FRONTIER:

Demonstration and Evaluation of Intelligent Transportation Systems for the Rural Highway Environment Pooled Fund Study

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TABLE OF CONTENTS

List of Tables

List of Figures

1. EXECUTIVE SUMMARY

1.1. Introduction

1.1.1. Background

The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) promoted research, demonstration and implementation of Intelligent Transportation Systems (ITS) technology. To date, projects have primarily focused on applications of this technology in urban environments to address problems such as congestion, mobility and incident management. The nation's "real" rural highway system (two-lane highways) – which comprises over 80 percent of road mileage in the U.S. and accounts for approximately 40 percent of all vehicle-miles traveled each year – has largely been ignored with respect to ITS.

The primary objective of this research effort was to prove that advanced technologies can be successfully transferred to rural environments. The obvious approach in this proof is to deploy, on a small scale, appropriate Intelligent Transportation Systems (ITS) technologies in rural areas and document the resulting benefits. Potential benefits from this effort align with the national ITS goals of improved safety, efficiency and convenience in travel. In addition, the lessons learned from this effort can further encourage support of and investment in rural ITS applications.

1.1.2. Project Selection Process

Participants in this project included representatives from eight State Departments of transportation: Montana, Idaho, Utah, Washington, Oregon, California, Wyoming, and Texas. These representatives comprised the Technical Advisory Committee (TAC). The TAC members provided guidance to the Western Transportation Institute (WTI) for the research, demonstration, and evaluation phases of the project, and were actively involved in the project selection process, which occurred in 1999.

Following a national and state specific review of efforts to quantify rural ITS benefits, WTI and the TAC developed demonstration project criteria reflecting gaps in existing rural ITS research. State Departments of Transportation were invited to submit projects for consideration, which were rated on criteria such as "rural focus," "uniqueness of effort," "cost realism," "quality of site selection," and "feasibility." The two projects selected for demonstration were:

- A **Rural Travel Time Estimation Project** in Oregon. This project was designed to provide travelers with real-time information about trip duration on a highly traveled rural highway in coastal Oregon.
- A **High Water Level Sensor Project** in Texas. The objective of this project was to provide critical real-time warning of roadway flooding conditions.

1.2. Rural Travel Time Estimation Project

Travelers routinely complain about lack of real-time information regarding trip duration on the highway. Detection of and response to incidents has been an ever-growing concern, and notification of the traveling public about incidents and, more importantly, expected delay/travel time is essential. To address these needs, the FRONTIER Project TAC selected a rural travel time estimation system for deployment and demonstration in Oregon to inform motorists and maintenance workers of possible delays or incidents.

The Rural Travel Time Estimation project used vehicle identification technologies to provide travel-time estimates for two contiguous highway segments near the Oregon coast. This stretch of highway is a significant rural travel corridor in the region and also connects two large tourist attractions: a casino on one end and Lincoln City, a popular coastal destination, at the other end. Congestion and incidents are a common occurrence on this corridor due to several factors, including a high percentage of slow moving trucks and campers/mobile homes, passing opportunities that are few and far between, mountainous terrain and speed zones.

Prior to system selection, WTI reviewed similar travel time estimation systems to learn from those experiences. Then, a general system engineering process was followed: applicable technologies were reviewed then a vendor was selected through a competitive open bid process.

The resulting system uses infra-red technology to read license plates for travel time measurement. The cameras along the corridor are calibrated to recognize the license plates of passing vehicles. The license plate numbers are privacy-protected numbers with encryption, and time-stamped tags are sent via telephone communications network to a central server. The server matches the timestamped tags collected at different checkpoints to identify vehicles that have passed between two or more locations. Using the matched vehicles passage times and the distances between observations, the system estimates the travel time between segments.

If the vision was fully and permanently deployed, the FRONTIER Rural Travel Time system could eventually provide travel information to motorists via portable variable message signs (VMS) along the corridor, ODOT's statewide traveler information system TripCheck (www.tripcheck.com), and the statewide traveler information 511 system. Motorists could then choose alternative routes and make travel decisions based on the travel time estimates.

The travel time system was installed in early 2001. It worked well initially (in March and April of 2001), but then developed a series of malfunctions (software issues, equipment failures) that prevented further data collection. The system was not fully functional again until the summer of 2004. WTI and Portland State University collaborated to collect data in the summer and fall of 2004, then began work on data analysis and evaluation. For the evaluation, researchers analyzed data collected by the system, including vehicle matches, travel time, travel speeds, and incident detection. To validate the accuracy, a comparative analysis was conducted with data from probe vehicles.

Two main conclusions can be deduced from the evaluation of the travel time system. First, the results of the preliminary analyses and the comparative travel time studies showed that when working, the system produced accurate travel time results. The system is capable of detecting and matching vehicles, measuring travel time statistics, measuring travel speed data, and documenting travel delays caused by incidents. The capabilities of the system were validated by the results of the field validation, which indicated that the system can reliably predict travel times within a minute, which is robust considering the length of the corridor (25 miles).

The second conclusion that must be drawn from this evaluation is that the potential capabilities of this system were overshadowed by operational and maintenance concerns. Because the system (and therefore its data) was viewed as unreliable, ODOT was reluctant to use or disseminate any of the system information to the public. Therefore, the system's potential as a public information tool has yet to be evaluated. Further research on travel time estimation systems is recommended to produce longer-term data on technical reliability, as well as to incorporate the data into traveler information systems.

1.3. High Water Level Sensor and Warning System

Weather and its related impacts are a significant issue to the safety of travelers and the operations of the transportation systems in rural America. Flooding and rapidly rising water have a significant impact on many transportation systems, and as such TxDOT was interested in this second FRONTIER demonstration project.

The second TAC selected project was the Highway Water Level Sensor System. The site for this project is located in Wise County, Texas on a two lane, undivided approach to a structure crossing the West Fork of the Trinity River.

Prior to system development, WTI conducted research on previous efforts to deploy similar high water warning system technologies. To guide deployment, TxDOT developed a concept of operations, then technologies were determined and a pre- qualified vendor was selected for system implementation.

This project placed infrared water level sensors at critical locations on each approach to the site. The sensors were placed to provide the first warning, or alert mode, when water was within two feet of reaching the roadway surface, as well as second warning, or alarm mode, when water reached the roadway surface. The sensors are interconnected to two advanced signing installations with LED flashers, which display the message “Possible Flooding/Water over Road/When Flashing” during alert mode, or “Do Not Enter/High Water” during alarm mode. The central computer also employs a pager notification system to ensure appropriate personnel are aware of the changing conditions, especially outside normal business hours when office personnel may not be monitoring the base station.

The high water system installation (which began in 2001) had several problems, including a lightening strike that took out several system components. However, the vendor and TxDOT had the system fully operational again in 2002. The next issue became an ongoing drought in Texas, which hindered the potential for any flood events. The first flood event during which data collection could take place occurred during the summer of 2004.

A flood event in June 2004 resulted in a successful activation of the warning system. In December 2004, the system also accurately detected ice on the road, and the ice detection light was activated. The accuracy of the weather data was also validated by a comparative analysis with a nearby NOAA weather station. Surveys and interviews conducted with maintenance personnel indicate that they are impressed with initial performance of the system, and are interested in installing additional systems at other locations.

1.4. Conclusions

This study basically consisted of rural deployments of two different ITS applications. The license plate reading based travel time system, at the time of deployment, was the only one of its kind in the U.S. The initial research showed that there were only a few vendors capable of building and maintaining the system. The travel time system had maintenance issues for the duration of the study, and was only fully operational for several months over a three year period.

Rural districts generally lack the manpower and other institutional resources to provide ongoing, high maintenance support to new technologies.

Conversely, the high water warning system was an application that was applied successfully in the urban environment in Texas and other states. Thus, this deployment involved taking a tested system and applying it in a new environment. The system was reliable and functioned well.

The two distinctly different results from these two projects suggest perhaps that the main hypothesis was basically correct, but incomplete. Advanced technologies can be successfully transferred to rural environments, *if rural conditions, challenges, and resources are adequately addressed in advance.* Urban ITS applications can not be *directly* transferred to the rural environment; they must be adapted to account for such factors as:

- remote locations
- significantly lower AADT
- technological infrastructure
- available staffing resources and expertise
- available fiscal resources to support testing and deployment delays

The FRONTIER project has helped to identify key factors that must exist to ensure successful deployment of ITS technologies in a rural environment. The lessons learned will contribute to the development of criteria for future rural deployments. This project in fact underscores the need for increased ITS research specifically aimed at rural challenges and deployed in rural environments.

1.5. Next Steps and Future Research

As a next step, the Technical Advisory Committee should develop an action plan for disseminating the information that was learned as part of this effort, in order to raise awareness of the need for rural ITS and its potential benefits. This heightened awareness, in turn, will likely provide a greater opportunity for increased focus on rural issues and targeted funding for rural efforts.

Based on the evaluation results of this effort, there are several additional areas that would make interesting and useful studies to DOT's in the rural environment. Future research ideas include:

- What is appropriate level (i.e., spacing) of detection for the rural environment?
- What percentage of rural ITS deployments are completed within the project's original schedule and budget? How many ITS projects are actually deployed, fully-functional, on time, in any environment?
- What impact do software and communications issues have on successful and useful deployment in the rural environment?
- What should be the requirements for testing new technologies before deployment in rural environments? Should only proven technologies be deployed in rural environments?
- What is the reliability of ITS devices in any environment? Is there a difference in reliability between urban and rural environments?

2. INTRODUCTION

This section will provide an overview of the FRONTIER project intent, background on the rationale for the project, participating partners, general methodology for accomplishing the project and report content.

2.1. Project Intent

The primary objective of this research effort is to prove that advanced technologies can be successfully transferred to rural environments. The obvious approach in this proof is to deploy, on a small scale, appropriate Intelligent Transportation Systems (ITS) technologies in rural areas and document the resulting benefits. This information, when shared with other rural areas, can help to encourage or "sell" the implementation of ITS to benefit rural travelers.

Secondary objectives of this project are to (1) encourage multi-state communication, cooperation, and coordination, (2) improve efficiency by reducing the tendency to "reinvent the wheel" from state to state and (3) advance the state-of-the-practice in rural ITS with "regional" deployment.

Potential benefits from this effort align with the national ITS goals of improved safety, efficiency and convenience in travel. The multi-state approach to this effort allows for further benefit. In the long-term, this effort may provide for "regional" rather than just site-specific deployment of ITS technologies. In addition, the lessons learned from this effort will further encourage support of and investment in rural ITS applications. This effort is intended to complement rather than duplicate other rural ITS-related efforts.

2.2. Project Background

The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) promoted research, demonstration and implementation of Intelligent Transportation Systems (ITS) technology. To date, projects have primarily focused on applications of this technology in metropolitan environments to address problems such as congestion, mobility and incident management. Even efforts designated as "rural" were instituted on multi-lane, high-volume, Interstate highways connecting major urban areas.

The nation's "real" rural highway system (two-lane highways) – which comprises over 80 percent of road mileage in the U.S. and accounts for approximately 40 percent of all vehicle-miles traveled each year – has largely been ignored with respect to ITS. This is true despite the fact that 61 percent of all fatal accidents occur on rural roads. An unproven assumption has been made that urban ITS applications are directly transferable to the rural highway environment to meet rural traveler needs. Unfortunately, little work has been conducted in rural areas to adequately dispute this assumption.

2.3. Project Participants

Participants in this project included representatives from eight State Departments of transportation shown in Figure 1 and Table 1. These representatives comprise the Technical Advisory Committee (TAC). The TAC was involved with the research, demonstration, and evaluation phases of the project. Specifically the TAC was involved with review of: national and state specific efforts to quantify rural ITS benefits, demonstration project criteria, preliminary and final proposals for potential demonstration, and system requirements. In addition the TAC members had the responsibility to select a contractor for system design and implementation, as well as serving as a first point of contact for WTI researchers seeking project related data.

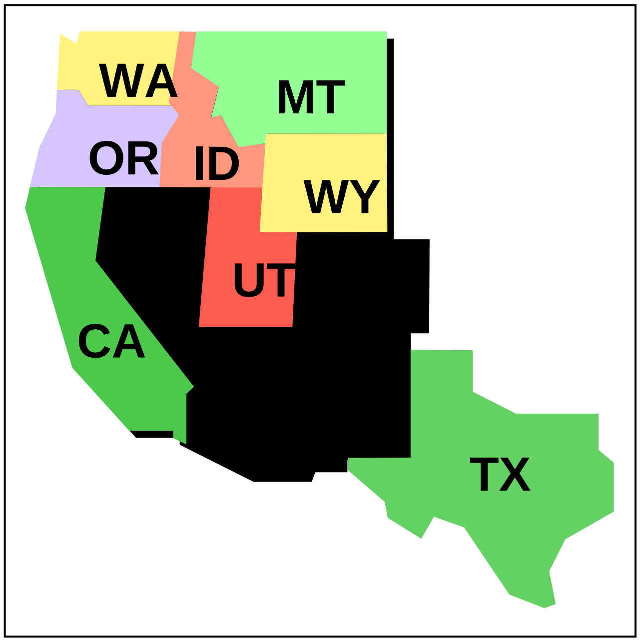

Figure 1. FRONTIER Pooled Fund States

Table 1. FRONTIER State DOT Representatives

State DOT	TAC Member	Title
Washington	Bill Legg	ITS Engineer, Advanced Technology Section
Oregon	Galen McGill	Manager, ITS Unit
California	Sean Campbell	ITS Development Engineer, Division of Research and Innovation
Idaho	Bob Koberlein	ITS Coordinator
Montana	Steve Keller	State Traffic Engineer and ITS Coordinator
Wyoming	Michael Patritch	Sr. Engineer, WYDOT Research Center
Utah	Richard Manser	ITS Engineer, Traffic Management Division
Texas	Tai Nguyen	ITS Engineer, TxDOT District 2

2.4. General Methodology

The research effort was accomplished through the following four phases:

- research,
- demonstration, and
- evaluation.

Phase I – Research consisted of a national and state-specific review of efforts related to ITS in rural areas. The solicitation, review, and selection of potential demonstration sites followed the review of previous efforts. Once selected, existing conditions were documented at each of the demonstration sites.

Phase II – Demonstration resulted in the development of detailed plans and specifications for implementation of selected ITS technologies at specific demonstration sites. Developing operational and maintenance procedures for the technologies deployed is critical to the success of any system and hence, were produced as part of the Demonstration Phase. After the demonstration technologies or groups of technologies were successfully installed, their operation was checked to ensure reliability and accuracy.

In *Phase III* - Evaluation: a methodology was developed which details how system benefits will be measured. While the Evaluation Phase followed the Demonstration Phase, some forethought was given to the evaluation requirements as part of Phase I - Research to ensure that existing conditions were adequately documented. Researchers considered both quantified benefits and perceived benefits of system operators and the general public. Particular focus was placed on describing the benefits resulting from improving, upgrading, or supplementing existing infrastructure.

The original scope for the project proposed a fourth phase – Continuance – which would have allowed for a formal, concentrated effort to be placed on disseminating the information that was learned as part of this effort. Continuance is recommended and discussed in the “Next Steps” section of this report.

2.5. Report Contents

This report documents the Research, Demonstration, and Evaluation Phases of this project. Specifically, this report describes the following:

- findings from previous ITS-related efforts in rural areas,
- the project selection process,
- the deployment and implementation process for selected projects,
- operational history of selected projects
- quantified and perceived ITS benefits resulting from the selected projects, as well as lessons learned, and
- conclusions from this effort and next steps including outreach efforts.

3. REVIEW OF PREVIOUS EFFORTS

This section will provide an overview and examination of previous efforts relating to overall ITS and rural needs, including a methodology and results. A subsequent review of specific ITS efforts relating to deployed projects is shown later in the report.

3.1. Methodology

Phase I began with a review of previous and ongoing ITS-related efforts in both participating states and nationally to avoid duplication. This gap-analysis of original research efforts began in 1998, and identified projects prior to 1998. Particular attention was paid to efforts that had previously quantified ITS-related benefits in any of the areas of focus. The usefulness of the previously gathered information was limited; much ITS related work that was performed at the time was performed in urban rather than rural areas. However, researchers nonetheless built upon previous efforts to the extent possible. Particular focus was placed on areas in need of further research as identified in previous efforts.

At the completion of this review, the information was summarized by the research team and distributed to the TAC members for review. TAC members were asked to supplement this information if any obvious related efforts were overlooked. WTI researchers made efforts to then incorporated and redistributed the updated information to all TAC members.

3.2. Findings

In order to determine the state-of-the practice at the time, researchers stratified rural ITS applications and the associated gap analysis by examining the Advanced Rural Transportation Systems cluster focus areas. The focus areas included Traveler Safety and Security, Emergency Services, Tourism and Traveler Information, Public Traveler/Public Mobility Services, Commercial Vehicle Operations, Infrastructure Operations and Maintenance, Fleet Operations and Maintenance. From this gap-analysis shortcomings were also examined. A summary of the analysis presented to TAC members follows.

Traveler Safety and Security

- Mostly implemented in urban areas
- Rural focus is on roadway hazard sensing at spot locations
- Benefits quantified with respect to reduced travel/response times and crash rates
- Common technologies include Variable Message Signs (VMS) and roadway condition sensors

Emergency Services

- Mostly implemented for large/urban fleet management
- Focus is on locating accidents, managing fleet vehicles and streamlining administrative functions
- Benefits quantified with respect to reduced response times

- Common technologies include global positioning systems (GPS), automatic vehicle location (AVL) and computer aided dispatch (CAD)

Tourism and Traveler Information

- Focus is on urban traffic management
- Benefits quantified with respect to reduced travel time
- Common technologies include some form of electronic information dissemination

Public Traveler/Mobility Services

- Mostly implemented in urban areas
- Focus is on making transit more demand responsive and providing information to transit users
- Benefits quantified with respect to increased ridership
- Common technologies include CAD, GPS and AVL

Commercial Vehicle Operations

- Implemented in rural and urban areas
- Focus is on streamlining regulatory and carrier functions and reducing travel delays
- Benefits quantified with respect to travel time and cost savings
- Common technologies include automatic vehicle identification (AVI), weigh-in-motion, AVL, and integrated communications

Infrastructure Operation and Maintenance

- Mostly implemented/concentrated in urban areas
- Rural focus is on information and resource management
- Benefits quantified with respect cost savings
- Common technologies include VMS, loop detectors, video surveillance and roadway condition sensors

Fleet Operations and Maintenance

- Implemented in urban and rural areas
- Focus is on maintaining accurate fleet location and on centralizing fleet operation
- Benefits quantified with respect to reduced travel/response time and administrative cost savings
- Common technologies include AVI, AVL, GPS and CAD

3.2.1. Summary

Based on the feedback from TAC members and preliminary research, it was determined that the shortcomings were that ITS was applied mostly in urban areas and focused primarily on urban issues such as congestion mitigation demand management, and information dissemination regarding alternate routes, alternate modes, and alternate travel times. In addition, it was determined that ITS projects were often implemented without clear evaluation methodology, limiting the usefulness of the research results for other agencies.

From these findings, the TAC identified a need for ITS research and deployment projects that:

- Tested current ITS technologies in a rural environment, and
- Developed ITS systems that addressed uniquely rural challenges, such as communications in remote locations, animal-vehicle conflicts, rural mobility in severe weather conditions, etc.
- Produced data and lessons learned that are applicable and available to other rural transportation agencies

The project selection process was developed to address these gaps in the current body of ITS research.

4. PROJECT SELECTION

WTI designed a project selection process that would be equitable and beneficial to all TAC members, and would make a significant contribution to the state-of-the-practice of rural ITS research. The following section provides details on the methodology, criteria, proposal process and final ranking and selection for project deployment.

4.1. Methodology

The project selection process consisted of three steps:

- defining demonstration project criteria,
- requesting, reviewing and selecting preliminary proposals for potential demonstration, and
- requesting, reviewing and selecting final proposals for potential demonstration.

4.1.1. Define Demonstration Project Criteria

In an effort to maximize this project's resources, WTI drew upon the expertise in each of the participating states to select appropriate locations for demonstrations. The research team developed a set of demonstration project criteria that helped each participating state in determining appropriate demonstration sites. In general, the selected demonstration project should:

- not duplicate efforts previously performed,
- have a high likelihood of proving benefits that align with the project goals,
- maximize use of existing data or minimize supplementary data collection efforts,
- fall within the funding scope of the project,
- have a high potential for public-private partnering to defray some of the deployment costs,
- have a potential for using existing resources to defray some of the implementation costs, and
- integrate with existing transportation-related systems to the extent possible.

Once WTI researchers developed the demonstration project criteria, the information was distributed to all TAC members for review and comment. A TAC meeting was held at the close of this task that allowed for further discussion of the demonstration project criteria among the TAC members.

4.1.2. Demonstration Project Selection Process and Criteria

For this study, project selection occurred in two phases. First, each state representative interested in pursuing a demonstration project submitted a brief one- to two-page description of the proposed project. An initial screening process was performed where each TAC member voted on which projects to pursue. Proposed project descriptions selected in this first phase were expanded to provide more detail.

The selection criteria were developed to complement the two-phase selection process. The selection criteria for the first phase consisted of major descriptors that were easily demonstrated in a brief proposal. The selection criteria for the second phase were more detailed and more suited for an expanded proposal. Criteria used for the initial screening included the following:

20 points ITS Focus: Based on the goals and objectives of this study, the project must have an ITS technology focus. Those projects that align with National ITS Architecture market packages will be required to adhere to the National ITS Architecture structure and National Transportation Communications Information Protocol (NTCIP) standards for implementation. Those projects that are uniquely rural and do not align with the National ITS Architecture market packages will rely on the Advanced Rural Transportation Systems (ARTS) rural system architecture currently under development. Projects should apply advanced and emerging technologies in the fields of information processing, communications, control and electronics to transportation operations and maintenance. The ultimate goal is to make the transportation system safer and more efficient for users and providers through the application of new technologies to recurring problems.

20 points Rural Focus: Based on the goals and objectives of this study, the proposed project is required to focus on mitigating rural rather than urban issues. However, it is anticipated that proposed projects will have differing degrees of *rural focus*. For example, rural projects benefiting rural areas will likely be weighted higher than rural projects benefiting intercity travel. For the purposes of this project, *rural* is defined as communities or areas with less than 50,000 residents.

20 points Uniqueness of Effort: The proposed project cannot duplicate other similar projects where new, original data cannot be obtained. For information related to other efforts, refer to the *Demonstration and Evaluation of ITS for the Rural Highway Environment Reference Guide* (Appendix A). Exact duplication of these other efforts should be avoided. However, these other efforts may spark ideas that can be applied in the participating states.

20 points Cost Realism: The anticipated cost of the project must be reasonable and appropriate for the project's available funding. The total deployment budget, including equipment and implementation costs, for this effort is $397,464. Proposed projects should not exceed this amount unless supplemented through innovative partnerships or alternative funding sources.

20 points Time Realism: The project must be completed within a timeframe that is useful and appropriate for this study. The project must be fully implemented by February 28, 2000 to allow sufficient time for evaluation of the system.

Following the initial screening and the preliminary selection of projects, detailed proposals were submitted. The following criteria were used to finalize project selection.

20 points Quantifiable Problem: To provide meaningful results, the proposed project should demonstrate a quantifiable problem that will be mitigated by applying ITS technology. This approach will provide statistically valid before/after comparisons that provide for scientific validation of the "success" of the project.

20 points Support of Evaluation Methodology: The proposed project should support the before/after evaluation.

Maximize Use of Existing Data: Does the proposed project maximize the use of existing data and minimize the need for supplementary data collection efforts?

20 points Site Selection: Is the proposed project a temporary deployment or is it part of a long-term ITS deployment plan supporting the National ITS Architecture using the NTCIP standards and/or the Advanced Rural Transportation Systems (ARTS) rural system architecture? In other words, to maximize the benefits of this project, is it planned to use the deployed ITS technology beyond this study?

Existing Transportation System Integration: Does the proposed project integrate well with the current transportation system? Does it align with regional goals and objectives?

20 points Feasibility: The proposed project should be financially and technically feasible.

Maximizing Existing Funding Levels: Each project should strive to defray cost to the maximum degree possible. One approach is to parallel costs of the selected pooled fund project with other planned projects within the state (i.e., piggyback on other project construction costs).

Private/Public Partnerships: To the extent possible, projects should demonstrate a strong possibility to promote and utilize private partners. Vendors may be willing to reduce the cost of equipment to demonstrate their technology.

20 points Results and Deliverables: The proposed project should provide results that are both defensible and transferable. The deliverables should enhance the implementation of the findings.

Sustainable Results: Will the methodology provide valued, defensible results? The results must provide statistically valid data that can scientifically prove or disprove a tangible benefit by using this technology.

Transferability of Results: Can the results be transferred to similar technology, but in different geographical locations?

4.1.3. Request, Review, and Select Preliminary Proposals for Potential Demonstration

The demonstration project criteria, in combination with the findings from the national/state-specific review, provided interested parties with the information needed to determine appropriate demonstration projects within their states (preliminary proposal submittal guidelines accompanied this material). This packet of material was sent to each of the TAC members. The TAC members were responsible for distributing this information to interested parties within their respective states. Each state representative interested in pursuing a demonstration project was asked to submit a brief, one- to two-page description of the proposed project, including its applicability, its likelihood of success, the availability of resources to support the effort, and its general funding requirements.

After a specified time period, the preliminary demonstration project proposals were requested, compiled, copied, and distributed to all TAC members for review. The TAC members were provided with a standard selection criterion and weighting scheme based on the proposed project's ability to meet the overall project goals. Each state had an equal vote in the selection process. If preliminary demonstration proposals were submitted that were similar in nature or that complemented each other and remain within the project scope, proposal combinations were considered. The TAC selected the most promising demonstration site candidates.

4.1.4. Request, Review, and Select Final Proposals for Potential Demonstration

State representatives whose projects were selected as one of the most promising alternative demonstration sites were asked by the WTI research team to expand their preliminary proposal into a more detailed proposal. State representatives were expected to describe the availability of previously collected data to support the quantification of benefits. State representatives were also asked to describe the potential for using existing, planned or proposed transportation-related systems for the current project, recognizing that additional benefits from ITS can be realized if value can be added to existing or planned systems. Anticipated benefits were detailed as part of this effort.

If projects were proposed that were similar in nature or that could complement each other and remain within the project scope, proposal combinations were recommended. Such a condition required the partnering of two state representatives from the same or different states to complete the more detailed proposal.

Again, after a specified time period, the detailed demonstration project proposals were requested, compiled, copied, and distributed to all TAC members for review. The TAC conducted a final screening to reduce the number of projects and request refinements to the selected proposals. At the close of this task, a TAC meeting was held. Further deliberation and final project selection occurred at this time.

4.2. Project Selection Results

Preliminary project selection results obtained through the TAC meeting are shown in Table 2. Point distribution and ranking are displayed for each project submitted. From Table 2, TAC members determined that there were similar themes and discussed which departments of transportation were willing to champion and be committed to all aspects of the deployment and evaluation. From these discussions, four ITS projects were initially selected. These projects, with their final scores and rankings are shown in Table 3.

However, through an investigation of realistic deployment costs for all four projects it was determined that four project costs exceeded the available budget. As a result, only two projects were selected to move forward.

The projects selected for demonstration were the two that received the highest rankings from the Technical Advisory Committee:

- The Oregon DOT Rural Travel Time Estimation Project. This project was designed to provide travelers with real-time information about trip duration on a highly traveled rural highway in coastal Oregon. TAC members were interested in evaluating the effectiveness of license plate matching technologies to determine travel times.
- The Texas DOT High Water Level Sensor project. The objective of this project was to provide critical real-time warning of roadway flooding conditions. Similar projects had been successfully deployed in urban locations, but not in rural areas.

The Rural Travel Time Estimation project proposal submitted by ODOT is included in Appendix A, and the High Water Level Sensor project proposal submitted by TxDOT is included in Appendix B.

Table 2 Preliminary project selection and ranking.

GENERAL PROJECT SUBMITTALS	STATE 1	STATE 2	STATE 3	STATE 4	STATE 5	STATE 6	STATE 7	STATE 8	TOTAL RAW SCORE	AVERAGE SCORE	RANKING
Maximum Possible Total Points	100 pts.	100 pts.	100 pts.	100 pts.	100 pts	100 pts	100 pts.	100 pts.	800 pts.	pts./8	
Road and Weather Information Via CB Radio (California)	-----Withdrawn-----										
Travel Time Estimates Based on Traffic Flow (California)	75	73	90	75	85	36	90	60	584	73	1
Intelligent Road Studs (California)	65	81	90	55	70	36	75	45	517	64.625	6
Real-time Information Indicating Crosswind and Gust Velocities with Respect to High Profile Vehicles to Prevent Overturning Crashes (Montana)	60	81	95	50	75	80	75	55	571	71.375	2
Standardized Road Reporting/Data Sharing (Montana)	40	71	70	40	70	40	80	15	426	53.25	10
Rural Travel Time Estimation (Oregon)	-----Combined with Travel Time Estimates Based on Traffic Flow (California) -----										
Highway Electrical and Lighting Monitoring System for Improved Maintenance of Safety Lighting at Rural Interchanges, Rest Areas and Comfort Stations (Texas)	50	81	90	50	60	80	65	80	556	69.5	4
High Water Level Sensors to Aid Maintenance Personnel's Rapid Response to Hazardous Water Crossing Locations (Texas)	65	68	100	55	65	36	85	85	559	69.875	3
Highway Advisory Radio Implementation on IH 35 and IH 10 Approaching San Antonio, Texas (Texas)	-----Withdrawn-----										
School Zone Flashing Beacon Pager Activation System (Texas)	-----Withdrawn-----										
Fog Detection System (Texas)	30	68	70	90	65	96	75	65	519	64.875	5
Advisory Speeds at Curve (Texas)	-----Withdrawn-----										
Moving Incident Detection for the City to the Country – Use of an On-demand Alarm Notification Enables Use of ITS Technologies in Rural Areas with Existing Communication Infrastructure (Texas)	30	68	80	45	80	36	75	50	464	58	9
Detecting and Disseminating Remote Weather/Traffic Information (Utah)	45	73	90	35	75	36	70	70	494	61.75	7
Intelligent Road Weather Information Systems (Utah)	-----Withdrawn-----										
Railroad Grade Crossing Project (Washington)	75	81	70	45	60	60	70	25	486	60.75	8

Table 3: Final Project Selection Scores and Rankings

	California	Idaho	Montana	Oregon	Texas	Utah	Washington	Wyoming	Total Point Score	Average Point Score	**Project Ranking**
Rural Travel Time Estimation (California/Oregon)	96	95	76	82	69	75	87	75	655	81.9	**1**
High Water Level Sensors to Aid Maintenance Personnel's Rapid Response to Hazardous Water Crossing Locations (Texas)	83	70	77	75	85	70	75	70	605	75.6	**2**
Highway Electrical and Lighting Monitoring System for Improved Maintenance of Safety Lighting at Rural Interchanges, Rest Areas, and Comfort Stations (Texas)	76	75	71	61	62	90	80	60	575	71.9	**4**
~~Fog Detection System (Texas)~~			Withdrawn because of duplication.								
Fog Detection for Improved Driver Guidance (California)	90	75	74	47	70	85	65	75	581	72.6	**3**

5. PHASE ONE: RESEARCH

In order to guide system design, development, deployment, and evaluation, WTI conducted research on previous efforts to deploy similar technologies.

5.1. Rural Travel Time Estimation System Research

5.1.1. Preliminary Review of Travel Time Estimation Systems

Prior to system selection WTI, in 1998, reviewed similar travel time estimation systems to learn from those experiences. A review of those systems is shown below.

Evaluation of Web Travel Time Estimates Released By FHWA

The Federal Highway Administration (FHWA) researched how the accuracy of travel time estimates on traveler information web sites affects user benefits. The report uses HOWLATE (Heuristic Online Web-Linked Arrival Time Estimator) to model the study based on archived Advanced Traveler information Systems (ATIS) travel time data in order to quantify the user benefits of regional ATIS deployment. The HOWLATE methodology quantifies time management benefits of ATIS use on a per trip basis for travelers who need to be on time.

Real-Time Traffic Speed Data Available to N. Virginia Commuters

Commuters in North Virginia have the ability to access travel times customized to their own routes. The program is available to WAP-enabled cell phones, wireless PDAs, and desktop PCs through a service provided by RatRaceUSA, Inc. Motorists are able to specify their own travel routes and access travel times on their chosen routes during commutes. The traffic congestion data is drawn from a network of 143 traffic sensor stations located throughout Northern Virginia's interstate highway system. The sensors gather data on travel speeds, lane occupancy, and vehicle counts. Data is then compared against historical average travel times and updated every minute.

Travel Time Estimates Using Transit Vehicles as Probes in Washington

Transit vehicles are being used as probes to estimated travel times in King County, Washington. These estimates increase the information density along the corridor, because previous efforts only used probe information at specified points. This system provides speed estimates that track the significant changes identified in inductance loop data.

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Overall Findings include:

- Real time travel time data becoming increasingly available.
- No consistent method for collection, fusion, and usage.
- Limited integration of real-time/historical data.
- Little focus on predictive/forecasted travel time data.
- Limited data available concerning arterials.
- Business model unclear.

- Benefits of travel time initiatives stem from increased coverage, not travel time itself
- Long term vision includes Automated Highway System with local deployments (10 yrs.), regional deployments (20 yrs.), and national deployment (30 yrs.).

5.1.2. Updated Review of Travel Time Estimation Systems

In 1998 initial research was conducted on the experience of other related travel time systems. This research was performed as part of the system requirements development step for the Rural Travel Time Estimation System project. At that time, there were only a few examples of existing travel time systems. Since that time, however, there have been several more applications of travel time estimation systems. This section presents a summary of updated comparative research on travel time systems (completed in 2002), which is shown in Table 4. The full paper containing the details of the research can be examined in Appendix C, including reference citations.

Table 4: Summary of Travel Time Systems Research

Location	Technology	Comments
Houston, Texas US 290	AVI (electronic toll tags at 0.5 mile spacing)	Study concluded that AVI could be economically used to collect travel time data
San Antonio, Texas IH-35	Loop detectors at 0.5 mile spacing	Study concluded that reasonable travel time data could be collected from loop detections
Columbus, Ohio I-70	Microwave radar detectors in a work zone	Study concluded that work zone travel times were accurately represented
Colorado I-70	Vehicles with GPS	Study concluded that number of probes needed to be increased to acquire more accurate/timely data
Boston, MA Central/Artery Tunnel	Loop detectors at 0.25 mile spacing	The system provided accurate real-time travel time information
Washington, DC CAPITAL ITS Operational Test	Utilized cellular phone tracking	Study concluded that geolocation of cell phones was not accurate enough to produce reliable travel time results
Western Massachusetts Route 9	License Plate reading technology	The study concluded that the system provided accurate travel time data over a 3.7 mile long roadway segment
Indiana	License plate reading technology	The study concluded that the equipment was too expensive to install and maintain for IDOT.
Florida SR 436	License plate reading technology	The study concluded that accurate travel time data was provided for a 2.2 mile segment
Transportation	Probe Vehicles	Established 5% threshold for

Research Board		determining accurate data when using probe vehicles for freeway travel time estimation

5.2. High Water Level Sensor Project

This section presents a summary of updated comparative research on high water systems (completed in 2002), which is shown in Table 5. The full paper containing the details of the research can be examined in Appendix D.

Table 5: Summary of High Water Systems Research

Location	Technology	Comments
Houston, Texas	29 weather and high water monitoring sites	Study concluded that the public used the additional weather information via website and signage
Dallas, Texas	42 weather and high water warning sites	Initial study was successful and the City expanded the system to a current total of 42 sites
Maricopa County, AZ	238 rain gauges, 136 stream gauges, and 22 weather stations	Created ALERT system after floods in late 1970's, and have been expanding it ever since
Savannah, GA	1 high water site with float gauge and CMS	Tested system at one location and in process of expanding to 40 other locations
Florida DOT	Numerous high water warning and weather stations sites	Successfully tested and then implemented system throughout southern Florida

The research showed that many DOT's, cities, and counties throughout the country have successfully tested and implemented high water warning systems. However, most of these systems, unlike this project, are in urban areas.

6. PHASE TWO: DEMONSTRATION

The purpose of this section is to summarize the deployment phase of the two TAC selected projects. Each project took a different deployment approach. For the Rural Travel Time Estimation Project a general system engineering process was followed: applicable technologies were reviewed then a vendor was selected through a competitive open bid process. For the High Water Level Sensor project, TxDOT developed a concept of operations, then technologies were determined and a pre- qualified vendor was selected for system implementation. The effectiveness of these approaches will be compared and contrasted in Conclusions section of this the report, but the approaches are important to highlight for this section.

6.1. Rural Travel Time Estimation System

Travelers routinely complain about lack of real-time information about trip duration on the highway. Detection of and response to incidents has been an ever-growing concern, and notification of the traveling public about incidents and, more importantly, expected delay/travel time is essential. To address these needs, the FRONTIER Project TAC selected a rural travel time estimation system for deployment and demonstration in Oregon to inform motorists and maintenance workers of possible delays or incidents.

6.1.1. Study Corridor

The Rural Travel Time Estimation project used vehicle identification technologies to provide travel-time estimates for two contiguous highway segments: on Oregon Highway No. 39 (Salmon River Highway), MP 0 to MP 25, and US 101 between Lincoln City and the US 101/Highway 39 junction (Figure 2).

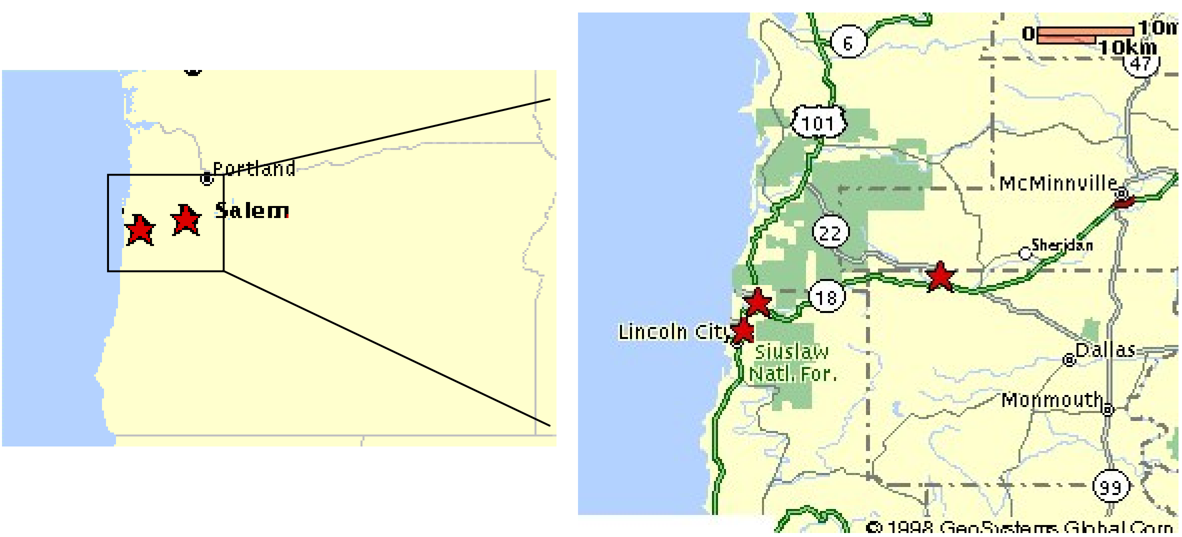


Figure 2. Rural Travel Time Estimation Project Limits

This stretch of highway is a significant rural travel corridor in the region and also connects two large tourist attractions: a casino on one end and Lincoln City, a popular coastal destination also with a casino, at the other end. The highway is mostly two lane, and traverses the Siuslaw

National Forest. 2002 ADT was 19,600 (17,881 in 1997), with the highest volume on a single day being 28967, which occurred in 1997. ADT from 1993 through 2002 is displayed in Figure 3.

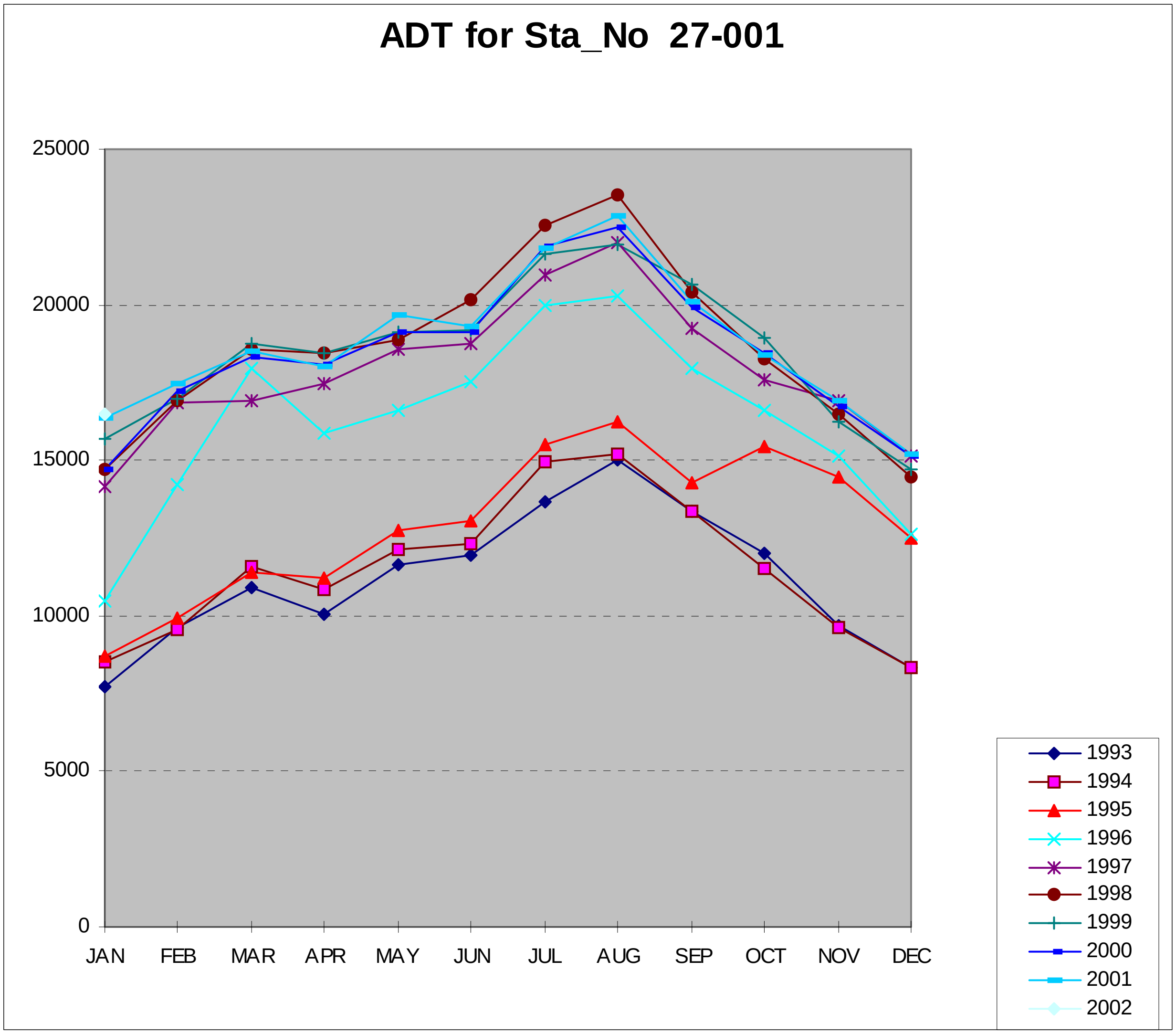


Figure 3. Oregon Highway 39, Salmon River Highway ADT

Congestion and incidents are a common occurrence on this corridor due to several factors, including a combination of inconsistent cross-sections, a high percentage of slow moving trucks and campers/mobile homes (about 10% of ADT), passing opportunities that are few and far between, mountainous terrain and speed zones (Figures 4, 5).

Figure 4. Salmon River Highway Access

Figure 5. Spirit Mountian Casino

6.1.2. General System Requirements

The systems engineering, deployment and implementation process consisted of three steps:

- defining general system requirements,
- soliciting, reviewing and selecting an outside contractor for system design and implementation, and

- overseeing system implementation

The WTI research team defined the general system requirements at each demonstration site. These requirements varied depending on existing site conditions, specific benefits to be realized and existing infrastructure that required integration. The general system requirements guide an outside contractor in determining if they can meet the needs of the system and at what cost.

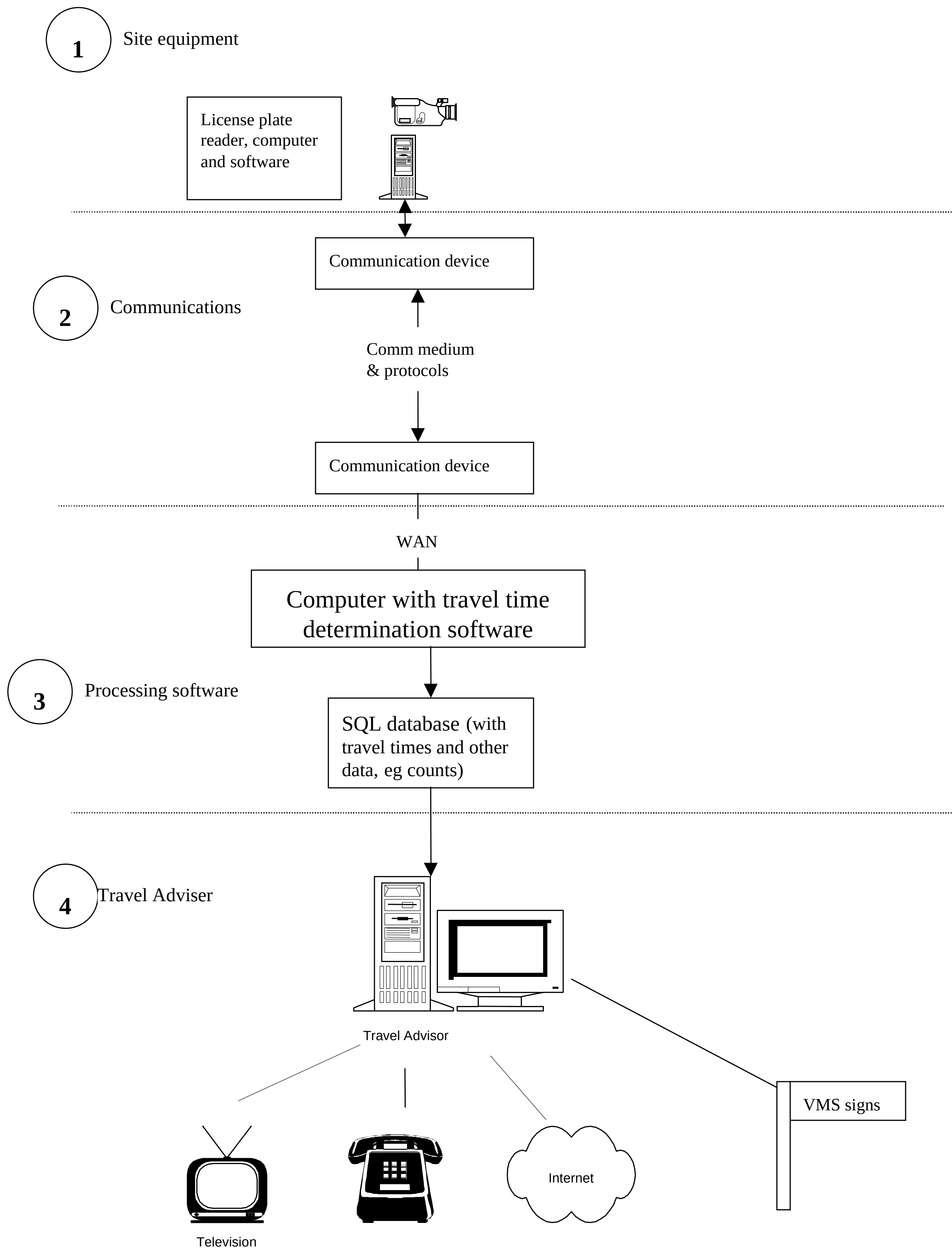
The general system requirements were presented to TAC members at the TAC meeting. All TAC members were encouraged to actively participate in the definition of system requirements. This approach was intended to produce system requirements that not only met the specific needs of this project, but that would also be widely transferable to other states.

Specific system objectives of the project were to:

- provide continuous real-time trip duration estimates that would feed into Oregon's Traveler Information System to provide pre-trip travel estimates, and en-route travel information.
- investigate vehicle identification technologies and how to deal with privacy issues
- facilitate faster rural incident detection and response
- integrate with the existing Traveler Information System
- provide a system solution for travel time information for FRONTIER states.

The system was envisioned to have four main components (Figure 6):

1. The onsite equipment that would do the data acquisition, selected to be easily interchangeable.
2. The communication component includes the actual communication medium and protocols, together with any devices (eg modems) that connect field equipment to ODOT's Wide Area Network
3. The processing software has an open architecture at both its data input and data output ends. (Data input comes from the site equipment and data output goes to a Traveler Information System server - a Microsoft SQL database format for the output is probably be the most compatible for most agencies.) The openness of the architecture is essential in ensuring interfaces with FRONTIER member states' traveler information system needs.
4. The ATIS server software that would provide for the dissemination of the travel time information using a browser interface on ODOT's website. [Note: ODOT currently offers a speed map on its TripCheck website (www.tripcheck.com) that provides speed data for the Portland urban area.]



5.

Figure 6. Travel Time Estimation Project Concept of Operations of Operations

The project establishes three checkpoints as indicated on the above map at which vehicle identification technologies were implemented. The US 101 section is considered essential because often times congestion on this short section occurs irrespective of the congestion level of the other stretch, and is thus a concern for motorists planning to travel on this segment.

License plate recognition (LPR) were recommended for this project. The system incorporates algorithms to track vehicles moving past consecutive checkpoints, calculates a real-time moving average of travel times, and provides this information to motorists.

The three locations selected as checkpoints for onsite installations are:

1. OR 22/ Hwy 39 intersection (Valley Junction), MP 23. This location has an existing ODOT camera installation, and hence has a pole, a cabinet, power and a phone line. The site has no nighttime illumination
2. US 101/ Hwy 39 junction, MP 0.34 . This site has a cantilevered sign support that extends over half highway. The sign is illuminated and therefore power is readily available, and there is a telephone riser box about 230 feet from the cantilever support. The site has minimal artificial lighting.
3. US 101 at West Devil's Lake Road, the first signalized intersection in Lincoln City. The site has power, communications availability, and street lighting. A nearby DMV office provides possible easy access to ODOT's WAN. The highway has multiple lanes in this section, but has one through lane (see Figure 7).

