data | Cost | Dissemination | | | | Effectiveness | Lessons Learned |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | State | City and Road | Category | Detector | Number | Detection Rate | Match Rate | | | Method | Number | Cost | Information | | |
| 1 | 2011 | Arizona | Chandller, three arterials | Project Practice | Bluetooth | 7 fixed+2 floating | | | Loop detector data | | DMS | 3 | | Travel time (Arterial +Freeway) | The survey indicated information on DMS were accurate and helpful | One DMS, One Route; |
| 2 | 2009 | Missouri | St. Louis, 15 arterial corridors, 180+ intersections | Project Practice | Sensys | | almost 100% | 30% to 70%. | Bluetooth data side-fire radar data | | DMS | | | Travel time (Arterial +Freeway) and Travel time (Arterial Only) | Mitigate potential traffic congestion | Expensive, provide other data such as traffic volume, low maintenance work (except repave) |
| 3 | 2009-2010 | Texas | Houston, three-mile corridor and a six-intersection arterial grid | Pilot Study Practice | Bluetooth | 10 | | | | | | | | | | |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 2011- | Texas | Houston citywide | Existing State | Toll tag reader (before 2011) and Bluetooth (2011 start to take place) | | | | | | Houston TranStar and DMS | | | | | Bluetooth detectors could provide comparable detection and matching rate to toll tag readers with half price. |
| 5 | 2014- | Texas | Houston citywide | Project In Progress | Bluetooth | 650 | | | | Estimate : $2,500 per unit | DMS, and Houston TranStar | 91 | Estima te: $10,00 0 per unit | Travel time | | |
| 6 | 2010- 2012 | Utah | Utah, I-15 and parallel arterial State Street | Project Practice | Sensys | | | | | | Utah Commute r Link website and Trailblaze r Signs | 8 | | Direction and Travel time | Significant reduction in delays, congestion, confusion, and collisions. | |
| 7 | 2017 | Florida | Palm Beach and Broward area | Existing State | Bluetooth (BlueTOAD) | 43+75 | | | | | DMS | 4+23 | | Arterial Travel Time, Incident Messages, General Public Service Announcement s | | |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | Current | Florida | Statewide | Existing State | Bluetooth (BlueTOAD), microwave vehicle detection sensors, cameras along roadways, road rangers, highway patrol, Waze and so on | | | | | | 511 and DMS | | | Arterial Travel Time, Incident Messages, General Public Service Announcements | | |
| 9 | 2008 | Illinois | Chicago, a signalized urban street | Pilot Study Practice | Automatic Vehicle Location on bus | | | | | | | | | | | buses can be probes for travel information on signalized urban streets, especially under medium to heavy traffic conditions. |
| 10 | 2010 | Illinois | Statewide | Existing State | Loop detectors, toll tag readers, microwave radar, infrared, ultrasonic, acoustic, video image processing, and movement of transit | | | | | | Freeway DMS and Arterial DMS, Travel Midwest | 42+14 | | | | |
| 11 | 2009 | Illinois | Chicago, Cicero Ave, and Archer Ave | Pilot Study Practice | Sensys and Bluetooth | 6+4 | | | | | | | | | | BlueTOAD displayed as an accurate travel time data collection methods |
| 12 | 2007 | Minnesota | Twin Cities, 50 arterial links | Pilot Study Practice | License plate method | | | | | | | | | | | Singapore and Skabardonis-Dowling models gave better results |
| 13 | 2009 | Minnesota | Highway 55, 7 miles | Pilot Study Practice | Loop detector | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 2015 | Minnesota | CSAH 81 corridor | Pilot Study Practice | Bluetooth | 8 | 3% to 11.4% | | Directional tube counts | Total: $48,000 | | | | | | 1. Bluetooth readers can provide accurate travel time information for corridors with ADT greater than 15,000 ADT. 2. Two Bluetooth devices at the end of the corridor were not necessary because the antenna coverage was not an issue.3. It was better to place the Bluetooth devices 400 feet away from the intersections. |
| 15 | Current | Washington | Seattle citywide | Existing State | License Plate Reader and Wi-Fi (2015, Acyclica) | | nearly 50% | | | $2,000 per unit | Arterial DMS and Seattle Traveler Map | 31 | | Arterial travel time | | |
| 16 | Current | Washington | Statewide | Existing State | Loop detector | | | | infrared, radar, sound or video imaging and Bluetooth | | | | | | | |
| 17 | 2011 | Pennsylvania | Philadelphia, Verree Road, 13 signalized intersections, 3.9 miles, 35 mph | Pilot Study Practice | Bluetooth (BlueTOAD) | 3 | | | | Standard: $14,665; Min ofi: $11,640 | | | | | | 1. The Bluetooth method is more cost effective. 2. A more realistic approach to measuring travel time. 3. The requirement for a certain technology awareness/knowledge to operate the device |
| 18 | 2011 | Georgia | Atlanta, Spring Street, 0.9 miles | Pilot Study Practice | Bluetooth Station (four Bluetooth readers in each) | 2 | 4.44% and 8.27%. | | | | | | | | | 1. Bluetooth travel time was accurate except during congestion. 2. During congestion, the Bluetooth travel times were shorter than the GPS travel times. |
| 19 | 2012 | Georgia | Cobb County, Fulton County, and City of Alpharetta | Project Practice | Bluetooth (BlueTOAD) | 19+12+4 | | | | | Georgia DOT website, Arterial DMS | 4 | | Travel time | | |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 2014 | North Carolina, Maryland, New Jersey, Pennsylvani a, Virginia | See Table III-20 | Study Practice | Bluetooth | | | | INRIX, Here, TomTom | | | | | | | |

## Appendix IV: Agency Survey Answers

As part of the state-of-the-practice review, the research team interviewed three agencies which have deployed systems to provide travel times on non-freeways, **Table IV-23**.

