#### **Research Project Work Plan**

for

#### Wireless Data Collection System for Travel Time Estimation and Traffic Performance Evaluation

Project Number SPR 737

Submitted by

David S. Kim, Ph.D., Associate Professor<sup>1</sup> J. David Porter, Ph.D., Associate Professor<sup>1</sup> Mario E. Magaña, Ph.D., Associate Professor<sup>2</sup>

Oregon State University

<sup>1</sup>School of Mechanical, Industrial and Manufacturing Engineering 204 Rogers Hall Corvallis, Oregon 97331

<sup>2</sup>School of Electrical Engineering and Computer Science 1148 Kelley Engineering Center Corvallis, Oregon 97331

for

Oregon Department of Transportation Research Section 200 Hawthorne SE, Suite B-240 Salem, Oregon 97301-5192

September 2010

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#### 1.0 Identification

1.1 Organizations Sponsoring Research

Oregon Department of Transportation (ODOT) Research Section 200 Hawthorne SE, Suite B-240 Salem, OR 97301-5192 Phone: (503) 986-2700

Federal Highway Administration (FHWA) Washington D.C. 20590

Oregon Transportation Research and Education Consortium (OTREC) Portland, Oregon

1.2 Principal Investigators:

David S. Kim, Ph.D., Associate Professor (PI) School of Mechanical, Industrial and Manufacturing Engineering Oregon State University 204 Rogers Hall Corvallis, OR 97331 Email: <u>david.kim@oregonstate.edu</u>

J. David Porter, Ph.D., Associate Professor (Co-PI) School of Mechanical, Industrial and Manufacturing Engineering Oregon State University 204 Rogers Hall Corvallis, OR 97331 Phone: (541) 737-2446 Email: <u>david.porter@oregonstate.edu</u>

Mario E. Magaña, Ph.D., Associate Professor (Co-PI) School of Electrical Engineering and Computer Science Oregon State University 1148 Kelley Engineering Center Corvallis, OR 97331 Phone: (541) 737-3149 Email: magana@eecs.oregonstate.edu 1.3 Technical Advisory Committee (TAC) Members

Galen McGill, ITS Manager, ODOT Dennis Mitchell, Region 1 ITS/Traffic Engineer, ODOT Nathaniel Price, FHWA Willie Rotich, City of Portland June Ross, Research Coordinator, ODOT Jason Shaddix, Information Systems, ODOT Doug Spencer, ITS Standards Engineer, ODOT Don Crownover, Transportation Data Section, ODOT

1.4 Project Champion

Galen McGill, ITS Manager, ODOT

#### 2.0 Problem Statement

Having accurate and continually updated travel time and other performance data for the road and highway system has many benefits. From the perspective of the road users, having real-time updates on travel times will permit better travel and route planning. This would also be of tremendous value to delivery and transportation companies. For state departments of transportation (DOTs) that maintain, upgrade, and manage the road and highway system, such road and highway performance data collected over time will permit more efficient and effective use of limited resources for upgrades, expansions, and maintenance.

Economical widespread collection of such data is currently being explored by taking advantage of existing wireless technology. Travel time data collection based on the collection of media access control (MAC) addresses from Bluetooth-enabled devices is being examined by multiple states (Wasson, et al. 2008, Barcelo, et al. 2010, Haghani, et al. 2010, Quayle, et al. 2010). A MAC address is a unique 48-bit hexadecimal (i.e., base 16) number, which consists of 12 characters and is transmitted as part of the Bluetooth communications protocol. Past and ongoing research has demonstrated the feasibility of reading MAC addresses from Bluetooth-enabled devices present in vehicles moving past a fixed location and recording the time of this reading. If the same MAC address is read at a different location, then a travel time data sample can be generated. If the same MAC address is read multiple times by the same reader at an intersection it may be possible to obtain estimates of delays at the intersection. While the technology used to collect such travel time samples is evolving, there is little published information research available that specifically addresses the processing and synthesizing of collected data to compute travel time estimates, and the relationship between the amount of data collected and the accuracy of the travel time estimates. There is also no published research examining if the data collected from a single Bluetooth reader at an intersection can be utilized to derive intersection performance measures (e.g., average wait time). Such issues are the focus of the proposed research.