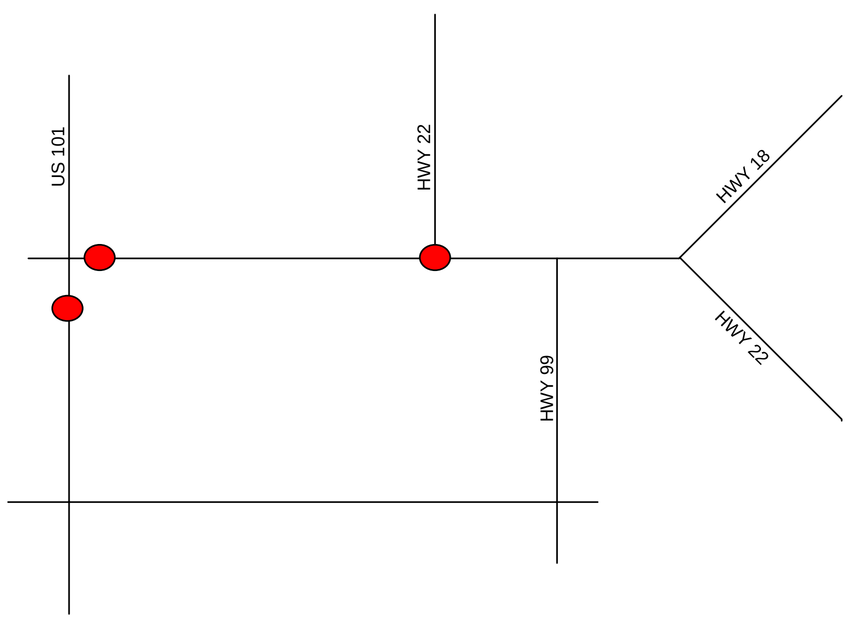


Figure 7. Proposed Camera Monitoring Sites

This travel estimate is then fed into the Traveler Information system. ODOT deploys portable VMS signs at strategic decision points leading to this corridor to help travelers chose the route of preference. (An alternate route to the coast is available.)

The estimated average can also be compared to a pre-established free-flow (or more appropriately ‘normal uncongested’ flow) travel time. Significant differences alert a dispatch/maintenance station for proper response after the incidents (if any) are verified. It was not certain how timely this incident detection would be, but it served as a basis for possible further refinement.

6.1.3. System Selection Process and Deployment

Once the general system requirements were finalized soliciting, WTI and the TAC began the process of reviewing and selecting an outside contractor for system design and implementation, and overseeing system implementation.

6.1.4. Solicit, Review and Select System Design and Implementation Contractor

A competitive process was used to select a vendor for system design and implementation. The Montana Department of Transportation, acting as the administrative agency for this effort, was responsible for *contracting* with the selected vendor. However, the TAC members *selected* the vendor. General system requirements were distributed to interested vendors. Proposals/cost estimates were submitted. Selection criteria were based on cost, previous success with similar systems and timeliness. Once the TAC selected a vendor, close cooperation between the vendor and the WTI research team took place to ensure that the system met previously specified general system requirements. The vendor was responsible for ensuring system reliability. Again, TAC members who were not directly affected by the selection of a vendor for a particular project (i.e., there are no demonstration projects in their state), were encouraged to share their knowledge with the other TAC members.

Investigations and literature review of the current technology revealed three potential vendors. Their products, services, and bids are included in the original project proposal in Appendix A.

6.1.5. Oversee System Implementation

System success depends heavily on the system’s ability to meet the specified functional requirements and to operate effectively. If problems exist with the operation of the overall system or any of its components, the evaluation of the system will be skewed. The WTI research team relied heavily on the respective state departments of transportation who oversaw the implementation of the system at each demonstration site. Adherence to the National ITS Architecture and state-developed ITS standards was monitored cooperatively by the WTI research team and the respective state representatives.

6.1.6. System Description

The FRONTIER Rural Travel Time system consists of six license plate recognition cameras mounted on poles above the roadway placed at two locations on OR-18 and one location on US-101 just north of Lincoln City as shown in Figure 8 and 9. Each installation consists of two cameras, one for each direction. The distance between cameras 2 and 3 (Segment 1) is 3.15 miles and the distance between cameras 1 and 2 (Segment 2) is 22.25 miles. The total corridor length is 25.4 miles.

Figure 8 Camera Installation Sites

Figure 9. Typical Camera Pole Mounting Installation

The FRONTIER Travel Time system logic was previously shown in Figure 6. The license plate reading cameras used for this research are made by Telematica Systems Limited (TSL); TSL is an associate company of the Trafficmaster group and describes the system as Passive Target Flow Measurement (PTFM). The system uses infra-red technology to read license plates for travel time measurement. Similar to the London Congestion Charging system, the cameras along the corridor are calibrated to recognize the license plates of passing vehicles. The license plate numbers are privacy-protected numbers with encryption, and time-stamped tags are sent via telephone communications network to the central server. The server matches the timestamped tags collected at different checkpoints to identify vehicles that have passed between two or more locations. Using the matched vehicles passage times and the distances between observations, the system estimates the travel time between segments based on an algorithm that also incorporates the number of vehicles passing the license plate readers and presumably other quality control factors. [The camera system is proprietary and therefore this research did not have access to nor test the algorithms used to predict the travel times.] If fully and permanently deployed, the FRONTIER Rural Travel Time system could eventually provide travel information to motorists via portable variable message signs (VMS) along the corridor, ODOT's statewide traveler information system TripCheck (www.tripcheck.com), and the statewide traveler information 511 system. Motorists could then presumably choose alternative routes and make travel decisions based on the travel time estimates.

6.1.7. System Deployment Timeline

The purpose of this section is to summarize the actual deployment timeline of the Rural Travel Time Estimation project, and how it varied from the original project plan. Some of these deployment changes are directly relevant to the subsequent evaluation of the deployment effectiveness.

The FRONTIER project was initiated in 1998. The initial year of the project was spent in development of the project hypothesis, and development of project ideas to test the hypothesis. Once project ideas were developed, WTI and the TAC went through a detailed evaluation of potential projects and made selections in 1999.

Once the travel time project was selected, the ODOT initiated its normal bidding process. Bids were put out in 2000, and after the most appropriate bid was selected, the project was deployed in 2001.

The travel time system worked well initially (in March and April of 2001), but then developed a series of malfunctions that rendered the data collection useless. ODOT and the vendor repeatedly attempted to fix problems, ranging from software issues to field equipment failures. However, the system was not fully functional until the summer of 2004. During this time period, WTI and PSU could not collect any usable data. PSU was under contract to collect travel time data in 2002.

The duration of the rural travel time estimation project extended longer than anticipated for several reasons.

- The project bidding and deployment process took longer than anticipated.
- System failures occurred immediately after deployment, which delayed collection of data
- The travel time system did not work properly until the summer of 2004.

During the time periods when the system was not functioning, WTI minimized project efforts and expenses to save resources for when data was collected. There were several discussions with TAC members about whether or not to continue or stop the project, and each time the decision was made to continue to wait for good data collection.

After the data was collected in summer/fall of 2004, work began on analyses of the data and development of the final report. Data analysis and the final report were completed within 6 months of the end of the data collection period.

6.2. High Water Level Sensor Project

Weather and its related impacts are a significant issue to the safety of travelers and the operations of the transportation systems in rural America. Flooding and rapidly rising water have a significant impact on many transportation systems, and as such TxDOT was interested in this second FRONTIER demonstration project.

6.2.1. Study Corridor

The second TAC selected project was the Highway Water Level Sensor. The site for this project is located in Wise County, Texas on Farm-to-Market road 3259 near the town of Paradise (Figure 10). The facility is a two lane, undivided, asphaltic concrete pavement surface connecting Farm-to-Market road 51 to State Highway 114. The specific site is a crossing of the West Fork of the Trinity river. In 2003, the AADT for this road was 1,800.

According to the TxDOT Wise County Resident Area Engineer, the hazardous high water conditions at this site actually occur on the approaches to the structure over the Trinity river, rather than at the structure itself (Figure 11).

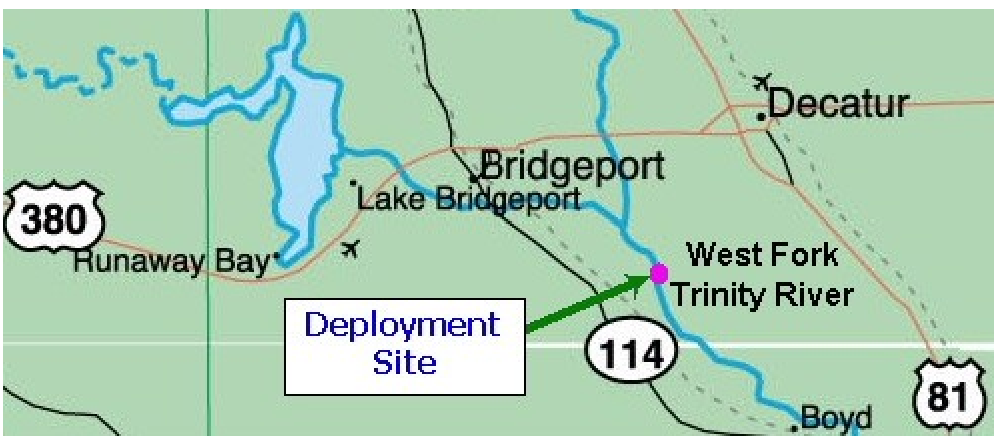


Figure 10 Highwater Level Sensor Project Study Site

Figure 11. Approaches to Trinity River Bridge on FM-3259

6.2.2. System Requirements

The objective of this project was to provide critical real-time warning of roadway flooding conditions, both on-site to the motorists directly affected by the condition and remotely to TxDOT – Fort Worth maintenance residency. This real-time warning was intended to generate the lead-time necessary for maintenance/operations personnel to respond to the conditions and determine the need for a road closure, or other corrective actions, to protect motorist safety. The project's control systems would not initially be integrated with the department's existing Intelligent Transportation System (ITS) initiative, known as TransVISION. The project would function as a stand-alone initiative for rural ITS applications, and to evaluate the effectiveness and efficiency of the concept and equipment. If the concept is viewed as proven, the next anticipated actions would be to expand the coverage of this proposal to other sites in Wise County and in the other counties served by this district.

6.2.3. System Description

High water level sensors were used to monitor the surface water depth in flood-prone areas, in order to aid maintenance personnel's rapid response and to enhance the traveler safety. The real-time and predictive information was collected to improve the reliability and timeliness of advice given to motorists. This project placed commercially available infrared water level sensors at critical locations on each approach to the site. The sensors were placed to provide the first warning, or alert mode, when water was within six inches of reaching the roadway surface (Figure 12). The second sensor was placed to provide the second warning, or alarm mode, when water reached the roadway surface. Each sensor installation contained two mechanical float switches, and a local controller equipped with a Variable High Frequency (VHF) radio transceiver and a solar power system. The VHF transceiver provided local interconnection with the two advanced signing installations (Figure 13).

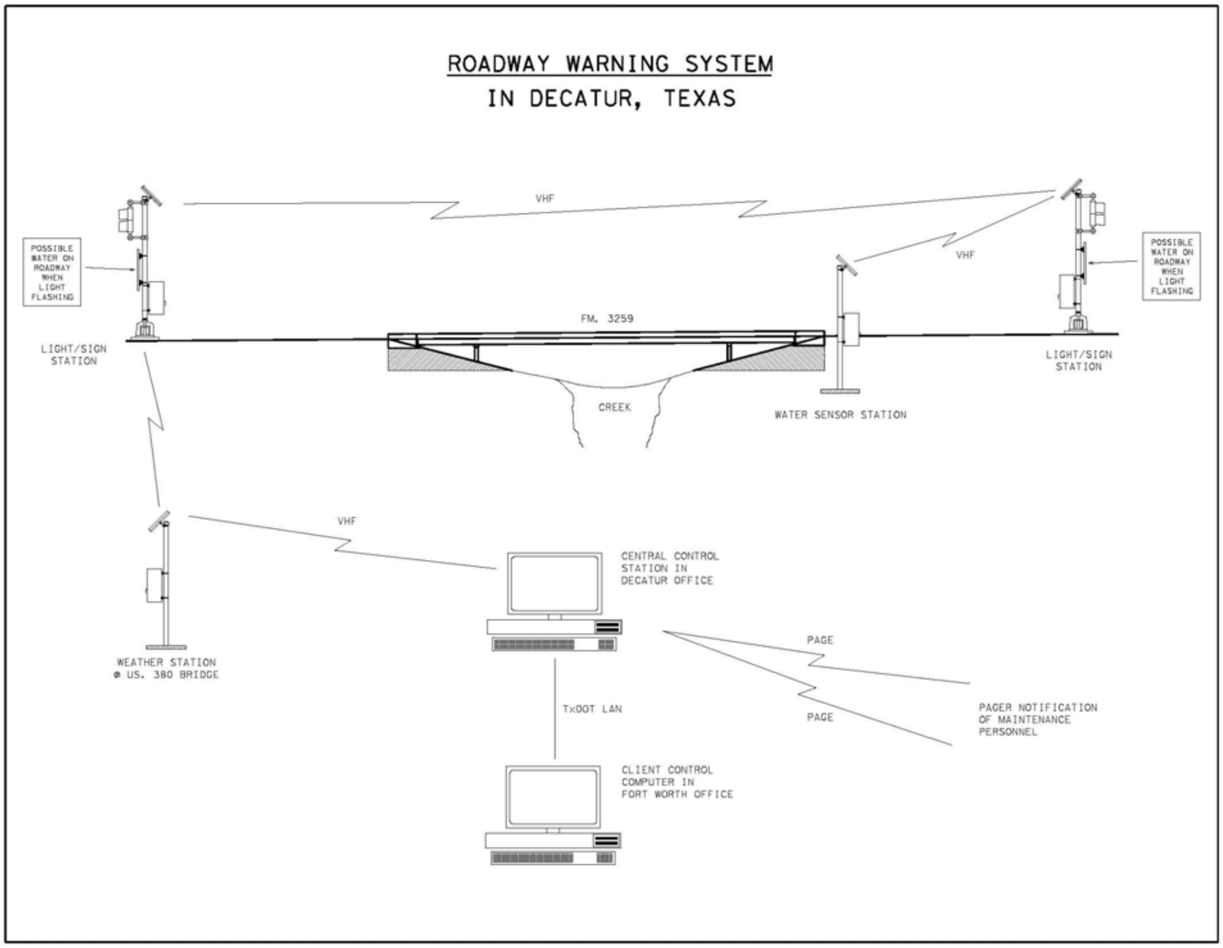


Figure 12: Conceptual Design for High Water Warning System

The advanced signing installations were placed approximately ¼ mile from the affected approach(s). The sign installations were configured to activate amber LED flashers when either sensor station provided a first level warning, or alert. The amber LED flashers accompanied the default signing display of “Possible Flooding / Water over Road / When Flashing”. When either sensor station activated a second level warning, or alarm, both signing installations activated red LED flashers and changed the accompanying signing display to “Do Not Enter / High Water”. These signing installations also contained a pole mounted NEMA enclosure housing a controller, along with a mechanical changeable message sign (CMS), red and amber Light Emitting Diode (LED) flashers, solar power system, and VHF radio transceiver for interconnection with each other and the sensor assemblies. One of the signing installations was designated as the master and contained a cellular telephone for communications with the central computer (Figure 14).

A central computer equipped with the vendor’s software provided a “base station” for monitoring sensor outputs remotely. The base station provided a “heartbeat” function to monitor status sensors, batteries and other field components. The base station also provided the ability to reset the field components condition or over-ride a local reset based on maintenance personnel’s evaluation of conditions (Figure 15).


Figure 13 Roadway and Water Level Sensors

Figure 14 Advanced Signing Installation

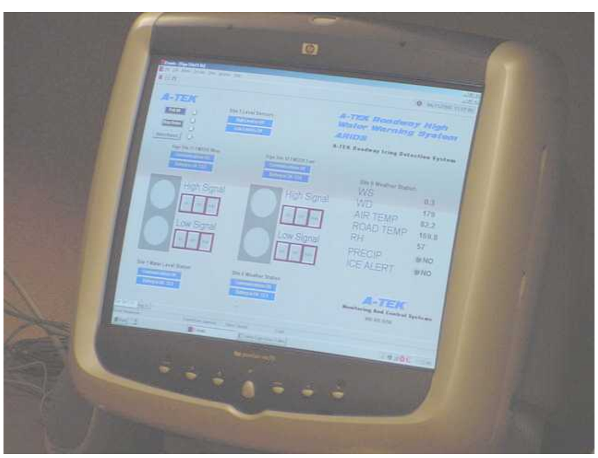



Figure 15 Field Communications System

The central computer also employed a pager notification system to ensure appropriate personnel were aware of the changing conditions, especially outside normal business hours when office personnel may not be monitoring the base station.

6.2.4. System Deployment Timeline

The purpose of this section is to summarize the actual deployment timeline of the High Water Level Sensor project, and how it varied from the original project plan. Some of these deployment changes are directly relevant to the subsequent evaluation of the deployment effectiveness.

The FRONTIER project was initiated in 1998. The initial year of the project was spent in development of the project hypothesis, and development of project ideas to test the hypothesis. Once project ideas were developed, WTI and the TAC went through a detailed evaluation of potential projects and made selections in 1999.

Once the high water project was selected, the Texas Department of Transportation (TxDOT) went through its normal bidding process. Bids were put out in 2000, and after the most appropriate bids were selected, the project was deployed in 2001.

The high water system installation had several problems, including a lightening strike that took out several system components. However, the vendor and TxDOT had the system fully operational again in 2002. The next issue became an ongoing drought in Texas, which hindered the potential for any flood events. Since the project inception, there were no flood events until the summer of 2004.

The duration of this project extended longer than anticipated for several reasons.

- The project bidding and deployment process took longer than anticipated.
- System failures occurred immediately after deployment, which delayed collection of data
- The high water site did not flood until 2004

During the time periods when the system was not functioning, or there were no flood events, WTI minimized project efforts and expenses to save resources for when data was collected. There were several discussions with TAC members about whether or not to continue or stop the project, and each time the decision was made to continue to wait for good data collection.

After the data was collected in summer/fall of 2004, work began on analyses of the data and development of the final report. Data analysis and the final report were completed within 6 months of the end of the data collection period

7. PHASE THREE: EVALUATION

The purpose of this section is to describe the evaluation process, and then summarize the principal evaluation results for each of the two Frontier projects.

7.1. Evaluation Planning Process

The planning process of quantifying ITS benefits at each of the selected demonstration sites was accomplished through four tasks:

- conducted a state-of-the-practice literature search of related evaluation plans, including TEA-21 ITS evaluation guidelines
- documented existing conditions at each demonstration site,
- conducted meetings with TxDOT and ODOT representatives to identify their evaluation objectives, and
- based on discussions with site demonstration DOT's, WTI developed an evaluation methodology and plan which was presented to the TAC in the spring of 2002 at the Rural ITS conference in Monterrey, CA. Based on the TAC comments, the evaluation objectives were refined and evaluation scope of work prepared.

7.1.1. Evaluation Objectives

It is anticipated that if the rural ITS project were successful at the test site, similar projects would be introduced and implemented regionally and nationally. Therefore, the objective of these evaluation projects was to determine whether the deployed systems were a good investment. Specifically, each evaluation intends to answer the following questions:

- Is the overall safety improved, in terms of reduction in incident detection time and accident frequency?
- Is the overall mobility improved, in terms of decreased travel time delay and/or better customer satisfaction?
- Is the overall efficiency improved, in terms of increased throughput or effective capacity?
- Is the overall productivity improved, in terms of cost savings?
- Is the information provided to DOT maintenance personnel valuable in their operations?
- Are motorists responding to the information presented to them?
- Are the technologies accurate, reliable, and easy to use?

7.1.2. Evaluation Plan

Based on the TEA-21 ITS evaluation guidelines, it was envisioned that the following tasks will be conducted as a part of each evaluation. These tasks are described below.

Task 1: Project Management

Critical to the success of this and any project is the development of an appropriate project scope to provide initial direction and ongoing guidance for the evaluation team. This task covers overall project management activities that may assist in promoting communication between project sponsors and the evaluation team.

Task 2: Safety Data Analysis

The purpose of the safety data analysis is to determine whether the implemented systems improve the overall safety at the deployment site. Relevant data will be collected from the DOT maintenance residency for the before/after comparison. If enough data are available, the hypothesis that the ITS system significantly improves the overall safety of the site will be tested, using speed studies or other appropriate studies for the site.

Task 3: Mobility Data Analysis

The purpose of the mobility data analysis is to determine whether the implemented ITS system improves the overall mobility at the deployment site. Travel time delay data will be collected from the DOT maintenance residency for the before/after comparison. Should such data be not available, the change in travel time delay perceived by customers will be collected from a motorist survey or other appropriate tool.

Task 4: Efficiency Data Analysis

The purpose of the efficiency data analysis is to determine whether the implemented ITS system improves the overall efficiency at the deployment site. Throughput or effective capacity data will be collected from the DOT maintenance residency for the before/after comparison.

Task 5: Cost Savings Analysis

The purpose of the cost savings analysis is to determine whether the implemented ITS system improves the overall productivity at the deployment site. The cost of this implemented ITS system will be compared to traditional system designed to address the same problem. Since there can be significant liability exposure for non-action in the hazardous traffic situations, the saved liability costs will be taken into consideration during the analysis.

Task 6: Maintenance Survey

Maintenance staff will be surveyed to determine what effects the real-time data had on maintenance operations near the deployment site.

Task 7: Motorist Survey

Motorists will be surveyed to determine the perceived benefits and effectiveness of the system. This survey will address questions concerning whether motorists noticed the signs and what effect did this have on their behavior.

Task 8: Technology Assessment

The purpose of this task is to assess the accuracy, reliability, and easiness to use of technologies applied in this deployment. Such information will be obtained through a combination of interviews with maintenance staff and hands-on operations by WTI staff. The reliability will also be established through reviews of maintenance records.

Task 9: Final Report

This task will accumulate and summarize the key findings from earlier tasks as well as address whether the initial goals and objectives of the project have been met and/or surpassed. Recommendations for further applications will also be discussed.

The full evaluation plans for two projects are included in Appendices E and F.

7.2. Rural Travel Time Estimation System Evaluation

7.2.1. Operational History

The Rural Travel Time Estimation System project was deployed in the spring of 2001. During the initial first two months (March and April of 2001) of system operation, the system was working and providing data. This data was used for some of the initial evaluation analyses. After some initial adjustments in May and June, the system collected additional data for the month of July (2001). After July 2001, the system failed to collect reliable data until the summer of 2004. As discussed previously, the system has not provided reliable, consistent data, because of variety of problems. These problems included system component failures, adjustment problems with cameras, and software problems. The main problem that kept the system non-functional for a long time was a faulty power supply model. The correct replacement part was not received from the vendor for almost a year.

Once ODOT received the part, the system was not fully repaired for nearly another year. This was due to the priorities of ODOT maintenance staff. ODOT maintenance staff attributed a low priority to restoring the system, since it was not critical to the safe operation of their roadway network, and there were a backlog of critical maintenance activities.

Since 2002, WTI and Portland State University (PSU) were on-hold waiting for the system functionality to be restored to conduct travel time studies and other data. In the summer of 2004, the system was finally repaired and functional, and PSU collected travel time data. Ironically, during this data collection effort, the system failed to collect any data for the eastbound direction on the second day.

Since the date of system turn on in March of 2001, the system has worked accurately for all segments for only three out of forty months (less than 1% of the time). It is worth noting again that for the field tests conducted in July 2004, the system was working on the first day, and failed the second day of tests.

ODOT has indicated that they will remove the system once the study is completed, to avoid further burdens on their maintenance staff. The reliability of the travel time system has been marginal, and it has been difficult for ODOT to dedicate maintenance personnel to the system. In conclusion, the inability of the system to work reliably greatly impacted the evaluation effort.

7.2.2. Initial Analysis of Travel Time Data

This section contains an initial analysis of available system data. Data was available from system archives for March, April, and July of 2001. The system was working reliably during this time period, shortly after it was installed. During the initial test phase of the system, the system was operational for March and April of 2001. The system then went through some modifications, and again was recording valid data for July 2001. After July 2001, the system did not record valid data till the repairs were complete in the summer of 2004.

Unfortunately during this time of initial system installation, no travel time studies/real-time data were collected. Thus a detailed comparative statistical analysis of the data cannot be made of this initial data. However, a detailed analysis is presented for the system for data collected in 2004 later in the report.

7.2.2.1. Link Descriptions

The system has three camera sites and four defined links along the Salmon River Highway. Link #1 is from Valley Junction to Otis, in the westbound direction. Link #2 is the corresponding link in the eastbound direction. Links 1 & 2 were set-up as the long distance links, and the distance between camera locations is approximately 22 miles. Links 3 & 4 are shorter links, from Otis Junction to Lincoln City, a distance of approximately 3 miles. The camera site is located just east of Lincoln City. Figures 16 and 17 show the corridor.

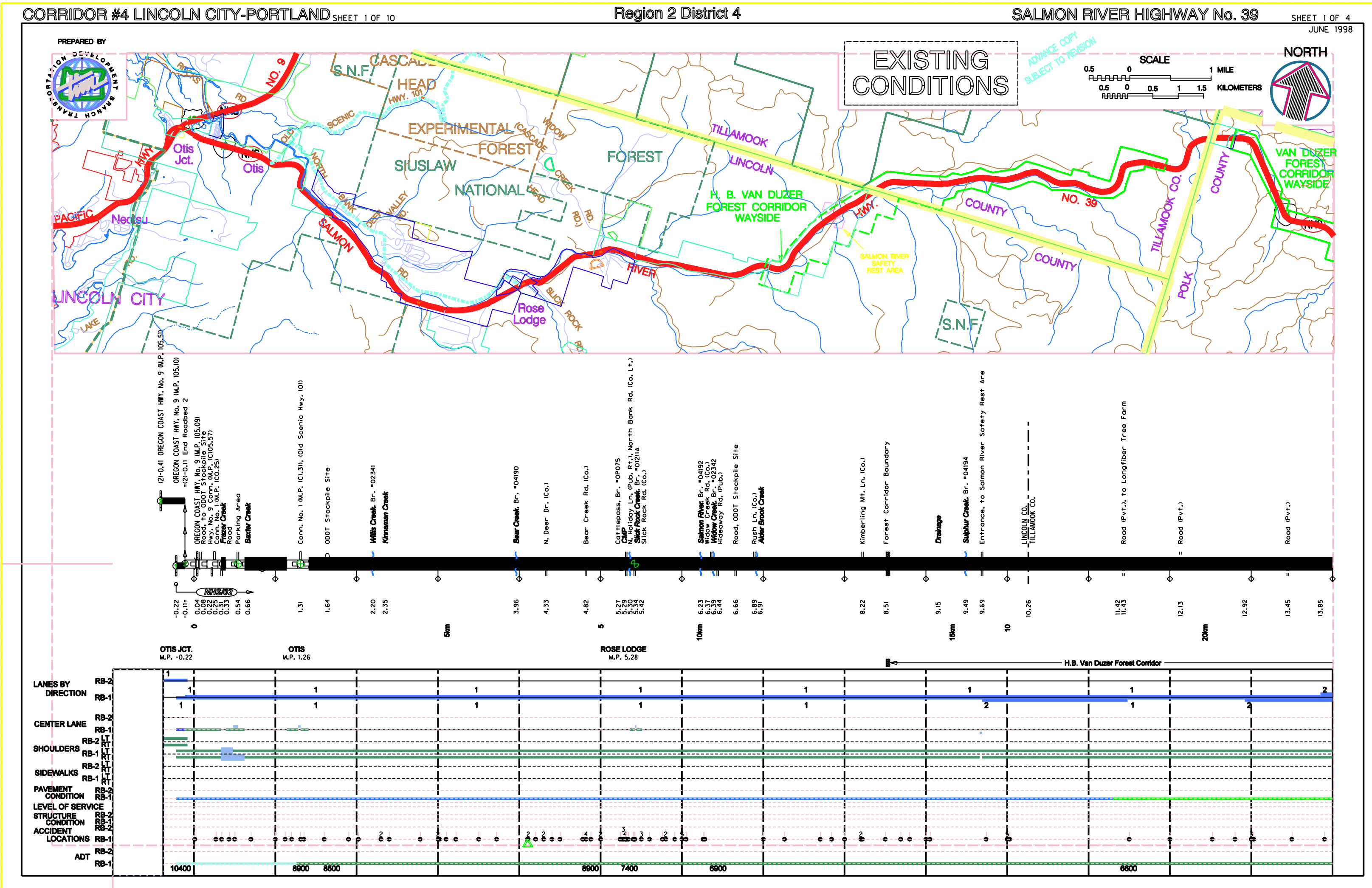


Figure 16: Corridor Map for Links 1 & 2

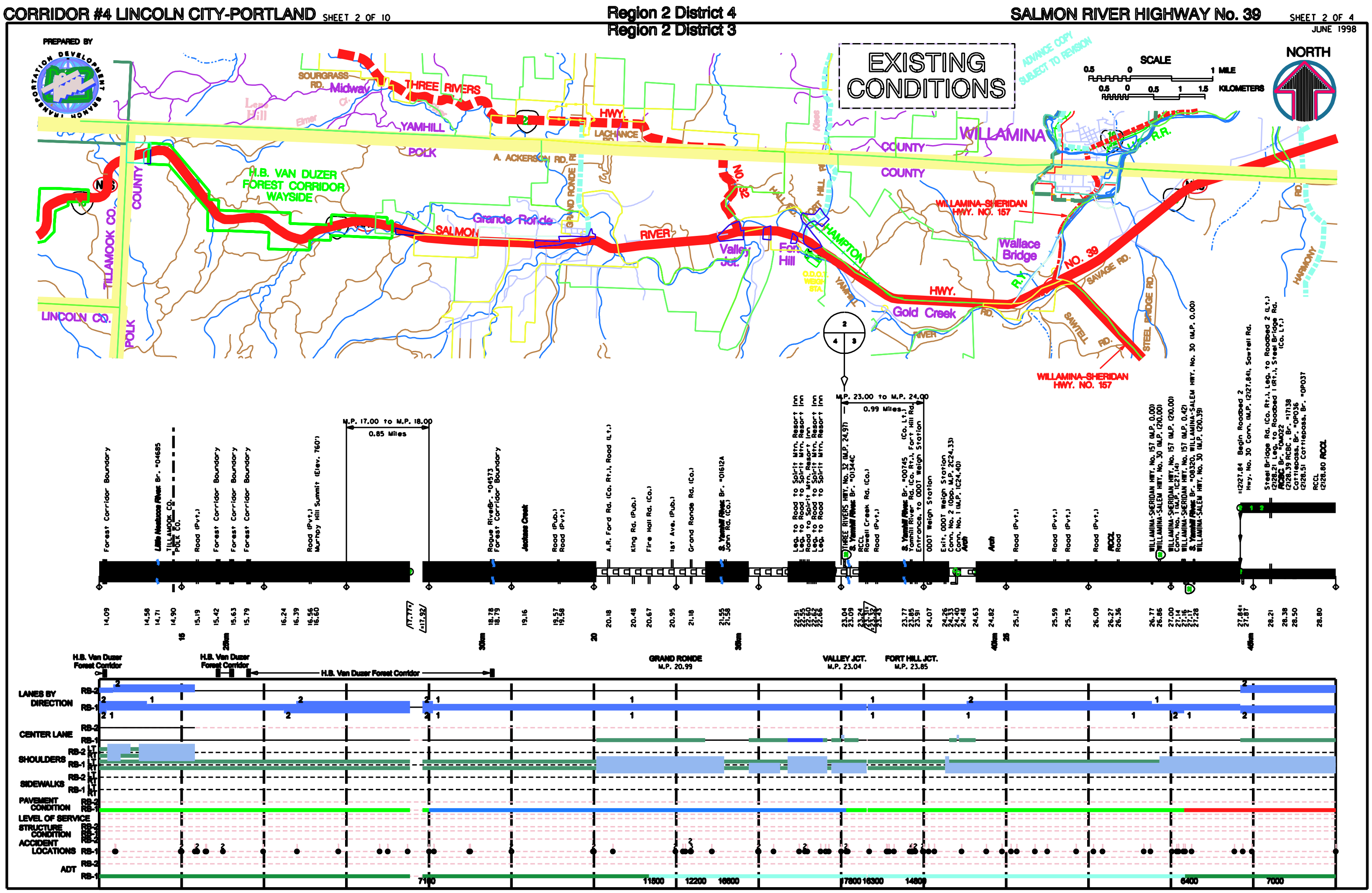


Figure 17: Corridor Map for Links 3 & 4

7.2.3. Sample System Data

The system records a variety of data for each car that passes, including the license plate information. The data is stored in a SQL database, and for each record, includes

- Numeric link Identification
- Textual description of the link
- Upstream site Identification
- Downstream site Identification
- Calculated Standard Journey Time (SJT)
- Current Average Journey Time (AJT) from the Matcher
- Calculated delay time (AJT – SJT).
- Calculated speed

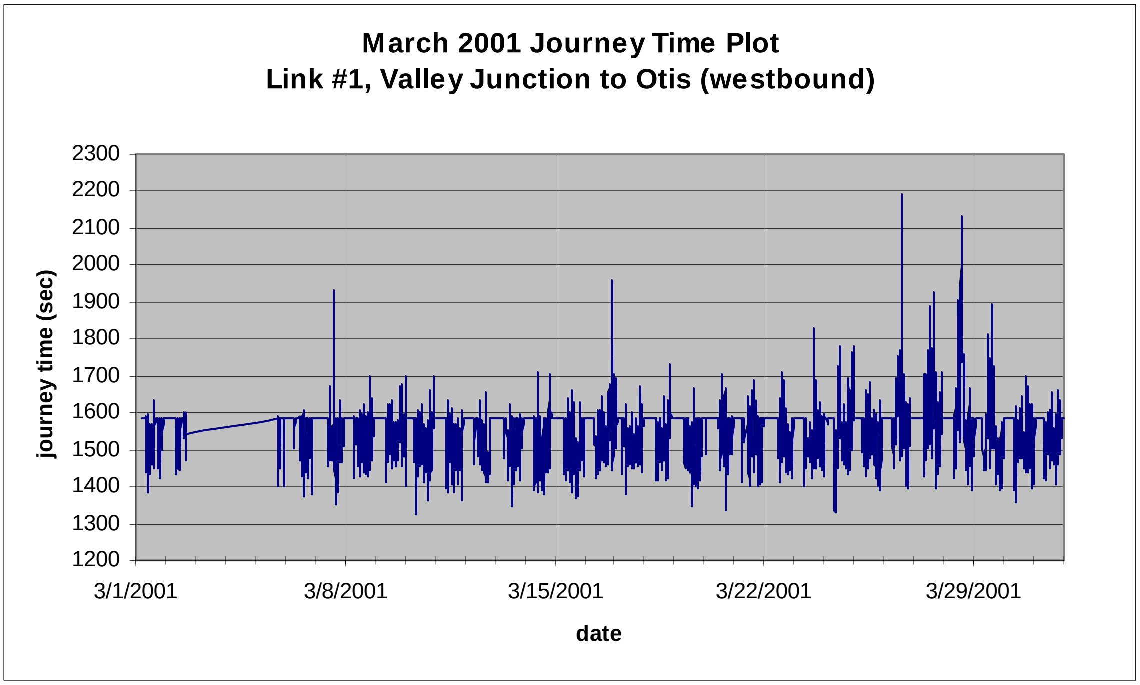
For this analysis, the relevant data was the link identification, Date/time stamp, journey time, and number of matches. A sample of the database output from the system is shown in Table 4. This sample shows data that was cleaned and sorted, i.e., data records with no matches were eliminated, data records with results outside of normal parameters were eliminated, and the data was sorted chronologically.

Table 6: Sample of Sorted Data Output from Travel Time System

	March 1-31, 2001			
Link ID	**Date/Time**	**Journey Time (minutes)**	**# matches**	**JT (sec)**
1	3/1/2001 4:05	26.38	1	1583
1	3/1/2001 7:05	26.38	1	1583
1	3/1/2001 7:09	26.38	1	1583
1	3/1/2001 7:11	26.38	1	1583
1	3/1/2001 7:33	26.38	1	1583
1	3/1/2001 7:39	26.38	1	1583
1	3/1/2001 7:45	26.38	1	1583
1	3/1/2001 7:53	26.38	1	1583
1	3/1/2001 7:55	26.38	1	1583
1	3/1/2001 7:57	24.47	1	1468
1	3/1/2001 8:01	24.47	1	1468
1	3/1/2001 8:05	25.05	2	1503
1	3/1/2001 8:15	23.98	1	1439
1	3/1/2001 8:21	25.42	3	1525
1	3/1/2001 8:41	26.38	1	1583
1	3/1/2001 8:59	23.03	1	1382
1	3/1/2001 9:05	24.82	1	1489
1	3/1/2001 9:09	25.42	1	1525
1	3/1/2001 9:13	24.30	1	1458
1	3/1/2001 9:15	24.42	1	1465
1	3/1/2001 9:21	24.55	1	1473

Figure 18 shows a plot of the travel time information for March 2001, for Link #1. The plots show the fluctuations in travel time over the month.

Figure 18: Sample Plot of Travel Time Data for March 2001



7.2.4. Data Results for Link 1, Valley Junction to Otis (westbound)

This section summarizes the results of the available data for Link #1 from March, April and July of 2001. Table 7 shows a summary of the average daily traffic volumes compared to the match data collected by the system. For March 2001, the total number of vehicles traveling westbound was 286,161. Out of this pool of vehicles, the system matched 13,499 vehicles traveling from camera site A to camera site B, which equates to a 4.7% match rate and about 435 matches per day during March. Table 7 summarizes the same information for April and July 2001.

Table 7: Traffic and Match Summary for Link #1

March 2001 Link #1				
	Total	**Westbound**	**Total WB for March**	
ADT	18521	9231	286161	
# records		6418.0		
# matches		13499.0	4.7%	
# matches/day		435.45		
April 2001 Link #1				
	Total	**Westbound**	**Total WB for April**	
ADT	18005	8924	267720	
# records		6467		
# matches		11386	4.3%	
# matches/day		379.53		
July 2001 Link #1				
	Total	**Westbound**	**Total WB for July**	
ADT	21809	10842	336102	
# records		3782		
# matches		8290	2.5%	
# matches/day		267.42		

Table 8 summarizes that travel time data statistics for Link #1. The table shows the average, median, mode, maximum, and minimum speeds for the link during each of the three months. The “average normal” statistic shows the travel time calculated removing any travel delays from the calculations, i.e. free flow conditions.

The typical travel time for Link #1 is 1,500 seconds or 25 minutes, equaling an average speed of 52.8 mph along the link. The average speed calculated by the system during normal traffic flows was 52. 6 mph for March, 53.0 mph for April, and 52.5 mph for July, which closely replicates the expected travel speed.

Table 8: Summary of Link Statistics for Link #1

Link 1, Valley Junction to Otis (westbound)					
March 2001	**Journey Time Statistics**				
		seconds	**minutes**	**hours**	**speed (mph)**
	Average	1534.9	25.58	0.43	51.6
	Median	1526.5	25.45	0.42	51.9
	Mode	1583.0	26.38	0.44	50.0
	Max	2188.0	36.47	0.61	36.2
	Min	1327.0	22.12	0.37	59.7
	Avg "normal"	1506.4	25.11	0.42	52.6
April 2001	**Journey Time Statistics**				
		seconds	**minutes**	**hours**	**speed (mph)**
	Average	1519.9	25.33	0.42	52.1
	Median	1511.0	25.18	0.42	52.4
	Mode	1583.0	26.38	0.44	50.0
	Max	2630.0	43.83	0.73	30.1
	Min	1293.0	21.55	0.36	61.3
	Avg "normal"	1494.3	24.91	0.42	53.0
July 2001	**Journey Time Statistics**				
		seconds	**minutes**	**hours**	**speed (mph)**
	Average	1527.7	25.46	0.42	51.8
	Median	1528.0	25.47	0.42	51.8
	Mode	1583.0	26.38	0.44	50.0
	Max	1798.0	29.97	0.50	44.0
	Min	1111.0	18.52	0.31	71.3
	Avg "normal"	1508.6	25.14	0.42	52.5

7.2.5. Data Results for Link 2, Valley Junction to Otis (eastbound)

This section summarizes the results of the available data for Link #2 from March, April and July of 2001. Table 9 shows a summary of the average daily traffic volumes compared to the match data collected by the system. For March 2001, the total number of vehicles traveling eastbound was 288,021. Out of this pool of vehicles, the system matched 17,450 vehicles traveling from camera site B to camera site A, which equates to a 4.7% match rate and about 432 matches per day during March. Table 9 summarizes the same information for April and July 2001.

Table 9: Traffic and Match Summary for Link #2

March 2001 Link #2				
	Total	**Eastbound**	**Total EB for March**	
ADT	17450	9291	288021	
# records		7023		
# matches		13410	4.7%	
# matches/day		432.58		
April 2001 Link #2				
	Total	**Eastbound**	**Total EB for April**	
ADT	18005	9082	272460	
# records		7165		
# matches		13103	4.8%	
# matches/day		422.68		
July 2001 Link #2				
	Total	**Eastbound**	**Total EB for July**	
ADT	21809	10968	340008	
# records		2909		
# matches		5669	1.7%	
# matches/day		182.87		

Table 10 summarizes that travel time data statistics for Link #2. The typical travel time for link #2 is 1,500 seconds or 25 minutes, equaling an average speed of 52.8 mph along the link. The average speed calculated by the system during normal traffic flows was 52.9 mph for March, 53.2 mph for April, and 52.9 mph for July, which closely replicates the expected travel speed.

Table 10: Summary of Link Statistics for Link #2

Link 2, Otis to Valley Junction (eastbound)					
March 2001	**Journey Time Statistics**				
		seconds	**minutes**	**hours**	**speed (mph)**
	Average	1526.1	25.43	0.42	51.9
	Median	1519.0	25.32	0.42	52.1
	Mode	1583.0	26.38	0.44	50.0
	Max	1993.0	33.22	0.55	39.7
	Min	717.0	11.95	0.20	110.5
	Avg "normal"	1496.0	24.93	0.42	52.9
April 2001	**Journey Time Statistics**				
		seconds	**minutes**	**hours**	**speed (mph)**
	Average	1521.8	25.36	0.42	52.0

	Median	1513.0	25.22	0.42	52.3
	Mode	1583.0	26.38	0.44	50.0
	Max	3415.0	56.92	0.95	23.2
	Min	570.0	9.50	0.16	138.9
	Avg "normal"	1487.9	24.80	0.41	53.2
July 2001	**Journey Time Statistics**				
		seconds	**minutes**	**hours**	**speed (mph)**
	Average	1516.4	25.27	0.42	52.2
	Median	1507.0	25.12	0.42	52.6
	Mode	1583.0	26.38	0.44	50.0
	Max	3355.0	55.92	0.93	23.6
	Min	1303.0	21.72	0.36	60.8
	Avg "normal"	1496.3	24.94	0.42	52.9

7.2.6. Data Results for Link 3, Otis to Lincoln City (westbound)

This section summarizes the results of the available data for Link #3 from March, April and July of 2001. Table 11 shows a summary of the average daily traffic volumes compared to the match data collected by the system. For March 2001, the total number of vehicles traveling westbound was 135,237. Out of this pool of vehicles, the system matched 23,183 vehicles traveling from camera site B to camera site C, which equates to a 17.1% match rate and about 747 matches per day during March. Table 11 summarizes the same information for April and July 2001.

Table 11: Traffic and Match Summary for Link #3

March 2001 Link #3			
	Total	**Westbound**	**Total WB for March**
ADT	8725	4362.5	135237.5
# records		9346	
# matches		23183	17.1%
# matches/day		747.84	
April 2001 Link #3			
	Total	**Westbound**	**Total WB for April**
ADT	9003	4501	135038
# records		8777	
# matches		18479	13.7%
# matches/day		615.97	
July 2001 Link #3			
	Total	**Westbound**	**Total WB for July**
ADT	10905	5452	169020
# records		2909	
# matches		5669	3.4%
# matches/day		182.87	

Table 12 summarizes that travel time data statistics for Link #3. The posted speed limit travel time for link #3 is 215 seconds or 3.6 minutes, equaling an average speed of 40 mph along the link. The average speed calculated by the system during normal traffic flows was 47.1 mph for March, 47.4 mph for April, and 46.6 mph for July.

Table 12: Summary of Link Statistics for Link #3

Link 3, Otis to Lincoln City (westbound)					
March 2001	**Journey Time Statistics**				
		seconds	**minutes**	**hours**	**speed (mph)**
	Average	189.9	3.16	0.05	45.5
	Median	184.0	3.07	0.05	47.0
	Mode	215.0	3.58	0.06	40.2
	Max	782.0	13.03	0.22	11.0
	Min	145.0	2.42	0.04	59.6
	Avg "normal"	183.5	3.06	0.05	47.1
		1515159.5			
April 2001	**Journey Time Statistics**				
		seconds	**minutes**	**hours**	**speed (mph)**
	Average	185.0	3.08	0.05	46.7
	Median	183.0	3.05	0.05	47.2
	Mode	215.0	3.58	0.06	40.2
	Max	256.0	4.27	0.07	33.8
	Min	143.0	2.38	0.04	60.4
	Avg "normal"	182.3	3.04	0.05	47.4
July 2001	**Journey Time Statistics**				
		seconds	**minutes**	**hours**	**speed (mph)**
	Average	190.1	3.17	0.05	45.4
	Median	187.0	3.12	0.05	46.2
	Mode	215.0	3.58	0.06	40.2
	Max	333.0	5.55	0.09	25.9
	Min	136.0	2.27	0.04	63.5
	Avg "normal"	185.6	3.09	0.05	46.6

7.2.7. Data Results for Link 4, Otis to Lincoln City (eastbound)

This section summarizes the results of the available data for Link #4 from March, April and July of 2001. Table 13 shows a summary of the average daily traffic volumes compared to the match data collected by the system. For March 2001, the total number of vehicles traveling eastbound was 135,237. Out of this pool of vehicles, the system matched 32,194 vehicles traveling from camera site C to camera site B, which equates to a 23.8% match rate and about 1,038 matches per day during March.

Table 13 summarizes the same information for April and July 2001.

Table 13: Traffic and Match Summary for Link #4

March 2001 Link #4			
	Total	**Eastbound**	**Total EB for March**
ADT	8725	4362.5	135237.5
# records		11738	
# matches		32194	23.8%
# matches/day		1038.52	
April 2001 Link #4			
	Total	**Eastbound**	**Total EB for April**
ADT	9003	4501	135038
# records		11374	
# matches		28693	21.2%
# matches/day		956.43	
July 2001 Link #4			
	Total	**Eastbound**	**Total EB for July**
ADT	10905	5452	169020
# records		4024	
# matches		10819	6.4%
# matches/day		349.00	

Table 14 summarizes that travel time data statistics for Link #4. The posted speed limit travel time for link #3 is 215 seconds or 3.6 minutes, equaling an average speed of40 mph along the link. The average speed calculated by the system during normal traffic flows was 49.4 mph for March, 47.4 mph for April, and 48.8 mph for July.

Table 14: Summary of Link Statistics for Link #4

Link 4, Lincoln City to Otis (eastbound)					
March 2001	**Journey Time Statistics**				
		seconds	**minutes**	**hours**	**speed (mph)**
	Average	181.0	3.02	0.05	47.7
	Median	176.0	2.93	0.05	49.1
	Mode	215.0	3.58	0.06	40.2
	Max	642.0	10.70	0.18	13.5
	Min	115.0	1.92	0.03	75.1
	Avg "normal"	174.9	2.92	0.05	49.4
April 2001	**Journey Time Statistics**				
		seconds	**minutes**	**hours**	**speed (mph)**
	Average	185.0	3.08	0.05	46.7
	Median	183.0	3.05	0.05	47.2
	Mode	215.0	3.58	0.06	40.2
	Max	256.0	4.27	0.07	33.8
	Min	143.0	2.38	0.04	60.4
	Avg "normal"	182.3	3.04	0.05	47.4
July 2001	**Journey Time Statistics**				
		seconds	**minutes**	**hours**	**speed (mph)**
	Average	180.4	3.01	0.05	47.9
	Median	178.0	2.97	0.05	48.5
	Mode	176.0	2.93	0.05	49.1
	Max	215.0	3.58	0.06	40.2
	Min	137.0	2.28	0.04	63.1
	Avg "normal"	176.9	2.95	0.05	48.8

7.2.8. Initial Analysis of Incident Data

WTI analyzed incidents reported during March and April of 2001. There were six incidents recorded by ODOT. A prior analysis of the system data for March and April 2001 revealed that the system was functioning, and reporting data. For each of the six reported incident dates, we present information on the incident and how the system was reporting travel times during the time of the incident.

7.2.8.1. March 8, 2001

The incident occurred at milepost 20, near Grande Ronde. The incident was called in at 7:06 am, and was declared cleared at 10:19 am. The incident involved a pick-up truck that hit a pole off the side of the road.

The system showed no measurable delay for either Link 1 (WB) or Link 2 (EB).

7.2.8.2. March 13, 2001

The incident occurred at milepost 19.5, near Grande Ronde. The incident was called in at 7:36 am, and was declared cleared at 9:28 am. The incident involved a car fire, and the notes indicated that the road had to be shut down.

The system showed some moderate delays for Link 2, (EB) as shown in Figure 19. The peak delay was 130 seconds (about 2 minutes) at 8:07 am. Link 1 (WB) showed no delay.