**Table IV-23. Summary of Arterial Travel Time Practice from Agency Survey**

| | GDOT (Atlanta) | Houston Transtar | MoDOT (St. Louis) |
|---|---|---|---|
| **Partnerships** | GDOT/County - State Provided ATMS software | GDOT/County/City/Academia partnership | |
| **Data source** | | | |
| **Bluetooth** | X | X | |
| **Wi-Fi** | | X | |
| **Radar** | | | |
| **Loop** | | | X (since removed) |
| **Video** | | | |
| **System Age (yrs)** | 3-4 | | 10 |
| **Deployment Type** | Blanket | Phased by corridor | Phased over 10 yrs |
| **Detector Location** | Major Intersections | Intersections | varied |
| **Spacing** | Approx 1 mi | Approx 0.5-1.5 mi | varied |
| **Probe Vehicle data?** | HERE (starting 2019) | NO | Yes (RITIS - HERE) |
| **Private Data** | HERE (starting 2019) | NO | RITIS - HERE |
| **Dissemination** | | | |
| **DMS** | X | X | X |
| **511** | | | |
| **Website** | X (No push notifications) | X (No push notifications) | X |
| **Mobile App** | X (No push notifications) | X (No push notifications) | |
| **Social Media** | | X | |
| **Sign Location** | Heavy arterials | Signalized Intersections | Major Interchanges and Major Arterial Diversion Routes |
| **Considerations** | DMS in advance of decision points | DMS in advance of decision points | |
| | Existing Sign Clutter | | |

| | | | |
|---|---|---|---|
| **Other** | Color-Coded DMS Message | Found Wifi has detection Bias for travel speed | In pavement (Sensys) detectors required too much maintenance |
| | Phasing out Bluetooth for HERE data | | HERE data is as, or more, accurate then road sensors |

The detailed answers from each of the three agencies are shown below:

**IV.1 GDOT Interview**

**Agency: Georgia Dept of Transportation**

**Name/Title: Mark Demidovich, Asst State Traffic Engineer**

**Area(s) Served with Arterial Travel Time: Surface streets in Cobb Co, GA**

### State/City Plan

Q1. Does your state currently provide travel time information to the public on non-freeways? Can you briefly describe the project(s)/program(s)? Yes, in Georgia we post arterial travel times on several CMS. The signs are actually owned by our partner jurisdiction, Cobb County; however, we all share the same ATMS software and the actual travel time calculations take place within the State-provided software.

We do not provide arterial travel time data on our website or apps or 511 system. Freeways only.

### Data Source

Q2. How are you collecting real-time travel time data? Do you use traffic detectors? If so, what type? (Loop detectors, Microwave radars, Side fire radar, Bluetooth detectors, Wi-Fi detectors, or other detectors) We use a combination of Bluetoad data, video detection (Trafficon) and radar detection (Wavetronix). Many of the arterial signs display comparative travel times for arterial and freeway; the arterial data comes from Bluetoad and the freeway data is Trafficon/Wavetronix.

*If using detectors*:

> Q3. When were these data collection devices installed? What were the project costs for the installation of different devices? Where these projects completed in phases, if so how were the phases broken out? The Bluetoad detectors were installed approx. 3-4 years ago. As these were installed by our County partners, I don't have cost info handy. As far as I know, they were all installed at one time.

Q4. What are densities for each type of data detection devices? Bluetoad detectors are at each major intersection along the arterials. The travel time 'segments' become the links between two adjacent intersections (nodes). Roughly, these are about 1 mile apart, although in some cases closer than that.

On the freeways, our standard detector spacing is 1/3 mile.

Q5. How much maintenance have your data collection devices required? How are you handling this maintenance and what is the cost? Our county partner maintains the Bluetoad arterial detection system.

Q6. Do you use probe vehicles for any purpose? Not on arterials (yet). We have been using probe data (INRIX and HERE) for several years on the freeways. However, we just went "all-in" with HERE and now will be getting statewide data for both freeways and arterials and will start using this data more and more for arterial detection. In fact, Bluetoad data will be mainly phased out over the next year or two. We feel that probe data accuracy on arterials has improved over the years and are confident enough to use it to provide info to the public. Plus, it doesn't require the maintenance of any roadside detectors.

Q7. Does your state use private sector data? (vendor, real-time) No, other than what's listed under Q6.