This project will address issues related to the processing and synthesis of this data to generate travel time performance measures. A number of issues related to data processing and synthesis need to be addressed.

A partial list of issues that need to be researched includes:

- How should data collected by the DCUs be filtered? Some MAC addresses are read a large number of times on specific days indicating that most of these records may not be used for travel time calculations. Filtering this data before computing travel times will increase computational efficiency.
- Specific procedures for identifying travel time sample data outliers and non-vehicle related data. Under very congested conditions very slow travel times must be distinguished from non-vehicle travel times.
- The amount, format, and length of time data is stored.

- Development of methods to estimate the precision of travel time performance measures.
- Utilization of MAC-based data to estimate other traffic performance measures at intersections and on highways (e.g., traffic volume).
- Understanding the impact of average vehicle speeds and different traffic states (stationary vs. moving) near an intersection or on a highway, on the MAC addresses recognized by a reader.
- Understanding the effect that antenna and reader design variables have on the precision and accuracy of travel time estimates.
- Evaluation of the impact of pushing data from readers to a central server vs. pulling data from the readers. Examine if pushing data provides significant benefits with respect to providing "real time" travel time information.
- Assessment of the information flow volume assuming a wide-scale implementation of Bluetooth (BT) readers.

#### 3.0 Background

The Bluetooth technology used to collect travel time samples is evolving (Wasson, et al. 2008, Haghani, et al. 2010), but there is little published research available that specifically addresses the processing and synthesizing of collected MAC address data. In Wasson, et al. 2008, Haghani, et al. 2010, and Quayle, et al. 2010, simple heuristic procedures are utilized to filter out travel time samples that appear to be outliers. These procedures are based on the assumption of normally distributed travel times and independence of the samples. Procedures to adjust the thresholds that segregate outliers have also been developed. No formal testing of these procedures was documented and no filtering of MAC addresses is conducted. Barcelo, et al. 2010 have applied Kalman filtering to forecast future travel times along a specific travel corridor when BT-based data collection devices are available to provide real-time travel time data. There are still many data synthesis and processing issues that require investigation.

MAC address data collected at the Wallace Road test site indicate filtering procedures for the MAC addresses before any matching is attempted may significantly reduce the volume of data that requires additional processing. For instance a MAC address may be read hundreds of times on a particular day and only several times on other days indicating that the vehicle may have been parked close to the reader when it was detected hundreds of times. During the testing of one antenna in the prior project phase over 50% of the MAC addresses read over a one week period were from the same MAC address. It was read over 60K times. Removing this data will clearly reduce the volume of data that must be manipulated later.

This research project will utilize the infrastructure developed in a recently completed ODOT/OTREC funded project that focused on the implementation of a Bluetooth-based travel time data collection system and antenna evaluation. Bluetooth-based data collection units (DCUs) were installed at two locations on Wallace Road in Salem, and five locations along Highway 99 in Tigard. The Wallace Road DCUs are installed at locations that are not close to any signalized intersection, whereas the Highway 99

installations have multiple DCUs installed at relatively high volume signalized intersections. Currently the data collected at the Wallace Road installations can be accessed remotely, and the routines to periodically and automatically download data into an ODOT database are currently being developed and implemented. The data at the Tigard installation must currently be accessed manually, but the networking infrastructure enabling remote access is scheduled to be completed before the start of this project. Computer routines have been developed that will use downloaded DCU data as input and automatically compute travel time samples after some simple data filtering. No additional data processing has been completed.

#### 4.0 **Objectives**

The objectives of the proposed project are:

- 1. To develop the data processing and travel time performance estimation procedures (implemented in prototype software) that utilize MAC address data collected by Bluetooth-based DCUs so that, in combination with the hardware and data collection system design completed in an earlier project, ODOT will have an implementable travel time data collection system utilizing the wireless reading of MAC addresses.
- 2. To investigate the use of MAC address data from single Bluetooth-based DCUs to compute intersection performance measures.
- 3. To develop the framework for travel time and intersection performance data reports that can be utilized to support planning, operations and traveler information functions.