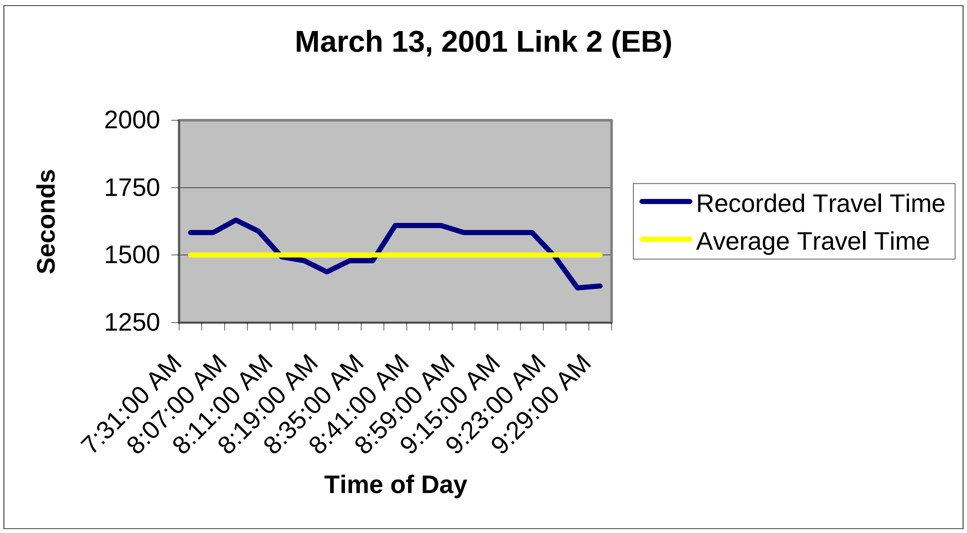


Figure 19: Delay data for March 13, 2001 Link 2 EB

7.2.8.3. March 19, 2001

The incident occurred at milepost 3, near Bear Creek. The incident was called in at 3:07 pm, and was declared cleared at 4:30 pm. The incident involved one car, which was reported to be partially blocking the eastbound lane.

The system showed some moderate delays for Link 1 (WB), as shown in Figure 20. The peak delay was 150 seconds (about 2-1/2 minutes) at 2:58 pm. Link 2 (EB) showed no delay.

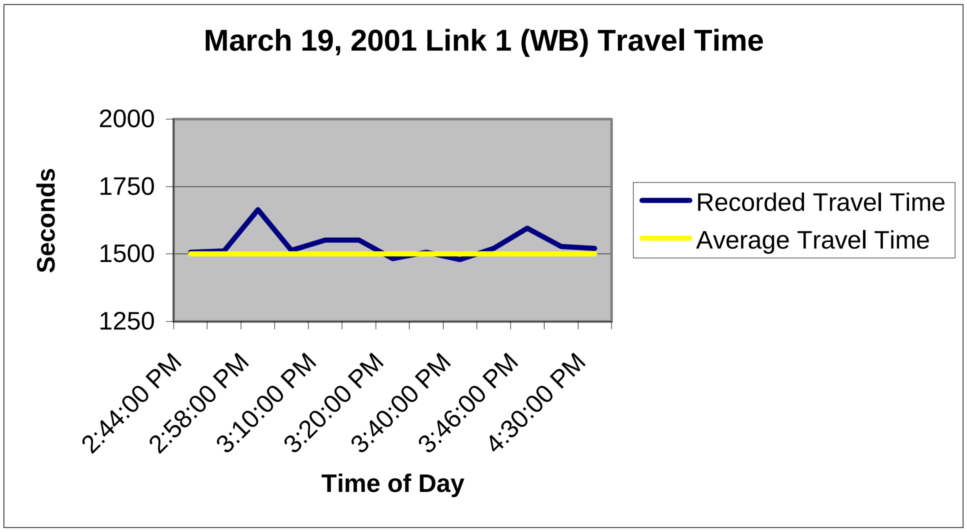


Figure 20: Delay Data for March 19, Link1 WB

7.2.8.4. March 26, 2001

The incident occurred at milepost 20, near Grande Ronde. The incident was called in at 1:51 pm, and was declared cleared at 3:14 pm. The incident involved three cars heading westbound, and there was glass/debris on the roadway.

The system showed some significant delays for Link 1 (WB), as shown in Figure 21. The peak delay was 688 seconds (over 11 minutes) at 2:12 pm. Link 2 (EB) showed some moderate delays. The system showed that normal travel times did not return till after 5 pm. For this week, traffic volumes were heavier than normal because of spring break.

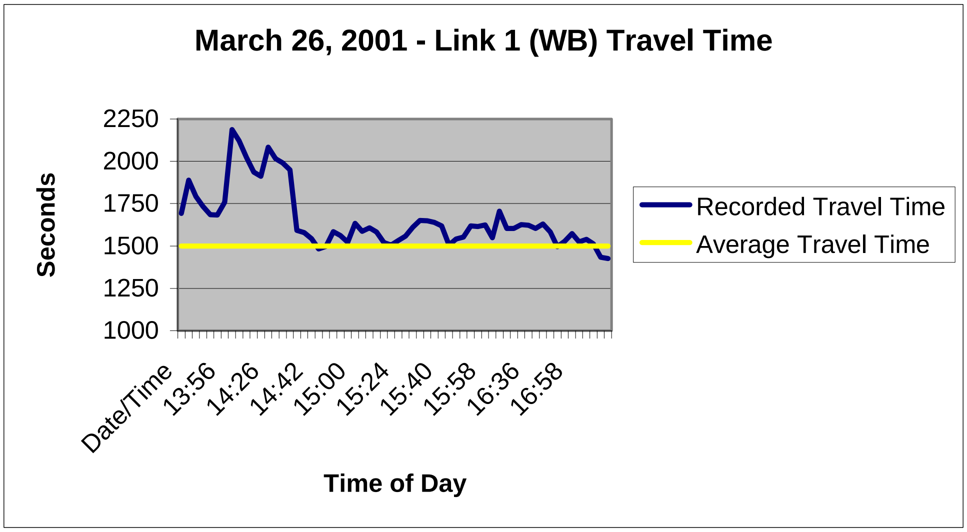


Figure 21: Delay Data for March 26, 2001, Link 1 WB

7.2.8.5. April 9, 2001

The incident occurred at milepost 14, near the forest corridor boundary. The incident was called in at 6:56 am, and was declared cleared at 8:10 am. The incident involved one car off the eastbound side of the highway, and several cars were reported to stop and help.

The system showed some moderate delays for Link 2 (EB). Link 1 (WB) showed no delay.

7.2.8.6. April 16, 2001

The incident occurred at milepost 3, near Bear Creek. The incident was called in at 7:18 am, and was declared cleared at 10:38 am. The incident involved a tractor-trailer that fell on its side blocking the EB lane.

The system reported some interesting results for April 16th. During the reported time of the incident, the system recorded moderate delays for both EB and WB traffic. A plot of Link 2 (EB) is shown in Figure 22.

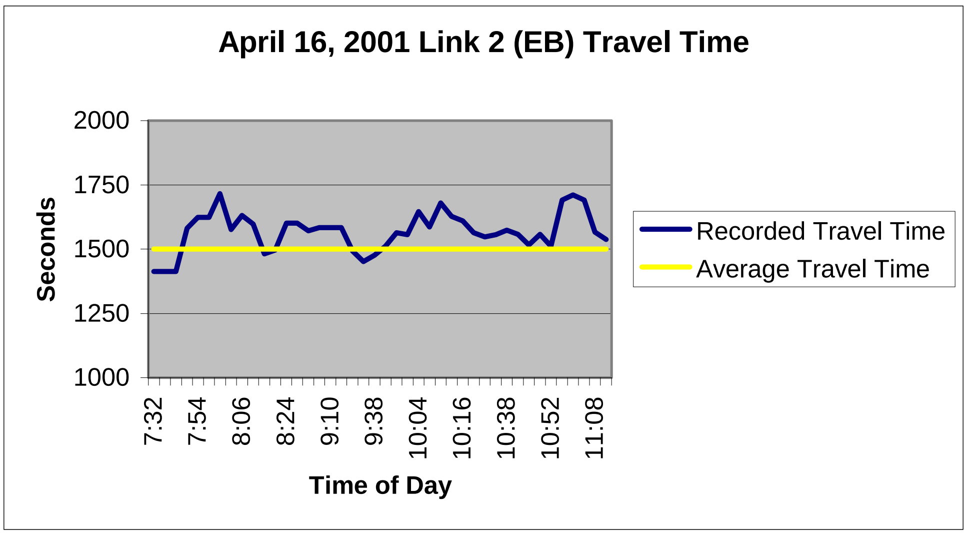


Figure 22: Delay Data for April 16, 2001, Link 2 EB

However, in the afternoon of April 16th, very significant delays were recorded in both directions. Figure 23 shows the delay for Link 1 (WB), which peaked at almost 19 minutes at 1:52 pm. This is well after ODOT reported the incident cleared, and no other incidents were listed. However, discussions with ODOT staff indicate that the truck was towed from the site in the afternoon, corresponding with the system delays.

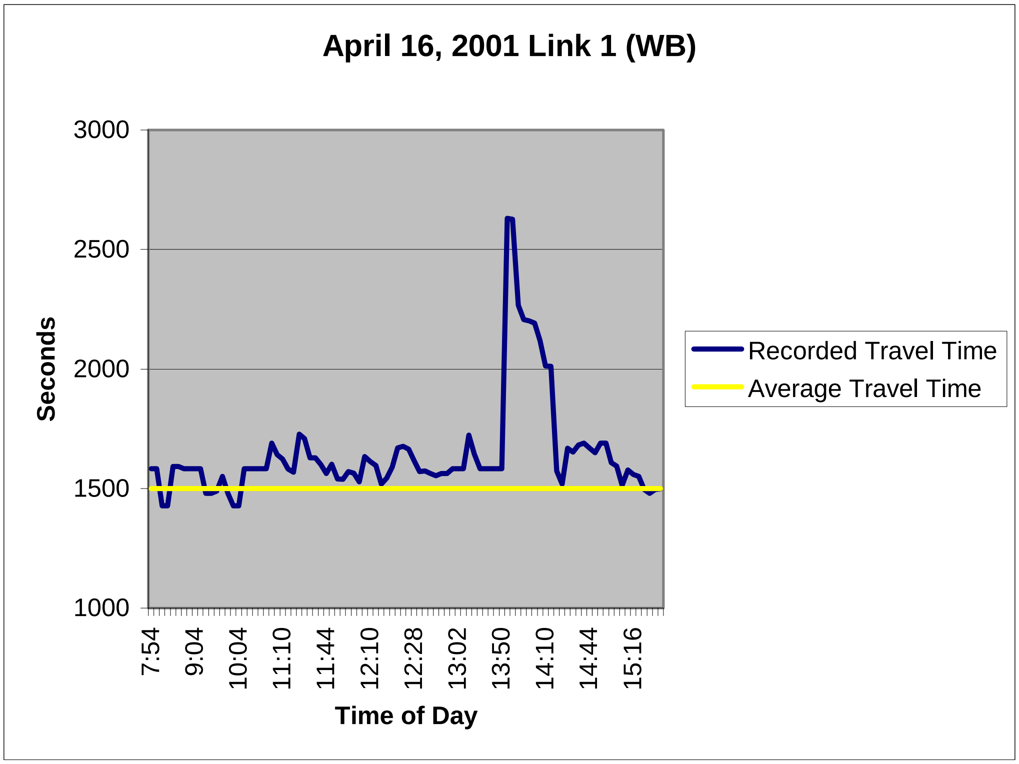


Figure 23: Delay Data for April 16, 2001, Link 1 WB

Recorded data for the EB travel time was very similar.

7.2.9. Comparative Travel Time Analysis

Portland State University, under contract to WTI, conducted a travel time analysis of the license plate recognition system. The travel time analysis compared the actual speed of vehicles traveling the study segments versus the reported speed of travel from the system. The study used the floating car method, where the study vehicles travel in a platoon at the speed of normal traffic. This travel time analysis will provide a direct comparison of real travel speeds versus system results.

The results of the PSU analysis are summarized below. The full report is contained in Appendix G.

7.2.9.1. Comparative Travel Time Data Collection

Two days were selected for validation of the Rural Travel Time Estimation System: Sunday, July 13, 2003 and Friday, July 2, 2004. The validation days were chosen because of the anticipated high volumes of traffic accessing the Oregon coast on summer and holiday weekends. The research team desired to study the Travel Time Estimation System with variable corridor travel times. However, on both days it turned out that there was minimal congestion in the study corridor (delays were noticed to the west of the study corridor on both days). Due to technical problems with the Frontier system on the second travel day, only the westbound cameras were operational. Therefore all data presented for July 2, 2004 only includes the westbound direction.

As an integral part of the evaluation, ODOT provided the research team with output from the Frontier system for the study days. The system compiles a set of variables including date, time, site ID, link ID (delineated as one to four depending on which of the four link trips the camera is recording), number of matched tags the cameras record from camera to camera, average travel time between sites, number of tags the cameras identify from the link within the two minute time period, and number of flags. The data used in this analysis were exported from the system in comma-separated format files making it easily configurable for spreadsheet software.

7.2.9.2. Probe Vehicle Data

The number of probes required to obtain the minimum sample-size to obtain reliable, unbiased estimates was determined. On July 13, 2003, six probe vehicles were used and on July 2, 2004 seven vehicles were used. Each test car drove from Lincoln City to Valley Junction and Valley Junction to Lincoln City, twice on both days. Probe vehicles left the initial starting point at approximately 10-minute headways.

On Day 2, only westbound data was collected because only the westbound cameras were in operation. While gathering data, the probe vehicles followed standard probe vehicle instructions by traveling at normal travel speeds.

Four (Day 1) or five (Day 2) probe vehicles were equipped with Palm OS handheld computer units equipped with Global Positioning System (GPS) receivers and the ITS-GPS software developed at Portland State University. On both days, two additional vehicles were equipped with laptop computers using CoPilot navigation software and GPS receivers. The GPS data collection devices were programmed to record date, time, time elapsed between readings, latitude, longitude, distance in miles traveled since last reading, and vehicle miles per hour at three-second intervals. An example of a data set is shown in Figure 24.

These time-stamped probe vehicle locations were used to construct trajectories (on a time-distance plane) for each vehicle run during the field experiments.

Date	GMT	Fixed' Time	Elapsed	Latitude	Longitude	Dist. Mile	Vel mi/hr	Dist. KM	Total Distance	Fixed' Distance
2004.07.02	23:27:51	15:27:51	3	45.06742	-123.57414	0.043542	52.250196	0.070076	0	0
2004.07.02	23:27:54	15:27:54	3	45.06729	-123.57501	0.043441	52.129488	0.069914	0.043441	0.045236167
2004.07.02	23:27:57	15:27:57	3	45.06714	-123.57589	0.044223	53.068072	0.071173	0.087664	0.09128665
2004.07.02	23:28:00	15:28:00	3	45.06697	-123.57679	0.045512	54.613822	0.073246	0.133176	0.138679399

Figure 24: Sample Data Set

Subsequent to the field experiments, the data were retrieved from the Palm devices and the laptop computers and assembled in a spreadsheet for data cleaning and statistical analysis. The distance between each point was calculated using the spherical geometry method. Upon review of the data, it was found that for some sections of the study corridor, the GPS devices lost a satellite and did not record location information. The device would attempt to gather data every three seconds until a satellite fix was re-established. As a result, total distances calculated for the trip did not match the measured road distance for a few trips.

Since the location information recorded by the GPS units is the distance between points as a straight line, the distances were interpolated accordingly throughout the data sets. For example, the total distance between the cameras was 25.4 miles but a probe vehicle only recorded 24.4 miles due to the GPS unit readings. The error was distributed among each of the data points for the trip using the following equation:

Interpolated Distance = Distance between readings*(25.4/total distance measured by GPS unit)

Test vehicle trajectories (plots of vehicle location versus time) like those shown in the previous figures were used to measure variations in speed and travel time for the probe vehicles.

7.2.9.3. Analysis of Comparative Travel Time Data

In order to compare the probe vehicle data and the system predicted travel time data, they were plotted using a time-space diagram for each study day and direction. These are shown in Figure 25 through Figure 32, where the *x*-axis is time and the *y*-axis is the distance along the highway. The predicted travel time between each camera is shown for departure time of each vehicle as a dashed line. In this case, the trajectory will always be straight line between camera locations, since no intermediate travel information is known. The slope of the line indicates the average travel speed for the corridor. For the study days, the Frontier system's average predicted travel times were 29 minutes for east and westbound on the first day and second day. The average predicted speed for all trips was approximately 51 mph. The probe vehicle trajectories were plotted knowing the vehicles' locations and time stamp every three seconds. Since the conditions were generally freely-flowing, the trajectories of the probe vehicles look almost identical to the Frontier system's predicted trajectories. If delay had been present, the probe vehicle trajectories would have varied over time. These figures demonstrate the close similarity between most of the system's predicted travel times and actual probe vehicle travel times for the days analyzed.

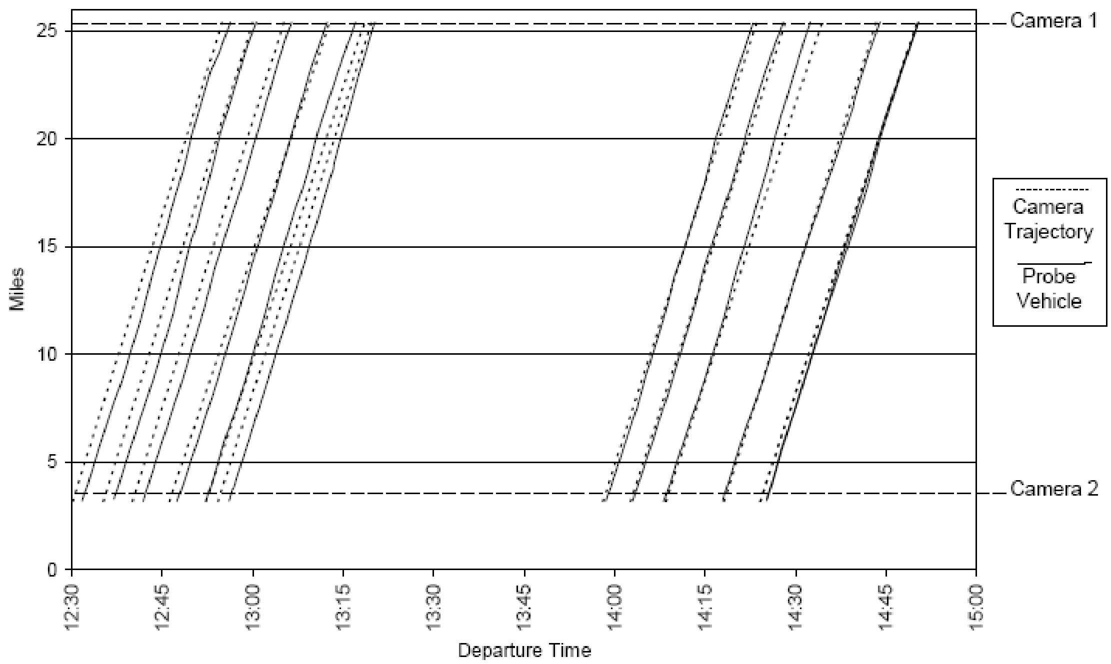


Figure 25: Day 1: Comparison Eastbound, Segment 2

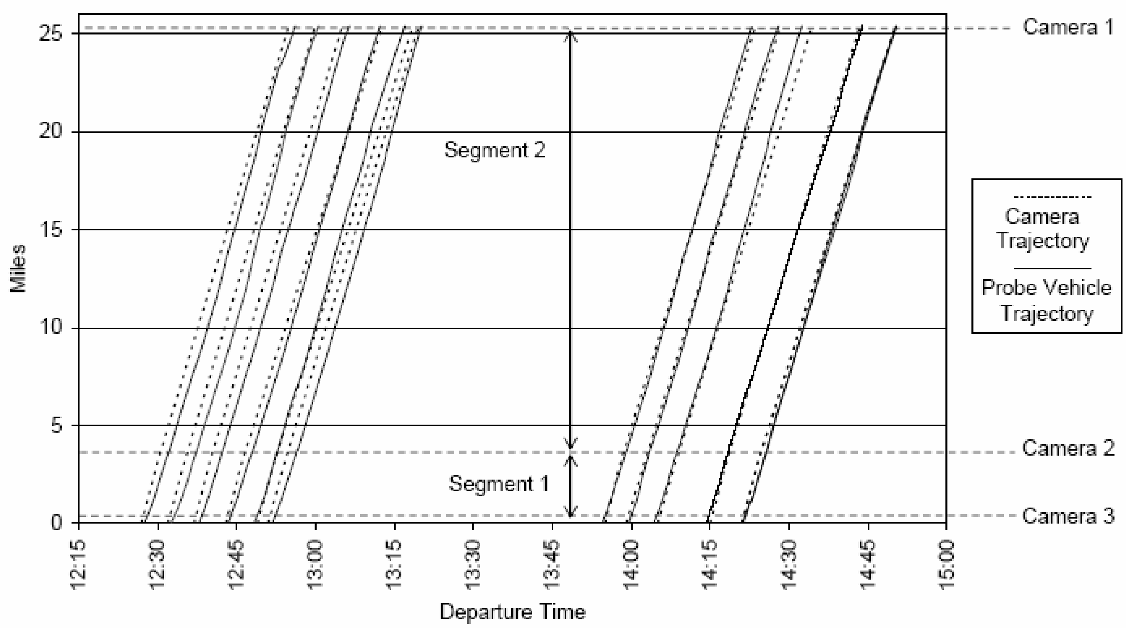


Figure 26: Day 1: Comparison Eastbound, Total

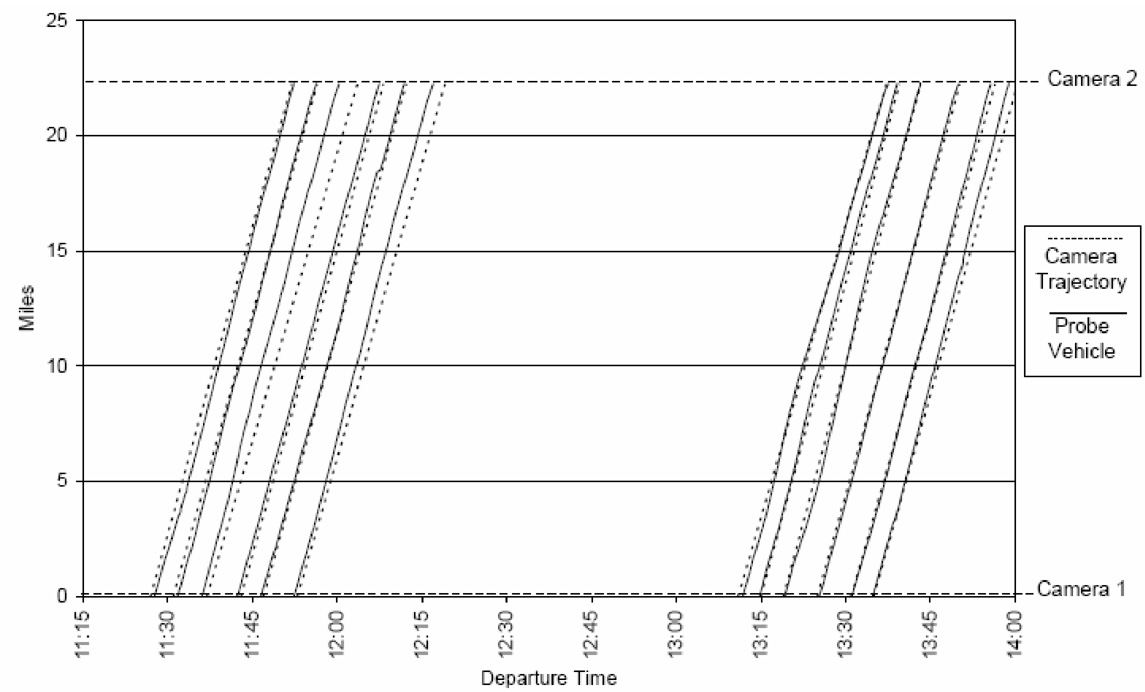


Figure 27: Day 1: Comparison Westbound, Segment 1

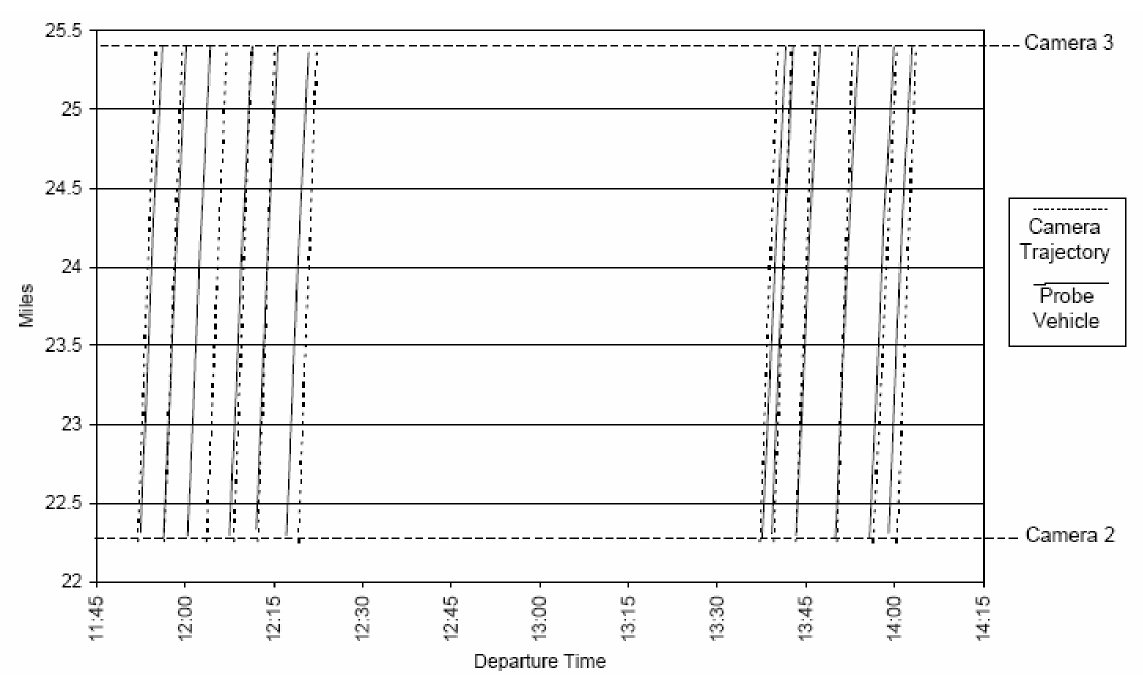


Figure 28: Day 1: Comparison Westbound, Segment 2

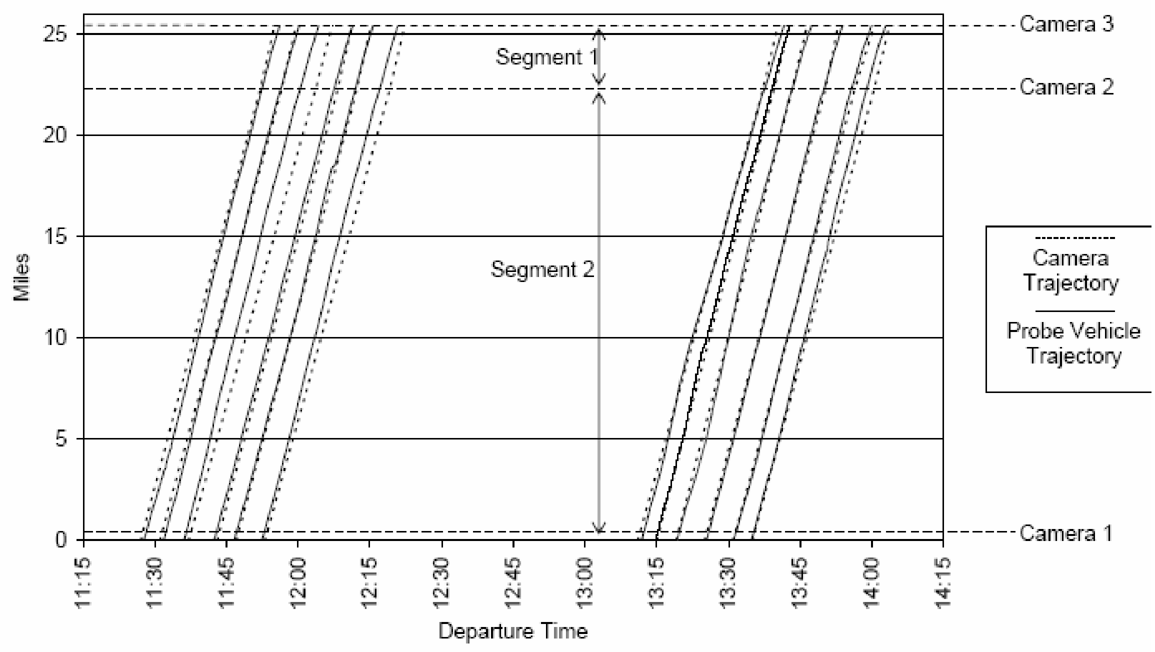


Figure 29: Day 1: Comparison Westbound, Total

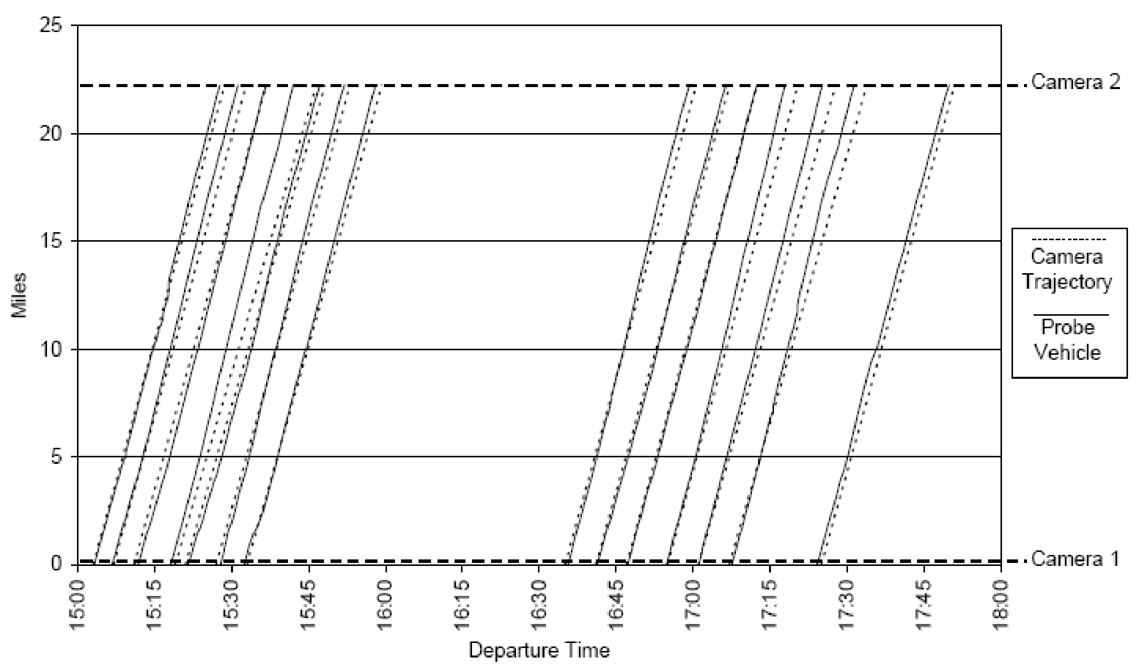


Figure 30: Day 2: Comparison Westbound, Segment 1

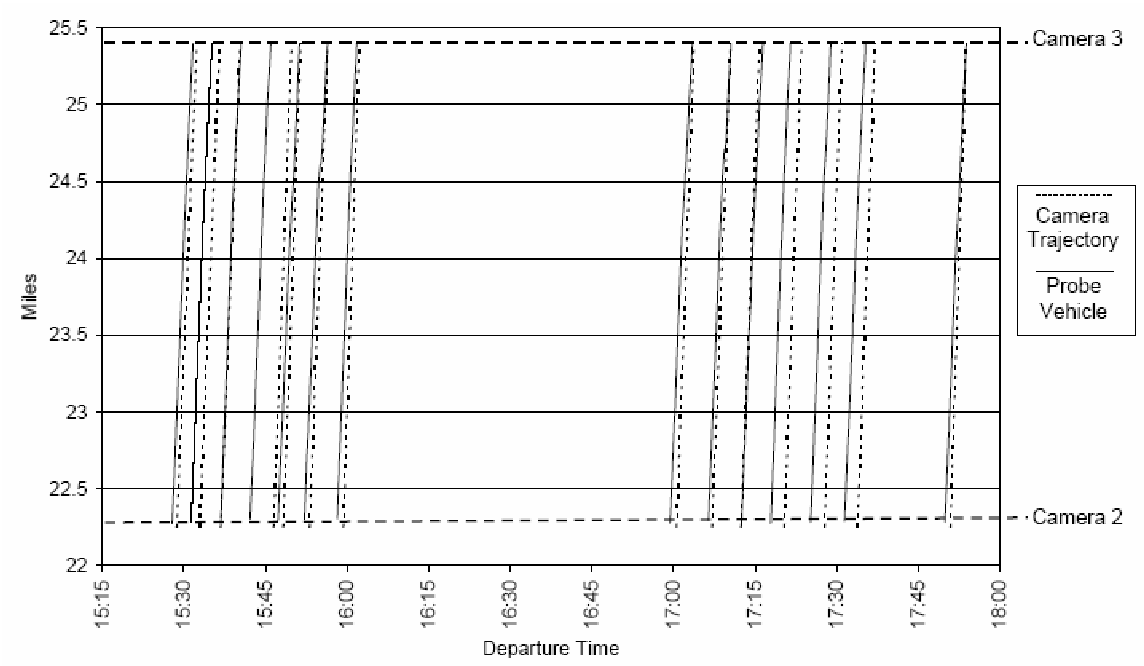


Figure 31: Day 2: Comparison Westbound, Segment 2

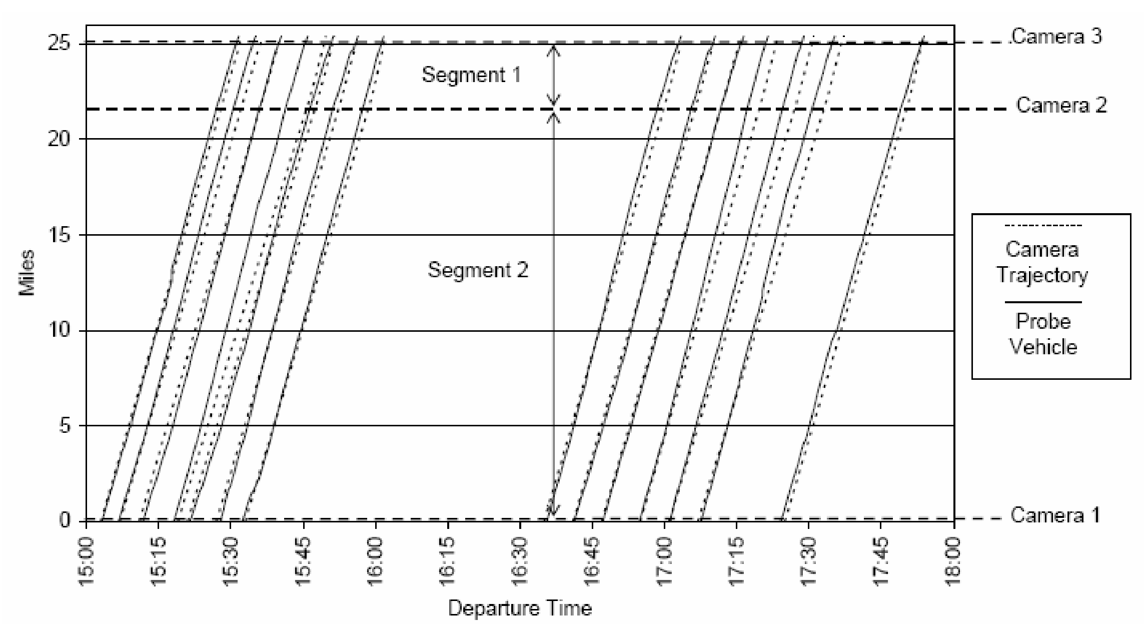


Figure 32: Day 2: Comparison Westbound, Total

Further statistical analysis was conducted to test the similarities between the mean trip time for each group of probe vehicle trips with the mean of the system predicted travel time using all times between the first and last probe vehicle departure. The summary statistics for westbound trips are shown in Table 15 and eastbound in Table 16. Since the Frontier system's output occurs about every 3 seconds, the *n* value for the system is larger than for the probe vehicles.

Table 15: Summary Statistics Westbound

	Westbound							
	Day 1				Day 2			
	Trip 1		Trip 2		Trip 1		Trip 2	
	Probe Vehicles	Cameras	Probe Vehicles	Cameras	Probe Vehicles	Cameras	Probe Vehicles	Cameras
n	7	16	7	26	6	14	6	13
Mean	28:42	29:39	28:19	29:12	28:34	28:43	28:32	28:21
Standard Deviation	00:38	00:37	01:06	00:26	00:23	00:36	00:40	00:45
Confidence Interval	00:28	00:18	00:49	00:10	00:18	00:19	00:32	00:25

Table 16: Summary Statistics Eastbound

	Eastbound			
	Day 1			
	Trip 1		Trip 2	
	Probe Vehicles	Cameras	Probe Vehicles	Cameras
n	6	13	6	12
Mean	28:26	28:40	28:45	28:59
Standard Deviation	00:19	00:50	00:35	00:22
Confidence Interval	00:15	00:27	00:28	00:12

The means were then plotted with each 95% confidence interval as shown in Figure 33. The various trips are defined by the groupings of probe vehicle departures. For example, in Figure 33, all probe vehicles departing from 15:00 to 15:30 are considered a trip. The results show that in all cases except for Day 2, Trip 1, the means are not significantly statistically different because there is some overlap between the probe vehicle and Frontier system travel time confidence intervals. Although there are some differences in the system's ability to predict shorter trips as mentioned below, the system is effective predicting the total 25.4 mile corridor trip.

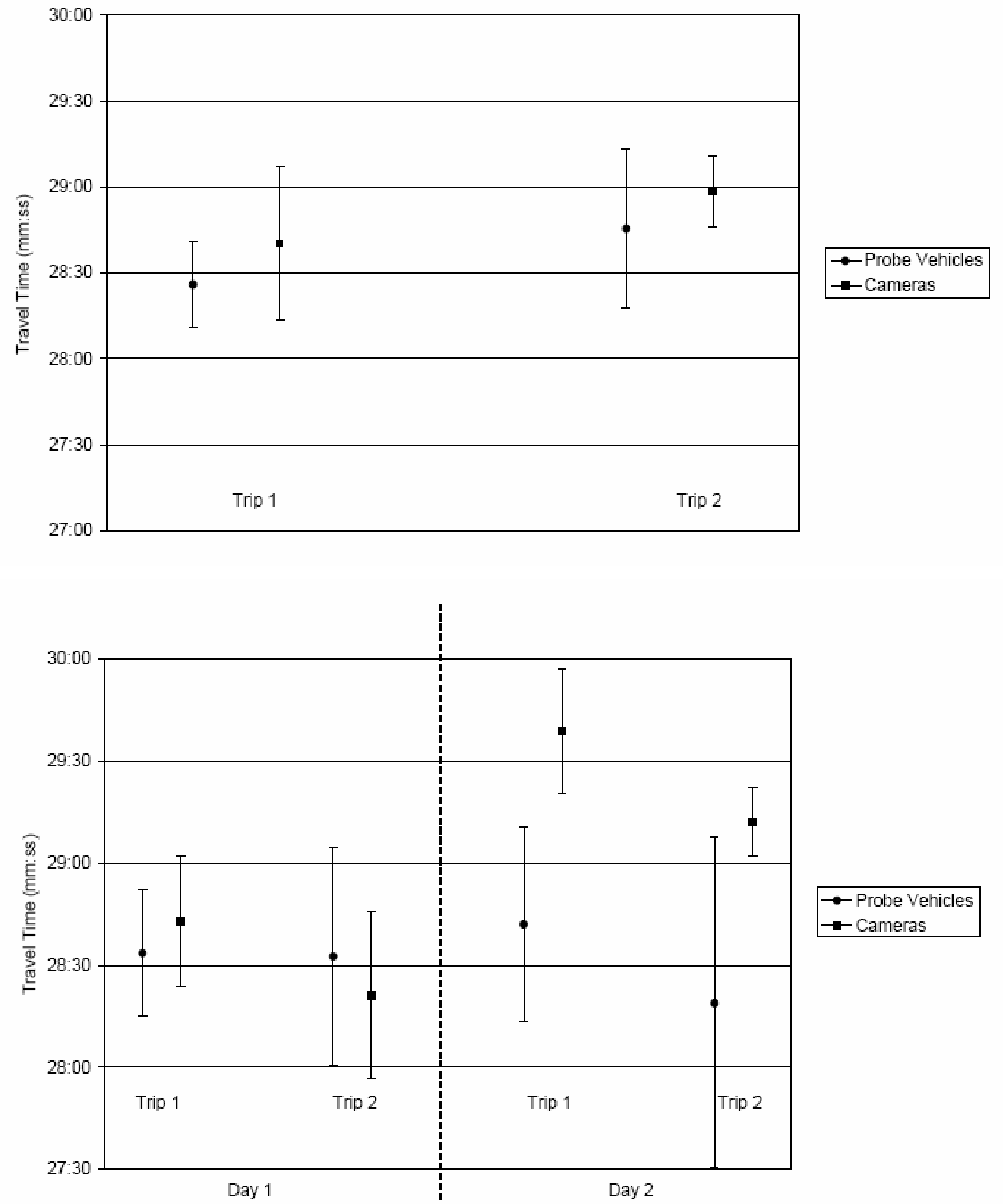


Figure 33: Means and Confidence Intervals for Probe Vehicle and Predicted Travel Times

Closer examination of the differences between the Frontier system predicted travel times and probe travel times reveals that errors for the shorter and longer segments are different. The plot in Figure 34 (a) shows travel time difference (predicted – probe vehicles) that the Frontier system generally predicted longer travel times than observed by the probe vehicles for the segment 1 (3.15 miles). The Frontier system predictions were a maximum of 56 seconds greater than the probe vehicle times and were consistent longer for all probe comparisons. However, for the longer segment 2 (22.25 miles), the system predicted a shorter time than all but one of the probe vehicle trips (Figure 34 (b)). For segment 2, the maximum difference of the system predicted times and the probe was 58 seconds.

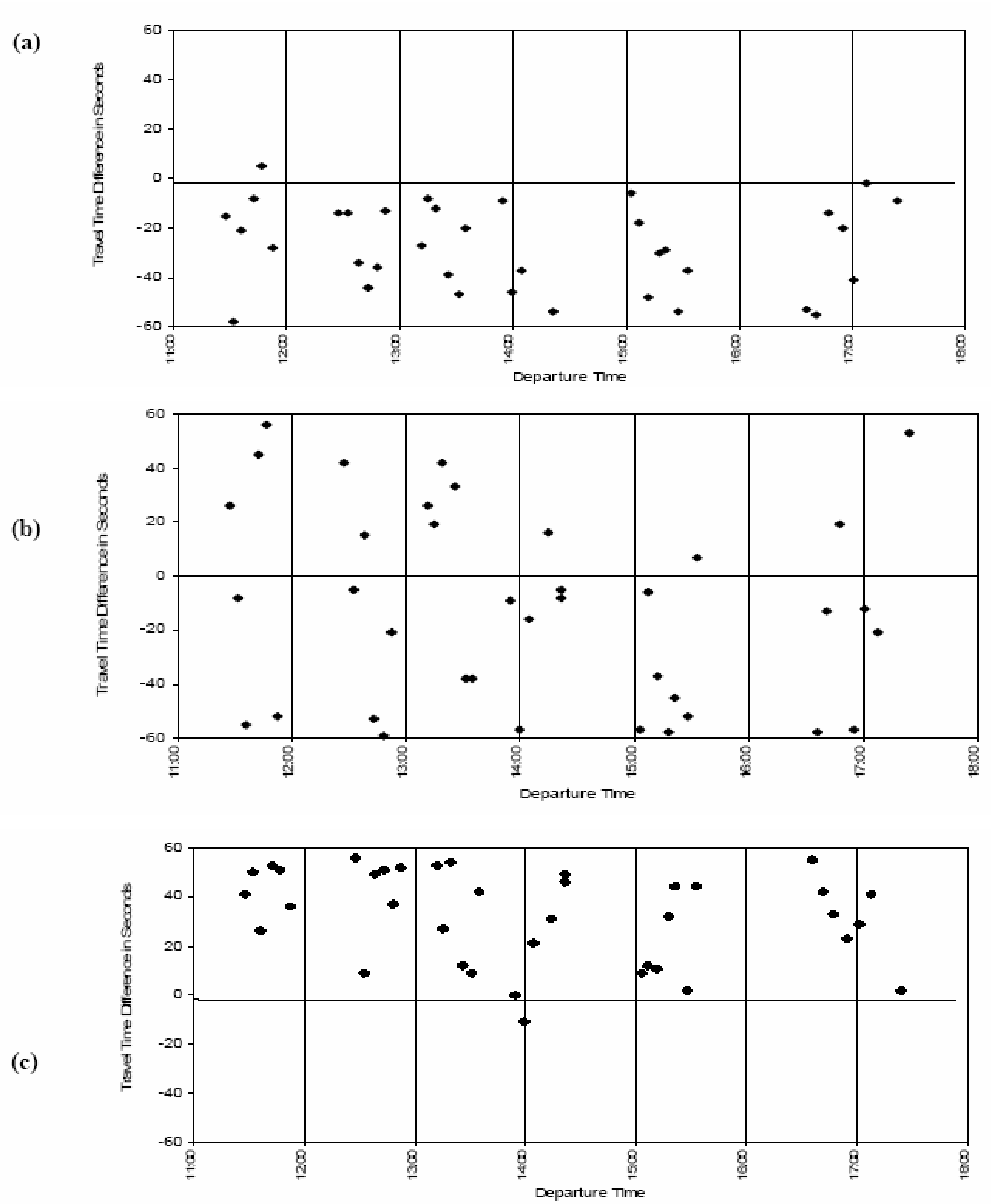


Figure 34: Difference between Probe Vehicle's Trip Times and Camera's Predicted Trip Times

7.2.9.4. Comparative Travel Time Analysis Results

Based on a comparison of the mean travel times for the days examined, the Frontier Travel Time system predicts trip times effectively for the total 25.4 mile trip based on only one of the six comparisons being significantly statistically different. As for the short segments 1 and 2, the cameras were also effective from a practical perspective.

7.2.10. Evaluation Conclusions

The purpose of this evaluation was to study the effectiveness of a travel time estimation system on a rural Oregon highway. Specifically, researchers sought to determine if it the system could produce accurate, reliable data for the purposes of keeping travelers informed of trip duration and potential delays. For this evaluation, researchers analyzed data collected by the system, including vehicle matches, travel time, travel speeds, and incident detection. To validate the accuracy, a comparative analysis was conducted with data from probe vehicles.

Two main conclusions can be deduced from the evaluation of the travel time system. First, the results of the preliminary analyses and the comparative travel time studies showed that when working, the system produced accurate travel time results. The system is capable of:

- Detecting and matching vehicles
- Measuring travel time statistics
- Measuring travel speed data
- Documenting travel delays caused by incidents

The capabilities of the system were validated by the results of the field validation, which indicated that the system is sufficiently accurate in predicting corridor travel times. Since the analyses were performed while generally free flow traffic conditions prevailed, the results of this field test have limited application. In general, however, it is shown here that the system can reliably predict travel times within a minute, which is robust considering the length of the corridor.

The second conclusion that must be drawn from this evaluation is that the potential capabilities of this system were overshadowed by operational and maintenance concerns. The system was non-functional for significant lengths of time due to initial system failures and ongoing repair and adjustment needs. The operation and maintenance requirements of devices in rural areas have a much greater impact on rural transportation districts. Rural transportation districts typically have less staff covering a greater area than their urban counterparts. Further, the introduction of the unique equipment for the travel time system required special skills to maintain and operate, and this also placed an additional burden on maintenance staff.

Because the system (and therefore its data) was viewed as unreliable, ODOT was reluctant to use or disseminate any of the system information to the public. Therefore, the system’s potential as a public information tool has yet to be evaluated. Further research on travel time estimation systems is recommended to produce longer-term data on technical reliability, as well as to incorporate the data into traveler information systems. Furthermore, these results underscore the need for ITS research specifically tailored to the conditions and resources of rural areas.

7.3. High Water Level Sensor Project Evaluation

The objective of this project was to provide critical real-time warning of roadway flooding conditions, both on-site to the motorists directly affected by the condition and remotely to TxDOT – Fort Worth maintenance residency. This real-time warning was intended to generate the lead-time necessary for maintenance/operations personnel to respond to the conditions and determine the need for a road closure, or other corrective actions, to protect motorist safety.

7.3.1. Operational History

The high water warning system was installed in the spring of 2001 by A-TEK. The system consisted of the float sensors, controller cabinets, communications, and warning signs. Additionally, the vendor installed a weather station with ice detection.

Initially, the system encountered problems due to communication inconsistencies, and also some software conflicts. The vendor modified the location of the VHF antenna to improve the communications, and the operating system software was upgraded to correct the software conflicts.

In the fall of 2001, a severe storm passed through the Decatur area, and the District maintenance facility was struck by lightning. The lightening caused significant damage to the system, including burning out the power supply and serial ports of the central computer, as well as modules and radios in the communications transceiver units at the central and repeater sites. The vendor undertook repairs in the spring of 2002, and restored system functionality.

Since that time, the system has been working reliably. However, during the evaluation phase of the project, from 2001-2004, that region of Texas experienced drought conditions. Thus, the site did not experience any flood events during the project’s evaluation phase. This lack of flood events hampered the evaluation effort.

7.3.2. Weather Station Analysis

To evaluate the accuracy of the weather station at the bridge site, a comparative analysis of weather data was conducted with a National Oceanic and Atmospheric (NOAA) weather station at a nearby airport. Air temperature, wind speed, and relative humidity data were collected at both sites on random days over a three-month period. Figure 35, Figure 36, and Figure 37 show the relative results for each measurement.