Q8. If you answered "no" to Q7, does your organization have any future plans for private party data: No

### Dissemination to Roadway Users

Q9. What kind of traffic information dissemination methods does your program use? (DMS? 511 website? others?) DMS only for arterial travel times (**Figure IV-33** to **Figure IV-39**). However, users can "read" what any sign in our system is saying on the 511GA website and apps.

Q10. Where are the signs located? What location selection criteria was utilized? What message(s) do you provide on your signs? The signs (about 12) are scattered throughout the county on mainly heavily-traveled roadways. There are challenges with selecting locations of arterial DMS as there is a lot more sign clutter than found on the freeways in general. Locations were generally selected in advance of major decision points, i.e. where a motorist could read the message and decide to stick with the arterial or turn and head to the freeway.

### Effectiveness

Q11. What is the effectiveness of the system? Have you conducted any evaluation (traffic studies) or post-deployment survey? No official surveys have been conducted, however, we generally use emails, phone calls, social media posts, etc to gauge the satisfaction of the public on things we do. So far, the feedback has been positive.

Q12: Other comments? See some sample pics below. Note that the color of the travel time digits are coded so that green numerals indicate a "good" time, yellow is "so-so" and red numbers mean "bad." Also, note that all of these example signs are on non-freeways, however, some of the messages are freeway times, and some are arterial times, and some are a mix.


**Figure IV-33. DMS at Barclay Circle**


**Figure IV-34. DMS at Wood Trail Ln**


**Figure IV-35. DMS at Akers Mill (North)**


**Figure IV-36. DMS at Campbell Rd**


**Figure IV-37. DMS at Sandy Plains Rd SB**


**Figure IV-38. DMS on Arterial**


**Figure IV-39. DMS at Windy Hill Rd at CMS**

### IV.2 MoDOT Interview

**Agency: MoDOT – St. Louis District**

**Name/Title: Justin Wagner, P.E. – Traffic Operations Engineer – Signals & ITS**

**Area(s) Served with Arterial Travel Time: 5 Counties in eastern MO**

**State/City Plan**

Q1. Does your state currently provide travel time information to the public on non-freeways? Can you briefly describe the project(s)/program(s)?

Yes, the State uses RITIS cell phone probe data from Here.com to populate TTs on the state-owned DMS boards.

**Data Source**

Q2. How are you collecting real-time travel time data? Do you use traffic detectors? If so, what type? (Loop detectors, Microwave radars, Side fire radar, Bluetooth detectors, Wi-Fi detectors, or other detectors)

The State uses RITIS cell phone probe data from Here.com to present the info to the drivers. Previously the district used Sensys in-pavement sensors on arterial routes to collect magnetic signatures of vehicles to match up further downstream for travel times. The state also had sidefire radar units to collect speed data which was then used to calculate travel times on interstates spread out over every mile of interstate

*If using detectors*:

Q3. When were these data collection devices installed? What were the project costs for the installation of different devices? Where these projects completed in phases, if so how were the phases broken out?

The Sensys devices were installed over a period of 10 years, and have come to the end of their useful life. The side fire radar units were also installed over a period of 10-15 years.

Q4. What are densities for each type of data detection devices?

Side fire units: one per mile in each direction of interstate

Sensys pavements sensors – a set of 5 per location in various lengths

Q5. How much maintenance have your data collection devices required? How are you handling this maintenance and what is the cost?

They required a good deal of maintenance, and a dedicated staff to configure and monitor the devices. Devices were replaced at cost when they stopped working, and are

Q6. Do you use probe vehicles for any purpose?

Question is too vague to answer

Q7. Does your state use private sector data? (vendor, real-time)

The State uses RITIS data from Here.com to collect cell phone location data which is used to calculate travel times. It is a contract with Here.com

Q8. If you answered “no” to Q7, does your organization have any future plans for private party data:

## Dissemination to Roadway Users

Q9. What kind of traffic information dissemination methods does your program use? (DMS? 511 website? others?)

We use DMS boards and our traveler information map to send data to the drivers

Q10. Where are the signs located? What location selection criteria was utilized? What message(s) do you provide on your signs?

We use federal highway approved messaging schemes. The locations of the DMS boards are in locations where the driver can make route adjustment decisions, mainly at major interchanges and major arterial routes for diversions.

### Effectiveness

Q11. What is the effectiveness of the system? Have you conducted any evaluation (traffic studies) or post-deployment survey?

The cell phone location data is very accurate and reduced the amount of misinformation to the driver as it is being updated continuously. The in-pavement sensors are difficult to keep running due to the number of devices needed and are being phased out where appropriate

Q12: Other comments?

None.

### IV.3 MoDOT Interview

**Agency: Houston Transtar**

**Name/Title:**

**Area(s) Served with Arterial Travel Time:**

### State/City Plan

Q1. Does your state currently provide travel time information to the public on non-freeways? Can you briefly describe the project(s)/program(s)?

Yes – TxDOT (early 90’s on freeways) and Houston (641 units)

### Data Source

Q2. How are you collecting real-time travel time data? Do you use traffic detectors? If so, what type? (Loop detectors, Microwave radars, Side fire radar, Bluetooth detectors, Wi-Fi detectors, or other detectors)

Bluetooth & Wifi

*If using detectors*:

Q3. When were these data collection devices installed? What were the project costs for the installation of different devices? Where these projects completed in phases, if so how were the phases broken out?