To achieve these objectives will require the research and development of a variety of data processing and analysis procedures, and a more complete understanding of the capabilities and limitations of travel time and intersection performance measure estimation based on the collection of media access control (MAC) addresses from Bluetooth-enabled devices.

#### 4.1 Benefits

The execution of the proposed research will result in a number of long term benefits to both ODOT and users of the highway and road system. The system will provide low-cost, widely available travel time data useful for traveler information and system operations. The major benefit from the perspective of the users is better travel and route planning, which results in less time and fuel wasted due to congestion. For ODOT and regional transportation agencies that maintain, upgrade, and manage the road and highway system, data from the system will permit a more efficient and effective use of limited resources for upgrades, expansions and maintenance. The result of better utilization of resources for maintaining and upgrading the road system is safer and more efficient travel as measured by shorter travel times and less delay.

Implementation at select locations will provide more data than previously available, and will reduce the cost needed to estimate travel times. Wide-scale implementation will provide data on a scale that was not previously accessible. There will also be a

tremendous reduction in the amount and cost of infrastructure needed to estimate travel times.

Additionally, this technology could easily be applied to evaluate the impact of different types of road improvement projects on travel time. For example, delays through construction zones could be estimated more accurately, thus providing ODOT with the ability to enforce contractual agreements with service providers as well as important traveler information.

#### 5.0 Implementation

The research team will make presentations to the appropriate officials as deemed necessary by the Technical Advisory Committee in order to disseminate this information to ODOT and other appropriate Oregon transportation agencies. In addition, a specific research task has been incorporated to document the organizational structure within ODOT that would support a wide-scale implementation of Bluetooth DCUs, the possible roles of various divisions within ODOT, the resources required, and the initial actions required for implementation.

Specific data processing and analysis procedures that are developed will be documented in a final report and will be provided in prototype software that can be adapted for production use and implemented by ODOT. Research results will be documented in one or more articles suitable for publication in an archival journal or presentation at a national conference.

#### 6.0 Research Tasks

Each of the specific tasks to be performed in the research project is described below.

#### Task # 1: Literature review

The literature review will focus on a number of technical issues relevant to travel time estimation from collected travel time samples. A variety of topics will be researched as shown in the following list:

- 1. Summary of existing Bluetooth MAC address matching data processing and analysis procedures.
- 2. Data filtering techniques.
- 3. Travel time sample accuracy.
- 4. Statistical analysis of collected non-independent travel time samples.
- 5. Prediction and forecasting methods.
- 6. Similar applications with high volumes of data networked into central locations to examine network operational protocols, data volume issues, and data storage issues.
- 7. Current and future ODOT travel time performance measures.
- 8. Advantages and disadvantages of "pulling" versus "pushing" data from the DCUs.
- 9. The implementation of new technology in ODOT (e.g., weigh-in-motion) to examine the resources and organizational structure that led to successful implementation.

Time Frame: 3 months

Responsible Party: Porter, Kim & Magaña at Oregon State University.

*Cost:* \$5,331(ODOT Cost); \$4,669 (OTREC Cost) [\$10,000 Total Task Cost]

Deliverable: Interim report #1 which will summarize the literature review. A

PowerPoint presentation for discussion with the TAC will summarize the outcomes of Task #1.

<u>TAC Decision/Action</u>: The TAC will review the literature review summary and provide comments. These comments will be addressed and incorporated into the final report. A presentation will be made to the TAC to review the results of Task #1 and discuss the schedule and plan for the upcoming tasks.

# Task # 2: Develop different methods for computing travel time samples from<br/>collected MAC addresses, and evaluate distributed vs. centralized data<br/>filtering.