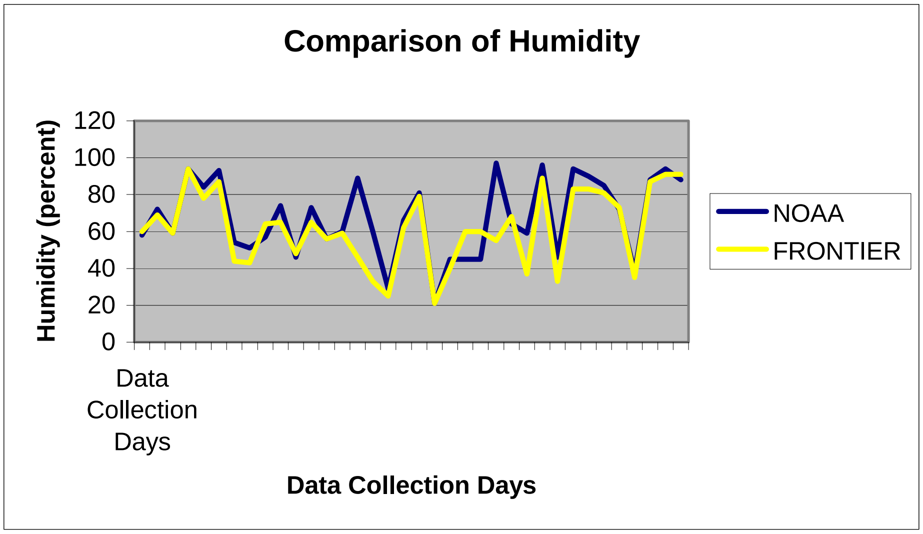


Figure 35: Correlation of Relative Humidity Data

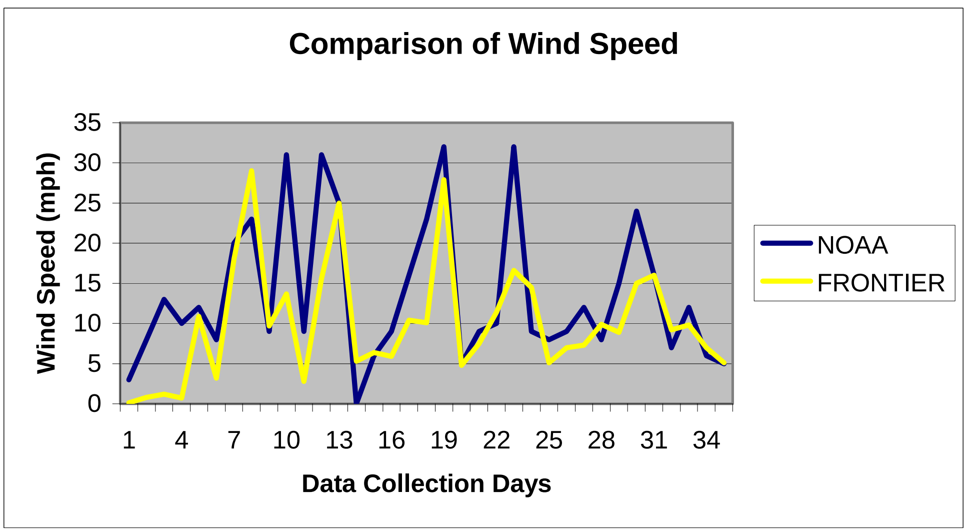


Figure 36: Correlation of Wind Speed Data

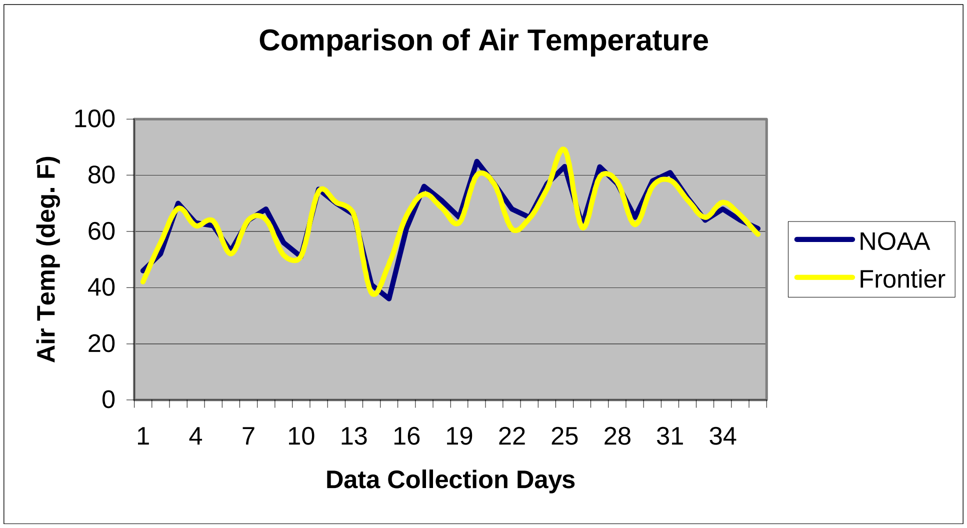


Figure 37: Correlation of Air Temperature Data

Researchers calculated the following correlation factors (R^2) for the comparison data:

Relative Humidity:	0.827
Wind Speed:	0.746
Air Temperature:	0.953

Values greater than 0.7 are considered to show a strong degree of correlation; therefore the results of the comparison validate the accuracy of the Frontier weather station. In addition, it is important to note that the Frontier site is on a depressed (lower elevation) section of road that is somewhat protected from weather conditions, while the NOAA airport site is located at a flat, open location. These differences may account for some of the variance in the data collected.

7.3.3. Summary of Maintenance Personnel Survey

WTI conducted an interview with several Wise County District Maintenance staff. The interviews were conducted despite that fact that the system had yet to be triggered by a flood event. To guide the interview process, WTI developed a questionnaire for maintenance personnel. The questionnaire included questions regarding:

- When and how often maintenance staff accessed the system
- Usefulness of the information
- How information was specifically used/applied to their maintenance duties
- Accuracy of data compared to other sources
- Reliability of system
- System's ease of use

- Driver/public comments received by staff regarding system

The entire, 3-page survey tool is shown in Appendix H. However, because of the lack of a flooding event, TxDOT requested that WTI not distribute a written survey. Instead, each staff person was invited to participate in a discussion on the project, and the survey questions were used to guide the discussion.

The following represents of a summary of the comments received.

Overall

- They like the system concept and operation.
- During flooding events in the past, they had to station maintenance personnel at the site to divert motorists.
- During storm events in the past, they had maintenance personnel drive by the site every 30 minutes to check for flooding.
- The system does save maintenance personnel time and effort.
- The weather station has been accurate.
- Initial system had PC stability problems on TxDOT network until vendor upgraded to Win XP.
- The system notification set-up (pager) works well.
- They rely on the weather station to plan for crew dispatch.
- They would like to have more weather stations and flood warning systems in their maintenance district.
- They perform preventative maintenance once a month on the system.
- They would like the addition of a video camera at the site for visual confirmation.
- They are cautious about the concept of using automated gates, although would consider it with video.
- Lightening protection initially was inadequate, but has been upgraded.
- Vandalism: solar panel was damaged by tossed beer bottle, and VHF antenna was shot.
- Would like system to provide e-mail notification in addition to pager
- Concern over battery life of only 3 days without solar feed, would like to see longer life.

7.3.4. Recent Flood Event

In 2004, the North Texas region experienced the wettest month of June in recent memory. For over two weeks heavy storms created flooding on several roadways in Jack, Johnson, Parker, and Wise counties.

On Tuesday night June 8th, 2004 a very heavy rain over Wise County caused water to rise over several roads and the monitored section of FM-3259 was flooded. Logs for the Central and the Client computers indicate the low sensor detected water rising at 5:43 AM. At 5:44 AM, the yellow flashing beacon for the advisory sign turned on. Eight minutes later, at 5:51 AM, the detector at the road surface level detected the rapidly rising water and changed the advisory message to a warning message. The "Do not Enter / High Water" message with a red flashing beacon activated at 5:52 am.

The maintenance crew, which came to close the manual gates, noticed the warning from a distance away. "The system was good and has performed in a timely fashion. We are looking into installing another station at a crossing known to flood frequently", said Decatur area engineer Bill Nelson.

7.3.5. Recent Ice Detection Event

During the last week of December, 2004, north Texas experienced some cold weather days with night-time temperature drops below freezing. On December 22, 2004 at 6: 34 PM, the US-380 bridge's pavement temperature dropped down to 34 degrees and, with light rain over the area, the Ice Alert Alarm went off for the first time.

The weather station generated a lot of excitement during ice storm response operations this year. Our inclement weather team saw the Ice Alert notification light and was impressed with the system's accuracy and timeliness. Randy Bower, the district maintenance assistant director comments that we should contact Brownwood district and install this kind of weather station to help response personnel answer the high volume of citizen phone calls about condition on interstate 20 at Ranger Hill.

8. CONCLUSIONS

The following section summarizes the conclusions and lessons learned from the FRONTIER project. This section includes a discussion on the overall project hypothesis, a comparison of evaluation objectives and results, lessons learned, and future issues for consideration.

8.1. Overall Project Hypothesis

The main hypothesis for this study was:

> "The primary intent of this project is to prove that advanced technologies can be successfully transferred to rural environments."

Based on this study's results, applying proven applications of ITS technologies in the rural environment can be successful, and provide many benefits to the district and their customers. However, rural districts should be cautious in applying new, unproven technologies in the rural environment.

Basically, there were two different ITS applications for this study. The license plate reading based travel time system, at the time of deployment, was the only one of its kind in the U.S. The initial research showed that there were only a few vendors that could even build the system, and some vendors would require creation of new technologies/systems. The travel time system had maintenance issues for the duration of the study, and basically was fully operational for only several months over a three year period. Rural districts generally lack the manpower and other institutional resources to provide ongoing, high maintenance support to new technologies.

Conversely, the high water warning system was an application that was applied successfully in the urban environment in Texas and other states. Thus, it was taking a tested system and applying it in a new environment. The system was reliable and functioned well.

8.2. Project Evaluation Objectives

The following tables summarize the results of the study compared to the initial evaluation objectives.

8.2.1. Travel Time System

Overall, the travel time system did not meet the stated evaluation objectives because of the reliability challenges. However, when working, the system did produce good data. A summary of the evaluation objectives and results is presented in Table 17.

Table 17: Travel Time System Evaluation Objectives and Results

Travel Time Estimation System	
Evaluation Query	**Result**
Are the technologies reliable, accurate, and easy to use?	The system was not reliable, functioning less than 1% of the time during the evaluation period. Even when functioning, the system was prone to not providing data for all segments. When it did function properly, the system produced reasonable results. ODOT staff found the maintenance of the systems difficult. ODOT staff found the central software portion of the system easy to use.
Is the overall safety improved, in terms of reduction in incident detection time and frequency?	When functioning, the system could be used to detect incidents. However, ODOT indicated that cell phone calls and other means would report the incidents faster and more reliably than the system.
Is the overall mobility improved, in terms of decreased travel time delay and/or better customer satisfaction?	The system has the potential to improve mobility by providing the information to the traveling public that could allow motorists to make choices on routes and departure times. However, ODOT was justifiably reluctant to post this information because of the reliability and accuracy issues. So, during the evaluation period, the system did not improve mobility or enhance customer satisfaction.
Is the overall efficiency improved, in terms of increased throughput or effective capacity?	The system has the potential to the efficiency of roadway operations, but this was not realized during this evaluation.
Is the overall productivity improved, in terms of cost savings?	No.
Is the information provided to the ODOT maintenance personnel valuable in their operations?	No.
Are motorists responding to the travel time information presented to them?	System information was never presented to motorists.

8.2.2. High Water System

Overall, the high water warning system did meet the stated evaluation objectives, and TxDOT was satisfied with the system performance. Unfortunately, because of the drought, full evaluation of the system could not be completed. A summary of the evaluation objectives and results is presented in Table 18.

Table 18: High Water Warning System Evaluation Objectives and Results

High Water Warning System	
Evaluation Query	**Result**
Is the overall safety improved, in terms of reduction in detection time and accident frequency?	Yes, anecdotal information from TxDOT and studies of other high water warning systems show that the system reduces the potential for incidents.
Is the overall mobility improved, in terms of decreased travel time delay and/or better customer satisfaction?	Yes, TxDOT indicated that by providing the information more quickly to the public, motorists can make the necessary changes to their routing sooner.
Is the overall efficiency improved, in terms of increased throughput or effective capacity?	Yes, the efficiency of the surrounding roadway network is improve by alerting motorists of the closed roadway, so motorists can make more informed routing decisions.
Is the overall productivity improved, in terms of cost savings?	Yes, TxDOT personnel saved time by utilizing the information from the system. The system reduced the number of trips personnel had to make to the site.
Is the information provided to TxDOT maintenance personnel valuable in their operations?	Yes, TxDOT maintenance personnel used the information form the system to guide their maintenance activities.
Are motorists responding to the information presented to them?	Yes, TxDOT staff indicated that motorists responded to the signs.
Are the technologies accurate, reliable, and easy to use	Yes, once system upgrades were installed TxDOT personnel found the system easy to use, and the data was accurate.

8.3. Lessons Learned

The following section summarizes the lessons learned from the project. The lessons learned include discussion on system accuracy, reliability, deployment, maintenance, usefulness, and potential enhancements. The section is organized in a question and answer format to be more useful to DOT's consider these applications and their implications.

8.3.1. System Accuracy

Did the Travel Time system collect enough license plate matches to be accurate?

Other research has identified a 5% guideline as needed to provide consistent real time information on traffic flow (Chen, M. and S. Chien, TRB, 2000). As shown in Table 19, the Travel Time system identified and matched less than 5% of the traffic volume on the long segment between Valley Junction and Otis (22 miles).

Table 19: License Plate Match Rate for Segment 1 (Valley Junction to Otis)

Time Period	Segment 1 Westbound	Segment 1 Eastbound
March 2001	4.7%	4.7%
April 2001	4.3	4.8%
July 2001	2.5%	1.7%

For the shorter segment between Otis and Lincoln City (3 miles), the system identified and matched well over 5% of the traffic volume, as shown in Table 20.

Table 20: License Plate Match Rate for Segment 2 (Otis to Lincoln City)

Time Period	Segment 2 Westbound	Segment 2 Eastbound
March 2001	17.1%	23.8%
April 2001	13.7	21.2%
July 2001	NR	NR

NR—data was not reported by the system for that segment

Thus, according to stated research guidelines from FHWA, the system did not match a high enough percentage of license plates on the long segment.

Did the Travel Time system report reasonable travel time estimates?

The results of the 2004 travel time and delay studies showed that the Travel Time system was statistically accurate in 5 out of 6 study periods (83 %). If we also include the three other runs on the second day where the Travel Time system failed in the eastbound direction, the success rate drops to 5 out of 9 (55%).

The initial analysis of Travel Time data from 2001 showed that when working, the system predicted travel time estimates consistent with the actual travel time along the corridor. The mean speed through the corridor was consistently reported at about 53 mph for both directions. The results of the initial analysis were confirmed by the data from July of 2004, as shown in Table 21.

Table 21: Mean Speed Predicted by Travel Time System

Time Period	Segment 2 Westbound	Segment 2 Eastbound
March 2001	52.6 mph	52.9 mph
April 2001	53.0 mph	53.2 mph
July 2001	52.5 mph	52.9 mph
July 2004	53.4 mph	52.9 mph

Thus, for periods of normal traffic flows, the system reported accurate travel time estimates.

How did the system respond to differing traffic conditions?

For the time periods that the system reported reliable data, WTI assessed the system's ability during known incidents. For March and April of 2001, ODOT had identified 6 major incidents within the study area. A summary of the incidents and the systems reaction to them is presented in Table 22

Table 22: System Response to Incidents

Time	Incident Type	Delay measurement	Comment
March 8, 2001	Truck hit utility pole-off roadway	None	Crash was in early morning, the truck was off the road, therefore no back-up may have been present
March 13, 2001	Car fire, partially blocking roadway	Yes, peak of 2 minutes	The system showed travel time delays within 5 minutes of incident
March 19, 2001	One car crash, partially blocking roadway	Yes, peak of 2-1/2 minutes	The system showed delay at time the incident was reported.
March 26, 2001	Three car crash, partially blocking roadway	Yes, peak of over 11 minutes	The system showed delay at time the incident was reported.
April 9, 2001	One car run off road	No	Early morning crash, and car was off the road, thee fore no delay was present.
April 16, 2001--AM	Truck rollover blocking one lane	Yes, over two minutes	The system showed delay 12 minutes after the incident was reported.
April 16, 2001—PM	Removal of truck	Yes, over 19 minutes	The system showed delay at time the incident was reported.

Did the High Water system collect accurate weather data?

To evaluate the accuracy of the weather station at the bridge site, a comparative analysis of weather data was conducted with a National Oceanic and Atmospheric (NOAA) weather station at a nearby airport. Researchers calculated the correlation factors (R^2) for relative humidity, wind speed, and air temperature data:

Relative Humidity:	0.827
Wind Speed:	0.746
Air Temperature:	0.953

Values greater than 0.7 are considered to show a strong degree of correlation; therefore the results of the comparison validate the accuracy of the Frontier weather station.

Did the High Water system record accurate water levels?

The system only reached the water level sensors one time during the evaluation period, and reported accurately at that time (June 2004). There is not enough data to support any accuracy conclusions.

8.3.2. System Reliability

Was the Travel Time system reliable?

Since the date of system turn on in March of 2001, the system has worked accurately for all segments for only three out of forty months (less than 1% of the time). It is worth noting again that for the field tests conducted in July 2004, the system was working on the first day, and failed the second day of tests. Thus, the system was not reliable nor was the data trusted by ODOT.

Was the High Water system reliable?

The High Water system, since the repair from the lightning strikes in the early part of 2002 has functioned reliably. It has been operational 100% of the time since the repairs. TxDOT staff trusts the system.

8.3.3. Deployment

Were the projects deployed on schedule?

Both projects were not deployed on schedule. Both had delays in delivery of materials, and both had initial software issues that delayed system start-up for several months. Anecdotally, conversations with DOT's indicate that delays related to software and communications issues are common for ITS projects. How much delay, and how typical is a subject for further research.

Thus, DOT's should be aware of and plan for delays in the start-up of ITS projects. DOT's should consider contractual arrangements that enforce and encourage on-time performance.

Was there a difference in the procurement process, and did it have an impact?

Because of the nature of the two projects, ODOT and TxDOT used different procurement processes. The Travel Time system was new technology, only a few vendors were available, none of which had any experience or history working with ODOT. In Texas, the HW system had been deployed in urban environments, and TxDOT was able to procure through an approved vendor list.

Simply, the vendor in Oregon was new to the region, and installing equipment new to the US. The vendor in Texas was on a pre-qualified list, and was installing proven equipment albeit in a different environment. Based on comments from ODOT and TxDOT staff, there was a significant difference in the responsiveness of the vendors. TxDOT staff were satisfied with their vendor, but ODOT staff were not satisfied. The TxDOT vendor had more of a vested interest, because they were on the pre-qualified list and had to perform successfully to remain on the list and compete for future projects. Although the ODOT vendor desired a successful project for enhancing future work opportunities, the failure would not ruin other opportunities with ODOT, since there were none.

8.3.4. Site Selection

Were the sites selected appropriate for evaluation?

Both sites had obstacles that affected the evaluation. Although both sites were appropriate for placement of the systems, whether they were the most appropriate placement for evaluation of the systems can be questioned.

First, the High Water site in Texas had a history of flooding, albeit it was limited and inconsistent. Prior to its selection, the site had flooded six times in the previous ten years:

- May 16, 1989 – June 22, 1989
- October 20, 1993 – October 21, 1993
- May 12, 1994 – May 16, 1994
- October 28, 1996
- February 21, 1997 – February 28,1997

Since the last occurrence in 1997, the site did not flood until the summer of 2004. This was further exacerbated by a drought that hit the region for the last several years. Even without the drought, the number of flood events that could have been reasonably expected was low. Furthermore, the site did not have a history of any crashes related to flood events, which eliminates any useful statistical before and after analysis of safety data. Thus, although TxDOT benefited from the placement of the system in Decatur and found it useful, it was not the best choice from an evaluation perspective.

Secondly, the site in Oregon required an extremely long segment (over 22 miles) to collect travel time information. Prior to this evaluation project, most travel time systems were set-up on links that ranged from ½ mile to 4 miles, and in urban areas with higher volumes. The project was purposely set-up to have a shorter segment (3 miles) to compare to the longer segment, but the long segment was just too long to reliably collect travel time information. Perhaps a more rigorous analysis of expected match rates, in a test lab, would have provided information on the distance limits of the system.

8.3.5. Usefulness of Data

Were the data collected and reported by the systems useful?

ODOT indicated that the Travel Time system data, if reliable, would have been very useful to them to provide to travelers for their TripCheck traveler information system. However, ODOT was intent on building customer confidence in the reliability of the information on Tripcheck, and did not trust the data from the TT system. The data would have provided travelers with current conditions, and allowed them an informed choice of alternate routes or alternate departure times.

TxDOT staff indicated that the weather data from the HW system data was useful to them. TxDOT routinely utilized the weather station information during storm events. During the one flood event, TxDOT used the information from the HW system

8.3.6. System Enhancements

Based on comments from ODOT and TxDOT staff, below is a list of suggested enhancements for the systems:

Travel Time system

- Improve system reliability
- Integrate system into Tripcheck (ODOT's traveler information system).

- For this system, the cameras had to placed over the road, which made maintaining the cameras more difficult. Newer systems have cameras that can be placed on the side of the road.

High Water system

- Integrate system into Ft. Worth ITS
- Provide e-mail notification
- Bolster lightning protection
- CCTV could be added to provide visual check. TxDOT stated that a low bandwidth CCTV or even a camera that took snapshots at periodic intervals would be valuable.
- TxDOT has concerns over the potential use of automated gates.

8.4. Overall Conclusions

The two distinctly different results from these two projects suggest perhaps that the main hypothesis was basically correct, but incomplete. Advanced technologies can be successfully transferred to rural environments, *if rural conditions, challenges, and resources are adequately addressed in advance.* Urban ITS applications can not be *directly* transferred to the rural environment; they must be adapted to account for such factors as:

- remote locations
- significantly lower AADT
- technological infrastructure
- available staffing resources and expertise
- available fiscal resources to support testing and deployment delays

The FRONTIER project has helped to identify key factors that must exist to ensure successful deployment of ITS technologies in a rural environment. The lessons learned will contribute to the development of criteria for future rural deployments. This project underscores the need for increased ITS research specifically aimed at rural challenges and deployed in rural environments.

9. NEXT STEPS AND FUTURE RESEARCH

The authors recommend that the Technical Advisory Committee discuss and consider an action plan for disseminating the information that was learned as part of this effort. Through this information dissemination, awareness of the need for and resulting benefits of rural ITS can be raised. This heightened awareness, in turn, will likely provide a greater opportunity for increased focus on rural issues and targeted funding for rural efforts.

Based on the evaluation results of this effort, there are several additional areas that would make interesting and useful studies to DOT's in the rural environment. Future research ideas include:

- What is appropriate level (i.e., spacing) of detection for the rural environment?
- What is the success rate of deployment on-time in rural? How many ITS projects are actually deployed, fully, functional, on time, in any environment?
- What impact do software and communications issues have on successful and useful deployment in the rural environment?
- What should be the requirements for testing new technologies before deployment in rural environments? Should only proven technologies be deployed in rural environments?
- What is the reliability of ITS devices in any environment? Is there a difference in reliability between urban and rural environments?

APPENDIX A

Oregon

John A. Kitzhaber, M.D., Governor

Department of Transportation
Traffic Management Section
5th Floor Transportation Bldg.
Salem, OR 97310-1354
(503) 986-3568

November 18, 1998

FILE CODE:

Jodi Carson
Western Transportation Institute
416 Cobleigh Hall, MSU-Rozeman
Rozeman, MT 59717-0395

FRONTIER Phase 2 Proposal

The Phase 2 proposal for "Rural Travel Time Estimation" is enclosed.

Please call me if you have any questions at (503) 986-3588.

Robert Fynn
Senior ITS Specilist

Enclosures

RF/cla

Frontier

Phase 2 proposal to WTI

Form 734-2272 (4/97)

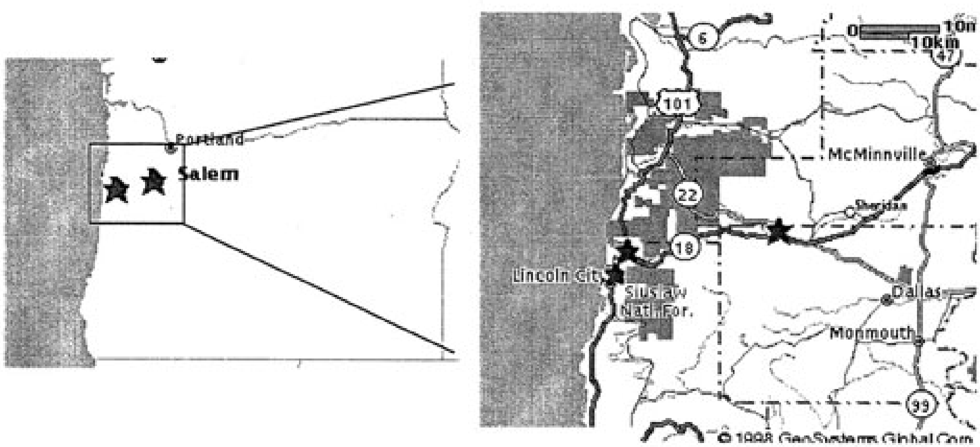
FRONTIER FHWA Pooled fund Project
Stage 2 Project Proposal – Oregon/California

Contact: Robert Fynn, ODOT, (503) 986-3588

Problem Title:
Rural Travel Time Estimation

Problem Description:
Travelers routinely complain about lack of real-time information about trip duration on the highway. Detection of and response to incidents has been an ever-growing concern, and notification of the travelling public about incidents and, more importantly, expected delay/travel time is essential. This project will use vehicle identification technologies to provide travel-time estimates on Oregon Highway No. 39 (Salmon River Hwy), MP 0 to MP 25.

Proposed Project and its Objectives:
This project will use vehicle identification technologies to provide travel-time estimates for two contiguous highway segments: on Oregon Highway No. 39 (Salmon River Hwy), MP 0 to MP 25, and US 101 between Lincoln City, and the US 101/Highway 39 junction. This stretch of highway serves significant rural travel and also connects two large tourist attractions: a casino on one end and Lincoln City, a popular coastal destination also with a casino, at the other end. The highway is mostly 2 lane, and traverses the Siuslaw National Forest. 1997 ADT was 17881 (11491 in 1994), with the highest volume on a single day in 1997 being 28967. A combination of inconsistent cross-sections, high percentage of slow moving trucks and campers/mobile homes (about 10% of ADT), passing opportunities that are few and far between, mountainous terrain and speed zones routinely cause congestion and incidents.



The project would establish three checkpoints as indicated on the above map at which vehicle identification technologies would be implemented. The US 101 section is considered essential because often times congestion on this short section occurs irrespective of the congestion level of the other stretch, and is thus a concern for motorists going to this destination.

License plate recognition (LPR) is being recommended for this project. The system would incorporate algorithms to track vehicles moving past consecutive checkpoints, calculate a real-time moving average of travel times and provide this information to motorists.

The system is envisioned to have four main components (see fig 1):

1. The onsite equipment that would do the data acquisition. This should be selected to be easily interchangeable.
2. The communication component will include the actual communication medium and protocols, together with any devices (eg modems) that would connect field equipment to ODOT's Wide Area Network
3. The processing software that would have an open architecture at both its data input (from the site equipment) and data output (to a Traveler Information System server - a Microsoft SQL database format for the output would probably be the most compatible for most agencies) ends. The openness of the architecture would be essential in ensuring interfaces with FRONTIER member states' traveler information system needs.
4. The ATIS server software that would provide for the dissemination of the travel time information using a browser interface on ODOT's website. ODOT has this currently in development.

The three locations which have been identified as checkpoints for onsite installations are (fig 2):

- OR 22/ Hwy 39 intersection (Valley Junction), MP 23. This location has an existing ODOT camera installation, and hence has a pole, a cabinet, power and a phone line. The site has no nighttime illumination
- US 101/ Hwy 39 junction, MP 0.34 . This site has a cantilevered sign support that extends over half highway. The sign is illuminated and therefore power is readily available, and there is a telephone riser box about 230 feet from the cantilever support. The site has minimal artificial lighting.
- US 101 at West Devil's Lake Road, the first signalized intersection in Lincoln City. The site has power, communications availability, and street lighting. A nearby DMV office provides possible easy access to ODOT's WAN. The highway has multiple lanes in this section, but has one through lane.

Investigations and literature review of the current technology revealed the following currently available vendors and their products/services (divided into components 1,2 and 3 as defined above, component 4 currently being developed by ODOT):

(a) ***Pearpoint Inc*** :

<u>Component 1</u>: The setup would include cameras mounted on overhead sign supports (or roadside pole at the proper camera angle). The cameras would be connected to license plate readers in a cabinet at the site. The license plate reader would convert the image captured by the camera to data (locally). It would read the license plate, convert it to a binary ID number ranging from 1 to 32767 (and dispose of the actual number read), time stamp the number and transmit it to a central server for travel time calculation. The algorithm supposedly ensures that there is less than a 0.1% chance that a vehicle ID number will be mismatched downstream.. The tag would be disposed of after use, such that the privacy of the driver and vehicle would be

preserved. The equipment would also read license plates at night, since it works only with an infra red illuminator installed at the sites, and doesn't rely on or respond to other light sources.
Component 2: Data transmission would be to via a local phone call (or possibly by radio modem or other communication method deemed feasible and economical) to the nearest ODOT facility/network connection point.
Component 3: Pearpoint Inc. of California has proprietary processing software from their affiliates TrafficMaster of UK. We could have Pearpoint essentially be system integrators and supply as with this software, but this then would not be public domain. Alternately we could have the software developed for and owned by FRONTIER. This would probably imply greater initial costs, some post-installation debugging, etc, but could be a better option since we have input into the development of the algorithms and software.

Anticipated costs (from Pearpoint) are as follows:

Cost of LPR equipment: 6 cameras, recognizer assemblies, illuminators	= $ 49,300
ALPR software dev't (on-site license recognition) and licensing	= $ 25,500
Travel-time estimate and algorithm and software development	= $ 30,600
On-site surveys and commissioning	= $ 19,380
Equipment installations, communication, travel time server, poles, etc*	= $ 30,000
TOTAL	**= $ 154,780****

ALPR software development would be to customize the software to recognize Oregon plates. Initial discussions indicate that this would be a one-time recognition/training cost for a state that wants to use the ALPR system. Annual fees for use of the ALPR will be waived. On-site surveys and commissioning would be to inventory the site, and ensure the system functions. Costs may be reduced due to the pre-existence of poles, etc. Pearpoint would not provide system integration or erection of poles, or arranging for phone connection, among other things.
* Estimate. Also includes cabinets, etc

(b) Computer Recognition Systems (CRS):

Component 1: Another system developed by Computer Recognition Systems, based in Cambridge, has a Numberplate Reading System (NRS) that performs similar functions, albeit with distinct differences. The NRS, which runs on a Windows NT platform, has been used primarily for violation enforcement (red light, speed, HOV). It may be adaptable for the project. It works by capturing the image of the license plate, and then using optical character recognition (OCR) and specified syntax –checking rules to read the license number. This system depends on ambient illumination at the site (daylight or installed night/infra-red illumination) and would be inoperable during periods of low light and poor visibility (snow, fog, etc). Product information claims an average recognition rate of 85-95% for unobstructed vehicle numberplates in good weather (and lighting). The NRS can supposedly also read all countries' plates at maximum vehicle speeds using visible or infrared illumination at night.
Component 2: NRS 'offers extensive communication facilities and extensive image and text database capabilities.' 'A range of network protocols is supported and the NRS can store data locally for later transmission should a communication link go down'.
Component 3: Product catalogs did not indicate any travel-time software. CRS is only a vendor of components, not a system integrator.

(c) Transformation Systems, Inc.

Component 1: Transfo is essentially a system integrator, and uses CRS's equipment; they've also started deploying a High Resolution Digital System which they say can be used for our application. Transfo supplied four cameras, lights and four LPRs to WsDOT for a border crossing time estimate project for about the $140,000 without system integration. The system has not yet been installed by WsDOT. They also partnered with TxDOT to implement a video based HOV enforcement project using LPR (more information on their website - http://www.transfo.com/recent.htm).

Component 2: No information was readily available but they indicated they could work with various communication interfaces.

Component 3: The total cost quoted above includes $125,000 for software. They were hesitant to give out too much information at this point, but are open for discussion of the project.

It is important to note that the travel-time estimation system can be built using different manufacturers/sources for the various components, if that is desired.

This travel estimate would then be fed into the Traveler Information system. ODOT intends to deploy some portable VMS signs at strategic decision points leading to this corridor to help travelers chose the route of preference. (An alternate route to the coast is available.)
The estimated average would also be compared to a pre-established free-flow (or more appropriately 'normal uncongested' flow) travel time. Significant differences would alert a dispatch/maintenance station for proper response after the incidents (if any) are verified. It is not certain how timely this incident detection will be, but will serve as a basis for possible further refinement.

Objectives of the project are:

- Provide continuous real-time trip duration estimates that would feed into Oregon's Traveler Information System to provide pre-trip travel estimates, and en-route travel information .
- Investigate vehicle identification technologies and how to deal with privacy issues
- Facilitate faster rural incident detection and response
- Integrate with the existing Traveler Information System
- Provide a system solution for travel time information for FRONTIER states.

Anticipated Benefits:

- Provide travelers the information needed to plan their trips before starting out, thus cutting down delay, congestion, pollution, noise etc
- Help with continuous monitoring of travel conditions and Levels Of Service
- Reduce traveler frustration about lack of incident information
- Provide faster incident detection and response technology, and potentially save lives. There were 189 accidents from 1995 to 1997, of which 9 were fatal
- Generate delay estimates for en-route advisories via VMS signs, HAR, etc

Data availability for project evaluation:

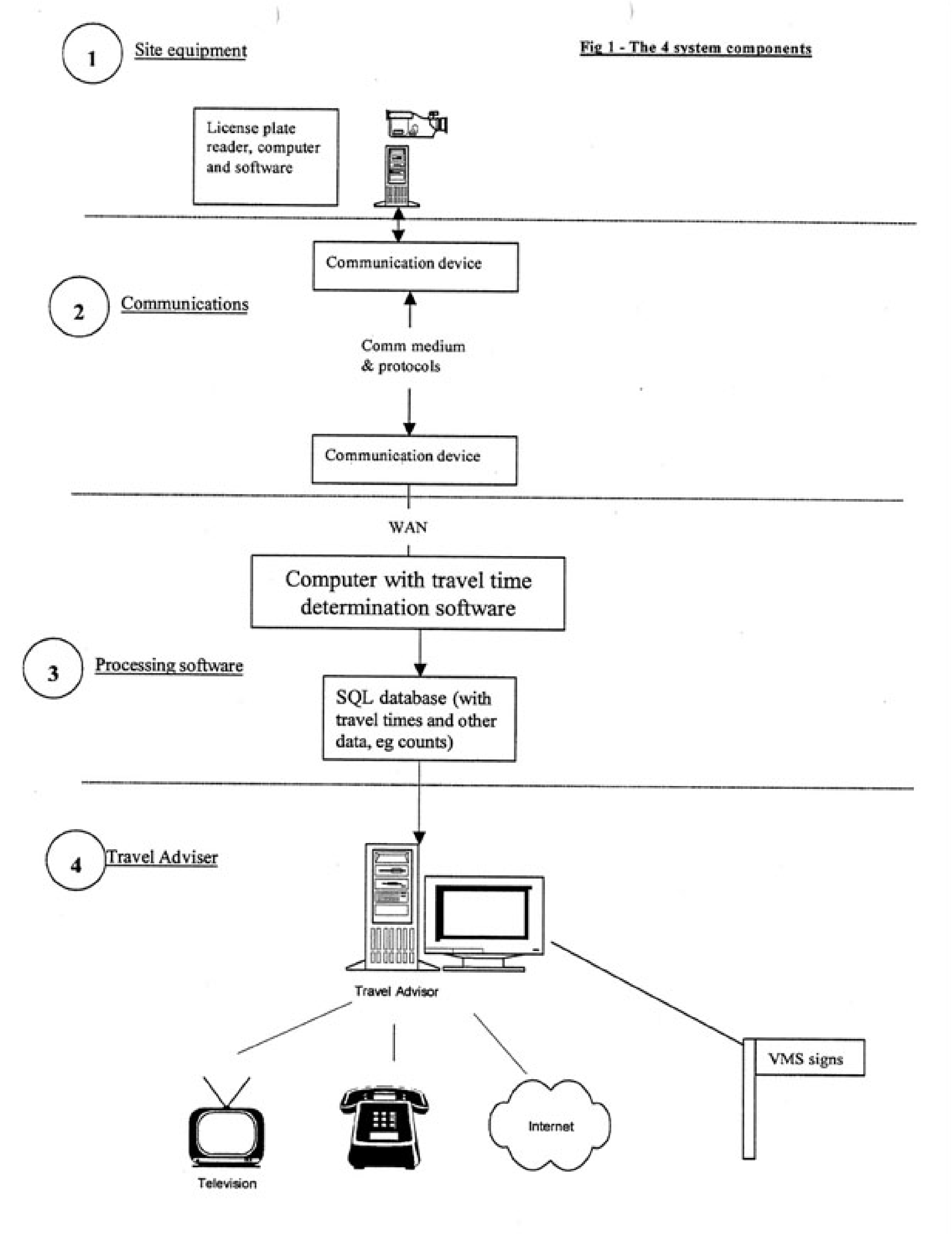
A permanent Automatic Traffic recorder (ATR) station situated at MP 23.76 provides vehicle classification data. Permanent count stations also exist on the alternate route to possibly provide information and correlation between increase in traffic on alternate route and message displayed on the VMS signs.
In a few months the experimental video system should generate speed and density/occupancy data at this same location.

Accident information is collected under Oregon's Safety Priority Indexing System (SPIS). Corridor studies have been done in the recent past that included some data collection. 1996 travel time estimates have been measured for different sections of this corridor on a per-mile basis for auto traffic, truck traffic and combined traffic. The data also has projected travel times per section under different scenarios.

****ODOT is prepared to provide some State of Oregon funding for the project.***

Estimated Timeline:

The estimated duration for ordering the equipment with the required algorithm, preparing the site, installing the equipment with all necessary communication links, to final commissioning, is 6 months


1 Site equipment
Fig 1 - The 4 system components
License plate reader, computer and software
Communication device
2 Communications
Comm medium & protocols
Communication device
WAN
Computer with travel time determination software
3 Processing software
SQL database (with travel times and other data, eg counts)
4 Travel Adviser
Travel Advisor
VMS signs
Internet
Television

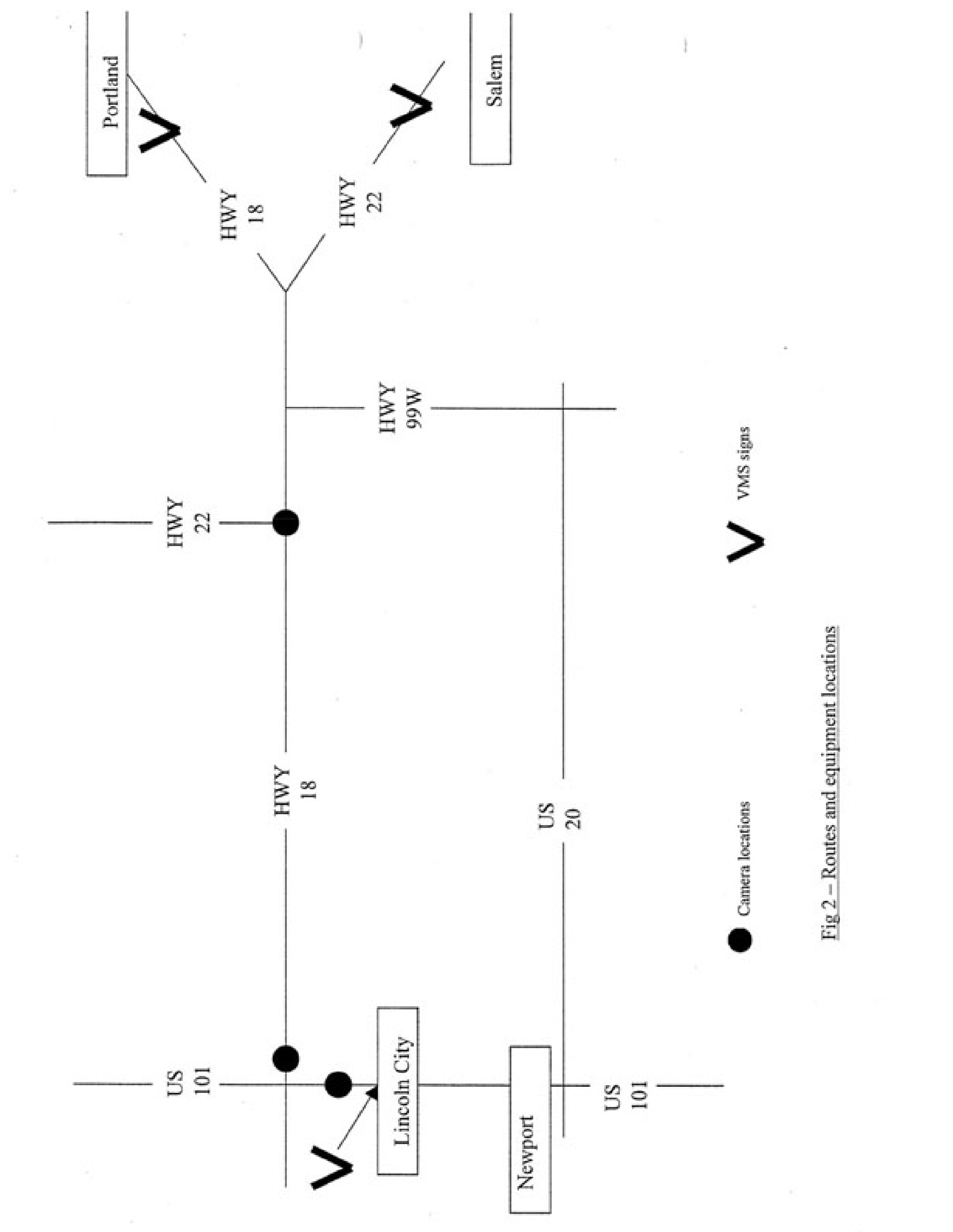


Fig 2 – Routes and equipment locations

APPENDIX B

FRONTIER

FHWA Pooled Fund Project

Detailed Proposal

CONTACT INFORMATION:

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Title: Intelligent Transportation Systems Manager
Affiliation: Texas Department of Transportation
Address: 2501 S. W. Loop 820
Fort Worth, Texas 76133
Phone: (817) 370-6624
Fax: (817) 370-6707
Email: tnguy@mailgw.dot.state.tx.us

PROBLEM TITLE:

High Water Level Sensors To Aid Maintenance Personnel's Rapid Response To Hazardous Water Crossing Locations.

PROBLEM DESCRIPTION:

We have several rural locations which have a history of "water over the roadway" problems. We would like to test a water level sensor installation on these two-lane facilities to reduce detection time of and improve response time to this hazardous condition.

The system we propose would use sensors to detect water above a safe level, and/or above the roadway surface. When activated by high water the system would access a cellular telephone to notify a central location "base station" of the conditions. The base station would provide pre-recorded voice and/or pager notification of the alarm condition to maintenance personnel. It is proposed that this system will also provide an immediate local warning to drivers by activating flashers on an appropriately located " Water over Road When Flashing" advisory or "Do Not Enter / High Water" warning sign, until maintenance personnel can arrive to place barricades if necessary.

To make this installation feasible and cost effective in rural areas, solar cells are envisioned as the power source and Cellular telephone is the recommended communications method.

PROPOSED PROJECT AND OBJECTIVES:

The objective of this project is to provide critical real-time warning of roadway flooding conditions, both on-site to the motorists directly affected by the condition and remotely to TxDOT - Fort Worth maintenance residency. This real-time warning will generate the lead time necessary for maintenance personnel to respond to the conditions and determine the need for a road closure, or other corrective action, to protect motorist safety.

The method proposed for providing this real-time warning is to install infrared water level sensors at a location identified by our Wise County Area Engineer. The proposed location has a history of flooding on the approaches to the structure, which creates an illusion of safety. The site will be more fully described in the following section "PROJECT SITE(S)".

The proposed project will place commercially available infrared water level sensors at critical locations on each approach to the site. These sensors will be placed in a vertical tube constructed to allow free flow of water, but to minimize interference from debris and sediment that the water may contain. The sensor installations, by nature, will not accommodate a breakaway mounting installation method. The sensors will be placed to provide the first warning, or alert mode, when water is within two feet of reaching the roadway surface. The second sensor will be placed to provide the second warning, or alarm mode, when water reaches the roadway surface. Each sensor installation will contain two infrared sensors, and a local controller equipped with a VHF radio transceiver and a solar power system. The VHF transceiver will provide local interconnection with the two advanced signing installations.

The advance signing installations, **Figure 1**, will be placed approximately ¼ mile from the affected approach(s). The sign installations will be configured to activate amber LED flashers when either sensor station provides a first level warning, or alert. The amber LED flashers will accompany the default signing display of "Possible Flooding / water over road / when flashing". If either sensor station activates a second level warning, or alarm, both signing installations will activate red LED flashers and change the accompanying signing display to "Do Not Enter / High Water". These signing installations will also contain a pole mounted NEMA enclosure housing a local controller, along with a mechanical changeable message sign, red and amber LED flashers, solar power system, and VHF Radio transceiver for interconnection with each other and the sensor assemblies. One signing installation will be designated as the master and will also contain a cellular telephone for communications with the central computer "base station". The signing installation will be installed with breakaway mounts to meet current roadside installation safety guidelines.

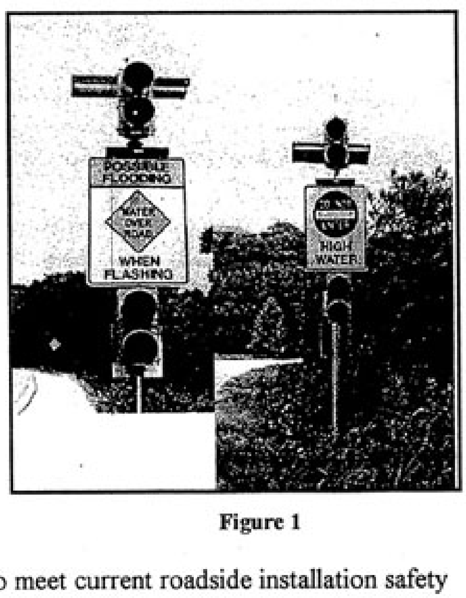


Figure 1

A central computer equipped with the vendor's software will provide a "base station" for monitoring sensor outputs remotely. The base station provides a "heartbeat" function to monitor status of sensors, batteries and other field components. The base station also provides the ability to reset the field components condition or over-ride a local reset based on maintenance personnel's evaluation of conditions. The central computer will also employ a pager notification system to insure that the appropriate personnel are aware of changing conditions, especially outside normal business hours when the base station may not be monitored by office personnel. **Figure 2** illustrates the conceptual system design for this proposal.

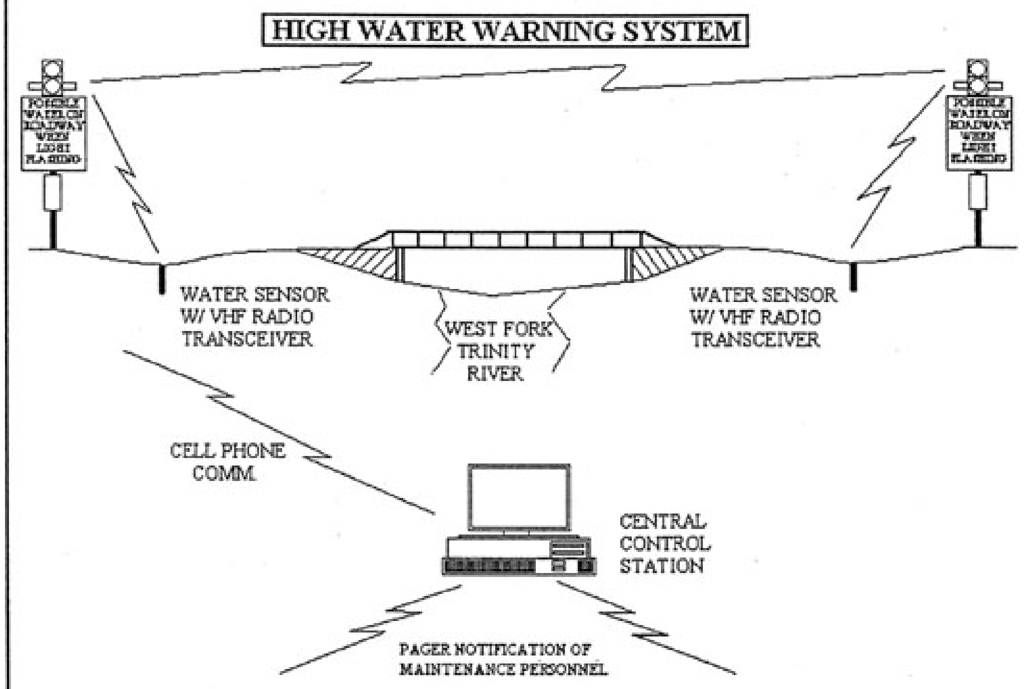


Figure 2

An option has been identified to also place a CCTV video camera near the field locations to provide additional service to maintenance and operations personnel, however this option is not included in the current proposal due to anticipated funding limitations. If funding permits TxDOT will investigate this enhancement at a later date, the enhancement is described herein for reference. Depending on site conditions, the video enhancement would consist of one or two 40' utility poles fitted with a fixed mount, or pan/tilt/zoom mounted, monochrome video camera in a controlled environment housing. The housing should be fitted with both heater and wiper mechanisms. The installation would also include a solar panel, a cellular telephone antenna and a small enclosure near the base of the pole containing the camera control receiver, a cellular telephone and modem, a solar charging system with batteries, and a commercially available video compression unit. During normal (non-incident) conditions the cellular telephone would be powered but the camera would not. During High Water alerts and/or alarms, maintenance and/or operations personnel would be able to dial-in to the camera, power the camera up and view the conditions reported by the detection system prior to dispatching maintenance personnel. This would provide additional awareness and information about site conditions that maintenance supervisors could use to determine proper response, and to allocate appropriate material and personnel resources.

ANTICIPATED BENEFITS AND DELIVERABLES:

The key benefit is to provide a reliable notification of dangerous "water over the roadway" conditions to motorists and appropriate agency maintenance, and/or operations, personnel whenever those conditions occur. There is significant liability exposure for non-action in these hazardous situations whether we were aware of them or not. This project attempts to improve agency awareness.

If this project proves viable and reliable, this warning system, deployed area-wide, will provide agency personnel the necessary notification of problem areas and the appropriate response time to protect the driving public and the department from a dangerous situation. The deployment will also provide an immediate local warning to motorists to protect them until agency personnel can arrive to manage the site.