2010-2012 to current on arterials – not providing data yet

Corridor at a time – use vendor tools to monitor the data gathering (Houston using Iteris)

Q4. What are densities for each type of data detection devices?

Arterial – 0.5-1.5 miles separation depending on corridor

Antenna noise becomes issue as closer

Houston located at signalized intersections (installed in cabinet) (powered through cabinet) solar is possible

Detectors ~ 2-5k per location for detector (with installation)

Q5. How much maintenance have your data collection devices required? How are you handling this maintenance and what is the cost?

Minimal (coms outages/power outages) Maintained through signal shop

Q6. Do you use probe vehicles for any purpose?

Performed comparisons to "floating car" TTS

Vender software provides outlier filters

Q7. Does your state use private sector data? (vendor, real-time)

TxDOT uses Enrix

Houston relies strictly on their own collected data

Q8. If you answered "no" to Q7, does your organization have any future plans for a private partner?

**Dissemination to Roadway Users**

Q9. What kind of traffic information dissemination methods does your program use? (DMS? 511 website? others?)

DMS (Travel time – multiple destination on same sign, some provide TT for 2 routes to same location), mobile app (static information – not location aware currently), social, media website, data can be made available to app developers

Used in ATMS to located problem location/changes in TT

Q10. Where are the signs located? What location selection criteria was utilized?  What message(s) do you provide on your signs?

Effectiveness

Q11. What is the effectiveness of the system? Have you conducted any evaluation (traffic studies) or post-deployment survey?

Floating car comparisons

Q12: Other comments?

Must be leery of wifi – detection bias tends to detect slow/stop vehicle at a higher rate (Particularly on arterials)

Omni directional radio communications

Data stored into eternity

Data considered as personally identifiable (therefore not public record)

# Appendix V: Brief Work Plan for Phase 2

In summary, the recommendation for Phase 2 includes the following:

- Data
  - Investigate the appropriateness of using private sector data directly for travel time provision for non-freeways and scenarios where that would be possible and eliminate the need for infrastructure. The data should concern traditional TMC-based data or more detailed sources such as *INRIX XD*. Updated knowledge and understanding of these datasets need to be developed.
  - Recommend data fusion approach and strategies to improve travel time provision, including the selection of detectors and private data sources for collecting and providing travel times.
  - Develop algorithms and software for travel time estimation and prediction under recurring and non-recurring congestion (e.g., incidents, work zones, weather events).
- Dissemination
  - Disseminate the traveler information through DMSs and OHGO with information dissemination plan, including the selection of locations of the DMSs, detectors, and message characteristics.
  - Investigate alternative modes of information dissemination, including using personal/in-vehicle devices and develop an overall framework to be included in the final recommendation/guide.
- Evaluation
  - Develop and execute methods for evaluating the effectiveness of deployed systems at multiple sites including examining travel time accuracy and performance evaluation of DMS influence on drivers, as well as a quantified assessment of benefits and costs on the testing routes, and benefit-cost ratio calculation.
  - Conduct post-deployment surveys with local travelers to understand the system effectiveness from the user perspective.
- Statewide Guide
  - Provide recommendations regarding the standard practice about providing travel times for non-freeways statewide in Ohio, regarding data sources, dissemination, evaluation, and integration of ATMS and other TSMO efforts.
  - Provide potential benefits and costs when the systems are deployed at different types of locations (high v.s. low volume, rural v.s. urban) based on the data collected from the test sites

## V.1 Data Strategies

### *V.1.1 Selected Detectors*

The state-of-the-practice review and analysis of alternatives indicate that Bluetooth, Wi-Fi, radar detectors, and In-pavement Magnetic Detectors are mature and widely used technologies in practice and they are considered most suitable for this project.

While Bluetooth and Wi-Fi can be used to measure travel times directly, point detectors (e.g., radar, In-pavement Magnetic Detectors), which can measure spot speeds, are usually deployed at multiple locations of a segment to collect data to infer the segment travel times. In fact, the practice review shows these two methods are advantageous to each other from different perspectives, such as data quality, latency, and cost.

Therefore, the UC team proposes a data fusion approach to improve travel time provision. UC will investigate multiple data sources, based on available detector resources, to understand the performance of each source of data. Then, UC will develop data fusion approaches to combine multiple data sources for travel time estimation and prediction. More details will be provided below in Section V.1.3.

The availability of the detector resources of the UC team is shown below.

- TEC Engineering of the UC team has constructed over two dozen portable Bluetooth and six portable Wi-Fi data collection devices. These devices are capable of collecting the MAC address of passing devices. The TEC units are powered via battery and store the collected data in an internal drive.
- In addition to the Bluetooth data collection devices, TEC has a dozen side fire remote traffic microwave sensors (RTMS) traffic counters. These devices are designed for portable, short term traffic data collection and have the ability to collect volume, classification and speed data. The radar data collection units are powered via battery and store time-stamped data in internal memory. These units can collect data for up to 12 lanes of traffic and up to 250 feet from the detector.
- GPS Traveler Data Loggers are available at UC and will be used to collect vehicle trajectories on the testing routes as the ground-truth data to validate the travel time data collected with the selected detectors and acquired private sector data such as INRIX or HERE data.