Utilize existing installed Bluetooth DCUs (Wallace Road, Salem and Highway 99, Tigard) and network infrastructure systems from the prior phase of this research to obtain MAC address data. Data collection from DCUs installed at intersections and nonsignalized segments of a road will be available continuously over the project time period. Identify alternative methods for computing travel time samples from this data. Results from the prior phase have shown that multiple MAC address reads from the same Bluetooth device commonly occur from a single DCU. Develop and conduct tests to understand the impact of vehicle speeds and different traffic states (stationary vs. moving) on the MAC addresses recognized by a reader. Evaluate the effectiveness of different methods by comparing against controlled travel time samples generated from test vehicles. Based on the results, compare distributed and centralized data filtering procedures of MAC addresses.

*Time Frame:* 6 months *Responsible Party:* Porter, Kim & Magaña at Oregon State University. *Cost:* \$15,993 (ODOT Cost); \$14,007 (OTREC Cost) [\$30,000 Total Task Cost] *Deliverable:* See Task #3. <u>TAC Decision/Action</u>: See Task #3.

## Task # 3: Develop and implement procedures for identifying and removing traveltime data sample outliers.

In this task, the research team will develop and implement procedures to identify outlier travel time samples. A couple of different procedures have been described in the research literature but no justification for the procedure is presented, and no tests of their effectiveness were presented. If possible, procedures will be developed from a sound theoretical basis; otherwise proposed procedures will be tested to justify their usefulness.

*Time Frame:* 6 months

Responsible Party: Porter, Kim & Magaña at Oregon State University.

*Cost:* \$15,993 (ODOT Cost); \$14,007 (OTREC Cost) [\$30,000 Total Task Cost] *Deliverable:* Interim report #2 summarizing the findings of Tasks #2 and #3. A

PowerPoint presentation for discussion with the TAC will summarize the outcomes of Tasks #2 and #3.

<u>TAC Decision/Action</u>: The TAC will review interim report #2 and provide comments. These comments will be addressed and incorporated into the final report. A presentation will be made to the TAC to review the results of Tasks #2 and #3.

# Task # 4:Develop and implement a data analysis methodology for generating travel<br/>time performance measures from collected travel time samples, and<br/>methods for utilizing travel time samples for short-term travel time<br/>prediction.

*Task #4a.* Develop and implement analysis procedures for generating "basic" travel time performance measures from travel time samples computed from the collected data. These measures will characterize average travel times, and will include statistical measures on the precision (variability) of the estimates.

*Task #4b.* Explicitly consider the time series and non-stationary nature of the data. Simulation will be used to generate similar travel time data over time that is non-stationary and correlated. Statistical procedures for computing performance measures from this type of data will be investigate and tested. This will include measures that characterize variability as well as average performance. These procedures will then be applied to data collected from a test installation and the results will be reviewed with the TAC.

**Task #4c.** Investigate and implement procedures for utilizing travel time samples for short-term travel time prediction. Various signal processing and data filtering techniques will be investigated as will forecasting approaches based on time series analysis methods. **Task #4d.** Test the implementation of providing "real-time" travel time updates on a Highway 99W variable message sign. The completion of this task is contingent on the installation and functioning of the planned variable message sign and the information systems infrastructure to electronically update messages.

#### *Time Frame:* 8 months

*Responsible Party:* Porter, Kim & Magaña at Oregon State University. *Cost:* \$36,655 (ODOT Cost); \$23,345 (OTREC Cost) [\$50,000 Total Task Cost] *Deliverable:* Interim report #4 incorporating the findings of Tasks #4a-4d. A PowerPoint presentation for discussion with the TAC will summarize the outcomes of Tasks #4a-4d.

<u>TAC Decision/Action</u>: The TAC will review interim report #4 and provide comments. These comments will be addressed and incorporated into the final report. A presentation will be made to the TAC to review the results of Tasks #4a-4d.

## Task # 5: Investigate the effectiveness of utilizing MAC address data collected at intersections generating other road system performance measures.

Develop and implement analysis procedures for generating other performance measures from collected data such as intersection wait times, traffic volume estimates. A single DCU installed at an intersection will read the same MAC address multiple times if the vehicle containing the BT device has to wait at the intersection. It is possible that this data can be used to generate data on intersection wait times. If volume data is also available then queuing theory results may be applied to obtain estimates of the number of vehicles that are present at an intersection. If possible the analysis methods will include statistical measures on the precision of the estimates. The procedures should explicitly consider the time series and non-stationary nature of the data.