Deliverables for this project will include design and operational experiences gained by the department and an evaluation by the department's maintenance/operations personnel of the real-world usefulness of this type of installation. Additionally, an outlined set of design, installation, maintenance and operations guidelines, specifications and standards plan sheets will be delivered for use by other agencies.

It is anticipated that the installations described in this proposal can additionally provide a reasonably priced foundation for additional rural and/or remote capabilities, depending on an agency's needs. By changing or adding the appropriate sensors an agency can deploy a remote site capable of any or all of the following envisioned capabilities:

- Detection of roadway icing conditions;
- Detection of visibility hazards, such as fog;
- Detection of hazardous high crosswind conditions;
- Monitoring of funding related environmental conditions, such as ozone.

While researching commercial availability of systems to support this High Water Detection System proposal, we discovered that reasonably priced sensors are available to allow an agency to tailor this proposal to any or all of the above listed capabilities.

DATA AVAILABILITY:

The data available for evaluation of the site and the effectiveness of this proposal includes the following:

- Average rainfall during a 24-hour period which causes the site to flood;
- Number of times during previous three years that the site has experienced water over the roadway;
- Number of times during the previous three years that maintenance personnel have had to close the site due to water over the roadway;
- Average time from water covering the roadway to notification of maintenance personnel to maintenance personnel arriving on-site.
- Number of property damage claims or injuries associated with High Water hazard at this site compared with county-wide reports;

Data sources include:

- Master accident listing;
- TxDOT Maintenance and Engineering records;
- Base station data logs (evaluation phase);

PROJECT SITE(S):

The proposed site is located in Wise County, Texas on Farm-to-Market road 3259 near the town of Paradise, as shown in **Figure 3**. The facility is a two lane, undivided, asphaltic concrete pavement surface connecting Farm-to-Market road 51 to State Highway 114. The specific site is a crossing of the West Fork of the Trinity river.

According to the Wise County Resident Area Engineer, the hazardous High Water conditions at this site actually occur on the approaches to the structure over the Trinity river, rather than at the structure itself.

There are no existing transportation systems at the proposed site.

The proposed project's control systems will be not initially be integrated with the department's existing Intelligent Transportation System (ITS) initiative, known as TransVISION. The project will function as a stand-alone initiative for rural ITS applications, and to evaluate the effectiveness and efficiency of the concept and equipment. If the concept is proven, the next anticipated actions will be to expand the coverage of this proposal to other sites in Wise County and in the other counties served by this district.

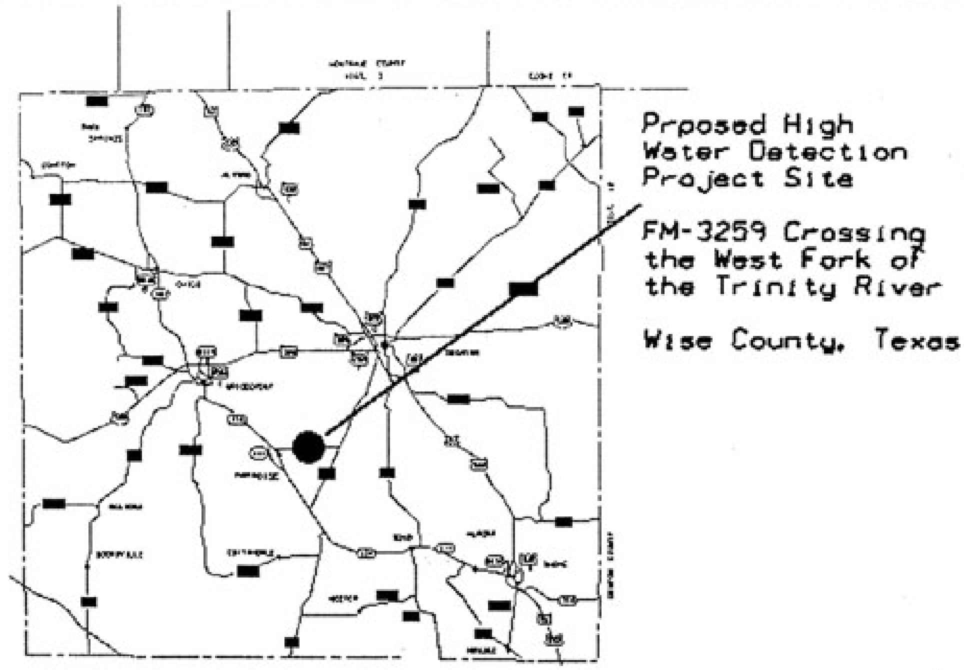

Prposed High
Water Detection
Project Site
FM-3259 Crossing
the West Fork of
the Trinity River
Wise County, Texas

Figure 3

ESTIMATED EQUIPMENT AND IMPLEMENTATION COSTS:

A commercial product was located to perform the required functions of this proposal. Discussion of this proposal with Department engineering/maintenance personnel and the vendor produced the following equipment requirements:

Component Listing and estimated pricing:

Qty	Model #	Description	Price (each)
2	1200	Sentry II Roadway High Water Warning System, includes: (2) infrared sensors, (2) light/sign stations. Each light/sign station includes: one 36" x 36" changeable message sign (high intensity), (1) amber 12" LED flasher, (1) red LED flasher, (1) Model 4600 controller/VHF radio transceiver w/ antenna , (1) 100 Amp - 12 VDC GelCell battery w/ solar charger and regulator, (1) 15' x 4" aluminum pole, (1) 18" x 24" x 18" aluminum enclosure, all cables and mounting hardware, (1) set Complete Installation, Operating and Maintenance Manuals.	$ 10,988.00
2	3012	Additional remote roadway wireless water level sensor station, includes (2) infrared sensors with VHF radio transceiver.	$ 3,395.00
2	9015	Upgrade light/sign stations to break-away pole mounts: includes base, collar and pole.	$ 595.00
1	8002	Central Computer Display and Remote Control Station, includes current technology personal computer w/ printer, receiver, Sentinel software, and dial-out.	$ 5,595.00
1	7402	Cellular phone auto-dialer module	$ 2,500.00
1	N/A	System installation, configuration and testing provided by vendor.	$ 5,000.00
	Sub-Total		**$43,051.00**
	+	Incidentals and Contingencies (10%)	$ 4,305.00
	Total		**$ 47,356.00**

To insure cost and quality controls, we believe that procurements for this project should be a proprietary purchase. This method will allow local TxDOT purchasers to negotiate the final price with a short list of qualified vendors known to be able to deliver the specified items, within the specified timeframe. To further control costs, TxDOT will provide all necessary traffic control and will make department owned equipment and operators available to the vendor for operations such as drilling foundation cores. TxDOT will also provide inspection services for this project.

The optional video enhancement for this project would require:

- Two 40' utility poles;
- Two monochrome closed circuit television cameras, with manual zoom lens;
- Two controlled environment housings, with heater and wiper mechanism;
- Two fixed camera mounts compatible with pole type used;
- Two pole mounted NEMA enclosures (2' x3', approximately);
- Two camera control receivers;
- Two solar power systems with extended storage capacity to service heater applications;
- Two cellular telephone systems with modems;
- Two video compression systems compatible with dial-up/cellular telephone service;
- One video compression system central unit compatible with field units and dial-up/cellular telephone service.

The cost of the optional video enhancement is estimated at $60,000.00, for this project.

ESTIMATED TIMELINE:

The estimated duration of equipment purchase and installation is 6 months.

Due to the need for specific environmental conditions to evaluate the effectiveness of this proposal, TxDOT suggests a lengthy evaluation period on the order of 2-3 years.

APPENDIX C

Rural Travel Time Estimation

(Literature Search for the Frontier Pooled Fund Study)

1.0 Introduction

Travel time estimation is an important input for ATIS applications, which are suitable to be adopted in rural transportation settings (e g., Oregon in this project). The real-time information provides motorists opportunities to make informed decisions. It is also used to implement traffic management applications and strategies for optimizing network productivity.

1.1. Topic Areas

- Other travel time estimation projects
- Use of video for license plate reading
- Product information from manufacturers of license plate reading systems
- Privacy issues related to reading license plates
- Use of traveler information by the traveling public in rural areas
- Benefits of travel time estimation/traveler information in rural areas
- Algorithms used for travel time estimation

1.2. Methodology

1. TRIS Online v2.6 database: keyword search

Keywords used:

- "Travel time estimation"
- "Travel time" and estimation and rural
- "Traffic surveillance" and "incident detection" and project
- "License plate" and reading
- "License plate" and privacy
- "Traffic surveillance" and privacy
- "License plate" and manufacturer
- "Information dissemination" and traveler
- "Traveler information" + rural
- "Travel time" and estimation and algorithm and accuracy

2. Yahoo! Advanced Search

Keywords used:

- “Travel time estimation”
- Video and “license plate reading”
- Privacy and “license plate reading”
- Product and “license plate reading”
- “Traveler information dissemination”
- “Rural traveler information” and benefits
- “Travel time” and estimation and benefits

1.3. Summary of Results

1.3.1. Other travel time estimation projects

1. Review of Current Practices on Freeways (Paracha and McDermott, 2001)

The objective of the paper is was to improve the understanding of current practices related to real-time travel time data collection, applications, issues, and effectiveness. In addition to an extensive literature review, a survey of thirteen transportation agencies was conducted. The survey results indicate that motorists like this information and would like to have more reliability, coverage, and predictability.

2. Travel Time Estimation on Freeways Using Loop Detectors and AVI Technologies

In the paper (Ford, 1998), a literature review, phone interviews and a questionnaire were used to help identify the current state-of-the-practice and the advantages and disadvantages for loop detectors and Automatic Vehicle Identification (AVI) technologies used for travel time estimation on freeways.

It was found that many state agencies are familiar with installing and maintaining loop detectors and that the cost of a loop detector system to measure travel time is relatively low. However, the travel time data is subject to errors in high speed or congested conditions. Loop detectors are also prone to failure and often require maintenance, which often leads to lane closures and the interruption of traffic.

Travel time can be accurately estimated with minimal roadway equipment by using AVI technology. Radio frequency antennas are often mounted on existing structures and spaced up to 10.8 km between reader stations. AVI technology is ideal for traffic management and ATIS due to their numerous uses of accurate travel time data. However, the biggest drawback of AVI is the capital and installation cost.

3. Evaluation of Travel Time Estimation Methodologies (Hamm, 1993)

The report investigates different travel time estimation methodologies in order to evaluate their advantages, limitations accuracy, ease of measurement, and applicability for different uses. The first section of the report describes four existing methods that are currently used to collect travel time data: floating car, license plate matching, cellular telephone reporting and detector systems.

The second section identifies emerging technologies: automatic vehicle identification and global positioning.

4. Travel Time Estimation in Houston and San Antonio (Eisele and Rilett, 2002)

The paper describes how ITS data can be used to provide travel time information specific to commercial vehicles and to perform transportation system monitoring. Data were collected along a two-mile (3.2-kilometer) freeway segment in Houston (US 290) instrumented with AVI at 0.5-mile spacing. Data were also collected along a two-mile (3.2-kilometer) freeway segment in San Antonio (IH-35) instrumented with inductance loop detectors at 0.5-mile spacing. Commercial vehicle travel time data were simultaneously collected by video along the corridor for comparison to AVI and inductance loop detectors. Instrumented test vehicle data were also simultaneously collected using distance-measuring instruments (DMIs) along the corridor at less than five-minute headways.

The results provide insight into how corridor travel time mean and variance may be estimated from both AVI and inductance loop detectors, and how these estimates compare to estimates of mean and variance for commercial vehicles. It was found that it may be reasonable to provide travel time maps and information in real-time specifically for commercial vehicles for just-in-time or fleet operations. ITS travel time data sources, such as AVI in Houston, were also found to provide a very cost-effective data collection method.

5. A Real-time Travel Time Prediction System in a Freeway Construction Work Zone

The paper (Zwahlen and Russ, 2002) summarizes the evaluation of the accuracy of displayed travel times from a real-time travel time prediction system (TIPS) in a construction work zone, The system includes changeable message signs (CMSs) displaying the travel time and distance to the end of the work zone to motorists, which are computed by an intelligent traffic algorithm and travel-time estimation model of the TIPS software. The inputs for the model are taken from strategically placed microwave radar sensors that detect the vehicle traffic on each lane of the freeway. The TIPS system also includes the computer and microcontroller computing the travel times, 220 MHz radios for transmitting data from the sensors to the computer and from the computer to the CMSs, and trailers with solar panels and batteries to power the radar sensors, CMSs, and radios.

TIPS was specially developed for applications in freeway work zones, but can be used on any freeway that experiences recurring congestion. It is recommended that the Ohio DOT implement TIPS in suburban or rural freeways (Pant, 2000).

6. Using Cell Phones as Traffic Probes in the San Francisco Bay Area (Ygnace, Drane, Yim and Lacvivier, 2000)

The report describes research that evaluated the feasibility of using cell phones as traffic probes in the San Francisco Bay Area. The report discusses the associated institutional environment, followed by a review of cellular positioning techniques. Results from analytical and simulation models are reported. The report concludes with a discussion regarding how a field trial could be implemented, which would consist of making actual travel time measurements using one or more cellular telephone systems, making ground truth measurements using existing technologies, and comparing the results with a Global Positioning System (GPS) vehicle probe solution.

7. Estimating Link Travel Time on I-70 Corridor in Rural Colorado (Khan and Thanasupsin, 2000)

The report represents the findings of a study that demonstrates the feasibility of estimating link travel time and speed in real-time for rural, mountainous sections of interstate freeway in Colorado using vehicles instrumented with GPS receivers, serving as probes in traffic streams.

The system configuration developed includes a cost-effective, portable GPS deployment unit, communication links to a server PC and an integrated prototype system for vehicle tracking and estimating link travel time statistics. This study was carried out in two phases. The objective of the first phase was to identify a cost-effective means of monitoring traffic within a rural, mountainous stretch of the I-70 freeway. An algorithm was developed to estimate average link speed, travel time and the standard error of estimates to provide user information on the reliability of the estimates based on the probe data. In the second phase of the project, a real-time demonstrational prototype was developed to receive, process and estimate link travel time and speed statistics in real-time. The system was tested off-line and on-line based on field data received from the I-70 corridor. In addition, GPS receivers were deployed using a commercial vanpool service and the system was evaluated further.

8. The Central Artery/ Tunnel project in Boston, Massachusetts (Gregorski, 2000)

The "brains" of the system, the two redundant, mirror-image central processing units and the operations control center (OCC), are already working. The goals of the system are efficient travel control, rapid incident detection and incident management, support for the police and fire agencies, environmentally safe tunnels, and efficient operations and management. Within the overall system, over 1,400 loop detectors measure traffic volume and occupancy, including video detection systems, which are currently being field-tested, to supplement the loop detectors and integrate traffic surveillance and monitoring.

9. Arterial Link Travel Time Estimation in the Minneapolis/St. Paul area

The envisioned operational tests of ATIS and ATMS in the Minneapolis/St. Paul area call for the provision of timely and reliable travel times over an entire road network. The project (Zhang, Kwon, Wu, Sommers, and Habib, 1997) examines the development of improved arterial travel time models using loop detector data. In the first phase, researchers reviewed existing travel time models, collected traffic data, and developed a travel time database. The second phase will seek to develop and evaluate new travel time estimation models.

10. CAPITAL ITS Operational Test and Demonstration Project

Focus of the project (University of Maryland - College Park, Transportation Studies, 1997) was assessing the viability of using cellular-based traffic probes as a vehicular traffic surveillance technique in the Washington D.C. metropolitan area. The project had three objectives: 1) to determine if cellular phones provide a cost-effective means of wide area traffic surveillance; 2) to determine if this type of information can be effectively integrated into a real-time area-wide traffic management system; and, 3) to determine if packet data transmission over a cellular phone communications network provides an effective means of disseminating real-time traffic information. Results were promising, however, the project did not produce the level of accuracy as hoped for due to several factors, including: geolocation accuracy, speed estimation algorithm, and incident detection algorithm.

11. Construction of the AVI System on the Metropolitan Expressway

AVI terminal equipment has been installed at 19 points on the Metropolitan Expressway to collect license plate information (Morikawa, Takahashi, Yano, Hirao, Kojima, Komada, and

Shimada, 1996). Travel times are calculated using speed data from vehicle detectors, but with AVI terminal equipment, vehicle identification has become possible offering improved accuracy. Although such travel time information is the result of making the best use of features of AVI terminal equipment, this equipment can also be applied to many systems, e.g., the Dynamic Origin-Destination (OD) information. The paper describes the AVI system structure, travel time verification results, the authors' concrete policies regarding equipment installation for Dynamic OD information using AVI terminal, and discusses the feasibility of AVI applied systems.

12. Travel Time Estimation and Incident Detection Software of ADVANCE (1991-1996)

The ADVANCE archive (http://ais.its-program.anl.gov/advance/reports/travel.time.software.html) contains the reports that document the development of the software algorithms used at the Traffic Information Center to estimate and predict both average and dynamic (real-time) travel times in the ADVANCE network, based on data obtained in real time from remote sources such as vehicle location probes, in-pavement traffic volume and occupancy detectors, and anecdotal incident reports.

13. Travel Time Estimation On Japanese Rural Expressways

In order to estimate the time required to pass through the bottleneck sections on Japanese rural expressways, the highway authorities have equipped their expressway systems with vehicle detectors or AVI systems.

The objective of the study (Makigami, Murakami, Takeuchi, and Shimizu, 1995) is to investigate the reliability of the travel time information obtained. A traffic survey was conducted along with travel time measurements using AVI cameras; the traffic flow was recorded using television cameras at a junction. From the results, an investigation was undertaken to determine the relationship between the rate of recognition of vehicle license numbers and recording conditions, such as traffic volume fluctuation and traffic jam conditions. Particular attention was paid to the accuracy and reliability of travel time measurements from the video recordings.

14. Santa Monica Freeway Smart Corridor Demonstration Project (Roseman and Skehan, 1995)

Transportation engineers from the City of Los Angeles DOT working closely with JHK & Associates have developed an arterial incident detection methodology. They have produced an algorithm that has been integrated into a multi-agency traffic management system. The integrated arterial incident detection system currently provides automated incident surveillance on the five-hundred forty signalized intersection Smart Corridor arterial network.

See also: Caltrans Realtime Freeway Speed Map at http://www.dot.ca.gov/traffic/.

15. TRANSMIT Project (Marshall and Batz, 1994)

The Transportation Operations Coordinating Committee's System for Managing Incidents and Traffic (TRANSMIT) within the greater New York City area was initiated to establish the feasibility of using Electronic Toll and Traffic Management (ETTM) equipment for traffic surveillance and incident detection applications. ETTM technology offers the potential for using vehicles equipped with toll tags to serve as vehicle probes within the traffic stream of the area for which surveillance is being established.

16. Automated Travel Time Information System on Route 9 in Western Massachusetts

A travel time information system using automated license plate imaging has been implemented on a segment of Route 9 in western Massachusetts. Video cameras view license plates of passing vehicles at both the upstream and downstream ends of the 3.7-mile long segment (Shuldiner and Upchurch, 2001).

The video image is interpreted by video-imaging software to "read" the license plate number. The time of passage is time-stamped at both the upstream and downstream locations. License plate matching routines provide continuously updated average travel times between the two locations. Travel time information is currently disseminated via a website on a near real-time basis. In the future it will be provided to the public via additional media through a regional Traveler Information Center. This information will also be provided to the local Massachusetts Highway Department office to alert the agency to possible incidents or severe congestion.

1.3.2. Use of video for license plate reading

1. License Plate Matching Techniques (http://www.fhwa.dot.gov/ohim/handbook/chap4.pdf)

The chapter in Travel Time Data Collection Handbook by FHWA, Office of Highway Information Management contains information on travel time collection using license plate matching techniques. Four basic methods of collecting and processing license plates are considered in this chapter: Manual, Portable Computer, Video with Manual Transcription, and Video with Character Recognition.

2. Travel Time Estimation Using Geo-referenced Aerial Video

The University of Arizona is working on a new technique that uses aerial video, GPS and computer vision technology to collect and reduce travel time data along major arterial streets. Some advantages of aerial video over test cars are that travel time estimates from aerial video eliminate driver subjectivity and supply information about within-platoon travel time variation. Aerial video can also provide more detailed information than license plate matching and other ITS techniques, including data on speed density, delay, turning counts, platoon dispersion and other important traffic parameters that traditionally require separate data collection efforts (Angel and Hickman, 2002).

3. Video License Plate Data Reduction (Gupta, Fricker, and Moffett, 2002)

Although automated license plate readers are being implemented with success elsewhere, their dependence on high-end equipment makes them too expensive for most applications in Indiana. The paper reports on an attempt to use standard video cameras and tapes, readily available video processing equipment, and open-source software to minimize the human role in the data reduction.

The process of automatically transcribing video data can be divided into sub-processes. Analog video data are digitized and stored on a computer hard disk. The resulting digital images are further processed, using image-processing algorithms, to locate and extract the license plate and time stamp information. Character recognition techniques can then be applied to "read" the license plate "number" into an electronic file for the desired analysis. The Video License Plate Data Reduction (VLPDR) software described in the paper can identify video frames that contain vehicles, and discard the remaining frames. VLPDR can locate and read the time stamps in most of these frames. Although VLPDR cannot "read" the license plate numbers into a data file, this final step is made easier by a user-friendly graphical user interface. VLPDR saves manual data reduction by an estimated 60 percent.

4. Barcode Reading

The article (Crawford, 2001) looks at barcoding applications in automatic license plate recognition (ALPR) technology. It describes trials in which barcodes invisible to the naked eye were read using proprietary camera technology. The system was able to capture, within a few hundred milliseconds, virtually blur-free images of barcodes attached to the sides of vehicles.

5. Applications and Evaluation of Automated License Plate Reading Systems

Typically, ALPR systems are used for enforcement type applications and data collection applications including parking lot management, origin-destination studies, traffic flow studies, high occupancy vehicle analysis, and weigh in motion systems. An ALPR system consists of three main components; a device for detecting vehicle presence, a digital video camera and an image processor. The image processor identifies the license plate according to embedded pattern recognition algorithms. The accuracy of the pattern recognition algorithms used in the image processor is an important concern when evaluating ALPR systems.

The paper (Rossetti and Baker, 2001) covers the basic architecture of ALPR systems, followed by discussion of several current applications of ALPR systems. Several alternative suppliers of ALPR systems are then presented. Finally, a possible method for evaluating the systems is suggested.

6. Video-Based Vehicle Signature Analysis and Tracking

The report (MacCarley, 1998) describes the results of a project that verified and tested a system for the non-intrusive tracking of individual vehicles on freeways for data collection purposes. The concept involved the use of a computer vision method to make measurements of external dimensions, points of optical demarcation, and predominant colors of each vehicle. The system employed a video camera as the primary sensor and detection modules monitoring traffic lanes. For each passing vehicle, a Video Signature Vector (VSV) was measured and transmitted. VSVs were then matched to re-identify each vehicle at each detectorized site, thus determining the progress of the vehicle. The potential applications for this tracking system include traffic flow model validation, generation of origin-destination data, travel time estimation, validation of local modal-based emission models, and law enforcement.

7. Automated License Plate Recognition with A Neural Net Based Accelerator

The paper (Nallamothu and Wang, 1997) presents a method to read license plate numbers from pictures taken with a digital camera and recognize the characters with the help of a neural network based microprocessor. The research includes the detection of the license plate location in the digital image and the segmentation of individual characters in the license plate number.

8. A Machine Vision System (Shuldiner and Woodson, 1997)

A machine vision system capable of automatically processing license plate images from videotape or live video is described. A special feature of this system identifies the presence of a license plate anywhere in the field of view and captures this license plate image for subsequent processing and transcription to a computer file using optical character recognition techniques. The captured video license plate image can also be presented to a human operator for manual transcription. The video/machine vision system functions equally well with overhead views of traffic, such as from highway overpasses, and with roadside views from highway shoulders and medians. It operates effectively at all highway speeds without supplemental lighting under most weather conditions during daylight hours and, with supplemental lighting, at night. The self-triggering plate capture feature obviates the need for external triggers such as treadles or light beams to signal the presence of a vehicle in a given video frame. As such, the system is mobile and extremely flexible and is well suited both for collecting data at multiple sites for a one or two day period and for semi-permanent or permanent installations.

9. Comparison in Manual and Machine Vision Transcription of Videotaped License Plate Records (Hu, 1995)

An automated machine vision license plate reading system was used in the place of human operators to transcribe videotaped license plate images into a computer file. This license plate reading system was evaluated by the Volpe National Transportation Systems Center (VNTSC) in an extensive series of travel time surveys conducted in 1993 for the FHWA. A sample of 12 hours of the 1500 hours of videotaped license plate records collected in the course of the VNTSC surveys was analyzed frame-by-frame at the Universiy of Massachusetts at Amherst using both manual and machine vision transcription procedures.

It was determined that both the manual and machine vision procedures produce essentially identical, precise and statistically robust estimates of mean travel times between survey stations. The machine vision system produced estimates in as little as one-tenth the time required by manual operators.

10. Application of Video/Machine Vision Technology in Traffic Data Analysis

The paper (D'Agostino and Shuldiner, 1994) examines the use of Hi-8mm video cameras (camcorders) and an automatic license plate reading system, based on machine vision technology, to perform travel time calculations. The paper also looks at the logistics of conducting extensive traffic surveys, lessons applicable to survey design, and the quantity and statistical significance of the data required.

1.3.3. Product information from manufacturers about license plate reading systems

1. Recognition Handbook (Nelson, 2001)

The article focuses on license plate recognition (LPR) technology and its application to AVI. It relates how the technology has been under-utilized, much of it due to reports of marginal system performance. In an effort to dispel the negative reputation, the LPR industry is enhancing the hardware, recognition software, applications programming, and proprietary system configurations. An overview is given of various manufacturers and their enhanced products.

2. Eye of The Beholder: Video-based AVI (Nelson, 1997)

The article describes how license plate recognition systems, using video-based AVI technology, are being embraced as a mainstream traffic management tool. The author warns however, of the necessity of carefully examining a manufacturer's claims of accuracy.

3. Transformation Systems, Inc. (Transfo)

Url: http://www.transfo.com/detect.htm

Transfo offers advanced machine vision technology supplied by CRS to provide automated video image vehicle detection systems (VIVDS) based on their Traffic Analysis System (TAS2) and compatible camera systems. The TAS2 makes use of proprietary algorithms and special image processing modules to achieve greater accuracy than is typical with other video detectors on the market today. These modules process video signals from multiple cameras and provide advantages over inductive loops and other vehicle sensors.

4. PULNiX America, Inc.

Url: http://www.pulnix.com/ITS/ITS-prod2.html

The PULNiX Vehicle Imaging System (VIS) is a low cost imaging solution for violation enforcement systems and automatic license plate readers. The PULNiX Video Image Capture (VIC) Subsystem is designed for advanced ITS applications requiring high definition vehicle images.

5. 24 More Manufacturers of License Plate Recognition Systems at Expo1000.com

Url: http://www.expo1000.com/parking/prod_list.asp?pc=0490

1.3.4. Privacy issues related to reading license plates

1. Traffic System Causes Privacy Outcry (Gaudette, 2002)

Traffic sensors being installed along San Francisco Bay area highways will be able to track a quarter million drivers who use FasTrak along their commutes. Proponents say the $37 million enhancement to the region's electronic toll system will be a boon to commuters, providing motorists real-time information about some of the nation's worst road congestion via cell phone, radio or Internet. Traffic planners will be able to gather crucial data on problem areas. But despite government assurances, the new program is also raising fears that drivers' privacy will be invaded.

2. CCTV Privacy Survey and Examples of Existing Privacy Policy

The report (Clinger and Abedon, 2001) reviews privacy policies that are in place or being developed with regard to closed circuit television (CCTV) video cameras on public roadways. This document is designed to be a resource and not a comprehensive research report on CCTV video privacy policy. This document relays CCTV privacy policy information compiled through an electronic mail survey and a general publication review.

3. Data Privacy to the Rescue

One article (Burns, 2000) looks at the privacy issues associated with the Maryland Mass Transit Administration's video capture of license plates on Interstate 95 for a travel survey. Another article (Slevin, 1999) looks at the privacy issue as it relates to data collected at electronic clearance stations.

4. Influence of Public Acceptance on What IVHS Can Achieve (Wigan, 1995)

The paper discusses how the privacy aspects of Intelligent Vehicle Highway Systems (IVHS) raise concerns and thus have delayed adoption of some of the systems with identification and tracing capacities. The ownership and use of data collected in the course of IVHS operations presents both revenue opportunities and problems, and change the basis of enforcement systems. The cost of making any major errors in implementing IVHS could easily make it extremely difficult to deploy further systems. It is argued that adoption of a number of principles could safeguard the potential benefits at an acceptable social cost.

1.3.5. Use of traveler information by the traveling public in rural areas (any surveys, different dissemination methods, etc.)

1. Dissemination devices and typical information (Thompson, 1999)

A traveler information system may have any one or more of the typical dissemination devices listed below as well as others not listed:

- Cable television
- Commercial radio
- Dynamic message signs
- Radio traveler information reports (such as highway advisory radio)
- Dedicated telephone traveler information systems
- Kiosks
- Internet
- Hand-held devices
- In-vehicle devices
- Typical information collected and disseminated to travelers may include, but is not limited to:
- Traffic conditions.
- Roadway conditions.
- Incident information.
- Work-zone information.
- Emergency management information.
- Real-time transit information.
- Weather conditions.
- Transit schedules and routes.
- Real-time traffic information.
- Local area information.
- Tourist area information.
- Alternate route information.
- Employee ride-share information.

- Yellow pages information (hotels, restaurants, local businesses, private transportation services, other public and private services, local information, points of interest, maps, and directions, etc.).
- Tourist attractions and park information.

2. Rural ATIS: User Needs and Technology Assessment (Zarean, Williams, Leonard, and Sivarandan, 1997)

The document describes the research design and findings from rural traveler surveys to identify and prioritize traveler information needs in rural and small urban areas. Information was gathered in focus group discussions and telephone interviews with travelers in rural areas, and consultations with agencies engaged in collecting, coordinating, and disseminating information to rural travelers. The report also describes the nature of and quantifies the magnitude of rural traveler information problems. This document also examines technologies available or under development which are applicable to rural advanced traveler information systems. The application of technologies to data collection, data aggregation/processing, traveler interface, and communication in a rural environment are broadly assessed. The document also summarizes current initiatives relevant to rural applications of ATIS and presents an overview of project findings to date.

3. Traveler Information En Route Needs and Available Services for Visitors to National Parks (Helmuth and Dudek, 2002)

The objectives of the paper were 1) inventory current traveler information provided en route for visitors at a number of national parks; 2) determine the similarities and differences in the traveler information provided among national parks; 3) identify information needs and preferred methods and locations for national parks to provide the information for visitors destined to or while at national parks; and 4) explore whether intelligent transportation systems technology can satisfy the en route needs of visitors to national parks. Surveys were conducted with seven national parks and with four private organizations whose clients and members are visitors of national parks. The results indicated visitors want more information than is currently provided by national parks. Recommendations to improve information transfer to national park visitors by using ITS elements were made.

4. Traveler Information Services in Rural Tourism Areas

Appendix B: QUALITATIVE INTERVIEWS AND FOCUS GROUPS

Appendix C: OBSERVATIONS AT TOURIST INTERACTIONS WITH KIOSKS

Appendix D: SYSTEM/HISTORICAL DATA ANALYSIS

5. Advanced Traveler Information Services in Rural Tourism Areas: Branson Travel and Recreational Information Program (Missouri) and Interstate 40 Traveler and Tourist Information System (Arizona)

Final Report: http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/@3201!.pdf

Tourist Intercept Surveys: http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/@3501!.pdf

Observations at Tourist Interactions with Kiosks: http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/@3801!.PDF

The I-40 TTIS (Traveler and Tourist Information System) Tourist Intercept Survey: http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/4PQ01!.PDF

6. Transit Information Delivery for APTS (Peng and Jan, 1999)

Described and categorized are means of information dissemination systems and their roles in advanced public transportation systems (APTS). An evaluation framework is developed to assess different media on the basis of seven criteria: accessibility, versatility and interactivity, information carrying capacity, user friendliness, costs to install, costs to use, and ease of implementation.

The evaluation shows that the Internet and kiosks have the highest overall ranking. These are capable of delivering a variety of information, can provide interactivity to users, and if designed properly can have a user-friendly interface. Variable message signs and closed-circuit televisions are ranked as good for their modest costs and the variety of information they can deliver. They are appropriate to both wayside and in-terminal information displays. Other emerging technologies, such as automated voice annunciators and personal communication devices, are promising for the future but are not ready for implementation.

7. Disseminating Traffic Information by ATMS (Stout, Poe, and Dixon, 1997)

Recent improvements in traffic sensor and data acquisition methods now allow public agencies to expand the capabilities of their Advanced Traffic Management Systems (ATMS). The research project synthesized the state-of-the-practice of traffic information dissemination within U.S. by conducting a survey of some of the agencies that are operating traffic management centers and disseminating traffic information.

8. Internet: An Effective Tool for Disseminating Traveler Information (Shull, 1996)

The objectives of the project were to: 1. identify examples of the use of the Internet for conveying advanced traveler information to facilitate the pre-trip planning process; 2. identify the difficulties (from the provider's perspective) in conveying static, real-time, and interactive information to the public via the Internet; catalogue these difficulties and recommend approaches to circumvent these problems; 3. identify special design considerations from the perspective of the user of the system; identify human factors issues related to the dissemination of travel information; and 4. recommend ways for a transportation agency to improve the dissemination of transportation information to the public via the Internet.

9. AM Radio: A Low-Cost Tool for Rural Areas (Castle Rock Consultants, 2000)

The Herald Field Operational Test (FOT) tested AM radio as a low-cost way to broadcast traveler information in rural areas. It is proved technically feasible to broadcast data over AM without degrading the audio programming.

10. ATIS Using Low Power Television Stations (McGowan and Dellenback, 1995)

The TransGuide ATMS installed in San Antonio, Texas, by the Texas Department of Transportation (TxDOT) is one of the most advanced systems in the United States. Traffic congestion can be identified by the central computer within 2 minutes and the motorist warning signs can be reconfigured within 15 seconds to minimize traffic congestion. The system utilizes high resolution video cameras to view incidents in the operations control center (OCC).

Operators view a graphic map to determine the overall traffic conditions in the metropolitan area. At high magnification levels, the graphical map shows traffic flow down to the lane level. TxDOT has initiated a program known as the "Media Distribution Plan," which will facilitate the transfer of information from the OCC to media organizations for dissemination to motorists. The importance of the concept is that the TransGuide system maintains real-time data for the entire project area and it is not possible for the media outlets to acquire this information without utilizing the TransGuide System. TxDOT will purchase a low power television station as a technology for the distribution of data. The advantage of the low power television station is that the information can be broadcast over the entire metropolitan area. Receiving the data requires a low-cost antenna. The data to be transferred includes: 1) live video; 2) graphical map; 3) scenario data; 4) lane closure data; and 5) other advanced traveler information systems information. The last four data items will be encapsulated and sent in the vertical blanking interval of the broadcast signals.

11. TMCs: Traveler Information Dissemination Strategies (Alsop, 1996)

The Office of Traffic Management and Intelligent Transportation Systems Applications surveyed transportation management centers (TMCs) across the USA to form an inventory of the strategies currently being used for traveler information dissemination. The objective of the document is to quantify these strategies, and then make the information available to the public.

12. Tourist Oriented Directional Sign (TODS) Program Unveiled in Traverse City (Michigan Department of Transportation, 1998)

Url: http://www.mdot.state.mi.us/communications/press/files/072998.htm

13. Electronic Traveler Information System To Guide Visitors Off I-80 (Dave Snitily, 1997)

Url: http://www.visitnebraska.org/links/sponsorship/etis.htm

The system includes four elements, a World Wide Website, travel counselor workstations with Web site access at selected rest stops, a video monitor system, and touch screen kiosks placed in private businesses across the state. All of these elements working together create a self-sustaining project that will provide valuable, current information to the 12 million vacationers who travel I-80 each year.

14. Temporary ITS for the Reconstruction of I-496 (Michigan Department of Transportation)

Url: http://www.camsys.com/idas/CaseStudies/CaseStudy2/CaseStudyBody.htm

The information collected through the CCTV cameras, queue detection devices, and microwave detectors was processed and disseminated through the following information sources: Portable Dynamic Message Signs (PDMS), World Wide Web Server, Video Monitoring Stations, and Telephone Hotline Information System.

15. Regional Traveler Information Center (RTIC) (Arizona Department of Transportation)

Url: http://www.pagnet.org/its/its_rtic.html

The RTIC is developed to serve as a clearinghouse for dissemination of information to the public and commercial interests. All regional traffic, transit, rideshare, and road condition information and related data will be consolidated into a central database for distribution to travelers, transportation agencies, fleet dispatch centers, emergency service dispatch, and private traveler information providers.

Traveler information dissemination will include information kiosks, cable TV, radio, dial-up voice response system via telephone, Variable Message Signs (VMS), and Internet web page.

16. Incident Management and Traveler Information Exchange/Sharing in Texas

The report (Finley, Durkop, Wiles, Carvell, and Ullman, 2001.) presents a review of the practices and technologies being used in Texas for incident management and traveler information exchange and sharing. All of the districts investigated (Dallas, Fort Worth, Houston, and San Antonio) share video (real-time continuous and snapshots), speed information, real-time incident information, and scheduled lane/road closure information with other public and private entities.

The most common method utilized by Texas Department of Transportation (TxDOT) for disseminating information is the internet. TxDOT also extensively operates dynamic message signs to provide information to travelers en route. Other methods employed include direct connections (e.g., fiber), email, telephone, fax, low power television, in-vehicle navigation units, lane control signals, and kiosks.

1.3.6. Benefits of travel time estimation/traveler information in rural areas

1. ITS Benefits and Unit Costs Database (U.S. DOT Joint Program Office for Intelligent Transportation Systems)

Url: http://www.benefitcost.its.dot.gov/

2. Cost-Benefit Analysis of A Rural ATIS (Ullah, O'Neill, and Bishop, 1994)

A life-cycle cost model is developed to evaluate a proposed rural Advanced Traveler Information System (ATIS). Costs used in this model include capital investment (in equipment, facilities, and installation), and operation and maintenance costs. A cost-benefit analysis is reported. System benefits are equated to potential reduction in the number of accidents that occur while the ATIS is in place.

3. Alternative Methods For Valuing Economic Benefits of Transportation Projects

The paper (Weisbrod and Grovak, 2001) examines and contrasts alternative types of economic impact analysis. It focuses primarily on measures relating to economic development, which is frequently cited as a primary goal for highway investment projects. Data and findings from a highway study in Kentucky are used to explore: (1) differences in the definitions of economic benefits inherent in the various types of analysis, (2) reasons for their differing findings on the value of benefits, and (3) issues affecting their interpretation and use for decision-making.

4. On-Time Reliability Impacts of Travel Time Estimation

Internet-based ATIS provide the urban traveler with estimated travel times based on current roadway congestion. The report (Wunderlich, Hardy, Larkin, and Shah, 2001) describes an innovative analytical method, which applies dynamic programming techniques to archives of observed roadway congestion to quantify the impact of regular ATIS utilization by urban commuters. Using results from a large-scale case study in the Washington, DC area, we show that even though over time ATIS users realize only marginally reduced in-vehicle travel time, they do realize substantial time management benefits from improved on-time reliability and trip predictability.

5. Expected Safety Benefits of Implementing ITS in Virginia: Literature Synthesis

Several ATMS technologies improve safety, primarily through reducing congestion. In general, this reduces crash risk, particularly for multivehicle crashes. Advanced Traveler Information Systems (ATIS) provide information to the public by such means as the broadcast media, cable television, highway advisory radio, and the Internet. Although no studies document an impact, a simulation study showed that such a system has the potential to reduce crash risk. Advanced Public Transportation Systems (APTS) and Advanced Rural Transportation Systems (ARTS) could have a positive impact on safety through the deployment of Mayday systems and alarms and other security warning devices that notify authorities in the event of an incident. In addition, Commercial Vehicle Operations (CVO) applications have the potential to reduce the risk of fatalities and serious injuries. (Jernigan, 1998)

6. How Advanced Traveler Information Can Increase Rural Highway Safety

The article (Jorgensen, 1997) gives a quick overview of how the safety of traveling on rural roads has improved due to advanced technologies. Focus is on three technologies: 1) Advanced Traveler Information Systems (ATIS) which can provide real time travel advisory information, 2) Traveler Information Systems (TIS), which provide destination-oriented information for travelers, and 3) Road and Runway Weather Information Systems (RWIS), which predict when ice will form on the pavement.

1.3.7. Algorithms used for travel time estimation

1. Empirical Comparison of Travel Time Estimation Methods (Zhang, Rice, and Bickel, 1999)

The paper performs an empirical comparison of travel time estimation methods that are based on single-loop detector data. The first estimation method includes a regression method that is based on an intuitive stochastic model. The second estimation method is a conventional one using an identity relating speed, flow and occupancy with the assumption of a common vehicle length.

The comparison is comprised of three interrelated parts: local comparison, comparison of estimated section travel times over a prolonged stretch of freeway with multiple links and a visualized approach which enables the investigation of performance patterns in time and space of the estimation methods.

2. Section Travel Time Estimation from Point Detection Data

The paper (Oh, Jayakrishnan, and Recker, 2002) points out a deficiency of point measurements obtained from inductance loop detectors in estimating travel times under congested traffic condition and proposes a theoretically sound and practically applicable travel time estimation algorithm that uses the same loop detector data. The main idea of the algorithm is based on the concept of section density that can be easily obtained by observing in-and-out traffic flows between two point detection stations. Travel times estimated from the proposed method are compared to those of other methods via both simulated and real traffic data. While the method estimating travel time based on spot speeds tends to underestimate section travel times due to failure of capturing the congestion occurring between detector stations, the proposed section-density-based method provides accurate travel time estimates.

3. Travel Time Estimation Using Multiple Point Detection of Traffic

The paper (Cortes, Lavanya, Oh, and Jayakrishnan, 2002) develops a methodology to find appropriate travel times for highway links using data from point detectors that could be at various points within the link, or could even be outside the link. The travel times are found using a definition that the appropriate value is the one experienced by a virtual vehicle reaching the mid-point of the link at the mid-point of the time step. A simple iterative scheme is proposed to find the travel time profiles. The accuracy of the scheme will depend on whether aggregated detector data or whether individual vehicle spot speeds are used. Comparison of estimated travel times with actual experienced travel times of all vehicles in a microscopic simulation shows the technique to give very good results, comparable to having a high number of probe vehicles reporting travel times.

4. Estimation of Travel Time Using Data from An Individual Dual Loop Detector

The paper (Coifman, 2002) presents a method for estimating link travel time using data from an individual dual loop detector. The technique exploits basic traffic flow theory to extrapolate local conditions to an extended link. The accuracy of the method suggests that the linear approximation of the flow density relationship is reasonable during congestion. Since the method uses data from a single point in space, changes in the traffic stream (such as an incident) may be over-represented or under-represented, but despite this limitation the estimation method is surprisingly accurate.

5. Aggregate- and Disaggregate-based Travel Time Estimations (Zietsman and Rilett, 2000)

Travel time estimation is important for a wide range of applications, including advanced traveler information systems (ATIS), sustainability analysis, and discrete choice modeling. Approaches to travel time estimation traditionally have been based on aggregate data sets that examine travel times over a number of days or travel times in previous time intervals. Automatic vehicle identification data make it possible to analyze travel time data at a totally disaggregate or individual commuter level.

It is postulated in this research that the capability of modeling travel characteristics on a disaggregate level can improve the accuracy with which performance measures are quantified. The test beds examined are a 22-km section of the I-10 corridor and a 21-km section of the US-290 corridor in Houston, Texas. It was found that aggregation across days, which does not consider the effect of individual days, is 63% less accurate than aggregation by days, which does consider the effect of individual days. Even though the latter technique was found to be more accurate, it was illustrated that 40% of the regular commuters' travel times are statistically different from these aggregate estimates. Similarly, for travel time variability, it was found that for approximately 20% of the cases the travel time standard deviations for regular commuters are statistically different from the aggregate estimates. These results illustrate the uniqueness of an individual commuter's travel patterns and emphasize the benefit of conducting analyses at the level of the individual commuter for both ATIS and sustainable transportation.

6. Travel Time Estimation Based on Vehicle Characteristics

The paper (Shimoura, Nishimura, Tenmoku, and Kawasaki, 2001) describes an algorithm for matching vehicles based on characteristics that are measurable using vehicle detectors and for estimating accurate travel times with short delay. It is shown that a practical level of travel time estimation can be achieved with this algorithm if only vehicle height is measurable. Estimation with the additional measurement of vehicle length would yield even more accuracy.

7. Development of VICS with Adaptive Parameter Tuning

The authors (Yamane, Kakuta, and Fushiki, 2000) developed the AMIS (Advanced Mobile Information Systems), which premises the VICS (Vehicle Information and Communication System) that provides drivers with traffic information in real time. The system has been in use since March 2000 in Hakodate, Hokkaido Prefecture. However, it is difficult to retain the stability of information accuracy in this district where traffic conditions change considerably with the seasons. Therefore, new methods were developed aiming at accuracy and stability of information as well as extension of service areas by using data from vehicle detectors on road as efficiently as possible. The evaluation on the target road gave good results. In particular, the on-line parameter tuning method for travel time estimation was very effective and it should be able to deal with changes of traffic conditions in the future.

8. Determining the Minimum Number of Probe Vehicles Required

Using probe vehicles to collect real-time traffic information is considered an efficient method in real-world applications. Although it usually is assumed that link travel time is normally distributed, it is shown, on the basis of simulation results, that sometimes this is not true. A heuristic of determining the minimum number of probe vehicles required is developed to accommodate this situation (Chen and Chien, 2000).

One objective of the DACCORD project is to implement and evaluate different types of travel time estimation and prediction algorithms. Probe data are used for this purpose. The amount of travel time dispersion and travel time dynamics can be identified by specifying a travel time data model and estimating its parameters using a maximum likelihood estimator. Once identified, these parameters are used to define a new off-line travel time estimator, and to determine the minimum number of probe data required for a certain accuracy level (Vad der Zijpp and Hoogendoorn, 1998).

9. A Prediction Model Based on Kalman Filtering Theory (Zhu and Wang, 2000)

The paper presents an analysis of travel time estimation methods, followed by a real-time isoparametric travel time prediction model that is based on Kalman filtering theory. The model is able to predict travel time by using detected traffic volume on the basic link in urban transportation networks. Test results show that the model has no lagged prediction or oscillatory forecasting patterns.

10. Application of Fuzzy Logic and Neural Networks

The papers (Matsui and Fujita, 1998; Palacharla and Nelson, 1999) present fuzzy reasoning models to convert present data from detectors into estimated link travel times. The models incorporate flexible reasoning and capture nonlinear relationships between link specific detector data and travel times.

In the paper (Palacharla and Nelson, 1995), fuzzy sets are employed at the interface level and neural networks at the processing level to estimate arterial link travel times/delays from loop detector data. The idea is to eliminate the fuzzy rule based system and replace it with a neural network. This approach results in significant savings in time and effort as obtaining human expert's knowledge in terms of fuzzy rules is very difficult. The neural network itself figures out all the fuzzy rules relating input and output patterns based on the given data. The fuzzy logic techniques at the interface levels may be viewed as a form of data compression. This improves the neural network training process and also helps in interpreting the neural network outputs. The fuzzy neural network estimates travel times more accurately for both flow and occupancy values than any other approach. It gives 87 percent more accurate estimated travel times than the fuzzy expert system.

11. Estimation of Travel Time Distribution and Detection of Incidents

The paper (Anantharam, 1998) studies the problem of travel time estimation along a freeway section, based on data derived from vehicle detectors at multiple locations. The problem is viewed as one of pattern recognition. Algorithms are derived and used to estimate the distribution of the travel time between the detectors. The most promising algorithm is a dynamic programming algorithm based on sequence matching techniques.

1.4. References

Alsop, S. C., 1996. TRANSPORTATION MANAGEMENT CENTERS: TRAVELER INFORMATION DISSEMINATION STRATEGIES. FINAL REPORT. Report No. DOT-T-96-21. 55p.

Anantharam, V., 1998. ESTIMATION OF TRAVEL TIME DISTRIBUTION AND DETECTION OF INCIDENTS BASED ON AUTOMATIC VEHICLE CLASSIFICATION. PATH working paper; UCB-ITS-PWP-98-12. [21] p.

Angel, A. and M. Hickman, 2002. EXPERIMENTAL INVESTIGATION OF TRAVEL TIME ESTIMATION USING GEO- REFERENCED AERIAL VIDEO. National Research Council (U.S.). Transportation Research Board. Meeting (81st: 2002: Washington, D.C.). 19p.

Burns, M., 2000. I KNOW WHERE YOU WERE GOING LAST WEEK. Baltimore sun [online]. PATH Record Number 21336. 3p.

Castle Rock Consultants, 2000. HERALD FIELD OPERATION TEST EVALUATION: FINAL REPORT. 45p.

Chen, M. and S. Chien, 2000. DETERMINING THE NUMBER OF PROBE VEHICLES FOR FREEWAY TRAVEL TIME ESTIMATION BY MICROSCOPIC SIMULATION. Transportation Research Record, 1719: pp 61-68.

Clinger, S. and D. R. Abedon, 2001. SUMMARY OF FINDINGS FOR CCTV PRIVACY POLICY SURVEY AND EXAMPLES OF EXISTING PRIVACY POLICY. PATH Record Number 22931. 46p.

Coifman, B., 2002. ESTIMATING TRAVEL TIMES AND VEHICLE TRAJECTORIES ON FREEWAYS USING DUAL LOOP DETECTORS. Transportation Research. Part A: Policy and Practice, 36(4): 351-364.

Cortés, C. E., R. Lavanya, J. S. Oh, and R. Jayakrishnan, 2002. A GENERAL PURPOSE METHODOLOGY FOR LINK TRAVEL TIME ESTIMATION USING MULTIPLE POINT DETECTION OF TRAFFIC. National Research Council (U.S.). Transportation Research Board. Meeting (81st: 2002: Washington, D.C.). 27p.

Crawford, D., 2001. HIGHWAY SPEED READING: BARCODE READING OFFERS A NEW APPROACH TO SAFETY CHECKING. ITS international, 7(4): 53

D'Agostino, S. A. and P. W. Shuldiner, 1994. APPLICATION OF VIDEO/MACHINE VISION TECHNOLOGY IN TRAFFIC DATA ANALYSIS. Society of Photo-optical Instrumentation Engineers Bellingham, WA. Intelligent vehicle highway systems, 1994: 207-214.