### *V.1.2 Private Sector Data Selection and Validation*

More and more agencies are willing to purchase the private data, real-time and/or archived, as a service, instead of collecting raw data and maintaining the devices regularly. However, the reliability and accuracy of this private sector data is often a critical concern for transportation agencies, because these data sources and their related algorithms are proprietary. Therefore, evaluating and understanding the validity of private sector data in reporting travel times is quite necessary before providing the public the real-time travel time information based on the private sector data.

UC proposes to access INRIX and INRIX XD datasets and evaluate their quality and potential to be used directly for travel time provision as a part of this project. There are two purposes for this task:

- Understanding the quality of selected private sector data on arterials from different perspectives, such as travel time provision and performance reporting, providing a reference for ODOT future decision making (critical to understand the performance of the private sector data under different conditions, such as around bottleneck congestion, work zones, incidents, and signalized intersections.)
- Investigating the potential benefits of combining private sector data with deployed detectors, which are only at a limited number of locations.

### *V.1.3 Travel Time Estimation and Prediction*

Given the variety of sources of data for travel time provision, it is clear that each source of travel time data offers distinct advantages and disadvantages. It is highly unlikely that a single source of data will emerge as a clear winner that dominates all other approaches. Because of this, two aspects of the problem need to be discussed here.

First, it is necessary to choose one or more travel time data services to best meet the needs. To do so effectively, there is a need for a standard test procedure to use in assessing the quality of different travel time data services. For deployed traffic monitoring detectors, more attention should be given to 1) calibrating and maintaining the technologies and 2) developing algorithms to better estimate travel times. The validation of the algorithm requires a ground truth, which is usually collected by methods such as the floating car approach. For the private sector data, representative segments need to be identified and conventional, but mature, data sources are used to do an evaluation. The second aspect is to develop methods and algorithms to fuse multiple sources of the data and improve the accuracy of travel time estimation.

Another important issue is the definition of travel times. It can mean the instantaneous travel time of the road segment when drivers see the information on the DMS (i.e., at the beginning of the segment). The other is referred to as realized travel times– the travel times that the users actually experience when they complete traversing the segment. For a short roadway segment, the two may be similar to each other. For a relatively long segment, traffic conditions may change during the course of driving traversing the segment and therefore using instantaneous travel time, therefore, cannot accurately capture travel time. Instantaneous travel times may deviate substantially from the experienced travel time under transient states during which congestion is forming or dissipating during the trip (Mounce et al., 2007; Dudek et al., 2006). Estimating the realized travel times will require prediction of potential traffic state changes during a specific horizon. Machine learning and/or traffic models are usually applied online for this purpose.

There are a number of ways to estimate travel time prediction. For example, instantaneous and time-slice models using fixed sensor data, two Kalman filters, a k-NN method for multi-step-ahead travel time prediction, a particle filter approach for travel time prediction using real-time and historical data (Wu et al., 2015; Rakha et al., 2015). Chen and Rakha's study suggested that their proposed approach of non-explicit state-transition particle filter (NSPF) outperforms other methods by maintaining a stable performance of arterial travel time prediction for all test days, including instantaneous model, the first Kalman filter method (KF1), second Kalman filter method (KF2), and K-Nearest Neighbor (k-NN) approach.

The UC team is currently working with USDOT and Kanas City Scout (KC Scout) in developing a real-time system, IMRCP[3] (Integrated Modeling for Road Condition Prediction), to integrate weather and traffic data sources and predictive methods to effectively predict road and travel conditions in support of tactical and strategic decisions by travelers, transportation operators, and maintenance providers. The system collects and integrates environmental observations and transportation operations data; collects forecast environmental and operations data when available; initiates road weather and traffic forecasts based on the collected data; generates travel and operational alerts from the collected real-time and forecast data; and provides the road condition data, forecasts and alerts to users and other systems. For traffic prediction, the system combines traffic flow models and machine learning approaches in predicting real-time traffic speeds under various external events, such as weather, incidents, work zones, and special events. Moreover, IMRCP (**Figure V-40**) combines agency point detector data (i.e., loops of KC Scout, not deployed everywhere) and private sector data for network-wide traffic prediction. The IMRCP models can be adapted for use in this project.

[3] https://collaboration.fhwa.dot.gov/dot/fhwa/RWMX/Documents/2017%20WRTM%20Stakeholder%20Meeting,%20Raleigh%20NC%20(Aug.%2029-30,%202017)/IMRCP%20Flyer.pdf