*Time Frame:* 7 months *Responsible Party:* Porter, Kim & Magaña at Oregon State University. *Cost:* \$21,324(ODOT Cost); \$18,676 (OTREC Cost) [\$40,000 Total Task Cost] *Deliverable:* See Task #7. <u>TAC Decision/Action</u>: See Task #7.

#### Task # 6: Determine requirements for what data is stored and how long it is stored.

Stakeholders at ODOT will be consulted to develop data requirements that balance the information available with privacy and information system requirements. Data about the volumes of MAC addresses collected by the DCUs will be available.

*Time Frame:* 3 months *Responsible Party:* Porter, Kim & Magaña at Oregon State University. *Cost:* \$7,997 (ODOT Cost); \$7,003 (OTREC Cost) [\$15,000 Total Task Cost] *Deliverable:* See Task #7. <u>TAC Decision/Action</u>: See Task #7.

### Task # 7:Develop functional requirements for data processing and analysis<br/>software component.

Document the functional requirements for the analysis procedures to be applied to collected MAC address data. These requirements document the input data utilized and the values to be computed from this data, as well as the format of any graphs and figures used to present analysis results. All algorithms utilized in the analysis procedures will be documented.

#### *Time Frame:* 3 months

*Responsible Party:* Porter, Kim & Magaña at Oregon State University. *Cost:* \$7,997 (ODOT Cost); \$7,003 (OTREC Cost) [\$15,000 Total Task Cost] *Deliverable:* Interim report #5 with the results of Tasks #5, #6, #7, and #8 will be prepared for the TAC. A PowerPoint presentation for discussion with the TAC will

summarize the outcomes of Tasks #5, #6, #7, and #8.

*<u>TAC Decision/Action</u>*: The TAC will review interim report #5 and provide comments. These comments will be addressed and incorporated into the final report.

## Task # 8:Examine organizational structure, roles, resources, and actions required<br/>within ODOT to move forward with a wide-scale implementation of<br/>Bluetooth-based DCU for travel time data collection.

Document the organizational structure within ODOT that would support a wide-scale implementation of Bluetooth-based DCUs, the possible roles of various divisions with ODOT, the resources required, and the initial actions required for implementation. The purpose of this task is to better understand the administrative, legal, and organizational requirements that must be satisfied in order to implement Bluetooth-based travel time data collection on a wide-scale.

#### Time Frame: 14 months

*Responsible Party:* Porter, Kim & Magaña at Oregon State University. *Cost:* \$9,596 (ODOT Cost); \$8,404 (OTREC Cost) [\$18,000 Total Task Cost] *Deliverable:* Status reports on this task will be provided at each TAC meeting. Interim report #5 will include the results of this task. TAC Decision/Action: See Task #7.

#### Task # 9: Develop and prepare draft and final report.

The research team will prepare draft and final reports compiling the results of the entire project as well as final recommendations.

#### Time Frame: 2 months

Responsible Party: Porter, Kim & Magaña at Oregon State University.

*Cost:* \$5,331(ODOT Cost); \$4,669 (OTREC Cost) [\$10,000 Total Task Cost]

- *Deliverable:* The result of this task will be a draft final project report followed by a final project report. A PowerPoint presentation summarizing the project will be provided to the TAC.
- <u>*TAC Decision/Action:*</u> The TAC will meet to review the project and provide comments on the draft final report. The Principal Investigators will resubmit the final report which will incorporate and address TAC comments.

The following matrix summarizes the work tasks previously identified:

Task	Responsible Party	ODOT Cost	OTREC Cost	Total Cost	
Task #1: Literature review.Time Frame: 3 months.Deliverable: Interim report summarizing the literaturereview. PowerPoint presentation to TAC. <u>TAC Decision/Action</u> : The TAC will examine literaturereview summary and provide comments.	Drs. Porter, Kim and Magaña, OSU	\$5,331	\$4,669	\$10,000	
<i>Task #2:</i> Develop different methods for computing travel time samples from collected MAC addresses, and evaluate distributed vs. centralized data filtering. <i>Time Frame:</i> 6 months. <i>Deliverable:</i> See Task #3. <u>TAC Decision/Action</u> : See Task #3.	Drs. Porter, Kim and Magaña, OSU	\$15,993	\$14,007	\$30,000	
Task #3: Develop and implement procedures foridentifying and removing travel time data sample outliers.Time Frame: 6 months.Deliverable: Interim report summarizing the findings ofTasks #2 and #3. PowerPoint presentation to TAC. <u>TAC Decision/Action</u> : The TAC will review interimreport and provide comments.	Drs. Porter, Kim and Magaña, OSU	\$15,993	\$14,007	\$30,000	
Task #4: Develop and implement a data analysismethodology for generating travel time performancemeasures from collected travel time samples, andmethods for utilizing travel time samples for short-termtravel time prediction.Time Frame: 8 months.Deliverable: Interim report incorporating the findings ofTasks #4a-4d. PowerPoint presentation to TAC. <u>TAC Decision/Action</u> : The TAC will review the interimreport and provide comments.	Drs. Porter, Kim and Magaña, OSU	\$36,655	\$23,345	\$50,000	
Task #5: Investigate the effectiveness of utilizing MACaddress data collected at intersections generating otherroad system performance measures.Time Frame: 7 months.Deliverable: See Task #7.TAC Decision/Action: See Task #7.	Drs. Porter, Kim and Magaña, OSU	\$21,324	\$18,676	\$40,000	
Task #6: Determine requirements for what data is storedand how long it is stored.Time Frame: 3 months.Deliverable: See Task #7.TAC Decision/Action: See Task #7.	Drs. Porter, Kim and Magaña, OSU	\$7,997	\$7,003	\$15,000	
<i>Task #7:</i> Develop functional requirements for data processing and analysis software component. <i>Time Frame:</i> 3 months. <i>Deliverable:</i> An interim report with the results of Tasks #5, #6, #7, and #8. PowerPoint presentation to the TAC. <u>TAC Decision/Action</u> : The TAC will review the interim report and provide comments.	Drs. Porter, Kim and Magaña, OSU	\$7,997	\$7,003	\$15,000	
<i>Task #8:</i> Examine organizational structure, roles, resources, and actions required within ODOT to move forward with a wide-scale implementation of Bluetooth-based DCU for travel time data collection.	Drs. Porter, Kim and Magaña, OSU	\$9,596	\$8,404	\$18,000	

Task	Responsible Party	ODOT Cost	OTREC Cost	Total Cost
<i>Time Frame:</i> 15 months <i>Deliverable:</i> See Task #7. <u><i>TAC Decision/Action</i></u> : See Task #7.				
Task #9: Develop and prepare draft and final report.Time Frame: 2 months.Deliverable: Draft final project report and final report.A PowerPoint presentation summarizing the project willbe provided to the TAC. <u>TAC Decision/Action</u> : The TAC will meet to review theproject and provide comments on the draft final report.	Drs. Porter, Kim and Magaña, OSU	\$5,331	\$4,669	\$10,000
	TOTAL	\$118K	\$100K	\$218,000

All reports will be produced in the standard ODOT Research Unit report format unless some other format is deemed to be more appropriate as a supplement to the ODOT format.

#### 7.0 Time Schedule

This section specifies the time line for the project, listing the task headings and showing monthly and/or quarterly time blocks in which each task is scheduled. Also shown are interim and final deliverables. (The matrix below shows shaded cells and various symbols for designating task time lines and deliverables.) For the purposes of this proposal, the ODOT starting date has been assumed as October 1, 2010; however, this date is flexible and the schedule will be modified to reflect actual contract start time at some future date.