Eisele, W. L. and L. R. Rilett, ESTIMATING CORRIDOR TRAVEL TIME MEAN AND VARIANCE FROM ITS DATA SOURCES. Institute of Transportation Engineers. Today's Transportation Challenge: Meeting Our Customer's Expectations. [March 24 – March 27, 2002, Palm Harbor, Florida]. 16p.

Finley, M. D., B. R. Durkop, P. B. Wiles, J. D. Carvell, and G. L. Ullman, 2001. PRACTICES, TECHNOLOGIES, AND USAGE OF INCIDENT MANAGEMENT AND TRAVELER INFORMATION EXCHANGE AND SHARING IN TEXAS. Report No: TX-02/4951-1; TTI: 7-4951. 86p.

Ford, G. L. Jr, 1998. TRAVEL TIME ESTIMATION ON FREEWAYS USING LOOP DETECTORS AND AVI TECHNOLOGIES. Compendium: Graduate Student Papers on Advanced Surface Transportation Systems (1998). pp 115-152.

Gaudette, K., 2002. TRAFFIC SYSTEM CAUSES PRIVACY OUTCRY. Yahoo news. PATH Record Number 25772. 3p.

Gregorski, T., 200. GREAT EXPECTATIONS. Roads and Bridges, 38(12): 32-34.

Gupta, R., J. D. Fricker, D. P. Moffett, 2002. VIDEO LICENSE PLATE DATA REDUCTION. National Research Council (U.S.). Transportation Research Board. Meeting (81st: 2002: Washington, D.C.). 19 p.

Hamm, R. A., 1993. EVALUATION OF TRAVEL TIME ESTIMATION METHODOLOGIES. Texas Transportation Institute, College Station, Tex. Graduate student papers on advanced surface transportation systems. p. D-1-D.

Helmuth, J. L. and C. L. Dudek, 2002. TRAVELER INFORMATION EN ROUTE NEEDS AND AVAILABLE SERVICES FOR VISITORS TO NATIONAL PARKS. National Research Council (U.S.). Transportation Research Board. Meeting (81st: 2002: Washington, D.C.) 24 p.

Hu, A., 1995. VIDEO TECHNOLOGIES IN DATA ACQUISITION FOR TRANSPORTATION SYSTEMS MANAGEMENT AND PLANNING. Federal Transit Administration. In: Use of Video Machine Vision Technology to Estimate Travel Time. 110p.

Jernigan, J. D., 1998. EXPECTED SAFETY BENEFITS OF IMPLEMENTING INTELLIGENT TRANSPORTATION SYSTEMS IN VIRGINIA: A SYNTHESIS OF THE LITERATURE. Report No: FHWA/VTRC 99-R2. 20p.

Jorgensen, L., 1997. HOW ADVANCED TRAVELER INFORMATION CAN INCREASE RURAL HIGHWAY SAFETY. Tech transfer, 59: p. 4

Khan, S. I. and K. Thanasupsin, 2000. ESTIMATING LINK TRAVEL TIME ON I-70 CORRIDOR: A REAL-TIME DEMONSTRATION PROTOTYPE. Report No. CDOT-DTD-R-2000-15. 65p.

MacCarley, C. A., 1998. VIDEOBASED VEHICLE SIGNATURE ANALYSIS AND TRACKING. PHASE 1 VERIFICATION OF CONCEPT AND PRELIMINARY TESTING. PATH working paper; UCB-ITS-PWP-98-10. ii, 39 p.

Makigami, Y., Y. Murakami, H. Takeuchi, and K. Shimizu, 1995. BASIC STUDY ON TRAVEL TIME MEASUREMENT USING AUTOMATIC VEHICLE IDENTIFICATION SYSTEMS IN CONNECTION WITH CONGESTION. Steps Forward. Intelligent Transport Systems World Congress. [Nov. 9 - Nov. 11, 1995, Yokohama, Japan]. Vol. 1. p 181.

Marshall, K. R. and T. Batz, 1994. THE TRANSCOM TRANSMIT PROJECT: AN ALTERNATIVE APPROACH FOR TRAFFIC SURVEILLANCE AND INCIDENT DETECTION. Moving Toward Deployment. Proceedings of the IVHS AMERICA 1994 Annual Meeting. [April 17 – April 20, 1994, Atlanta, Georgia]. Vol. 2. 555-563

Matsui, H. and M. Fujita, 1998. TRAVEL TIME PREDICTION FOR FREEWAY TRAFFIC INFORMATION BY NEURAL NETWORK DRIVEN FUZZY REASONING. IN: NEURAL NETWORKS IN TRANSPORT APPLICATIONS. pp 355-364

McGowan, P. F. and S. W. Dellenback, ADVANCED TRAVELER INFORMATION SYSTEMS USING LOW POWER TELEVISION STATIONS. Steps Forward. Intelligent Transport Systems World Congress. [Nov. 9 – Nov. 11, 1995, Yokohama, Japan] Vol. 2. p756.

Morikawa, K., S. Takahashi, D. Yano, H. Hirao, M. Kojima, M. Komada, and S. Shimada, 1996. CONSTRUCTION OF THE AVI SYSTEM ON THE METROPOLITAN EXPRESSWAY. ITS America. Intelligent Transportation: Realizing the Future. Abstracts of the Third World Congress on Intelligent Transport Systems. [Oct. 14 – Oct. 18, 1996, Orlando, Florida]. n.p.

Nallamothu, S. and K. C. P. Wang, 1997. AUTOMATED LICENSE PLATE RECOGNITION WITH A NEURAL NET BASED ACCELERATOR. In: Frost, J. D. and S. McNeil, Imaging Technologies: Techniques and Applications in Civil Engineering. Second International Conference. [May 25 – May 30, 1997, Davos, Switzerland]. pp 166-174.

Nelson, L. J., 1997. EYE OF THE BEHOLDER: VIDEO-BASED AUTOMATIC VEHICLE IDENTIFICATION. Traffic technology international, June/July 1997: 105-107.

Nelson, L. J., 2001. RECOGNITION HANDBOOK. Traffic technology international, June/July 2001: 42-49.

Oh J. S., R. Jayakrishnan, andW. Recker, 2002. Section Travel Time Estimation from Point Detection Data. Submitted to the 82nd Annual Meeting of the Transportation Research Board, January 12-16, 2003,Washington, D.C. 13p.

Palacharla, P. V. and P. C. Nelson, 1995.ON-LINE TRAVEL TIME ESTIMATION USING FUZZY NEURAL NETWORK. Steps Forward. Intelligent Transport Systems World Congress. [Nov. 9 – Nov. 11, 1995, Yokohama, Japan] Vol. 1. p 112.

Palacharla, P. V. and P. C. Nelson, 1999. APPLICATION OF FUZZY LOGIC AND NEURAL NETWORKS FOR DYNAMIC TRAVEL TIME ESTIMATION. International transactions in operational research, 6(1): 145-160

Pant, P., 2000. A PORTABLE REAL-TIME TRAFFIC CONTROL SYSTEM FOR HIGHWAY WORK ZONES. Report No. FHWA/OH-2000/011. Final Report. 79p.

Paracha, J. N. and J. M. McDermott, 2001. FREEWAY TRAVEL TIME ESTIMATION AND APPLICATIONS IN REAL TIME. IN: COMPENDIUM: PAPERS ON ADVANCED SURFACE TRANSPORTATION SYSTEMS, 2001. Report No. SWUTC/01/473700-00003-3. pp 210-243.

Peng, Z. R. and O. Jan, 1999. ASSESSING MEANS OF TRANSIT INFORMATION DELIVERY FOR ADVANCED PUBLIC TRANSPORTATION SYSTEMS. Transportation Research Record, 1666: 92-100.

Roseman, D. and S. Skehan, 1995. AUTOMATED ARTERIAL INCIDENT DETECTION SANTA MONICA FREEWAY SMART CORRIDOR. 65th ITE Annual Meeting. 1995 Compendium of Technical Papers. [Aug. 5 – Aug. 8, 1995, Denver, CO]. pp 27-31.

Rossetti, M. D. and J. Baker, 2001. APPLICATIONS AND EVALUATION OF AUTOMATED LICENSE PLATE READING SYSTEMS. ITS America. Meeting (11th: 2001: Miami Beach, Fla.). ITS connecting the Americas: ITS 2001: conference proceedings. 9p.

Shimoura, H., S. Nishimura, K. Tenmoku, and N. Kawasaki, 2001. VEHICLE IDENTIFICATION AND TRAVEL TIME ESTIMATION BASED ON VEHICLE CHARACTERISTICS. SEI technical review, 51: p. 82-86.

Shuldiner, P. and J. Upchurch, 2001. AUTOMATED TRAVEL TIME DATA FOR A REGIONAL TRAVELER INFORMATION SYSTEM. ITE 2001 Annual Meeting and Exhibit. [Aug. 19 – Aug. 22, 2001, Chicago, Illinois]. 13p.

Shull, L. A., 1996. THE USE OF THE INTERNET AS AN EFFECTIVE TOOL FOR DISSEMINATING TRAVELER INFORMATION. Report No. SWUTC/96/72840-00003-1. 47p.

Slevin, J., 1999. LOCKHEED'S LONG MARCH: DATA PRIVACY TO THE RESCUE. ITS world, 4(4): 14-15.

Smith, B. L. and M. J. Demetsky, 1995. TRAFFIC FLOW FORECASTING FOR INTELLIGENT TRANSPORTATION SYSTEMS. FINAL REPORT. Report No. FHWA/VA-95-R24; VTRC 95-R24; Proj No. 3075-030-940. 31p.

Stout, T., C. Poe, and M. Dixon, 1997. OVERVIEW OF THE STATE-OF-THE-PRACTICE IN DISSEMINATING TRAFFIC INFORMATION BY ADVANCED TRAFFIC MANAGEMENT SYSTEMS. Report No. FHWA/TX-98/1752-1. 52p.

Thompson, R. D., 1999. Another Step Toward a Nationally Integrated Traveler Information System.

Ullah, K., W. A. O'Neill, and A. B. Bishop, 1994. COST-BENEFIT ANALYSIS OF A RURAL ADVANCED TRAVELER INFORMATION SYSTEM. Transportation Research Record, 1450: pp 25-33.

University of Maryland - College Park, Transportation Studies, 1997. FINAL EVALUATION REPORT FOR THE CAPITAL-ITS OPERATIONAL TEST AND DEMONSTRATION PROGRAM. 93 p. in v.

Vad der Zijpp, N. J. and S. P. Hoogendoorn, 1998. NETWORK LEVEL EVALUATION OF DTM TOOLS WITHIN DACCORD: AN ANALYSIS OF THE MINIMUM NUMBER OF PROBE VEHICLES REQUIRED. World Transport Research: Selected Proceedings of the 8th World Conference on Transport Research. [July 12 – July 17, 1998, Antwerp, Belgium]. Vol. 2. pp 469-482

Weisbrod, G. and M. Grovak, 2001. Alternative Methods For Valuing Economic Benefits of Transportation Projects. Prepared for the Transportation Association of Canada, Benefit Cost Analysis Symposium. February 2001. 20p.

Wigan, M. THE INFLUENCE OF PUBLIC ACCEPTANCE ON WHAT IVHS CAN ACHIEVE. Working paper / Institute of Transport Studies, University of Sydney; no. ITS-WP-95-1. PATH Record Number 6988. 23p.

Wunderlich, K. E., M. H. Hardy, J. J. Larkin, and V. P. Shah, 2001. On-Time Reliability Impacts of Advanced Traveler Information Services (ATIS): Washington, DC Case Study. Final Report.

Yamane, K., M. Kakuta, and T. Fushiki, 2000. DEVELOPMENT OF VICS WITH ADAPTIVE PARAMETER TUNING FOR PROVIDING TRAFFIC INFORMATION. World Congress on Intelligent Transport Systems (7th: 2000: Turin Italy). Proceedings: from vision to reality. 8 p.

Ygnace, J. L., C. R. Drane, Y. B. Yim, R. de Lacvivier, 2000. TRAVEL TIME ESTIMATION ON THE SAN FRANCISCO BAY AREA NETWORK USING CELLULAR PHONES AS PROBES. PATH working paper; UCB-ITS-PWP-2000-18. vii, 47 p.

Zarean, M., E. N. Williams, B. A. Leonard, and R. Sivarandan, 1997. RURAL APPLICATIONS OF ADVANCED TRAVELER INFORMATION SYSTEMS: USER NEEDS AND TECHNOLOGY ASSESSMENT. Report No. FHWA-RD-97-034. 111p.

Zhang, M., E. Kwon, T. Q. Wu, K. Sommers, and A. Habib, 1997. ARTERIAL LINK TRAVEL TIME ESTIMATION USING LOOP DETECTOR DATA - PHASE I. Report No. MN/RC-97/16; Final Report. 74p.

Zhang, X., J. A. Rice, and P. J. Bickel, 1999. EMPIRICAL COMPARISON OF TRAVEL TIME ESTIMATION METHODS. PATH research report ; UCB-ITS-PRR-99-43. 45 p.

Zhu, Z. and W. Wang, A TRAVEL TIME ESTIMATION MODEL FOR ROUTE GUIDANCE SYSTEMS. International Conference on Traffic and Transportation Studies (2nd: 2000: Beijing, China). Traffic and transportation studies: proceedings of ICTTS 2000. p. 547-552

Zietsman, J. and L. R. Rilett, 2000. AGGREGATE- AND DISAGGREGATE-BASED TRAVEL TIME ESTIMATIONS: COMPARISON OF APPLICATIONS TO SUSTAINABILITY ANALYSIS AND ADVANCED TRAVELER INFORMATION SYSTEMS. Transportation Research Record, 1725: pp 86-94

Zwahlen, H. T. and A. Russ, 2002. EVALUATION OF THE ACCURACY OF A REAL-TIME TRAVEL TIME PREDICTION SYSTEM IN A FREEWAY CONSTRUCTION WORK ZONE. National Research Council (U.S.). Transportation Research Board. Meeting (81st: 2002: Washington, D.C.). 23 p.

APPENDIX D

High Water Sensors

(Literature Search for the Frontier Pooled Fund Study)

1.0 Introduction

High water sensor is used to monitor the surface water depth on roadways, especially for flood prone areas, in order to enhance the traveler safety and reduce the travel risk. The related real-time information (such as high-water warning) is an important input for RWIS applications, which assist motorists in both pre-trip planning as well as en-route response to advisory information.

1.1 Topic Areas

Other high water sensor projects

Reliability/accuracy of water sensors

Product information from manufacturers

Safety/risk management issues related to high water on roadways

Evacuation plans/studies, for hurricanes etc.

1.2 Methodology

1. TRIS Online v2.6 database

Keywords used:

- “High water” and sensor (monitoring)
- Water and sensor (sensing)
- Water and roadway and high (safety)
- “Road surface” and water
- Surface and water and sensing
- Flood and warning

2. Yahoo! Advanced Search

Keywords used:

- “High water sensor”
- “High-water” and sensor
- “Water-level sensor” and road
- “High water warning system”
- “High water” and RWIS

- "High water" and sensing and road
- "High water" and roadway and safety ("risk management")
- Road and water-level and sensor and evaluation

3. Elsevier Science Direct: Water-level sensor

4. Websites of Florida DOT, Arizona DOT, Colorado DOT, and Caltrans

1.3 Summary of Results

1.4.1. Other high water sensor projects

1. Remote Automatic Monitoring and Public Information Systems for Hazardous Conditions (Weissmann, Haas, McKeever, and Greer, 1996)

The report identifies and evaluates existing remote automatic monitoring and public information systems for both ice detection on bridges and flood monitoring at low-water crossings. The report encompasses all aspects of these systems, including hardware, software, communications systems, data processing, and meteorological services. The study provides a survey of various state agencies and their experiences with these systems. In addition, the report discusses three alternatives for statewide implementation of these systems.

The alternatives examined are those considered by the Texas Department of Transportation (TxDOT), which include (1) the use of two turnkey systems throughout the state (one for ice detection and one for high-water detection); (2) multiple proprietary systems statewide (vendors could vary from district to district); and (3) a combination of components of various proprietary systems. The most feasible and cost-effective option is to allow each district to purchase a system that meets its needs while still remaining within budget. In order for this to work, systems from different vendors must be able to exchange information. Therefore, it is imperative that the systems purchased provide an open systems environment and use a standard data exchange protocol. The report concludes with suggestions for developing a set of implementation guidelines for a remote automatic monitoring and public information system for use during hazardous conditions.

2. Houston Roadways Monitored by TxDOT (Wright, 2000; Benz, 2002)

Url: http://tti.tamu.edu/researcher/v38n2/monitor_roadways.stm

The TxDOT has a system of 29 field sensors scattered throughout Houston that collect information on a variety of conditions, including depth of water on the roadway, the rate and accumulation of rainfall, air temperature and humidity, wind speed and direction and pavement temperature and moisture. The information is relayed to the ALERT database at the Harris County Office of Emergency Management. Once an alarm threshold is met, the information is relayed to the public via an interactive Web site and message signs. Surveys showed that travelers used the information from the signs and used the Web as their secondary source of weather information.

3. Flooded Roadway Warning System by City of Dallas, Texas

Url: http://www.ci.dallas.tx.us/sts/html/frws.html

The Flooded Roadway Warning System is made up of three components: A central computer system, one sensor at each site, and one to six changeable signs at each site. The sensor monitors the elevation of a nearby stream and reports every twenty minutes to the central computer. When the floodwater reaches the edge of the roadway, a float switch tells the sensor to signal the sign to change to the warning text and turn on the flashing lights. The sign sends a message back to the sensor confirming that everything is working properly. The sensor radios all this information back to the central computer. Pages are sent to staff and messages are printed out at the appropriate Street Services district alerting them of the need to place barricades at this location as soon as possible.

The signs and sensors are battery powered and recharged with solar cells. All communication between the sensors and signs and sensors and the central computer are by radio.

4. FCDMC ALERT (http://www.fcd.maricopa.gov/Services/ALERT/)

Flood Control District of Maricopa County (FCDMC) in Arizona operates a 24-hour rain, stream, and weather gauge network, which is in the National Weather Service ALERT (Automated Local Evaluation in Real Time) format. The ALERT system uses "automatic" telemetry gages for data collection. This means that the gauges transmit their information to the District base computer via VHF radio. The computer can then quickly compile the information and display it on video screens. The automatic gauges are powered by 12-volt batteries, which are recharged using small solar panels attached to the gauges.

5. A Flood-Warning Decision-Support System for Sacramento, California (Ford, 2001)

The automated flood-warning decision-support system (FW-DSS) components measure rainfall depths and water levels, transmit these observations in real time to an emergency operations center, and store and display this data. The FW-DSS includes forecasting models also, thus permitting recognition of and response to future threats.

6. A High-Water Warning System in Savannah, GA (Cycle, 2001)

When water rises to 5 inches on the low-lying Savannah street, a sensor sends a message to two traffic signs that flash an amber "X" warning drivers the street is closed because of flooding. If the test-models work well, the city may post similar signs in about 40 flood-prone areas. Each system costs $2,800. The high-tech signs can be seen a mile away in direct sunlight or at night. They will be posted at intersections, so drivers can turn off before they reach the flooded area.

7. A Flood-Warning System for Queensland, Australia (Martin, 2001)

In the remote open spaces of Queensland, Australia, flooding from tropical downpours can close roads without warning. Intelligent transportation systems (ITS) based on remote sensors are currently being developed to monitor creeks and rivers in unpopulated areas and report such disruptions to the police and the road authorities. Motorists are then warned not to venture out from regional centers.

The warning system is designed to improve the reliability and timeliness of advice given to motorists by obtaining real-time and predictive information. The Queensland Bureau of Meteorology's flood forecast models could then be used as a basis for estimating when particular roads will flood and for how long. This information can then be disseminated to road users via existing Department of Main Roads/Royal Auto Club of Queensland Internet and dedicated toll-free number, with interactive voice response services.

8. Colorado High-Water Warning System

Url: http://www.udfcd.org/fhn2000/fwarn.htm

Url: http://www.tfhrc.gov/pubrds/pr97-12/p18.htm (Public Safety Applications)

Spring and summer rainstorms in rural sections of Colorado often create flash flood conditions. To warn motorists when roads are likely to be under water, CDOT uses stream gauges to detect rising water levels and activate a variable message sign (VMS). This proactive high-water warning system has greatly reduced vehicular accidents at several critical channel crossings across Colorado.

9. Monitoring Bridge Scour with Buried Transmitters (Winter, 1995)

Bridge scour occurs when waterways are at high stage and the rock and sediments that support bridge piers are removed by water action. The Caltrans Division of Structures considers monitoring and quantifying scour a high priority problem. A conceptual design was developed that would use buried scour sensors placed at known depths in drilled holes. They would sense by tilting when scour reached their depth and would transmit that information to the surface with low frequency radio. A design was conceptualized, and Stolar Research Group of Raton, New Mexico, submitted a proposal to build the concept system.

10. SCAN by Caltrans (Hartwell, 1991)

The technology is described of SCAN (Surface Condition ANalyzer), which enables Caltrans to manage highway operation during inclement weather. SCAN reports pavement temperatures and indicates whether the road is wet or dry, and if water, frost, ice, snow, or chemicals are present. It also shows air temperature, humidity, wind speed and direction, and dew point and senses when precipitation is falling. The system operates with hockey puck-shaped epoxy sensors imbedded in the road surface. A capacitor within the sensor measures electrical charges that differ when water, snow, ice, or chemicals are present. Further details of the system are described. SCAN systems are used in 48 states including California, and in 8 countries.

See also: California Highway Road Condition at http://www.dot.ca.gov/hq/roadinfo/.

11. CO-OPS (http://co-ops.nos.noaa.gov/sensor.html#Air Acoustic Sensor)

The Center for Operational Oceanographic Products and Services (CO-OPS) uses an Air Acoustic Ranging Sensor to observe the water level. The sensor is a pulsed, acoustic-ranging device using the air column in a tube as the acoustic sounding path. The fundamental measurement is the time it takes for the acoustic signal to travel from the transmitter to the water surface and back to the receiver. The distance from a reference point to the water surface is derived from the travel time. A calibration point is set at a fixed distance from the acoustic transmitter and is used to correct the measured distance using the calibrated sound velocity in the tube.

12. Florida Flood Watch (http://floridadisaster.org/bpr/EMTOOLS/Severe/floods.htm)

Flash Flood Watch is issued by the National Weather Service (NWS) to alert the public that Flash Floods are a possibility in or close to the designated watch area. The public in the affected area is urged to be ready to take action in the event that a Flash Flood Warning is issued or flooding is observed.

13. Flood warning projects by David Ford Consulting Engineers

- Warning system: Sacramento County, CA (WatchDog)
- Flood warning system design: Reno, NV
- Flood response: Sacramento-San Joaquin, CA
- Flood response: Mecklenburg County, NC
- Flood preparedness plan: Reno, NV
- Warning system feasibility: Mission Hills, KS
- Flood warning system design: Atlanta
- Forecasting system: Choctawhatchee-Pea, AL
- Warning decision support system: Fort Collins, CO
- Inundation mapping: Fort Collins, CO
- Hazard info system: Birmingham, AL

1.4.2. Reliability/accuracy of sensors

1. The WL300 Water Level Sensor

Url: http://www.globalw.com/lvlsense.html

Overall Accuracy: ±0.2% (35°F to 70°F)

Resolution: Infinitesimal

Linearity and Hysteresis: ±0.1% FS

Response Time: 10 mS

2. The OSSI010-002B Water Level Sensor

Url: http://www.oceansensorsystems.com/OSSI010-002C.pdf

Data Accuracy ± 1.0%

Data Resolution 0.025%

Data Linearity ± 0.5%

3. Submersible Pressure Transducer from Sultron Corporation

Url: http://www.sutron.com/products/sensors/default.htm#Water Level

0.04% accuracy is available for the submersible pressure transducer.

4. Water level Instrument & Logger Model 6541

Url: http://www.unidata-europe.co.uk/logger6541.html

Resolution: 1.0mm or 0.2mm, 0.01 foot or 0.01inch, depending on the range selected.

Accuracy: Adjustable offset scale rotation reversal.

5. A Water-Level Sensor Using A Capacitance to Frequency Converter (Ross, 1983)

A capacitive water-level sensor using PTFE-insulated wire and a capacitance to frequency converter is described. Construction is simple, yet overall linearity is 0.1%. Temperature drift of the sensor is -0.05%K-1 and that of the converter is <0.01%K-1. Long-term stability of the sensor appears excellent. The converter draws only 150 mu A from a 5 V supply and is insensitive to supply voltage variations.

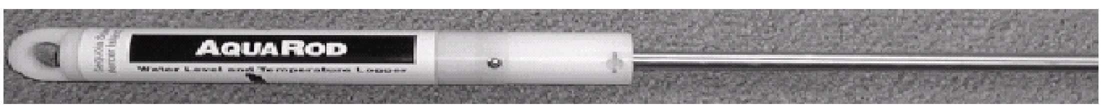
1.4.3. Product information from manufacturers

1. Developments in Structural & Geotechnical Monitoring

The article (Holzhausen, 2001) provides an overview of recent advances in structural and geotechnical instrumentation. The focus is on electronic monitoring systems used for measuring such parameters as structural strain and tilt, ground settlement, water levels and groundwater pressures, seepage and flow, and temperature. These systems include the measurement instruments (sensors) themselves, as well as data acquisition equipment.

2. Sequois Scientific, Inc.

Url: http://www.sequoiasci.com/product.asp?sku=14



The AquaRod is an inexpensive, easy-to-use alternative to pressure sensors, floats and data loggers. Originally developed for the U.S. Forest Service (http://www.stream.fs.fed.us/streamnt/pdf/SN_1-98.pdf) it has no moving parts and are accurate to 1/100th of a foot. Unlike pressure sensors, the AquaRod is freeze tolerant, not susceptible to plugging of the sensing port, and does not require a vent tube to the surface, desiccant bags or drying chemicals.

3. Fidelity Technologies Corporation

The FIDELITY HIGH WATER DETECTION AND WARNING SYSTEM provides continuous monitoring of water levels of streambeds that have the potential of impacting the public roadway system. When high water levels are detected, the system automatically warns motorists with changeable message signs and signals, and reports the alert status to appropriate Road Maintenance personnel. The system has been designed to provide reliability, minimal maintenance, and low recurring new system/installation costs (http://www.fidelitytech.com/hiwater.html).

4. Weather Safety Solutions LLC

The Intelligent Transportation Weather Hazard Warning System is described at http://www.weather-safety.com/flooding.htm (Also http://www.pressure-systems.com/kp2298.html). A Pressure Systems transducer sensor is mounted in an aluminum pole specially outfitted with screened venting to allow for water to enter and exit without dirt or debris. Also mounted on the pole is a programmable controller in an enclosure with relay contacts. The controller reads the drainage ditch water level and is calibrated to warn operation when the water level is approaching road level and alert drivers via flashers on a static flood warning sign when the water level is at critical non-passable point. The controller initiates

Operations contact via a self-dialing modem to send the agency alert. The warning flashers are started and stopped by the controller.

5. Global Water Instrumentation, Inc.

The Water Level Alarm (WA600, http://www.globalw.com/alarm.html) is a solid-state sensor for detecting the presence of conductive solutions. Each of them features two stainless steel electrodes that are positioned at a desired point for liquid detection. When fluid is detected, a relay closes in the unit and the signal can be used to sound an alarm or close a switch inside a piece of remote monitoring equipment. The relay output is fully isolated and can handle 2 amps of current.

The Water Level Sensor (WL300, http://www.globalw.com/lvlsense.html) consists of a solid-state pressure sensor encapsulated in a stainless steel submersible 3/4" diameter housing. Each of them has a two-wire 4-20 mA high level output, five full scales ranges, and is fully temperature and barometric pressure compensated.

6. Ocean Sensor Systems, Inc.

The OSSI010-002B Water Level Sensor (http://www.oceansensorsystems.com/OSSI010-002C.pdf) combines a rugged, sealed, waterproof package, low power microprocessor and a temperature stable, sensing circuit. The Water Level Sensor operates from 5.5V to 40VDC and has analog, serial data & 2 Alarms outputs. The serial data output string contains the water level & temperatures in ASCII or binary format. The Alarm Outputs are 350mA Open Drain type with 60V inductive load clamps. The Water Level Sensor can be programmed to free run or sample on demand.

7. Sultron Corporation

Url: http://www.sutron.com/products/sensors/default.htm#Water Level

0.04% accuracy is available for the submersible pressure transducer.

8. Milieutech Group, Unidata Division

Url: http://www.unidata-europe.co.uk/logger6541.html

Designed for high accuracy water level measurement, the Water level Instrument & Logger Model 6541 uses precision optical shaft encoder with low mechanical friction and inertia.

9. Miltronics, The Original Driveway Alert ™ System

Url: http://www.miltronics.com/transmitters.htm

Url: http://www.drivealert.net/acc_water2.htm

Url: http://www.alarm2020.com/acc_water.htm

High / Low Water Sensor / Transmitter: A sensor capable of sensing the presence of water and alerting you by transmitting a signal to one of their receivers (sold separately). Requires a 9-volt battery.

10. ASTI Transportation Systems, Inc.

Url: http://www.asti-trans.com/waterline_operation.htm

The Flooded Roadway Detector™ consists of a sensor and an electronics module that are connected via cable. Once the water has risen above certain point, the electronics module will activate the warning device supplied by the user. State-of-the-art timing circuitry allows the user to determine how long the warning device will remain energized after the water has receded to safe level.

1.4.4. Safety/risk management issues related to high water on roadways

1. High Water/Flood Safety Facts and Tips

Url: http://www.ruralmetrotn.com/public_html/images/road%20safety.pdf

Url: http://www.ci.alamo-heights.tx.us/ahpd/safety_highwater.htm

Url:
http://www.charmeck.nc.us/Departments/fire/emergency+management/flood+safety+tips.asp

Url: http://www.rsa-flood.com/rsaflood/tips.asp

Url: http://www.dem.dcc.state.nc.us/PIO/99huraw/FLOODSAFETY.htm

Url: http://www.gcpl.lib.sc.us/emp/FloodSafty.htm

2. Pavement Surface Water Phenomena and Traffic Safety (Black and Jackson, 2000)

To illustrate accidents on wet pavements with accumulations of water, actual case studies are presented. Current national traffic-crash statistics are inadequate to determine pavement surface water hazards' exact role in overall traffic-crash casualties. However, they are known to be associated with many head-on collisions, fixed-object collisions, and rollover crashes in states with greater rainfall.

The fact that surface water phenomena are usually associated with roadway drainage maintenance variables introduces separate transportation-engineering disciplines into the matter. The crashes and their causes offer an excellent opportunity for multidisciplinary engineering approaches and coordination in organizations responsible for roadway design, construction, and operations. It is also an application for road-safety audits.

3. Influence of Roadway Surface Discontinuities on Safety

It is generally recognized that discontinuities in roadway surfaces can cause problems with vehicle steering, braking, maneuvering, and response that lead to loss of control. Such discontinuities can play a significant role in the occurrence of traffic accidents and they should be considered when assessing maintenance policy, evaluating improvements. Discontinuities include deviations from the intended physical characteristics of the traveled surface that result from traffic loads, environmental effects, or other causes. In the context of this report they also include pavement edge geometry, water accumulation, and surface contaminants (Transportation Research Board, 1984).

4. Automated Flood Warning

Url: http://www.coe.montana.edu/wti/wwwshare/COATS/Apps/D/TabD-01.htm (Descriptions of Traveler Safety and Security Technologies)

Automated flood warning is a solar powered, cellular communication system to notify both maintenance personnel and motorists of “water on roadway” conditions. The system would be composed of a sensor connected to a cellular signal with a prerecorded message to notify maintenance crews when the water on the road reaches a significant level. Motorists would be notified by use of a warning sign with beacons triggered by the same sensor.

5. Surface Transportation Weather Applications (Pisano and Goodwin, 2002)

Weather threatens surface transportation nationwide and impacts roadway mobility, safety, and productivity. There is a perception that traffic managers can do little about weather. However, three types of mitigation measures—control, treatment, and advisory strategies—may be employed in response to weather threats. Road weather data sharing, analysis, and integration are critical to the development of better road weather management strategies. Environmental information serves as decision support to traffic, maintenance, and emergency managers; and allows motorists to cope with weather effects through trip deferrals, route detours, or driving behavior. The Road Weather Management Program of the Federal Highway Administration (FHWA) promotes and facilitates deployment of integrated road weather systems, decision support applications, and effective management practices.

1.4.5. Evaluation plans/studies

1. Roadway Flash Flooding Warning Devices Feasibility Study (Boselly, 2001)

The Intelligent Transportation Systems (ITS) Innovations Deserving Exploratory Analysis (IDEA) project explored the feasibility of a flash flood warning system for motorists on the road. A system with a modular design was proposed to allow flexibility in technology implementation and its components or subsystems were identified. These included water level sensors, data processing subsystem, and data dissemination subsystem, alerting subsystem, monitoring subsystem, motorist warning subsystem, traffic control subsystem and power subsystem. The system needs to be rugged, reliable and durable with a high operational capability. Recommendations for system development and testing were made. It was concluded that it is feasible to develop a low cost, durable system based on available technology that will automatically warn motorists and control traffic. The next phase will involve development of and testing of such a system.

2. High-Water Warning System Feasibility in Johnson County, Kansas

Url: http://ford-consulting.com/warningasystemafeasibilityqamissionahills_m.htm

3. An Economic Model for Remote High Water Detection Systems (McKeever, Haas, Weissmann, and Greer, 1998)

4. Active Microwave Remote Sensing of Road Surface Conditions (Tapkan, Yoakum-Stover, and Kubichek, 1996)

An active microwave sensing system is investigated to provide real-time information about road surface conditions. Microwave radiation is very sensitive to the presence of water in the medium through which it passes. Thus, the amplitude and phase of a wave reflected from a road contains information about water, snow, and ice accumulation.

Computer simulations of surface reflectivity based on the dielectric constant of various media were completed as a preliminary feasibility study. An experimental detection system was then constructed along with a liquid nitrogen-cooled asphalt test bed to simulate the road surface. Preliminary tests were conducted in the frequency range of 26.5 to 40 GHz. Microwave signals were directed to the asphalt surface by using a horn antenna, and a microwave antenna feeding a diode detector received the reflected signal. The resulting signal was then analyzed to extract the road surface information.

Tests indicated that wet snow and ice can easily be distinguished, although it is difficult to discriminate among dry snow, dry ice, and dry pavement conditions. This problem is addressed by sensing the road with two separate transmitter frequencies.

1.4 References

Benz, R., 2002. WHAT'S THE WEATHER LIKE? : STUDY HELPS MONITOR HOUSTON ROADWAYS. Texas Transportation Researcher, 38(2): 11.

Black, G. W., Jr and L. E. Jackson, 2000. PAVEMENT SURFACE WATER PHENOMENA AND TRAFFIC SAFETY. ITE Journal, 70(2): 32-37.

Boselly, S. E., 2001. ROADWAY FLASH FLOODING WARNING DEVICES FEASIBILITY STUDY. Report No. ITS-IDEA Program Project 79. Final Report. 33p.

Cycle, B. C., 2001. High-tech traffic signs warn motorists during floods. The Associated Press State & Local Wire, November 12, 2001, Monday, State and Regional, 281 words.

Ford, D. T., 2001. FLOOD-WARNING DECISION-SUPPORT SYSTEM FOR SACRAMENTO, CALIFORNIA. Journal of Water Resources Planning & Management, 127(4): 254-260.

Hartwell, G., 1991. SCANNING THE GRAPEVINE. AASHTO Quarterly Magazine, 70(4): 10-11.

Holzhausen, G. R., 2001. DEVELOPMENTS IN STRUCTURAL & GEOTECHNICAL MONITORING. Civil Engineering News, 13(6): 54-59.

Martin, K., 2001. SPEEDY FLOOD WARNINGS. World Highways/Routes du Monde, 10(5): 41-42.

McKeever, B., C. Haas, J. Weissmann, and R. Greer, 1998. An Economic Model for Remote High Water Detection Systems. ASCE Journal of Transportation. (Accepted & Pending), Aug 1998.

Pisano, P. and L. C. Goodwin, 2002. Surface Transportation Weather Applications.

Ross, P. J., 1983. A water-level sensor using a capacitance to frequency converter. Journal of Physics E: Scientific Instruments, 16(9): 827-828.

Tapkan, B. I., S. Yoakum-Stover, and R. F. Kubichek, 1996. ACTIVE MICROWAVE REMOTE SENSING OF ROAD SURFACE CONDITIONS. Snow Removal and Ice Control Technology. CONFERENCE PROCEEDINGS 16. [Aug. 8 – Aug. 16, 1996, Reno, Nevada]. pp 73-80

Transportation Research Board, 1984. THE INFLUENCE OF ROADWAY SURFACE DISCONTINUITIES ON SAFETY. State-of-the-Art Report. Report No. HS-038 006. 45p.

Weissmann, J., C. Haas, B. McKeever, R. Greer, 1996. PRELIMINARY REPORT ON A REMOTE AUTOMATIC MONITORING AND PUBLIC INFORMATION SYSTEM FOR HAZARDOUS CONDITIONS. Report No. FHWA/TX-98/1380-1. 80p.

Winter, W. A., 1995. MONITORING BRIDGE SCOUR WITH BURIED TRANSMITTERS. FINAL REPORT. Report No. FHWA/CA/TL-95/16; EA. 680100. 58p.

Wright, L., 2000. TRAFFIC MANAGEMENT FOR ENVIRONMENTAL CONDITIONS. ITE 2000 Annual Meeting and Exhibit. [Aug. 6 – Aug. 9, 2000, Nashville, Tennessee]. 10p.

APPENDIX E

Evaluation of the Oregon Rural Travel Time Estimation System

Plan Outline

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for the

Frontier Project
Technical Advisory Committee

In cooperation with the

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

1.0. Problem Description

The Frontier Project, a Federal Highway Administration (FHWA) Pooled Fund Study with eight cooperating states that included Montana, California, Idaho, Oregon, Texas, Utah, Washington and Wyoming, was initiated in June 1998. The goals of the Frontier Project were to prove successful technology transfer to rural areas, to provide "regional" deployment of Intelligent Transportation System (ITS) technologies, to quantify benefits of rural ITS, and to disseminate lessons learned to encourage increased focus on rural needs.

To meet these goals, the Frontier Project Technical Advisory Committee (TAC) selected four ITS systems for deployment and demonstration, of which a rural travel time estimation system was installed in Oregon to inform motorists and maintenance workers of possible delays or incidents along a busy stretch of the Salmon River Highway (Highway 39) and US 101.

The corridor of interest connects a popular casino at one end and the coastal resort of Lincoln City on the other. The Salmon River Highway is a mountainous two-lane road traversing the Siuslaw National Forest. It offers few passing opportunities and carries a high percentage of slow-moving trucks, campers, and mobile homes. Incidents, congestion, and delays are common along the corridor, particularly in the summer. From 1995 to 1997, this section saw 189 accidents, of which nine were fatal. To address the problem, a traffic monitoring system was placed at 10-mile intervals along the 34-mile stretch of highway. Cameras on poles are connected to a central computer server. The system is able to recognize license plate numbers, encrypt them to protect privacy, and use the resulting time-stamped codes to calculate average travel times. These times are then compared to normal travel times on uncongested highway. If the difference indicates congestion or delays, the system sends an alert to a dispatch/maintenance station. The system displays the information on the Internet and also transmits a message to portable variable message signs located at entrances to the corridor so motorists can better plan their travel and possibly take alternate routes.

Pole-mounted cameras record license plate numbers "coming and going" to determine average travel times on a rural Oregon Highway.

License plate reading technology is one of the major techniques available for determining travel time in a continual and real-time manner. A system featuring license plate matching with a machine vision system to automatically read the license plate captured on video was deployed for this project in Oregon. For the license plate reading (LPR) system, there are four main components: a camera, a light source, a triggering mechanism, and an image-processing algorithm.

The objective of the travel time estimation system was to provide real-time information of traffic incidents and congestion/delays, both on-site to the travelers directly affected by the condition and remotely to pre-trip travelers and the Oregon Department of Transportation (ODOT) maintenance division. The information of estimated travel time was intended to provide motorists opportunities to make informed decisions. Such information would also generate the lead-time necessary for maintenance/operations personnel to respond to the conditions. In general, the system was deployed to promote motorist mobility and can potentially be used to implement traffic management applications and strategies for optimizing network productivity.

1.1. Evaluation Objectives

It is anticipated that if the rural ITS project were successful at the test site, similar projects would be introduced and implemented regionally and nationally. Therefore, the objective of this evaluation project is to determine whether the rural travel time estimation system was a good investment. Specifically, the evaluation intends to answer the following questions:

- Are the technologies reliable, accurate, and easy to use?
- Is the overall safety improved, in terms of reduction in incident detection time and frequency?
- Is the overall mobility improved, in terms of decreased travel time delay and/or better customer satisfaction?
- Is the overall efficiency improved, in terms of increased throughput or effective capacity?
- Is the overall productivity improved, in terms of cost savings?
- Is the information provided to the ODOT maintenance personnel valuable in their operations?
- Are motorists responding to the travel time information presented to them?

1.2. Scope

Based on the TEA-21 ITS evaluation guidelines, it is envisioned that the following tasks will be conducted as a part of the evaluation.

2. Project Management
3. Technology Assessment / Performance Evaluation
4. Safety Data Analysis / Incident Detection Evaluation
5. Mobility Data Analysis / Reduced Congestion Evaluation
6. Efficiency Data Analysis / Route Diversion Evaluation
7. Cost Savings Analysis
8. Maintenance Survey
9. Motorist Survey
10. Final Report

These tasks are described below.

1.2.1. Task 1: Project Management

Critical to the success of this and any project is the development of an appropriate project scope to provide initial direction and ongoing guidance for the evaluation team. This task covers overall project management activities that may assist in promoting communication between project sponsors and the evaluation team.

1.2.2. Task 2: Technology Assessment / Performance Evaluation

The purpose of this task is to assess the reliability, accuracy, and easiness to use of the LPR technologies applied in this deployment. Such information will be obtained through a combination of surveying the ODOT maintenance staff and evaluation via a secondary method of travel time estimation. The reliability will also be established through reviews of maintenance records.

First, the capability of the LPR system to accurately estimate a travel time will be evaluated. The evaluation will be accomplished using the test vehicle technique, or more specifically, the floating car technique, to determine a travel time to which the travel time determined by the LPR system will be compared. The floating car technique is described in the "Travel Time Data Collection Handbook" developed by Turner et al [1], and the guidelines provided in the handbook will be used in the data collection effort.

A test vehicle will be obtained and driven past the first checkpoint, which is located at Valley Junction or MP 23 on ODOT 39. The observer records the time as the driver passes this checkpoint. The driver then drives according to the floating car technique, driving with the flow of traffic, attempting to pass as many cars as passed the test vehicle. When the next checkpoint is reached, the ODOT 9/ODOT 39 junction or MP 0.34, the time is again recorded on the data sheet. The test vehicle is then driven down to the third and final checkpoint, West Devil's Lake Road on ODOT 9, where the observer records the arrival time. While traveling the corridor, the observer also times and notes incidents and queuing. This technique will be repeated in the reverse order back to the first checkpoint. The whole process will be repeated until the desired sample size is obtained. The travel time determined by the float car technique is then calculated from the times recorded. The travel times calculated by the implemented LPR system for the test vehicle will be obtained from the system records. Also, the estimated travel time through the corridor that is calculated when the vehicle entered the corridor will also be obtained.

To confirm whether or not the LPR system calculates accurate travel times, a paired t-test will be used. The underlying hypothesis for this test states that the travel time experienced by a driver, in this case the test vehicle driver, is equal to the travel time determined by the LPR system. This hypothesis test assumes that the samples collected by the test vehicle and LPR techniques are independent. The test statistic for the t-test is:

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[1] Turner, Shawn M., William L. Eisele, Robert J. Benz, and Douglas J. Holdener. *Travel Time Data Collection Handbook.* Report No. FHWA-PL-98-035. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, March 1998.

$$t = \frac{\bar{d}}{s_d / \sqrt{n}}$$

Where: $\bar{d}$ = average percent error between the two systems' travel times

n = number of matched pairs

S_d = standard deviation of the matched pairs given as:

$$s_d = \sqrt{\left[\sum_{i=1}^{n} d_i^2 - \left(\sum_{i=1}^{n} d_i\right)^2 \Big/ n\right] \Big/ (n-1)}$$

Where: d_i = travel time for the i^{th} matched pair

A 95 percent confidence level will be used to accept or refute the hypotheses.

Second, after it is verified that the equipment is properly calculating travel times through the corridor, the research team will evaluate the accuracy between what the system estimated as the mean travel time through the corridor and the actual experienced travel time. To evaluate this accuracy, a two-sample t-test will be used. The underlying hypothesis for this test states the travel time displayed to the driver as he/she enters the corridor is equal to the travel time the driver actually experiences through the corridor. This hypothesis test assumes that the two travel times are independent. Further, the test statistic used varies depending on whether the assumption of equal variances between the test vehicle travel time and the estimated travel time samples holds. To confirm this second assumption, an F-test will be used:

$$F = \frac{S_1^2}{S_2^2}$$

Where: S_1 is the standard deviation of the test vehicle sample and

S_2 is the standard deviation of the estimated LPR sample.

If the variance equality assumption is accurate, the test statistic for the t-test is:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{s\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

where: $\bar{x}_1$ = the mean travel time experienced by the test vehicle

$\bar{x}_2$ = the mean travel time estimated by the LPR system

n_1 = the size of the sample collected with the test vehicle

n_2 = the size of the sample collected from the LPR system

s = the pooled standard deviation for the two samples given as:

$$s = \sqrt{\frac{(n_1 - 1) * s_1{}^2 + (n_2 - 1) * s_2{}^2}{n_1 + n_2 - 2}}$$

where all variables are as previously defined.

Should the assumption of equal variances between the two samples prove to be false, the test statistic for the t-test becomes:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

where all variables are as previously defined.

For both cases, a 95 percent confidence level will be used to accept or refute the hypothesis.

The suitable sample size for the previous experiment can be calculated using the technique provided in the "Travel Time Data Collection Handbook" (Turner et. al. 1998) [1].

Eqn 3-4: $n = \left(\frac{t * c.v.}{e} \right)$

Where: n= sample size

t = t-statistic

c.v. = coefficient of variation, and

e = relative allowable error.

Table 3-2 in the handbook gives the average coefficient of variation as 11% for an ADT of 15000-20000 and this corridor had a maximum ADT of about 19000 during 1999. The handbook specifies that a relative error of ± 5% for operations and evaluation studies be used. An assumption of a 95% confidence level is made. Because the t-statistic is based on degrees of freedom, which is dependent on the sample size, iteration is required. The actual iteration converges on 21.

1.2.3. Task 3: Safety Data Analysis / Incident Detection Evaluation

The purpose of the safety data analysis is to determine whether the implemented travel time estimation improves the overall safety at the deployment corridor.

Data regarding the incident detection time and frequency were collected by the ODOT maintenance division for both the periods before and after the implementation of the LPR system. Should there be enough data available, the before/after comparison can be performed.

To confirm whether or not the LPR system installation resulted in a significant change (positive or negative) in incident detection/response times, a two-sample t-test will be used. The underlying hypothesis for this test states that the average incident detection/response time prior to LPR system installation is equal to the average incident detection/response time following LPR system installation. The hypothesis test assumes the samples collected before and after installation are independent. The F-test and two-sample t-test are as previously defined, with variables X_1 taken from the before system installation sample and variables X_2 taken from the after system installation sample.

1.2.4. Task 4: Mobility Data Analysis / Reduced Congestion Evaluation

The purpose of the mobility data analysis is to determine whether the implemented travel time estimation system improves the overall mobility at the deployment site. The perceived change by customers in overall travel times along the route will be collected from the motorist survey to supplement the reduced congestion evaluation.

To evaluate whether or not the overall congestion has been reduced along the corridor, the research team will compare the travel times before and after system installation. Once the LPR system was installed and operational, it was operated for a period of one month, but the travel times it calculated were not displayed to motorists. After one month, the Variable Message Signs were turned on to display the travel times to motorists. The system was operated for an additional two months so travel times for the first three months of operation were obtained. Data for the first fully operational month was discarded, because the month should be allocated for drivers to become familiar with the system. The travel times were separated by days of the week and by time interval (i.e., Monday from 7:00am to 9:00am) so travel times for similar traffic conditions were compared.

To confirm whether or not the LPR system installation resulted in a significant change (positive or negative) in travel times through the corridor, a two-sample t-test will be used. The underlying hypothesis for this test states that the average travel time prior to LPR system installation is equal to the average travel time following LPR system installation. This hypothesis test assumes the samples collected before and after installation are independent. The F-test and two-sample t-test are as previously defined, with variables X_1 taken from the before system installation sample and variables X_2 taken from the after system installation sample.

1.2.5. Task 5: Efficiency Data Analysis / Route Diversion Evaluation

The purpose of the efficiency data analysis is to determine whether the implemented travel time estimation system improves the overall efficiency at the deployment site. Throughput or effective capacity data was collected by the ODOT maintenance division and can be used for the before/after comparison.

In addition, it is desirable to determine whether or not drivers reacted to the travel times by changing their routes or canceling/delaying their trip. To meet this need, the research team will determine if the deployed ITS system changed traffic volumes on the primary route, using a method roughly patterned after a method developed by Battelle for the I-40 TTIS Route Diversion Study (1998) [[2]].

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[2] Battelle. *I-40 TTIS (Traveler and Tourist Information System) Route Diversion Study - Test Plan.* Federal Highway Administration, U.S. Department of Transportation, Washington, DC, May 1998. http://www.its.dot.gov/eval/Documents/Arizona%20I-40%20Test%20Plan%202.pdf.

Automatic Traffic Recorders (ATRs) are currently present 0.7 miles east of the Valley Junction and at West Devils Lake Road in Lincoln City. The ATRs were used to calculate traffic volumes one hour prior to a delay message being displayed, while the delay message was displayed, and one hour after a delay message was displayed. To promote consistency with the data, a set of criteria was developed. First, a period of no delay should be present for 30 minutes before a delay message is displayed and traffic volumes recorded. Second, the delay message should be displayed for a minimum of 30 minutes and no more than one hour. Finally, the message must display a delay of more than 15 minutes or 10 mph.