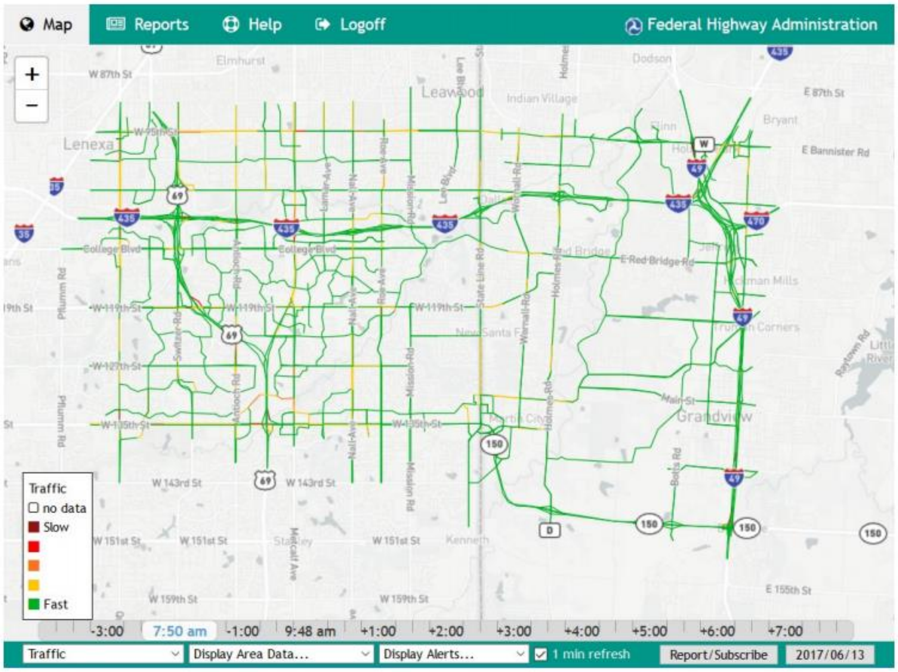



**Figure V-40. IMRCP Interface for Real-time Traffic Prediction**

An appropriate estimation and prediction method will be developed and selected in Phase 2 on the basis of the team's previous project experiences. Data reflecting historical trends will be synergized from experienced travel time datasets and private sector data courses. Such data fusion could be used to differentiate between recurring congestion and an incident. With the use of the GPS-equipped floating car method, ground-truth travel time datasets could be measured under prevailing conditions and then are compared with prediction data for performance evaluation.

### V.2 Information Dissemination Strategies

As discussed in Section 1, fixed or portable DMSs or DDMSs have been widely used to provide real-time en-route traveler information on freeways and arterials, and DMSs are still thus far the most widely used traveler information dissemination mode. Since portable DMSs could be deployed flexibly in the field, portable DMSs will be primarily used to facilitate field testing trials to be conducted in Phase 2, whereas Smartphone app with OHGO and OHGO website will be used as a supplementary tool for information dissemination.

#### *V.2.1 Locations of DMSs and Detectors*

The locations of DMSs are often determined based on unwritten practices and general policies. Agencies seldom implement methods to ensure that specific DMS locations are optimal. In general, locations of DMSs are aimed at helping reduce delay or travel time, increase throughput, and enhance safety (Mounce et al., 2007). The following factors should be considered when installing or locating the message signs:

A. message signs should be located sufficiently upstream of known bottlenecks and high crash locations to enable road users to select an alternate route or take other appropriate action in response to a recurring condition.

B. message signs should be located sufficiently upstream of major diversion decision points, such as interchanges, to provide adequate distance over which road users can change lanes to reach one destination or the other.
C. message signs should not be located within an interchange except for toll plazas or managed lanes.
D. D message signs should not be positioned at locations where the information load on drivers is already high because of guide signs and other types of information.
E. message signs should not be located in areas where drivers frequently perform
F. lane-changing maneuvers in response to static guide sign information, or because of merging or weaving conditions.

For Phase 2 research, the location selection of the traffic detectors should be considered in line with the consideration of locations of the fixed or portable DMSs. The location selection should be associated with the analysis of factors related to accidents/incidents, congestion, work zones, weather-related conditions, special events, general transportation messages, advertising, access to large traffic attraction or generation places. In order to reduce overall errors in travel times and space mean speeds, it is desirable to place travel-time detection sensors at least one mile apart. Sensors must also be placed on the major diversion routes to detect any vehicles that exit the main road.

The mathematical model (Schroeder et al., 2010) for estimating the unreadable distance at which a portable DMS becomes unreadable is recommended to be used, along with checking the MUTCD standards when determining locations of DMSs. It is suggested that field data should be collected to determine the readability distance and other important factors using GPS-equipped vehicles.

### *V.2.2 Message Characteristics*

MUTCD recommends the DMSs to disseminate, but not limited to, the following messages: incident management and route diversion, warning of adverse weather conditions, special event applications associated with traffic control or conditions, control at crossing situations, lane, ramp, and roadway control, priced or other types of managed lanes, travel times, Warning situations, traffic regulations, speed control, and destination guidance. (FHWA, 2009)

In order for DMSs to produce appropriate driver response, the messages must be meaningful, accurate, timely, and useful (Mounce et al., 2007). If the messages displayed on DMSs have not adhered to these guidelines, driver credibility will be lost. Dudek et al. (2006) further specified the DMS problems that lose the motorists' confidence, typically including: displaying inaccurate or unreliable information, or the information too late for drivers to make an appropriate response, and displaying messages that are too long for drivers to read. Therefore, message characteristics (e.g., font, size, an array of texts) will be investigated for the pilot deployment sites.