		FY11			FY12			
		Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	
<b>Project Tasks</b>		Oct - Dec	Jan - Mar	Apr - Jun	July - Sep	Oct - Dec	Jan - Mar	
<i>Task #1:</i> Literature	review.	*						
<i>Task #2:</i> Develop different methods for computing travel time samples from collected MAC addresses, and evaluate distributed vs. centralized data filtering.			†					
<i>Task #3:</i> Develop a procedures for iden removing travel tim outliers.	and implement tifying and he data sample			*				
<i>Task #4:</i> Develop and implement a	Task #4a		_					
methodology for	Task #4b							
time performance	Task #4c							
collected travel time samples.	Task #4d				*			
<i>Task #5:</i> Investigate the effectiveness of utilizing MAC address data collected at intersections generating other road system performance measures.					L			
<i>Task #6:</i> Determine what data is stored stored.	e requirements for and how long it is							
<i>Task #7:</i> Develop f requirements for da analysis software c	unctional ata processing and omponent.					*		
<i>Task #8:</i> Examine organizational structure, roles, resources, and actions required within ODOT to move forward with a wide-scale implementation of Bluetooth-based DCU for travel time data collection.								
<i>Task #9:</i> Develop a and final report	nd prepare draft						**	

\*Deliverables †TAC Meetings

#### 8.0 Budget Estimate

Two project budgets are shown below. The first shows the project budget by budget category. The second shows the project budget by quarter/fiscal year and funding source. Individual project expenditures are kept on file by the principal investigator as the project proceeds.

Category	ODOT		OTREC	Total		
Personnel						
Faculty	\$	20,774	\$ 9,188	\$	29,962	
Graduate Students	\$	30,231	\$ 33,075	\$	63,306	
Undergraduate Students	\$	478	\$ 522	\$	1,000	
Total Salaries	\$	51,483	\$ 42,785	\$	94,268	
Fringe Benefits						
Faculty	\$	9,764	\$ 4,318	\$	14,082	
Graduate Students	\$	4,827	\$ 5,281	\$	10,108	
Undergraduate Students	\$	42	\$ 46	\$	88	
Total Fringe	\$	14,633	\$ 9,645	\$	24,278	
Total Personnel	\$	66,116	\$ 52,430	\$	118,546	
Travel	\$	2,388	\$ 2,612	\$	5,000	
Tuition	\$	16,452	\$ 18,000	\$	34,452	
Supplies	\$	955	\$ 1,045	\$	2,000	
Indirect Cost	\$	32,090	\$ 25,912	\$	58,002	
ODOT Project Management	\$	7,000	\$ -	\$	7,000	
Total Project Budget	\$	125,000	\$ 100,000	\$	225,000	

#### **Project Budget By Budget Category**

#### **Project Budget by Funding Source and Quarter/Fiscal Year**

	FY 2011					FY 2012						
	Fall 2010		Winter 2011		Sp 2011		Sum 2011		Fall 2011		Winter 2012	
OTREC Total	\$	25,000	\$	25,000	\$	25,000	\$	25,000	\$	-	\$	-
ODOT	\$	1,183	\$	6,738	\$	1,184	\$	56,529	\$	26,183	\$	26,184
ODOT Staff	\$	1,000	\$	1,000	\$	1,000	\$	1,000	\$	1,000	\$	2,000
ODOT Total	\$	2,183	\$	7,738	\$	2,184	\$	57,529	\$	27,183	\$	28,184
Project Total	\$	27,183	\$	32,738	\$	27,184	\$	82,529	\$	27,183	\$	28,184

#### 9.0 References

- Barcelo, J., Montero, L., Marques, L., Carmona, C. (2010). Travel Time Forecasting and Dynamic OD Estimation in Freeways Based on Bluetooth Traffic Monitoring. TRB 2010 Annual Meeting Proceedings CD-ROM.
- Hagani, A., Masoud, H., Kaveh, F.S., Young, S., Tarnoff, P. (2010). Freeway Travel Time Ground Truth Data Collection Using Bluetooth Sensors. TRB 2010 Annual Meeting Proceedings CD-ROM.
- Quayle, S.M., Koonce, P., DePencier, D., Bullock, D. (2010). Arterial Performance Measures Using MAC Readers: Portland Pilot Study. TRB 2010 Annual Meeting Proceedings CD-ROM.
- Wasson, J.S., Sturdevant, J.R., Bullock, D.M. (2008). Real-Time Travel Time Estimates Using Media Access Control Address Matching. *ITE Journal*, 78(6), 20-23.