The traffic volumes recorded will be compared in this before-during-after evaluation. First, all the traffic volumes will be converted into equivalent vehicles per 30 minutes so consistent values can be compared. Next, a determination will be made to evaluate whether or not the traffic volumes decreased when a delay message was displayed, as it should if drivers were diverting, canceling or delaying their trips. To confirm whether or not the traffic volumes changed, a two-sample t-test will be used. The underlying hypothesis for this test states that the traffic volumes before are equal to the traffic volumes during a delay message. This hypothesis test assumes that the samples collected before and during the delay message are independent. Finally, a before-after evaluation will be conducted to determine if traffic volumes returned to the before traffic volumes after the delay message was terminated. This evaluation determined whether or not the change in traffic volumes was due to the delay message or other circumstances. To confirm this, another two-sample t-test was used. The underlying hypothesis for this test states that the traffic volumes before and after a delay message are equal. This hypothesis test assumes that the samples collected before and after the delay message are independent. For both the *before-during* comparison and the *before-after* comparison, the F-test and two-sample t-test are as previously defined, with variables X_1 taken from the before delay sample and variables X_2 taken from the during delay sample.

If traffic volumes decreased during the period of displaying delay messages and returned to normal afterward, then an assumption was made that drivers either used an alternate route or canceled/delayed their trip.

1.2.6. Task 6: Cost Savings Analysis

The purpose of the cost savings analysis is to determine whether the implemented travel time estimation system improves the overall productivity at the deployment site. The cost of this implemented ITS system will be compared to traditional systems designed to address the same problem. In addition, the benefits achieved by the ITS system in terms of improved incident detection, reduced congestion/travel times, and increased throughput along the corridor can be translated into cost savings in dollars.

1.2.7. Task 7: Maintenance Survey

Maintenance staff will be surveyed to determine what effects the real-time travel time information had on maintenance operations near the deployment site.

1.2.8. Task 8: Motorist Survey

Motorists will be surveyed to determine the perceived benefits and effectiveness of the system. This survey will address questions concerning whether motorists noticed the messages and what effect did this have on their behavior.

1.2.9. Task 9: Final Report

This task will accumulate and summarize the key findings from earlier tasks as well as address whether the initial goals and objectives of the project have been met and/or surpassed. Recommendations for further applications will also be discussed.

APPENDIX F

Evaluation of the Wise County FM3259 High Water Warning System

Plan Outline

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for the

Frontier Project
Technical Advisory Committee

In cooperation with the

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

1.0 Problem Description

The Frontier Project, a Federal Highway Administration (FHWA) Pooled Fund Study with eight cooperating states that included California, Idaho, Montana, Oregon, Texas, Utah, Washington and Wyoming, was initiated in June 1998. The goals of the Frontier Project were to prove successful technology transfer to rural areas, to provide "regional" deployment of Intelligent Transportation System (ITS) technologies, to quantify benefits of rural ITS and to disseminate lessons learned to encourage increased focus on rural needs.

To meet these goals, the Frontier Project Technical Advisory Committee (TAC) chose four ITS systems for deployment and demonstration, of which a high water level sensor and advisory system was installed in Wise County, Texas on FM3259. High water level sensors were used to monitor the surface water depth in flood-prone areas, in order to aid maintenance personnel's rapid response and to enhance the traveler safety. The real-time and predictive information was collected to improve the reliability and timeliness of advice given to motorists.

This project placed commercially available infrared water level sensors at critical locations on each approach to the site. The sensors were placed to provide the first warning, or alert mode, when water was within two feet of reaching the roadway surface. The second sensor was placed to provide the second warning, or alarm mode, when water reached the roadway surface. Each sensor installation contained two infrared sensors, and a local controller equipped with a VHF radio transceiver and a solar power system. The VHF transceiver provided local interconnection with the two advanced signing installations.

The advanced signing installations were placed approximately ¼ mile from the affected approach(s). The sign installations were configured to activate amber LED flashers when either sensor station provided a first level warning, or alert. The amber LED flashers accompanied the default signing display of "Possible Flooding / Water over Road / When Flashing". When either sensor station activated a second level warning, or alarm, both signing installations activated red LED flashers and changed the accompanying signing display to "Do Not Enter / High Water". These signing installations also contained a pole mounted NEMA enclosure housing a controller, along with a mechanical changeable message sign (CMS), red and amber LED flashers, solar power system, and VHF radio transceiver for interconnection with each other and the sensor assemblies. One of the signing installations was designated as the master and contained a cellular telephone for communications with the central computer.

A central computer equipped with the vendor's software provided a "base station" for monitoring sensor outputs remotely. The base station provided a "heartbeat" function to monitor status sensors, batteries and other field components. The base station also provided the ability to reset the field components condition or over-ride a local reset based on maintenance personnel's evaluation of conditions. The central computer also employed a pager notification system to ensure appropriate personnel were aware of the changing conditions, especially outside normal business hours when office personnel may not be monitoring the base station. Figure 1 illustrates the conceptual design for this project.

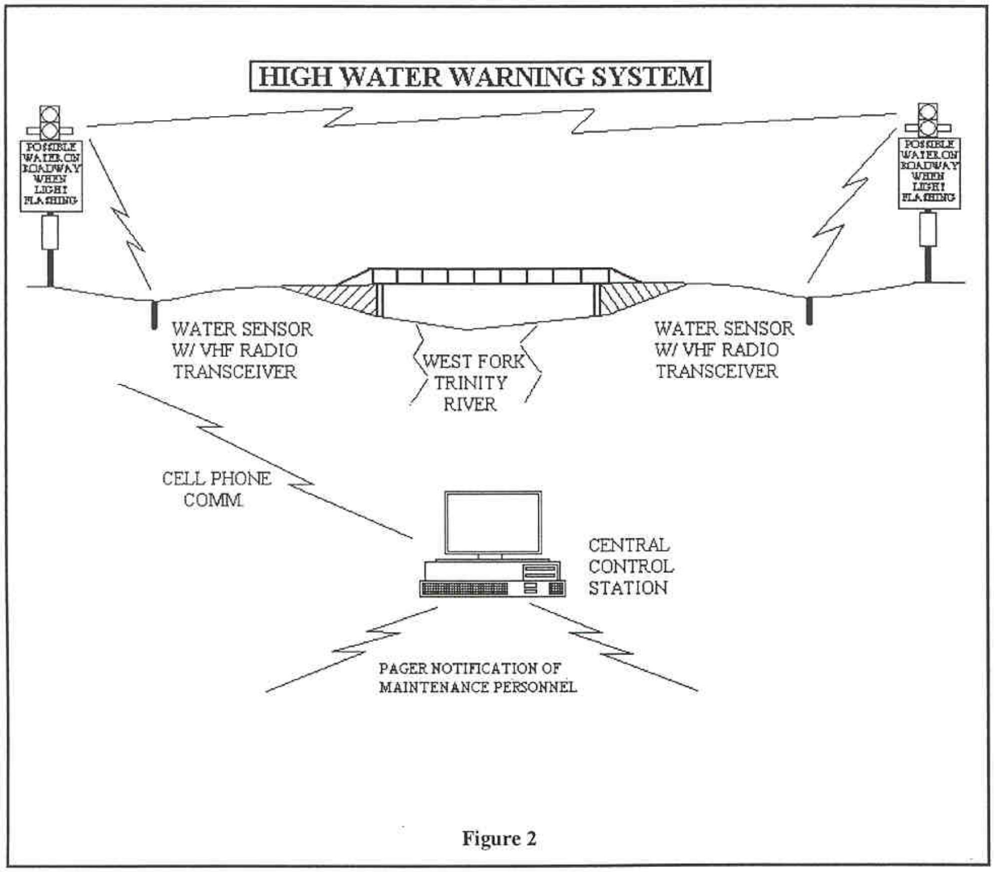

Figure 1: Conceptual Design of High Water Warning System.

The objective of this project was to provide critical real-time warning of roadway flooding conditions, both on-site to the motorists directly affected by the condition and remotely to TxDOT – Fort Worth maintenance residency. This real-time warning was intended to generate the lead-time necessary for maintenance/operations personnel to respond to the conditions and determine the need for a road closure, or other corrective actions, to protect motorist safety.

1.1 Evaluation Objectives

It was anticipated the installations for the High Water Warning System would provide a reasonably priced foundation for additional rural and/or remote capabilities, by changing or adding the appropriate sensors to meet the specific needs of an agency, such as detection of roadway icing conditions, fog, and high crosswinds. Therefore the objective of this evaluation is to determine whether this system was a good investment. Specifically, the evaluation intends to answer the following questions:

- Is the overall safety improved, in terms of reduction in detection time and accident frequency? Is the overall mobility improved, in terms of decreased travel time delay and/or better customer satisfaction?

- Is the overall efficiency improved, in terms of increased throughput or effective capacity?
- Is the overall productivity improved, in terms of cost savings?
- Is the information provided to TxDOT maintenance personnel valuable in their operations?
- Are motorists responding to the information presented to them?
- Are the technologies accurate, reliable, and easy to use?

1.2 Scope

Based on the TEA-21 ITS evaluation guidelines, it is envisioned that the following tasks will be conducted as a part of the evaluation.

1. Project Management
2. Safety Data Analysis
3. Mobility Data Analysis
4. Efficiency Data Analysis
5. Cost Savings Analysis
6. Maintenance Survey
7. Motorist Survey
8. Technology Assessment
9. Final Report

These tasks are described below.

1.2.1 Task 1: Project Management

Critical to the success of this and any project is the development of an appropriate project scope to provide initial direction and ongoing guidance for the evaluation team. This task covers overall project management activities that may assist in promoting communication between project sponsors and the evaluation team.

1.2.2 Task 2: Safety Data Analysis

The purpose of the safety data analysis is to determine whether the implemented high water warning system improves the overall safety at the deployment site. High water detection time and accident data will be collected from the TxDOT – Fort Worth maintenance residency for the before/after comparison. If enough data are available, the hypothesis that the high water warning system significantly improves the overall safety will be tested.

To evaluate potential accident reduction benefits of the warning system, speed studies may be conducted as an alternative for actual accident data. Such studies determine what effect the signing has on approaching speeds of vehicles, i.e., the differences in vehicle speeds when the sign is on versus off in different roadway conditions will be compared.

1.2.3 Task 3: Mobility Data Analysis

The purpose of the mobility data analysis is to determine whether the implemented high water warning system improves the overall mobility at the deployment site. Travel time delay data will be collected from the TxDOT – Fort Worth maintenance residency for the before/after comparison. Should such data be not available, the change in travel time delay perceived by customers will be collected from the motorist survey and used as the criteria instead.

1.2.4 Task 4: Efficiency Data Analysis

The purpose of the efficiency data analysis is to determine whether the implemented high water warning system improves the overall efficiency at the deployment site. Throughput or effective capacity data will be collected from the TxDOT – Fort Worth maintenance residency for the before/after comparison.

1.2.5 Task 5: Cost Savings Analysis

The purpose of the cost savings analysis is to determine whether the implemented high water warning system improves the overall productivity at the deployment site. The cost of this implemented ITS system will be compared to traditional system designed to address the same problem. Since there was significant liability exposure for non-action in the hazardous high-water situations, the saved liability costs will be taken into consideration during the analysis.

1.2.6 Task 6: Maintenance Survey

Maintenance staff will be surveyed to determine what effects the real-time high water data had on maintenance operations near the deployment site.

1.2.7 Task 7: Motorist Survey

Motorists will be surveyed to determine the perceived benefits and effectiveness of the system. This survey will address questions concerning whether motorists noticed the signs and what effect did this have on their behavior.

1.2.8 Task 8: Technology Assessment

The purpose of this task is to assess the accuracy, reliability, and easiness to use of technologies applied in this deployment. Such information will be obtained through a combination of interviews with maintenance staff and hands-on operations by WTI staff. The reliability will also be established through reviews of maintenance records.

1.2.9 Task 9: Final Report

This task will accumulate and summarize the key findings from earlier tasks as well as address whether the initial goals and objectives of the project have been met and/or surpassed. Recommendations for further applications will also be discussed.

APPENDIX G

PORTLAND STATE UNIVERSITY
DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING
CENTER FOR TRANSPORTATION STUDIES

Frontier Project Evaluation of Video Recognition Travel Time System

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Sponsored by

**OREGON DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION**

In cooperation with

Western Transportation Institute
Montana State University

DRAFT Research Report

July 2004

TABLE OF CONTENTS

DISCLAIMER

The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Oregon Department of Transportation or the U. S. Department of Transportation, Federal Highway Administration.

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. This document is disseminated through the Western Transportation Institute under the sponsorship of the U.S. Department of Transportation and through the Oregon Department of Transportation. The U.S. government assumes no liability for the contents or use thereof. The contents do not necessarily reflect the official views or policies of the U.S. Department of Transportation or Oregon Department of Transportation. This report does not constitute a standard, specification, or regulation.

LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

This paper summarizes the results of a field validation of a corridor travel time prediction system that uses automated license plate recognition–the Frontier Travel Time project. As part of the Frontier project, the Oregon Department of Transportation deployed a video image processing system with license plate recognition and privacy-protecting data encryption, a central server, and proprietary algorithms to predict corridor travel times on a 25 mile section of rural highway in northwest Oregon. The system predicted travel times were compared to data independently collected by probe vehicles equipped with Global Positioning System devices. The comparison shows that the predicted travel times were not statistically different than the travel times observed by the probe vehicles. Despite attempts to validate the system under congested conditions, all comparisons were made under essentially free flow travel. Further validation of the system in a congested corridor with alternate routes is recommended.

INTRODUCTION

Traveler information systems, designed to predict travel times and delays have primarily been implemented in large metropolitan areas. High volumes of commuter and time-sensitive freight traffic, availability of alternate routes, departure times and modes, and in many cases instrumented freeways, make developing these systems cost-effective and useful for the traveling public. The California-Oregon Advanced Transportation System (COATS) has been a joint effort between California and Oregon Departments of Transportation to demonstrate that advanced transportation technologies can successfully be transferred to rural environments.

The U.S. rural transportation network, consisting mainly of two-lane highways makes up more than 80 percent of the nation's highway mileage. Approximately 40 percent of vehicle-miles traveled (VMT) occurs on these rural facilities, and more than 60 percent of fatal crashes occur on rural roads. Rather than assuming that urban ITS technologies can be directly transferred to rural applications, the COATS program has sought to deploy, on a small scale, appropriate Intelligent Transportation System (ITS) technologies in rural areas, evaluate their performance and document the resulting benefits (*1*). Eight states (California, Idaho, Montana, Wyoming, Texas, Washington, Utah, and Oregon) have formed the Frontier pooled-fund study which has implemented and tested ITS technologies in rural locations.

As part of the Frontier Travel Time (FTT) project, the subject of this field validation, the Oregon Department of Transportation (ODOT) deployed a video image processing system with license plate recognition and privacy-protecting data encryption, a central server, and proprietary algorithms to predict corridor travel time and delay on a 25 mile section of rural Oregon Route 18 (OR-18). To validate the predicted travel times, probe vehicles were deployed over the same span of roadway on two separate days. In this paper, a description of the study corridor is presented followed a brief description of the Frontier Travel Time project. Next we describe the Frontier system data as well as the data collected by the independent probe vehicle deployments. Finally the paper summarizes the results of the analysis comparing the travel time measurements from the two sources, and offers some conclusions and recommendations.

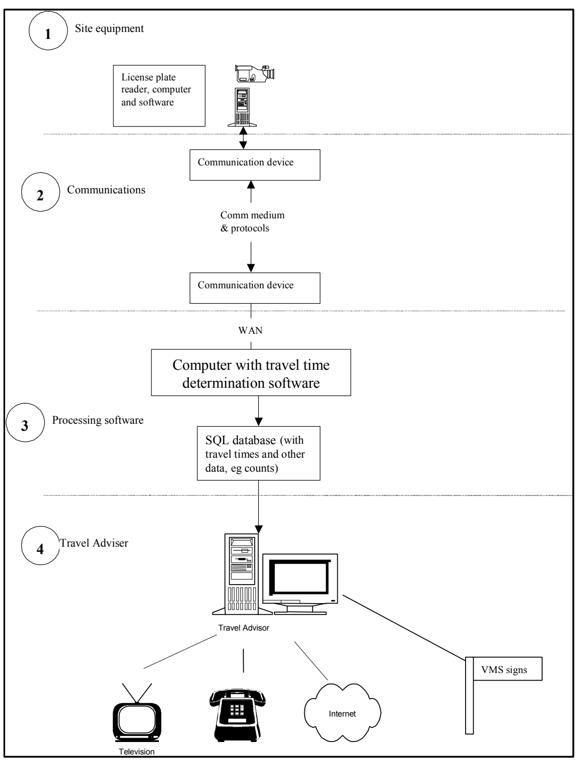
STUDY CORRIDOR

Oregon Route 18 (OR-18) connects the population in the mid-Willamette valley to U.S. Highway 101 (US-101) and the beaches of the Pacific coast. The study corridor is shown in Figure 1. To the east of the study segment, OR-18 continues to the southeastern Portland metropolitan area, and is joined by OR-22 which comes from the state capital in Salem. OR-18 is a rural highway characterized by heavy weekend and recreational traffic with destinations at the coast (including the Chinook Winds Casino Resort in Lincoln City) and the Spirit Mountain Casino located in Grande Ronde. The average daily traffic (ADT) between the eastern end of the study corridor and Grand Ronde is approximately 20,000 veh/day and between Grand Ronde and the western end near the coast, the ADT is 10,000 veh/day (*2*). OR-18 has no parallel detour routes and is a major truck route to the Oregon coast (*3*). The highway has primarily a 2-lane cross section, traverses rolling terrain of the Coast Range Mountains, and has passing lane sections throughout the study corridor. Anecdotally, OR-18 is known to be congested during holiday weekend periods, particularly during the summer. There are no traffic signals in the study corridor and there is a directional interchange located at the junction of OR-18 with US-101.

or more locations. Using the matched vehicles passage times and the distances between observations, the system estimates the travel time between segments based on an algorithm that also incorporates the number of vehicles passing the license plate readers and presumably other quality control factors. The camera system is proprietary and therefore this research did not have access to nor test the algorithms used to predict the travel times.

When fully deployed, the Frontier Travel Time system would eventually provide travel information to motorists via portable variable message signs (VMS) along the corridor, ODOT's statewide traveler information system TripCheck (www.tripcheck.com), and the statewide traveler information 511 system. Motorists could then presumably choose alternative routes and make travel decisions based on the travel time estimates.

Figure 2 – Travel Estimation System



Two days were selected for validation of the Frontier Travel Time System: Sunday, July 13, 2003 and Friday, July 2, 2004. The validation days were chosen because of the anticipated high volumes of traffic accessing the Oregon coast on summer and holiday weekends. The research team desired to study the Frontier Travel Time system with variable corridor travel times. However, on both days it turned out that there was minimal congestion in the study corridor (delays were noticed to the west of the study corridor on both days). Due to technical problems with the Frontier system on the second travel day, only the westbound cameras were operational. Therefore all data presented for July 2, 2004 only includes the westbound direction.

As an integral part of the evaluation, ODOT provided the research team with output from the Frontier system for the study days. The system compiles a set of variables including date, time, site ID, link ID (delineated as one to four depending on which of the four link trips the camera is recording), number of matched tags the cameras record from camera to camera, average travel time between sites, number of tags the cameras identify from the link within the two minute time period, and number of flags. The data used in this analysis were exported from the system in comma-separated format files making it easily configurable for spreadsheet software.

Figures 3-5 show the combined raw travel times for both east and westbound traffic for the 24-hours of the test days as predicted by the cameras. The Figures also show the devices' average predicted travel times of about 29 minutes for east and westbound on the first day and second day. The average predicted speeds for all the trips were around 51 mph. Figures 6-11 contain the trajectories of the cameras' predicted trip times from eleven different departure start times for July 13, 2003 and Figures 12-14 show the predicted trip times from the fourteen departure times on July 2, 2004. Figure 3 contains trajectories for the first eastbound segments, between Lincoln and Otis. Figure 4 includes trajectories from the second segments for eastbound trips as predicted by the cameras, between Otis and Valley Junction and Figure 5 includes data for the total eastbound trips as predicted by the Telematica system, combining both segments one and two. Figures 9-11 are the same as Figures 6-8, except they show trajectories for westbound trips segment one, two and the combined predicted times for the two test days. Figures 12-14 are the same trajectories, except that they show the second test day.

Figure 3 – Day 1: Frontier Travel Times, Raw Data: Eastbound, Lincoln City to Valley

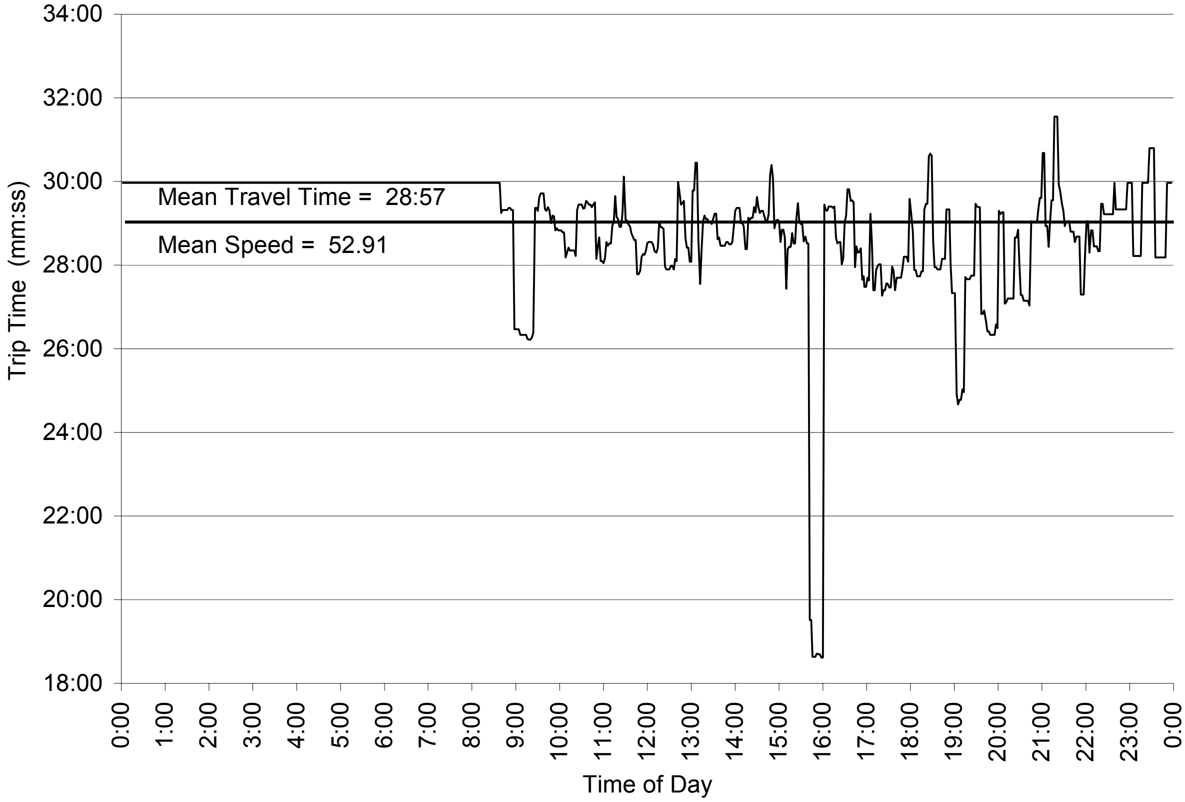


Figure 4 – Day 1: Frontier Travel Times, Raw Data: Westbound, Valley Junction to Lincoln City

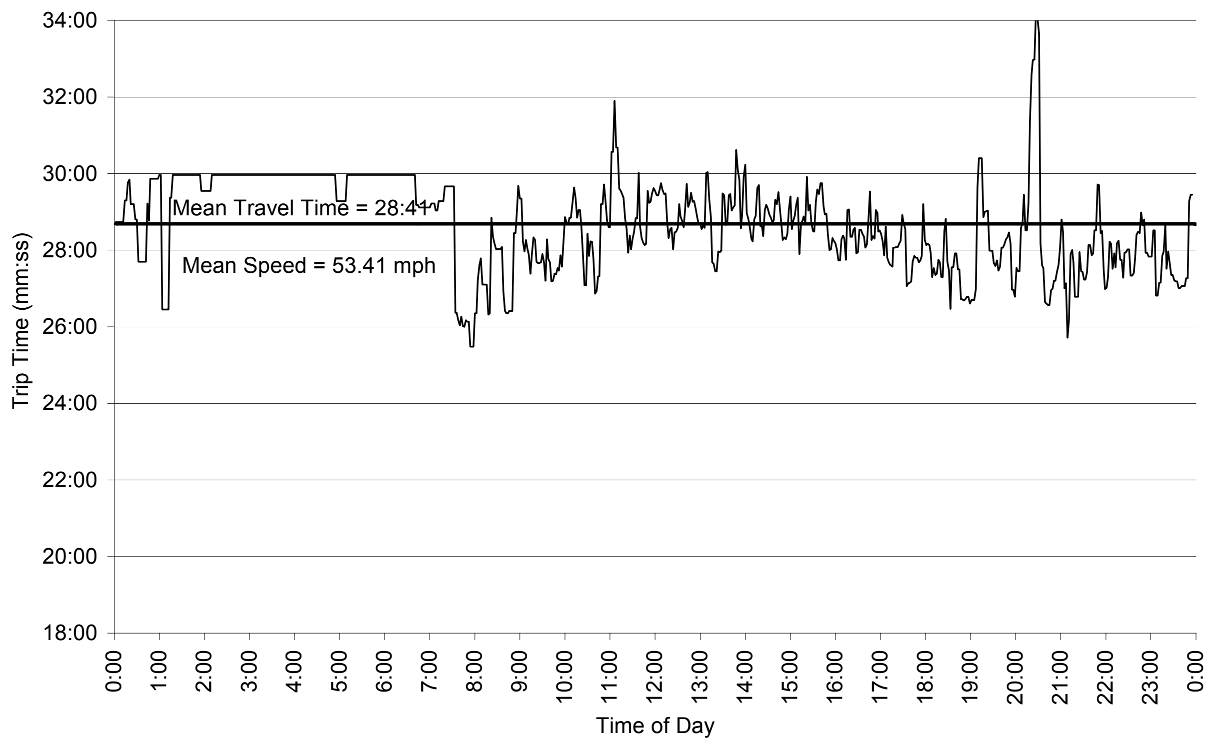


Figure 5 – Day 2: Frontier Travel Times, Raw Data, westbound

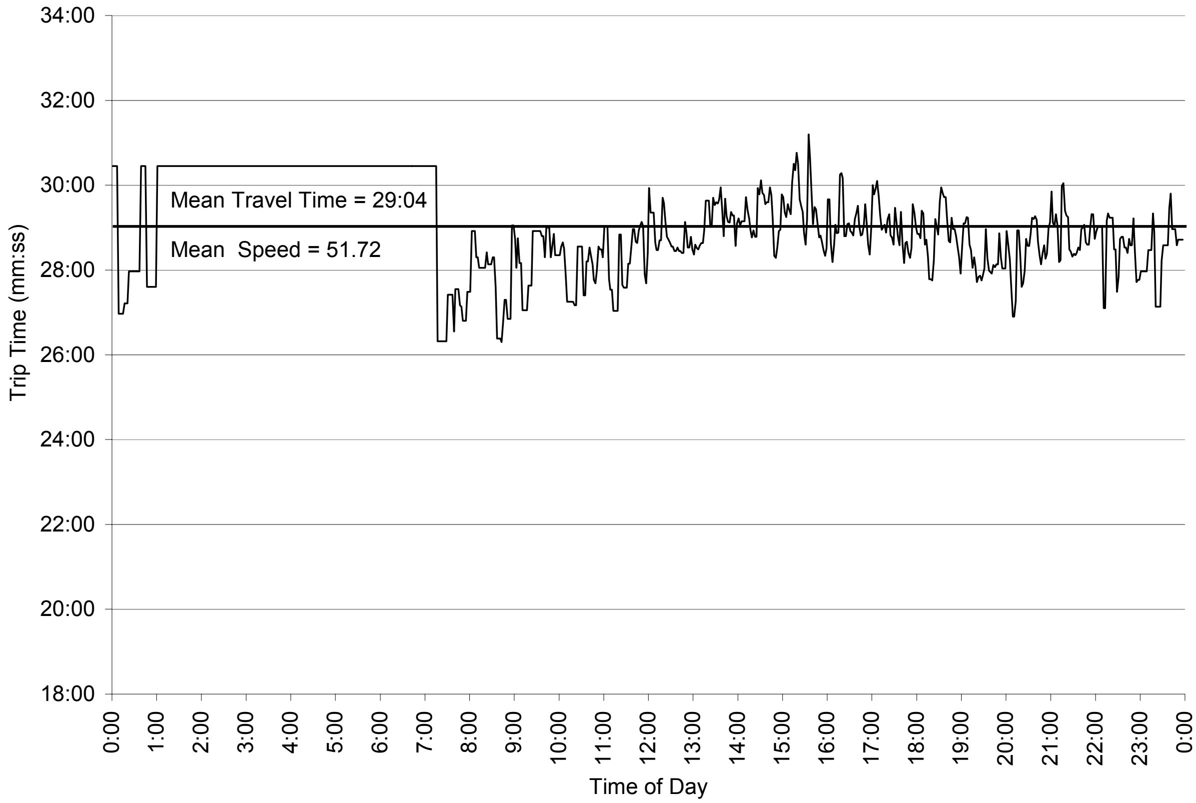


Figure 6 – Day 1: Cameras' segment 1, eastbound

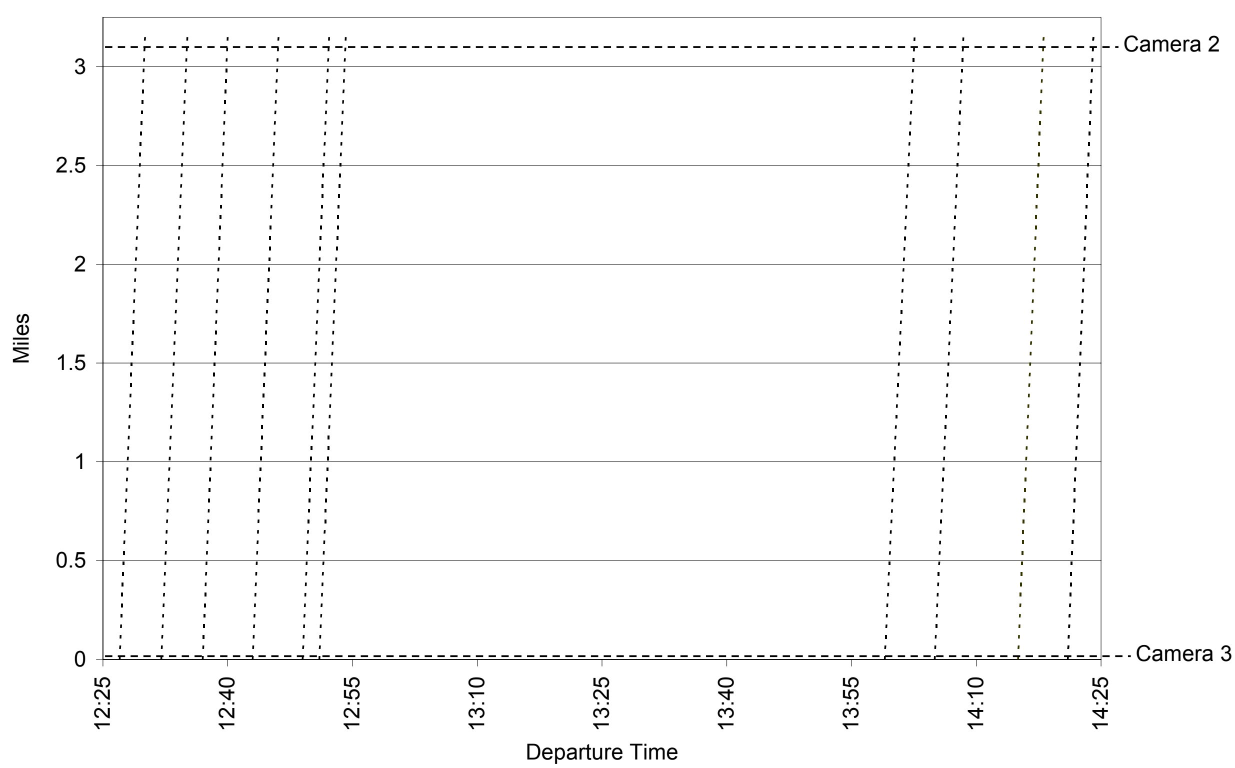


Figure 7 – Day 1: Cameras' segment 2, eastbound

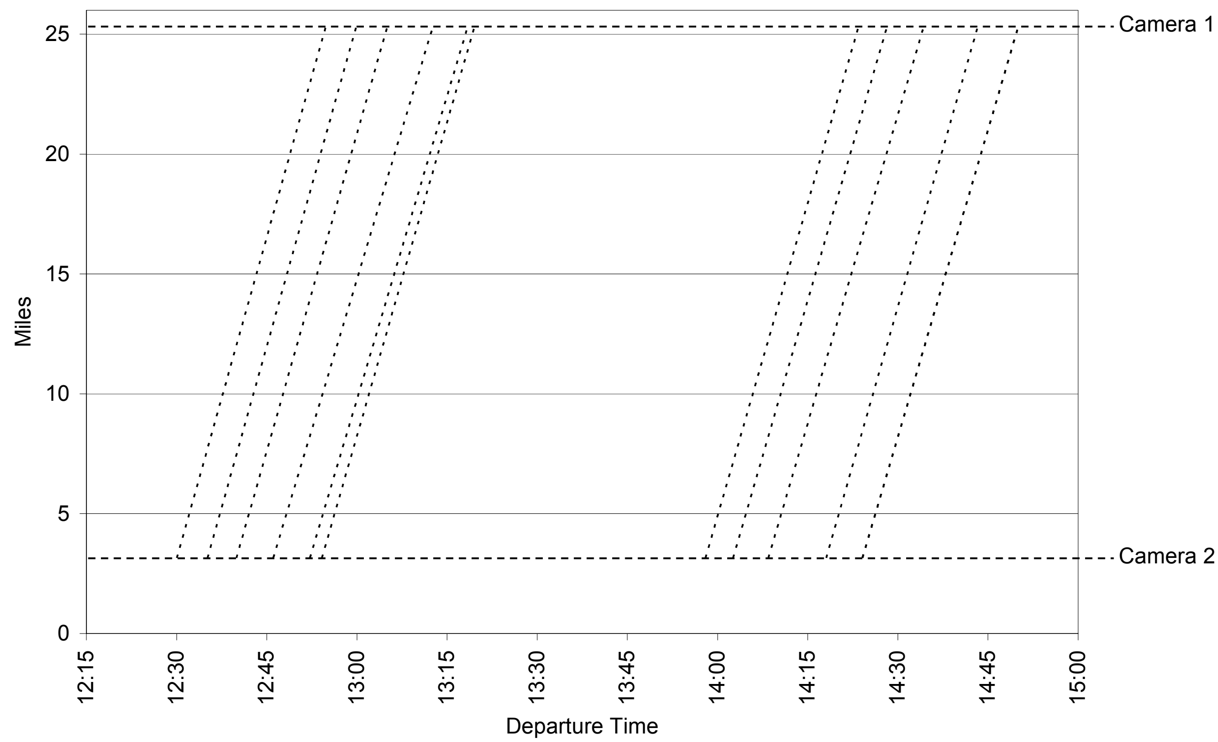


Figure 8 – Day 1: Cameras' total, eastbound

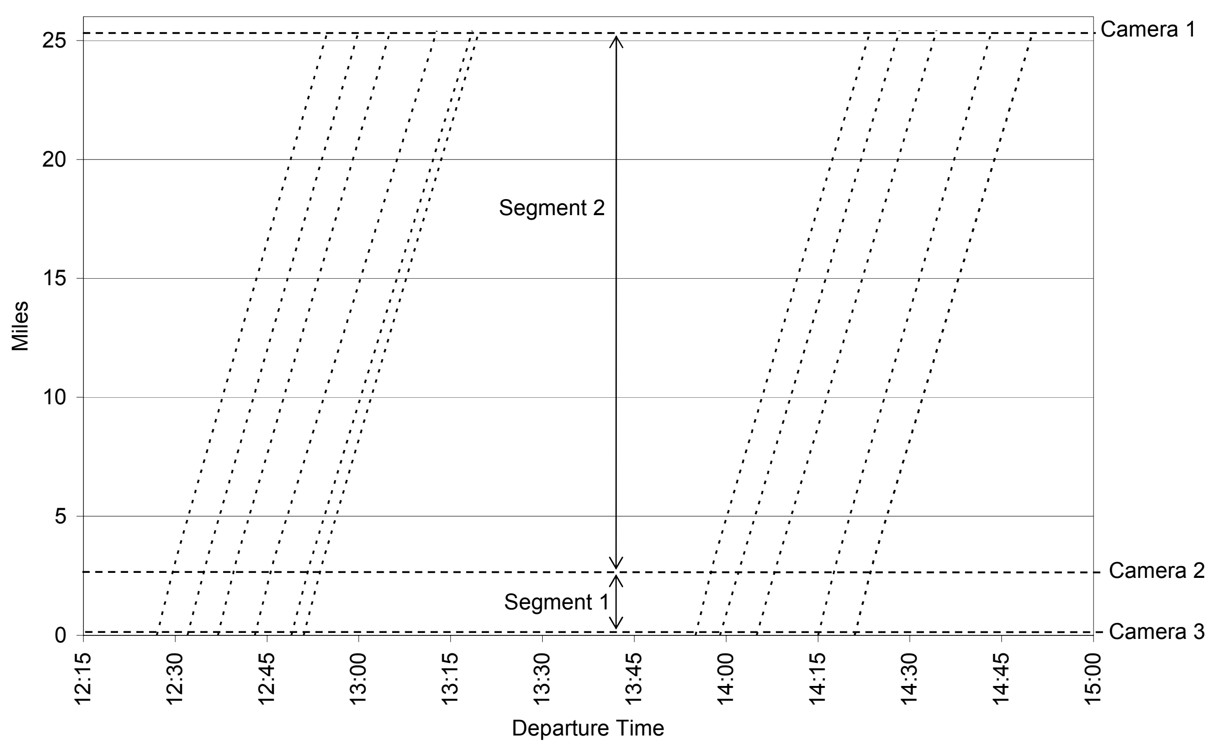


Figure 9 – Day 1: Cameras' segment 1, westbound

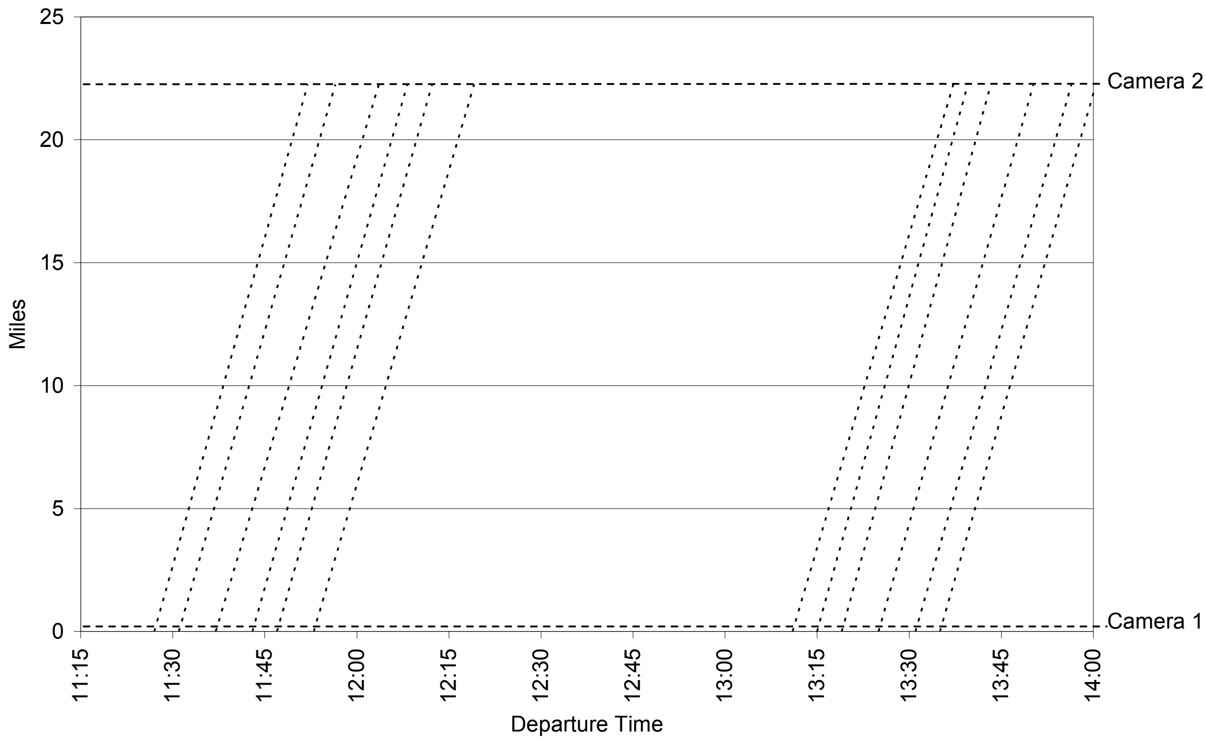


Figure 10 – Day 1: Cameras' segment 2, westbound

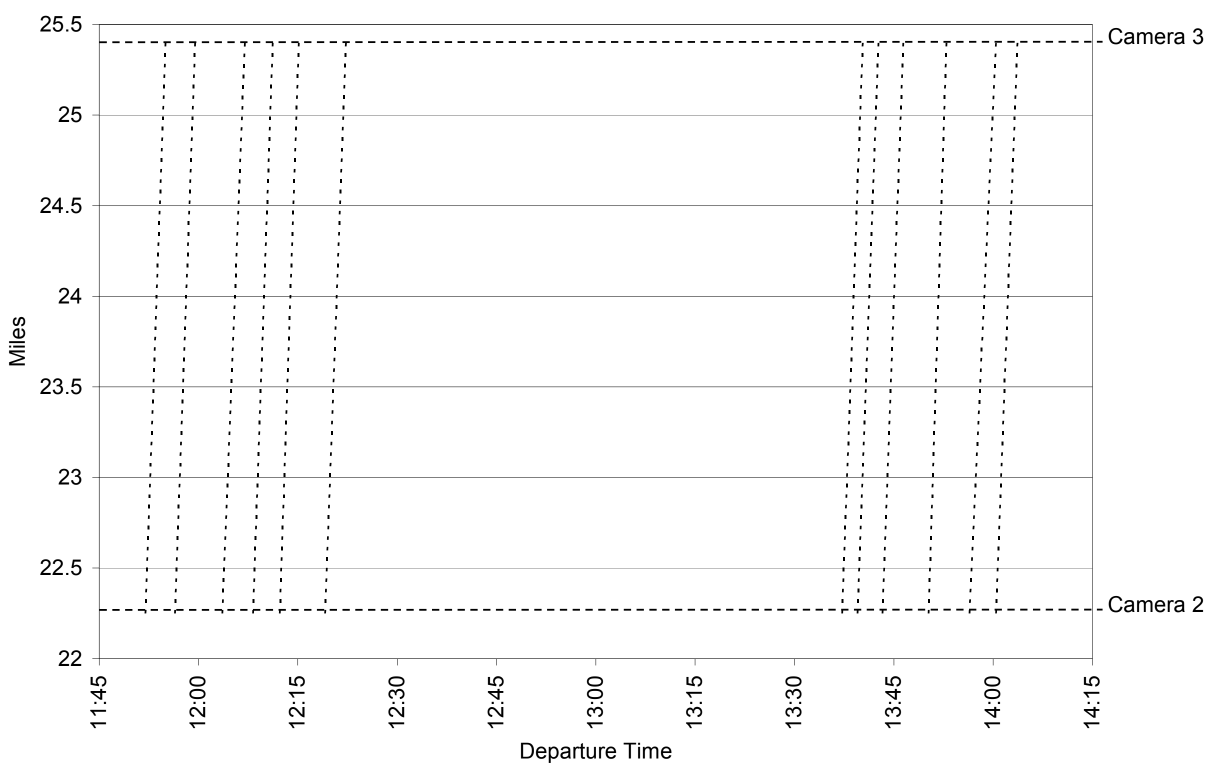


Figure 11 – Day 1: Cameras' total, westbound

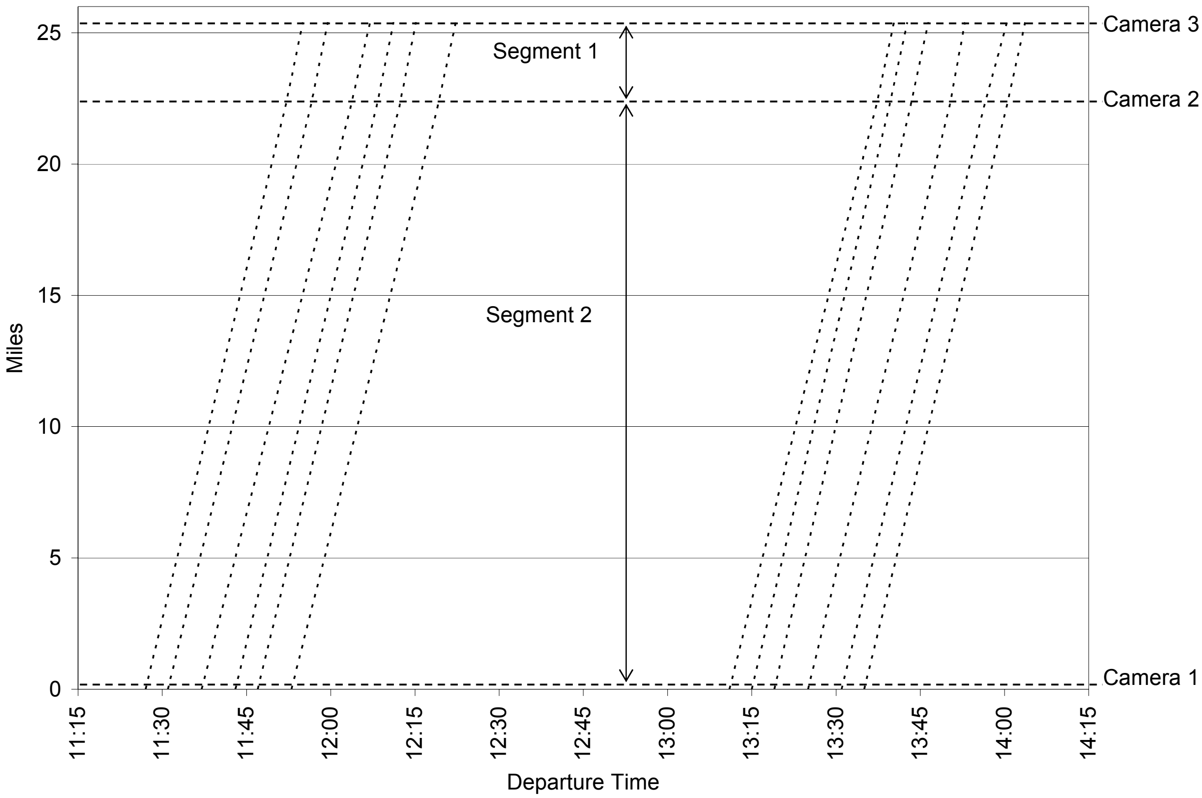


Figure 12 – Day 2: Cameras' segment 1, westbound

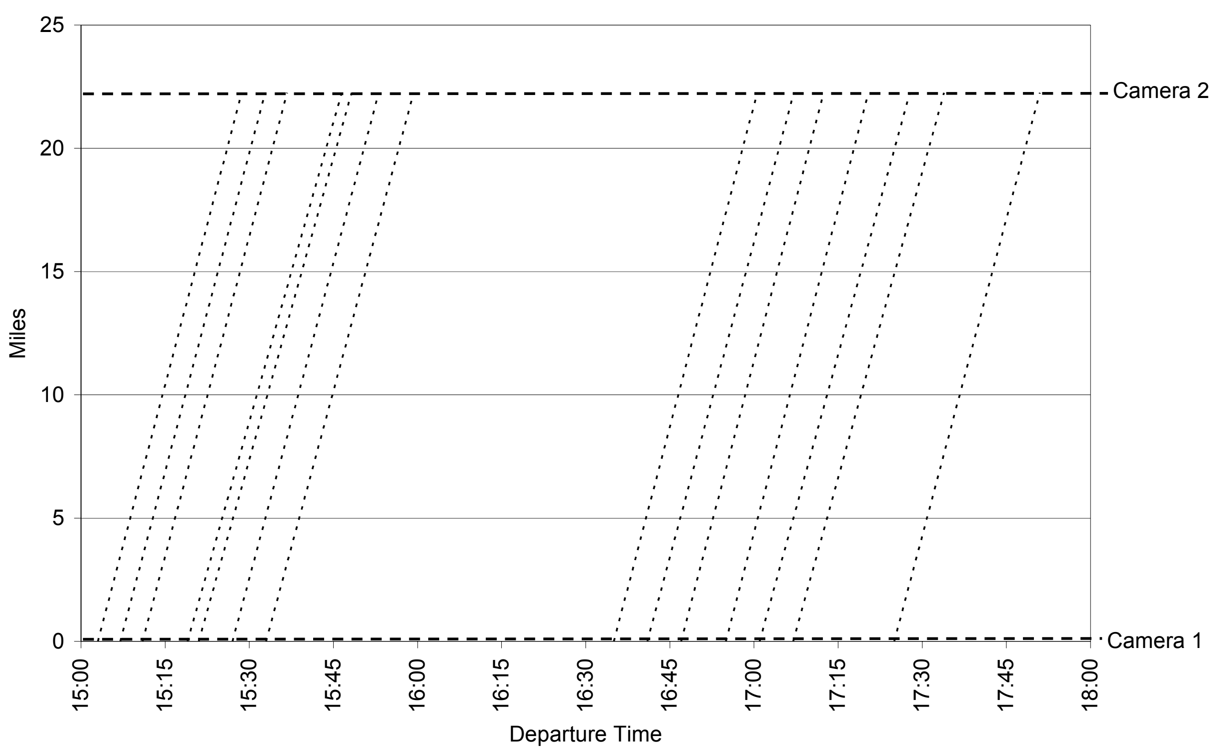


Figure 13 – Day 2: Cameras' segment 2, westbound

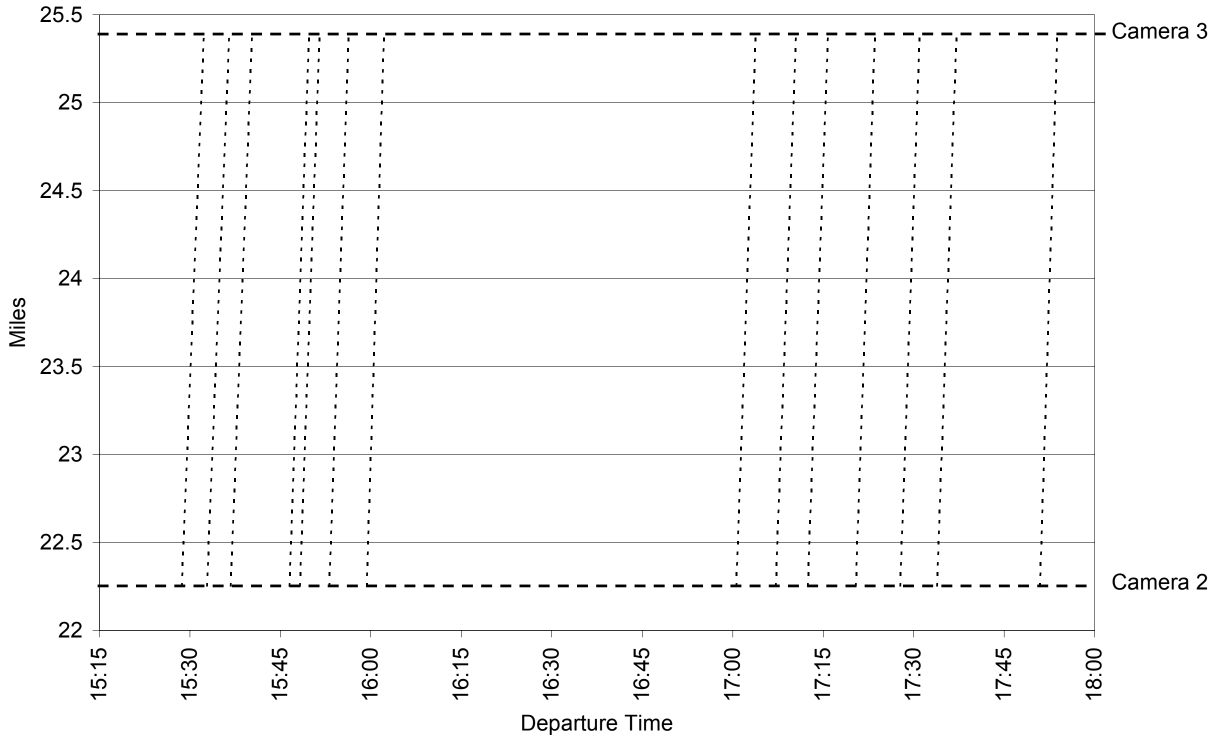
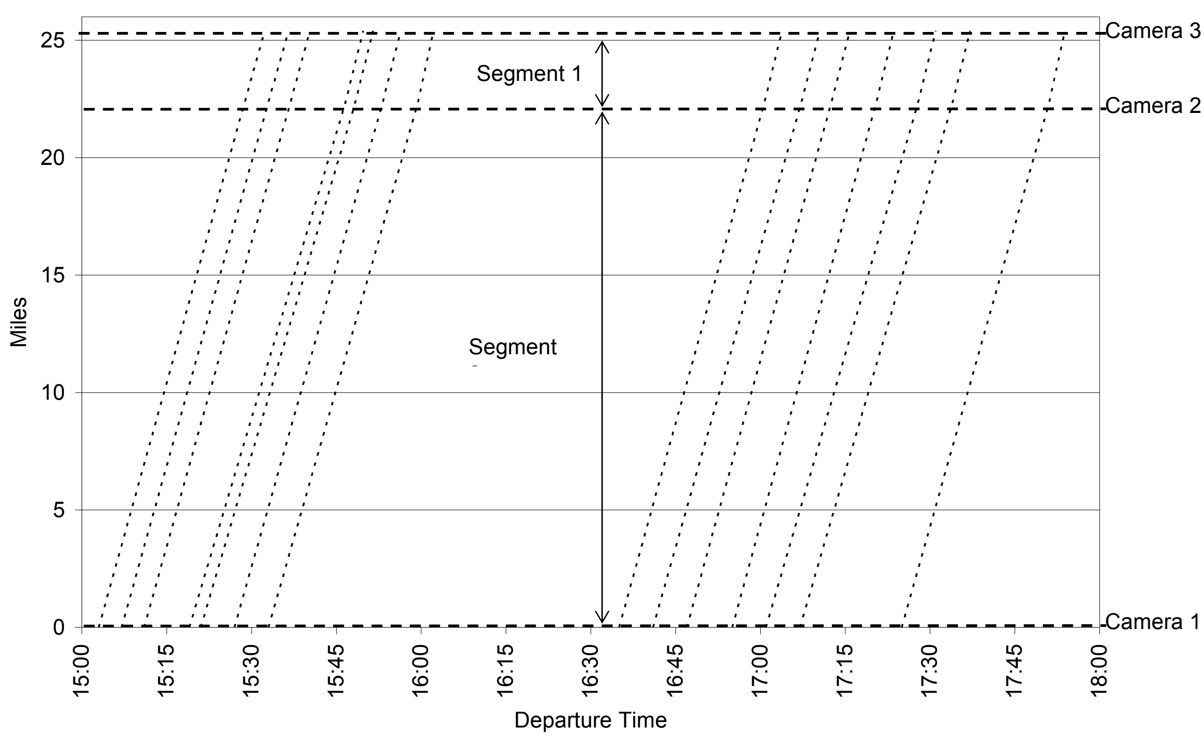


Figure 14 – Day 2: Cameras' total, westbound



PROBE VEHICLE DATA

The number of probes required to obtain the minimum sample-size to obtain reliable, unbiased estimates was determined (*6*). On July 13, 2003, six probe vehicles were used and on July 2, 2004 seven vehicles were used. Each test car drove from Lincoln City to Valley Junction and Valley Junction to Lincoln City, twice on both days. Probe vehicles left the initial starting point at approximately 10 minute headways. On Day 2, only westbound data was collected because only the westbound cameras were in operation. While gathering data, the probe vehicles followed standard probe vehicle instructions (*7*) by traveling at normal travel speeds.