## V.3 Evaluation and Analysis

### *V.3.1 Test Sites*

There are several potential "test routes" throughout the greater Cincinnati area. A couple of these routes are listed below, as illustrated in **Figure V-41**. The project team will work with ODOT and select up to 3 corridors to deploy these travel time systems for verification in multiple arterial settings.

- **Route 1:** *I-74 to I-75* vs. *North Bend to Westwood Northern Boulevard to Hopple*
- **Route 2:** In the Mt Healthy/North College Hill area you could compare *SR 126 to I-75* vs. *US 127 to Hopple*
- **Route 3:** From Fields Ertel to Kenwood *IR- 71 vs. Montgomery Road (US 22).*

- **Route 4:** *IR-275 to Blue Rock to SR126 back to US 27* vs. *US 27* (For instance, Rumpke sends some trucks via 275 to Blue Rock to SR126 as their standard route).
- **Route 5:** *IR-275 to IR-471 to US 50 to Broadway* vs. *SR-32 to SR-125 to US-50 to Broadway.*

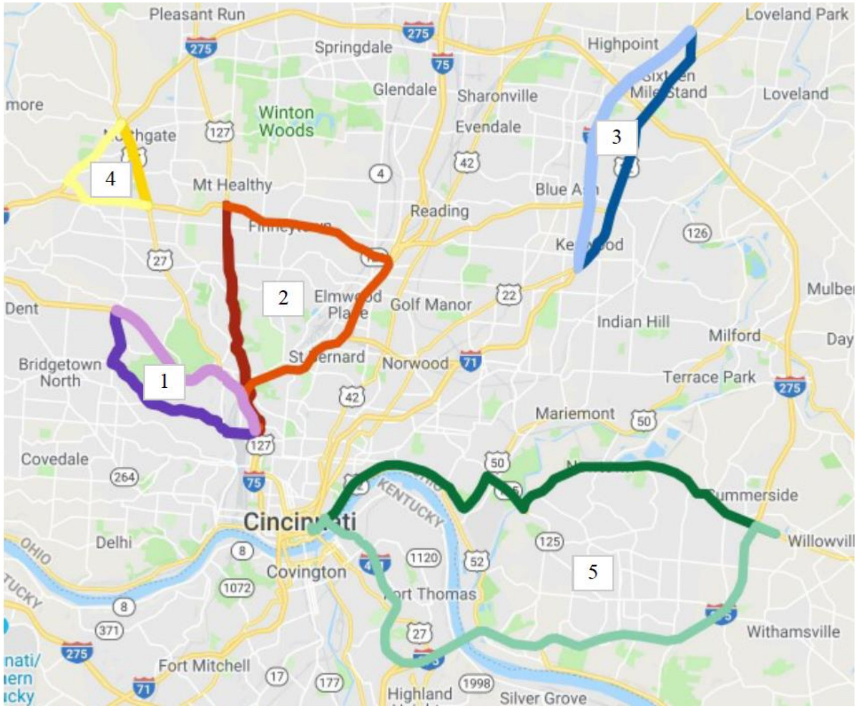



**Figure V-41. Suggested Routes for Phase 2 Studies**

*V.3.2 Travel Time Accuracy*

To validate the use of the detector and private sector data to estimate arterial travel times and developed travel time estimation and prediction models, a data collection plan and analysis procedure need to be structured. GPS-track floating car data will be used as the ground truth. The data collection items include, but not limited to, the following during time of day", "day of the week", and "weekend" or "speed bins":

- Experienced or realized travel times on the testing routes.
- Traffic volume, vehicle classification and speed data on the testing routes.
- Private sector based speed and travel time data on the testing routes (INRIX or HERE).
- GPS-equipped floating car trajectories.
- Weather and environment data.
- Geometry data of the testing routes.

Travel time data will be analyzed using a software package such as Tru-Traffic, Trav-Time or UC's own program developed using the statistical software R. Selected performance measures to include Mean Absolute Deviation (MAD), Mean Percent Error (MPE), Mean Absolute Percent Error (MAPE) and Root Mean Square Error (RMSE). The measures can be based on "time of day", "day of the week", "weekend", or "speed bins".

*V.3.3 Performance Evaluation of DMS Influence on Drivers*

Upon determination of the validity of the methods for collecting and calculating travel time data, the project team proposes to study the effectiveness of the DMS information in terms of re-routing the travelers. Once the main corridors and corresponding alternative routes are selected, existing DMS or portable DMS signs will be deployed along with the selected travel time collection devices.

The effectiveness of the DMS travel time information will be measured by the number of vehicles which alter their routes. As such, traffic counting devices will be deployed along the primary and alternative routes. Travel times for the corridor and/or alternative routes will be displayed on the existing or portable DMS devices and traffic volumes on each route will be collected.

The “Off-On” strategy will be implemented during the data collection. The “Off” means the DMSs are turned off and “On” means the DMSs are in operation. The “Off-On” study is similar to a before-and-after study, in which comparisons of the various types of collected data when the DMSs are off and after DMSs are on will be performed. The before-and-after data will be compared statistically to understand the DMS impact on travel time changes and traffic diversions if alternative routes exist. The performance measure selected for diversion is the percentage of diverted traffic. Through the data of the travel times and volumes on the primary and alternate routes, the changes in traffic system performance can also be captured.

It is noted that, when travel times are provided, travelers may divert to an alternative route even though they are not provided with alternative route information. Most of the agencies provide travel time information such that travelers can make re-routing decisions. Under some circumstances, particularly during extreme congestion or hazardous conditions, alternative routes may be provided. In some cases, both routes may be managed by the same agency and it is easier for an integrated management approach for both routes through dynamic rerouting. Displaying alternative routes or not is another factor to be investigated.

Additionally, a Revealed Preference (RP) survey can be conducted after travel times have been provided on the selected corridors. Compared with the Stated Preference (SP) survey, which creates hypothetical traffic and travel scenarios and requires participants to indicate potential decisions accordingly, RP inquires real travel experience of each participant. The UC team proposes post-deployment RP in understanding the actual traveler experiences, including perceived travel time accuracy and travelers’ attitude toward the non-freeway travel times.

### V.4 Recommendation for Future Statewide Plan

Based on the understanding of the above perspectives and actual deployment experience of this project, a general guide will be developed regarding the standard practice about providing travel times for non-freeways. The purpose of the guide is to provide ODOT with a statewide reference for future non-freeway travel time provision projects. The potential guide will include, but not limited to, the following information:

- Characteristics of each data sources, both detectors, and private sector data, in non-freeway travel time provision
- Travel time estimation and prediction for non-freeways
- DMS location and messaging strategies
- Standard practice for non-freeway travel time information system evaluation
- Other supporting information such as detector installation/calibration and emerging technologies

## V.5 Schedule and Proposed Cost

A preliminary schedule and budget of Phase 2 are shown in **Table V-24** and **Table V-25.**

**Table V-24. Schedule of Phase 2 Work Plan**

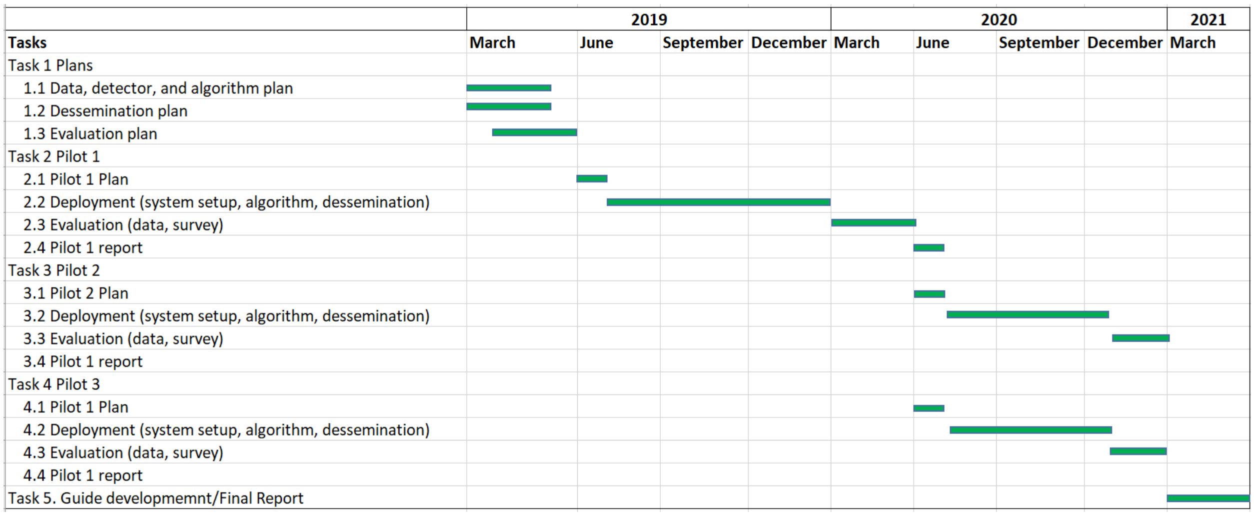



**Table V-25. Proposed Cost of Phase 2 Work Plan**

| **Tasks** | **Budget ($1000)** |
|---|---|
| Task 1 Plans | |
| 1.1 Data, detector, and algorithm plan | 20 |
| 1.2 Dessemination plan | 3 |
| 1.3 Evaluation plan | 3 |
| Task 2 Pilot 1 | |
| 2.1 Pilot 1 Plan | 5 |
| 2.2 Deployment (system setup, algorithm, dessemination) | 80 |
| 2.3 Evaluation (data, survey) | 30 |
| 2.4 Pilot 1 report | 5 |
| Task 3 Pilot 2 | |
| 3.1 Pilot 2 Plan | 3 |
| 3.2 Deployment (system setup, algorithm, dessemination) | 45 |
| 3.3 Evaluation (data, survey) | 20 |
| 3.4 Pilot 1 report | 5 |
| Task 4 Pilot 3 | |
| 4.1 Pilot 1 Plan | 3 |
| 4.2 Deployment (system setup, algorithm, dessemination) | 45 |
| 4.3 Evaluation (data, survey) | 20 |
| 4.4 Pilot 1 report | 5 |
| Task 5. Guide developmemnt/Final Report | 25 |
| Materials | TBD |
| **Total** | **317** |