Four (Day 1) or five (Day 2) probe vehicles were equipped with Palm OS handheld computer units equipped with Global Positioning System (GPS) receivers and the ITS-GPS software developed at Portland State University. On both days, two additional vehicles were equipped with laptop computers using CoPilot navigation software and GPS receivers. The GPS data collection devices were programmed to record date, time, time elapsed between readings, latitude, longitude, distance in miles traveled since last reading, and vehicle miles per hour at three-second intervals. An example of a data set is shown in Figure 15. These time-stamped probe vehicle locations were used to construct trajectories (on a time-distance plane) for each vehicle run during the field experiments.

Figure 15 – Sample Data Set

Date	GMT	Fixed' Time	Elapsed	Latitude	Longitude	Dist. Mile	Vel mi/hr	Dist. KM	Total Distance	Fixed' Distance
2004.07.02	23:27:51	15:27:51	3	45.06742	-123.57414	0.043542	52.250196	0.070076	0	0
2004.07.02	23:27:54	15:27:54	3	45.06729	-123.57501	0.043441	52.129488	0.069914	0.043441	0.045236167
2004.07.02	23:27:57	15:27:57	3	45.06714	-123.57589	0.044223	53.068072	0.071173	0.087664	0.09128665
2004.07.02	23:28:00	15:28:00	3	45.06697	-123.57679	0.045512	54.613822	0.073246	0.133176	0.138679399

Subsequent to the field experiments, the data were retrieved from the Palm devices and the laptop computers and assembled in a spreadsheet for data cleaning and statistical analysis. The distance between each point was calculated using the spherical geometry method (*8*). Upon review of the data, it was found that for some sections of the study corridor, the GPS devices lost a satellite and did not record location information. The device would attempt to gather data every three seconds until a satellite fix was re-established. As a result, total distances calculated for the trip did not match the measured road distance for a few trips. Since the location information recorded by the GPS units is the distance between points as a straight line, the distances were interpolated accordingly throughout the data sets. For example, the total distance between the cameras was 25.4 miles but a probe vehicle only recorded 24.4 miles due to the GPS unit readings. The error was distributed among each of the data points for the trip using the following equation:

Interpolated Distance = Distance between readings*(25.4/total distance measured by GPS unit)

Test vehicle trajectories (plots of vehicle location versus time) like those shown in Figures 3-14 were used to measure variations in speed and travel time for the probe vehicles. Figures 16-24 show these trajectories. Figures 16-18 are for eastbound probe vehicles, Figure 16 is from segment one between Lincoln and Otis, Figure 17 is for segment two between Otis and Valley Junction and Figure 18 is a trajectory of both trips combined. Figures 19-24 are for westbound trips on the two test days: Figure 19 and 22 are segment 1, from Valley Junction to Otis, Figure 20 and 23 are segment two from Otis to Lincoln City and Figure 21 and 24 include the total trips' combined trajectories. The twelve probe vehicle trips are presented for Day 1 and fourteen in total for Day 2. The trips are separated by time of departure on the x-axis and miles traveled on the y-axis. The dashed lines on the figures denote the points on the trips where the license plate reading cameras are located on the highways. The trajectories demonstrate that travel for the test cars were similar, the closer the lines are to vertical denotes the faster the trips.

Figure 16 – Day 1: Probe Vehicles segment 1, eastbound

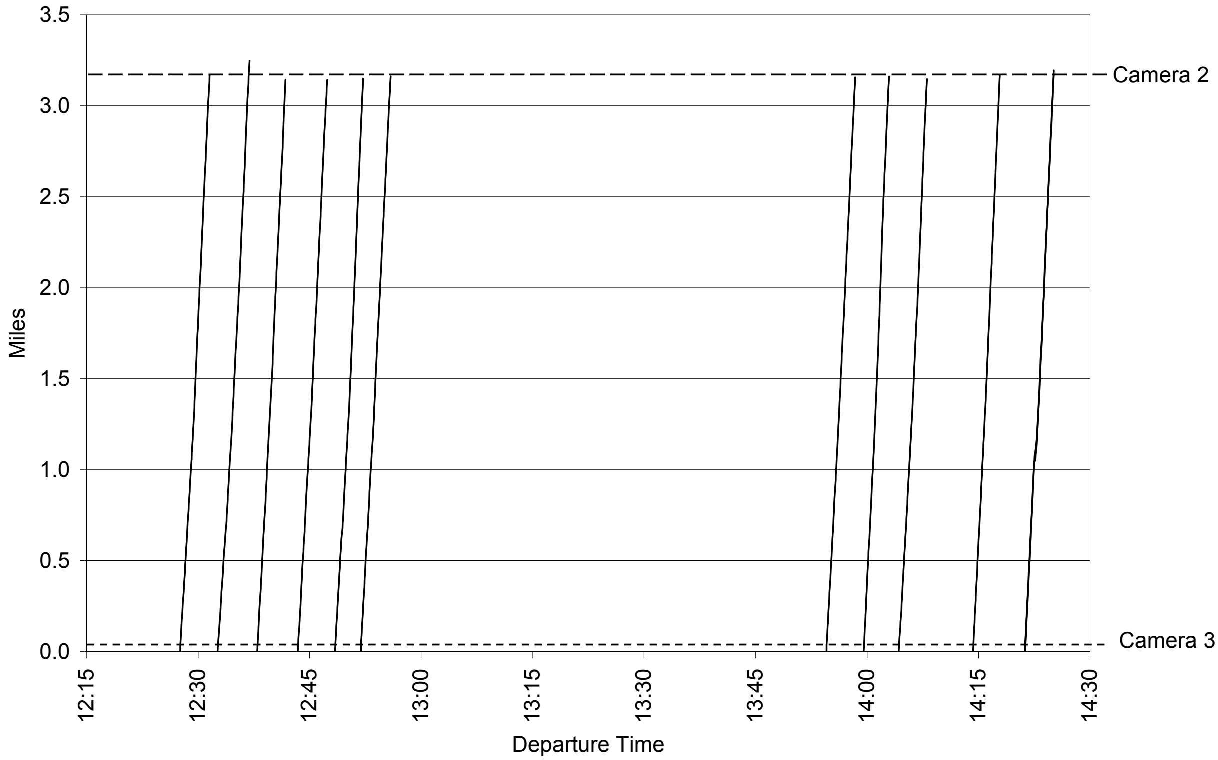


Figure 17 – Day 1: Probe Vehicles segment 2, eastbound

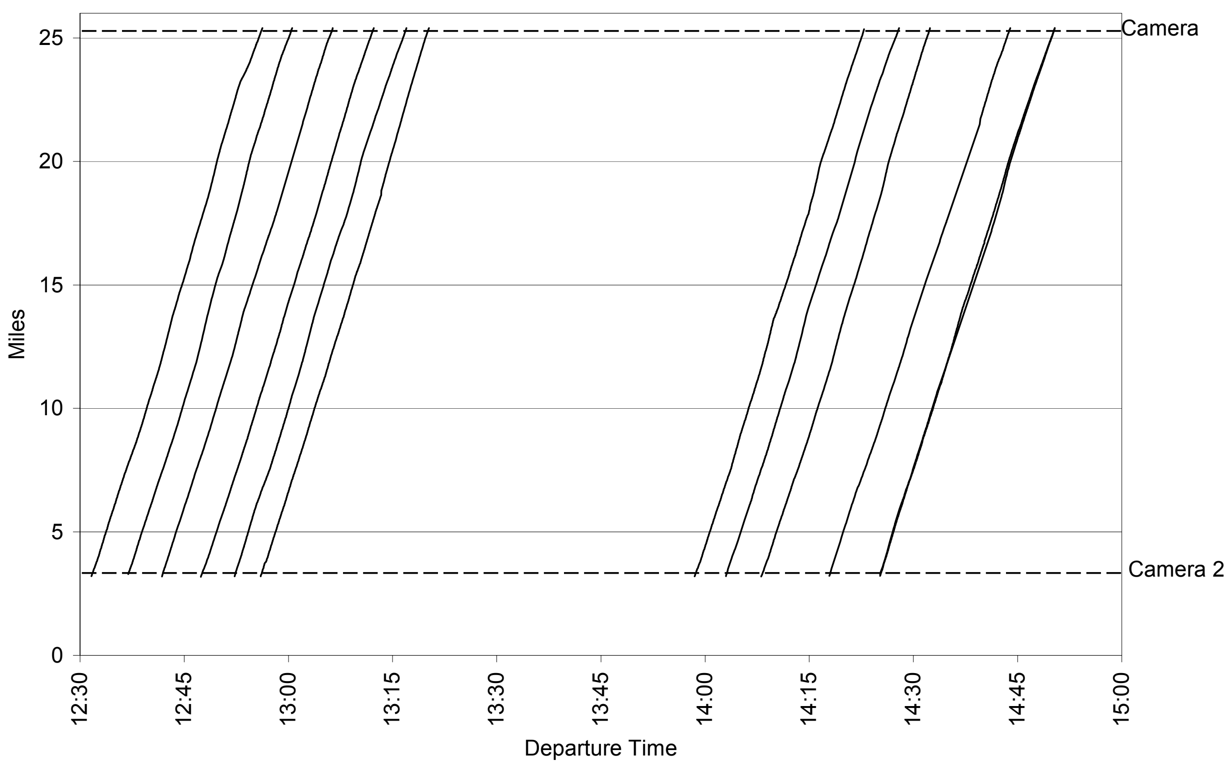


Figure 18 - Day 1: Probe Vehicles total, eastbound

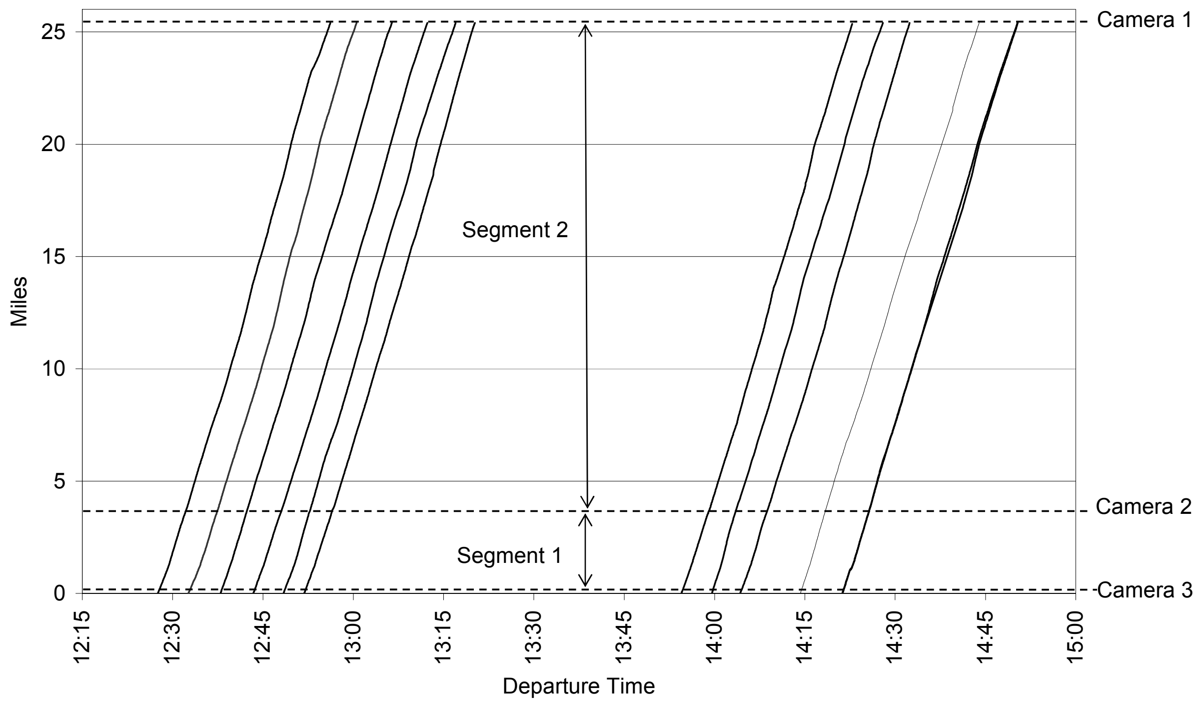


Figure 19 – Day 1: Probe Vehicles segment 1, westbound

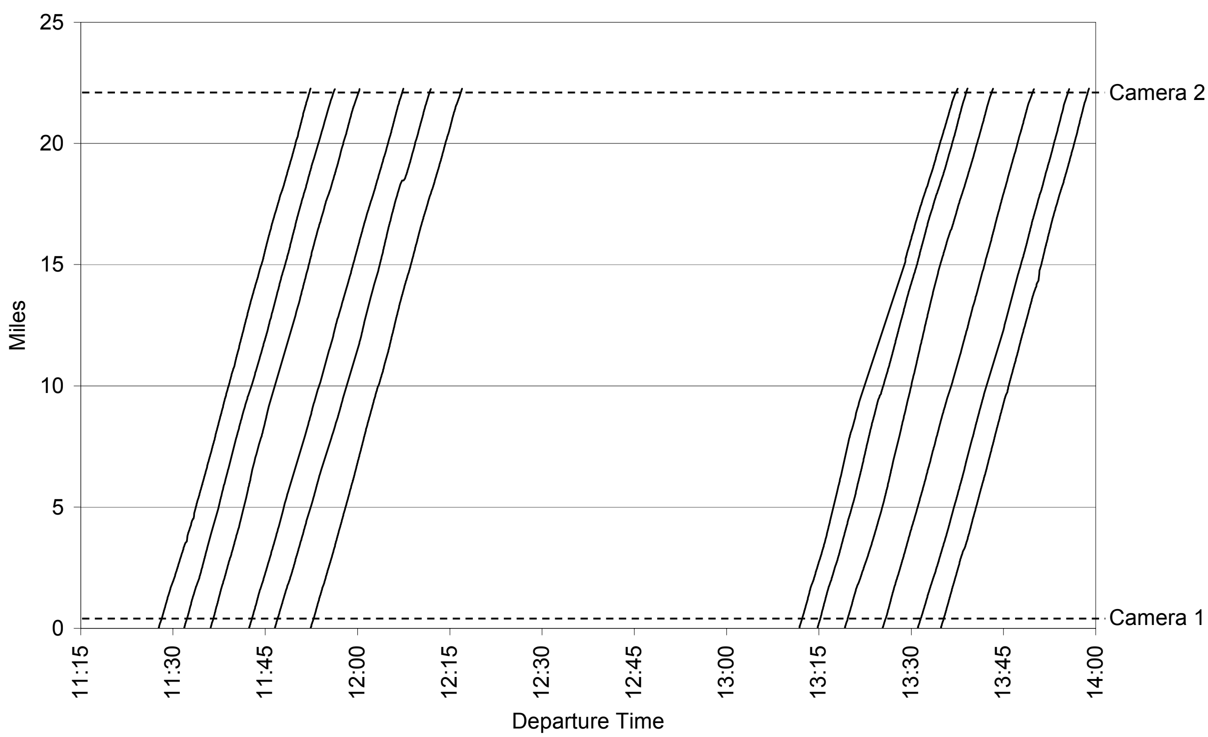


Figure 20 – Day 1: Probe Vehicles segment 2, westbound

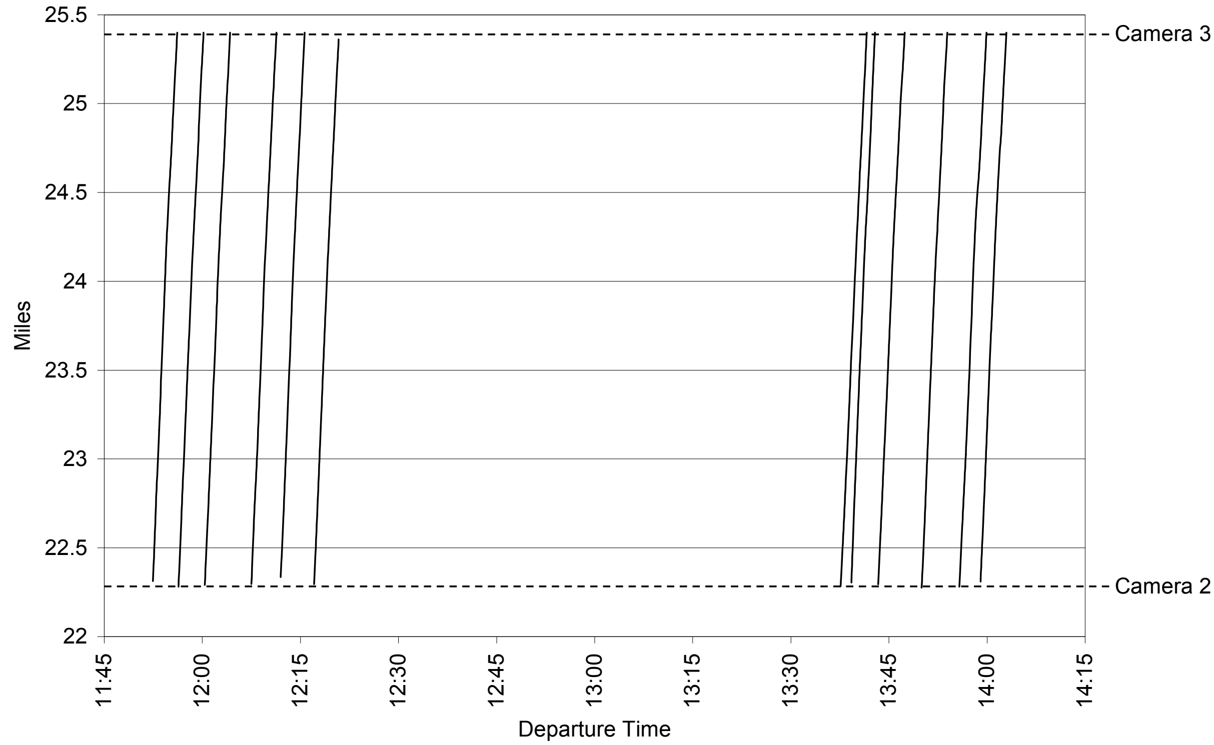


Figure 21 – Day 1: Probe Vehicles total, westbound

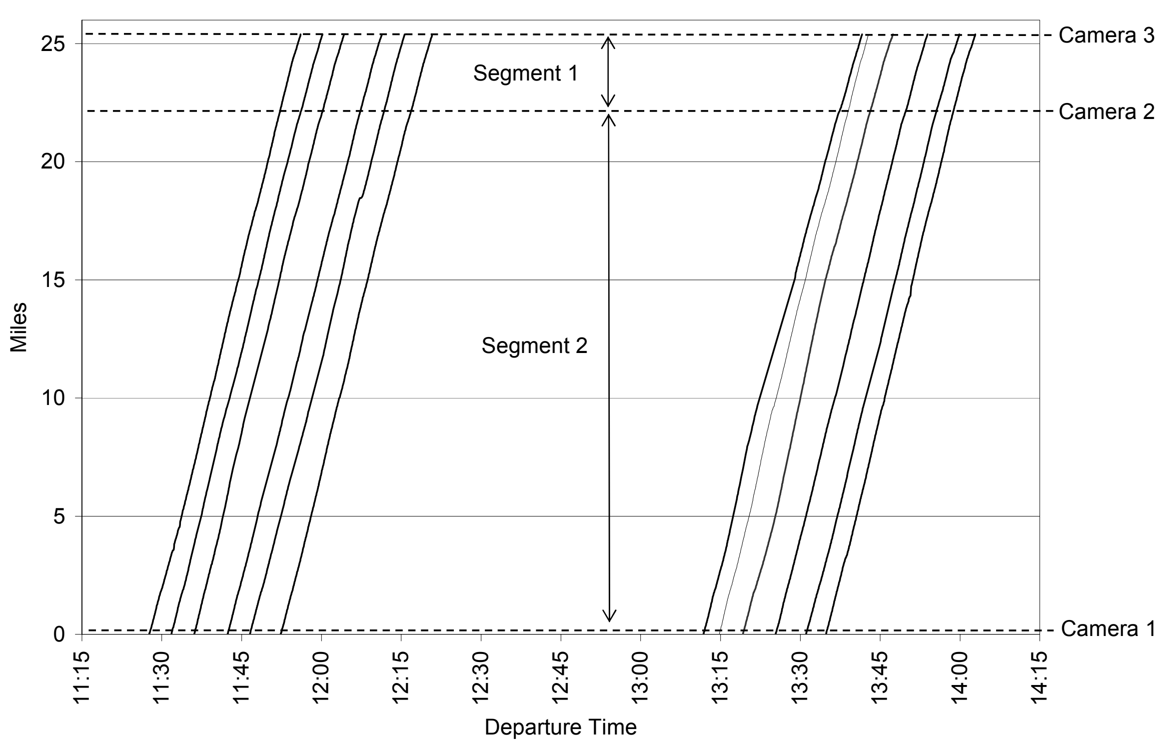


Figure 22 – Day 2: Probe Vehicles segment 1, westbound

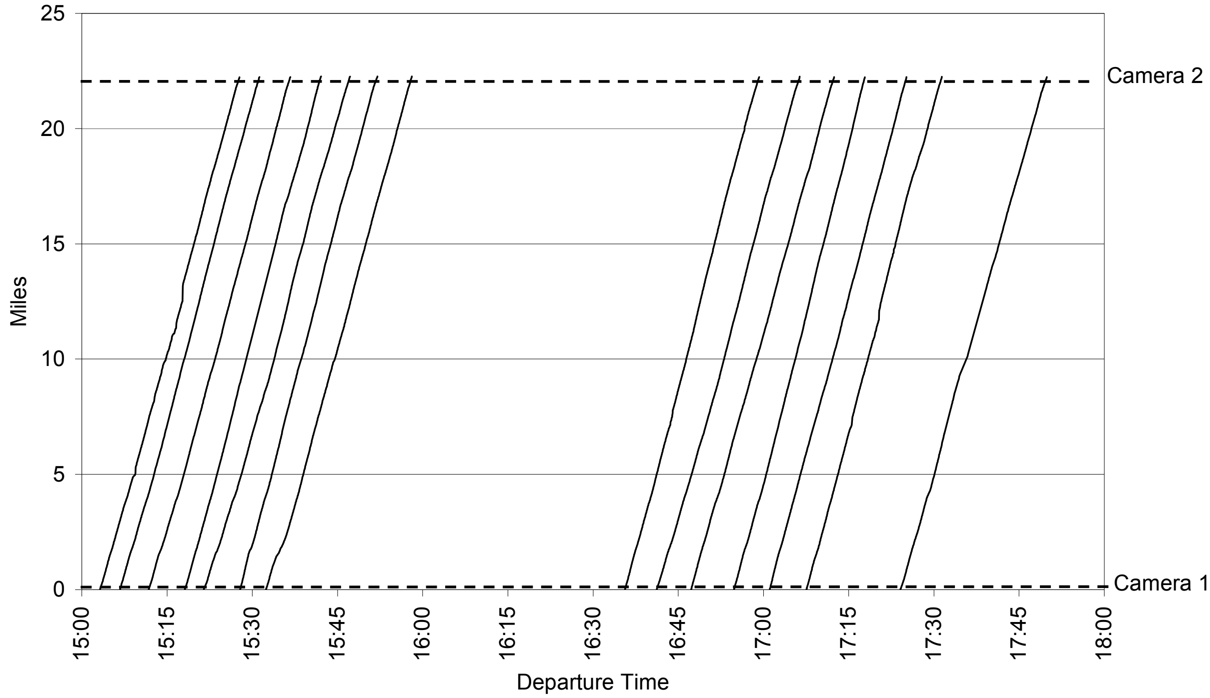


Figure 23 – Day 2: Probe Vehicles segment 2, westbound

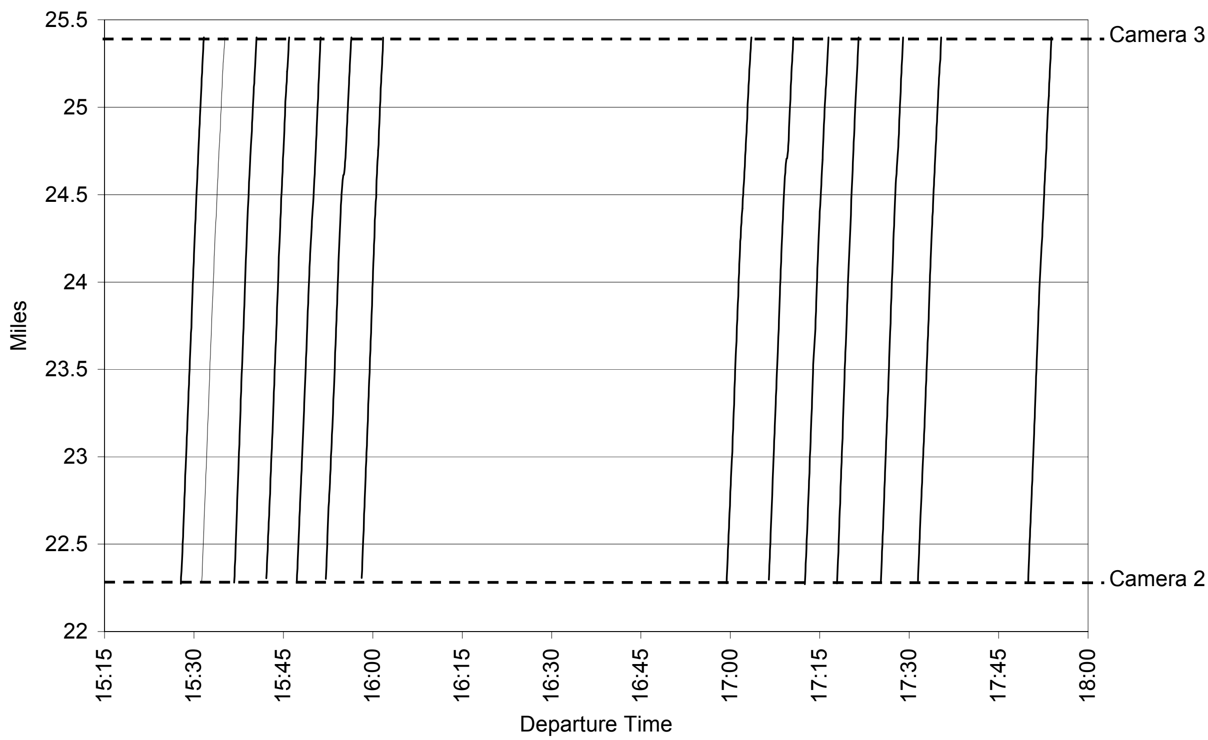
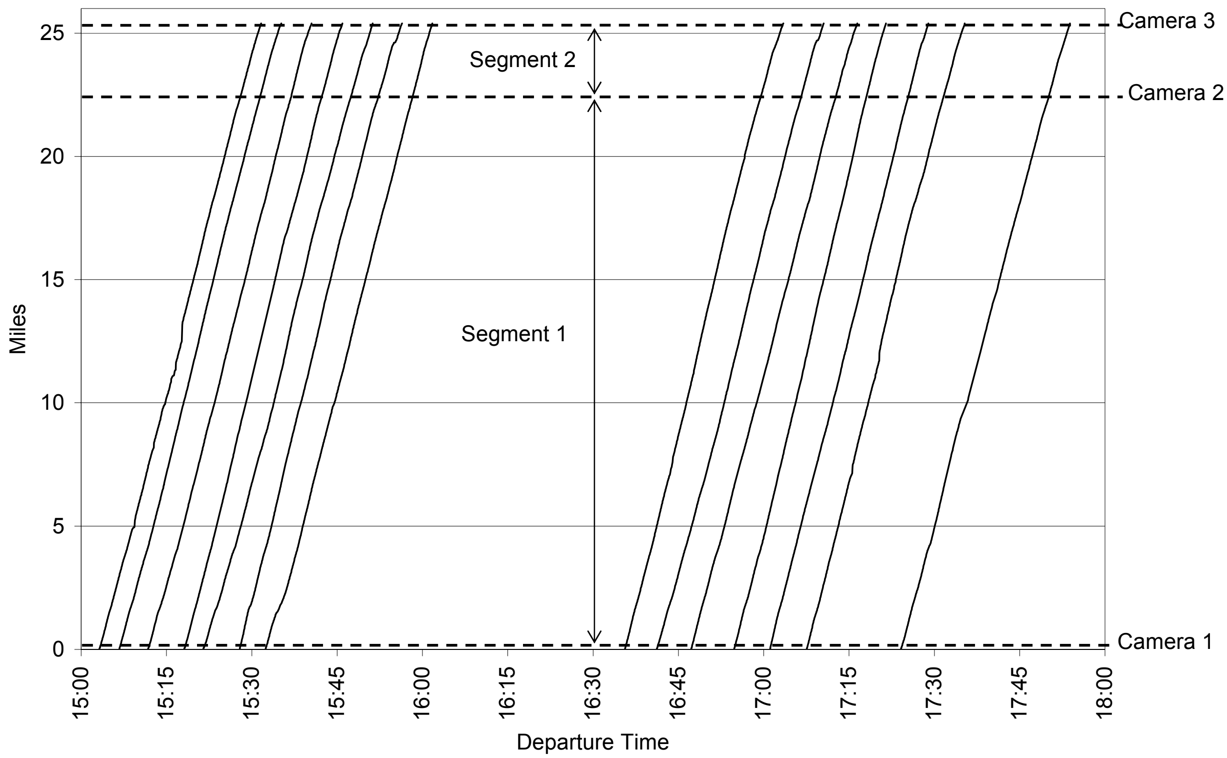


Figure 24 – Day 2: Probe Vehicles total, westbound



ANALYSIS

In order to compare the probe vehicle data and the system predicted travel time data, they were plotted using a time-space diagram for each study day and direction. These are shown in Figures 25-33, where the *x*-axis is time and the *y*-axis is the distance along the highway. The predicted travel time between each camera is shown for departure time of each vehicle as a dashed line. In this case, the trajectory will always be straight line between camera locations, since no intermediate travel information is known. The slope of the line indicates the average travel speed for the corridor. For the study days, the Frontier system's average predicted travel times were 29 minutes for east and westbound on the first day and second day. The average predicted speed for all trips was approximately 51 mph. The probe vehicle trajectories were plotted knowing the vehicles' locations and time stamp every three seconds. Since the conditions were generally freely-flowing, the trajectories of the probe vehicles look almost identical to the Frontier system's predicted trajectories. If delay had been present, the probe vehicle trajectories would have varied over time. These figures demonstrate the close similarity between most of the system's predicted travel times and actual probe vehicle travel times for the days analyzed.

Figure 25 – Day 1: Comparison eastbound, segment 1

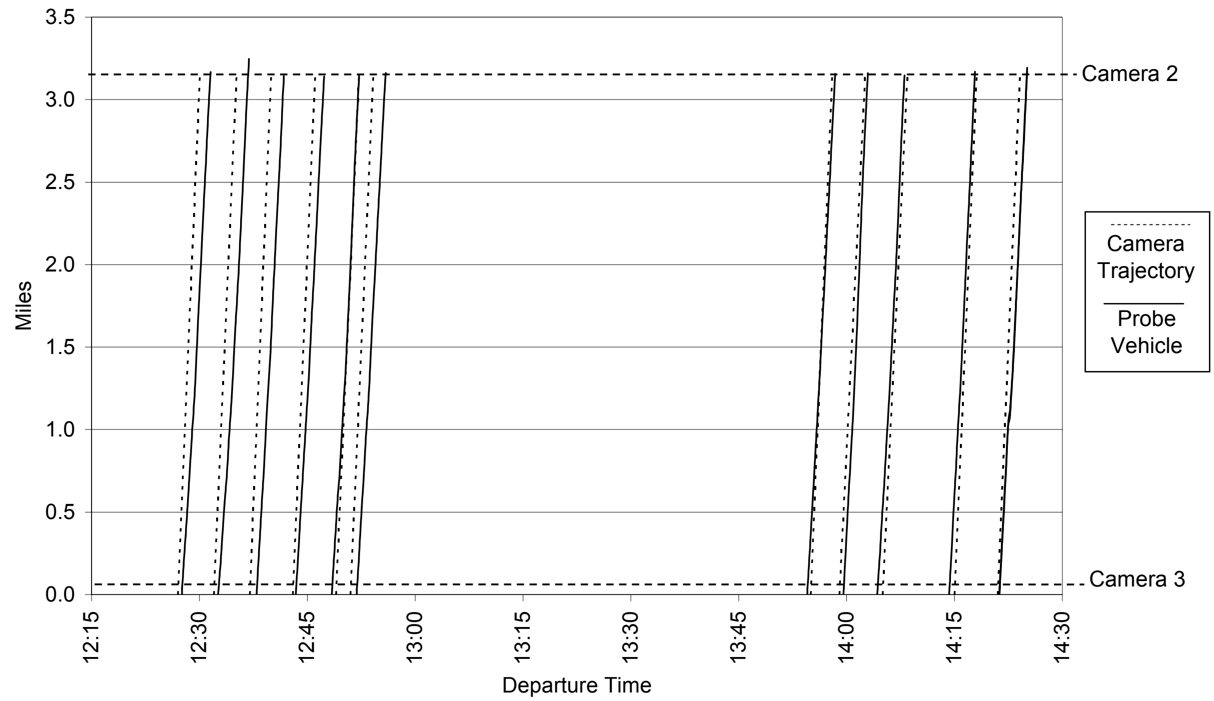


Figure 26 – Day 1: Comparison eastbound segment 2

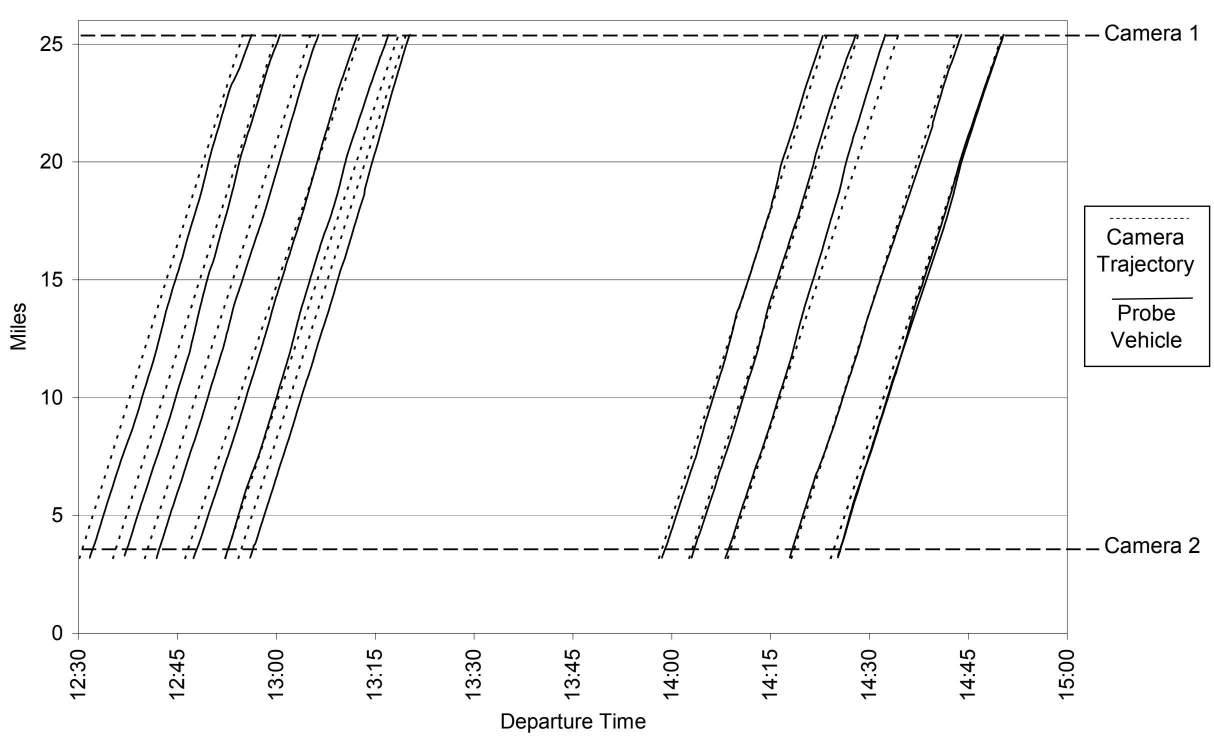


Figure 27 – Day 1: Comparison eastbound, total

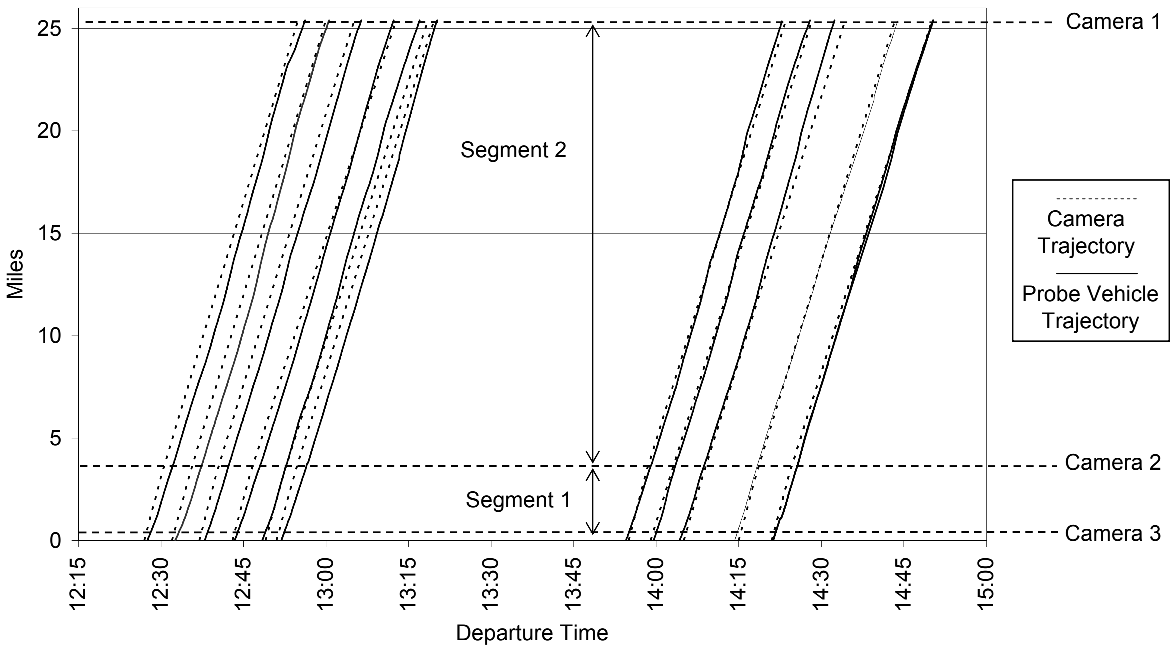


Figure 28 - Day 1: Comparison westbound, segment 1

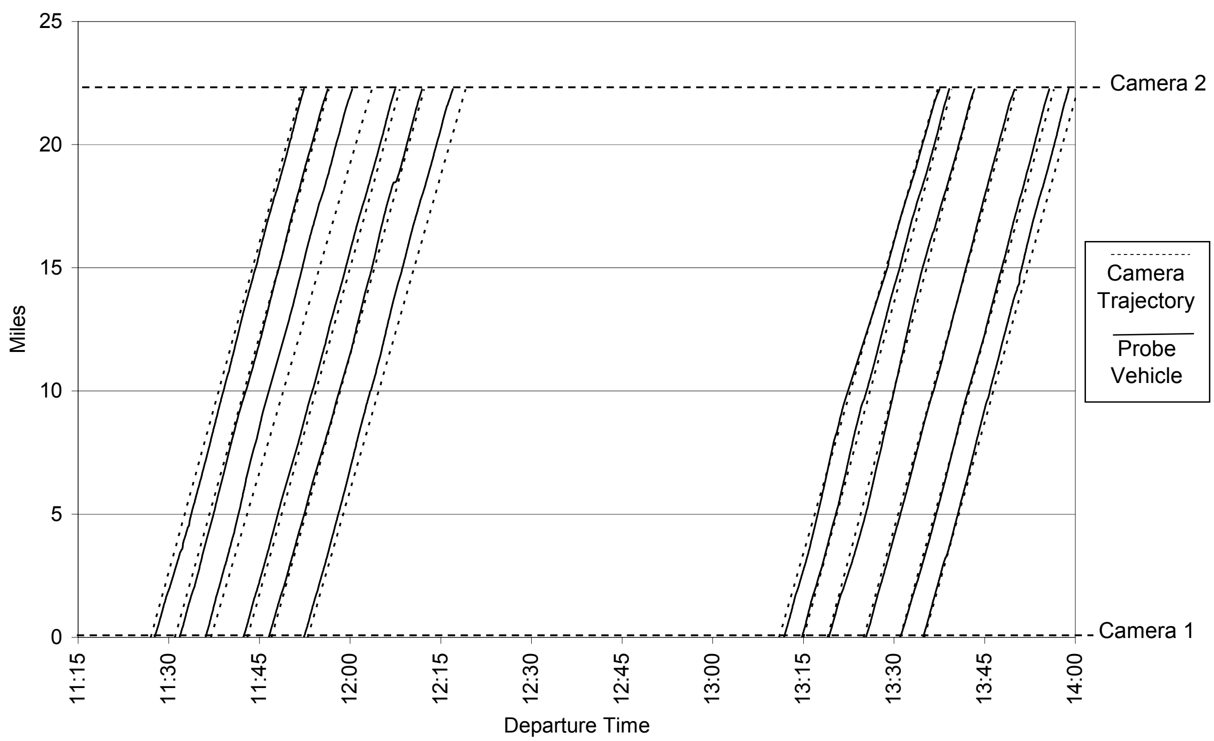


Figure 29 – Day 1: Comparison westbound, segment 2

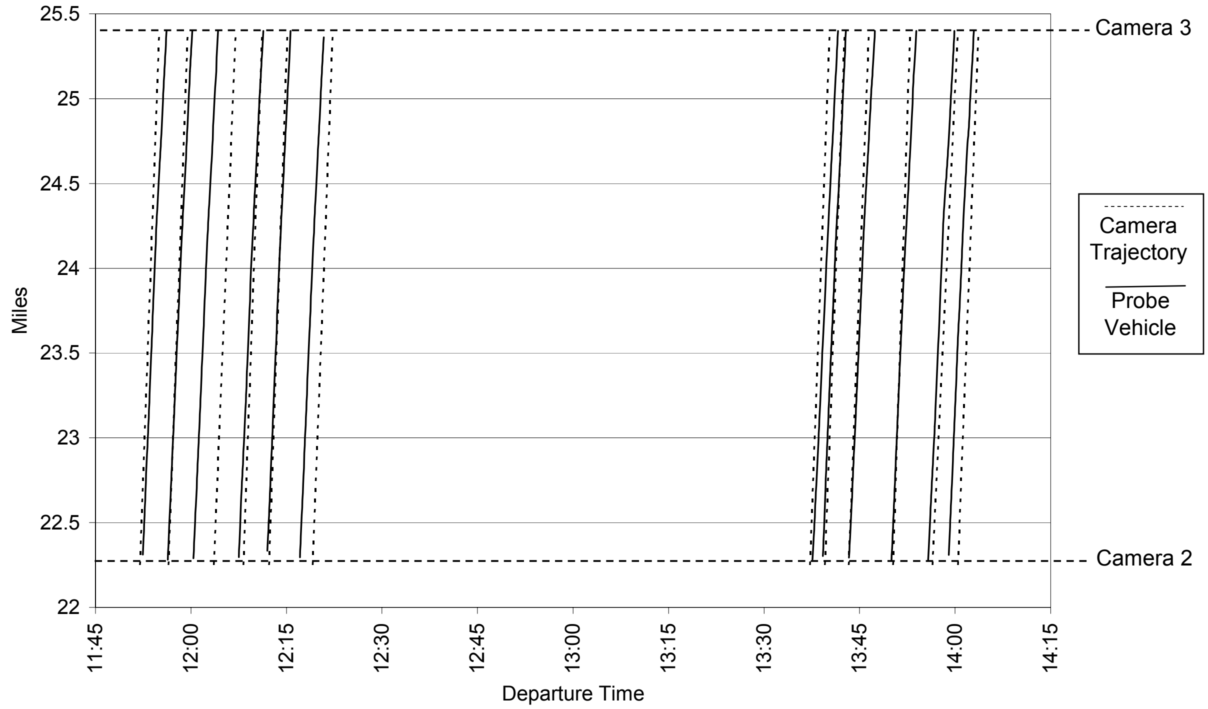


Figure 30 – Day 1: Comparison westbound, total

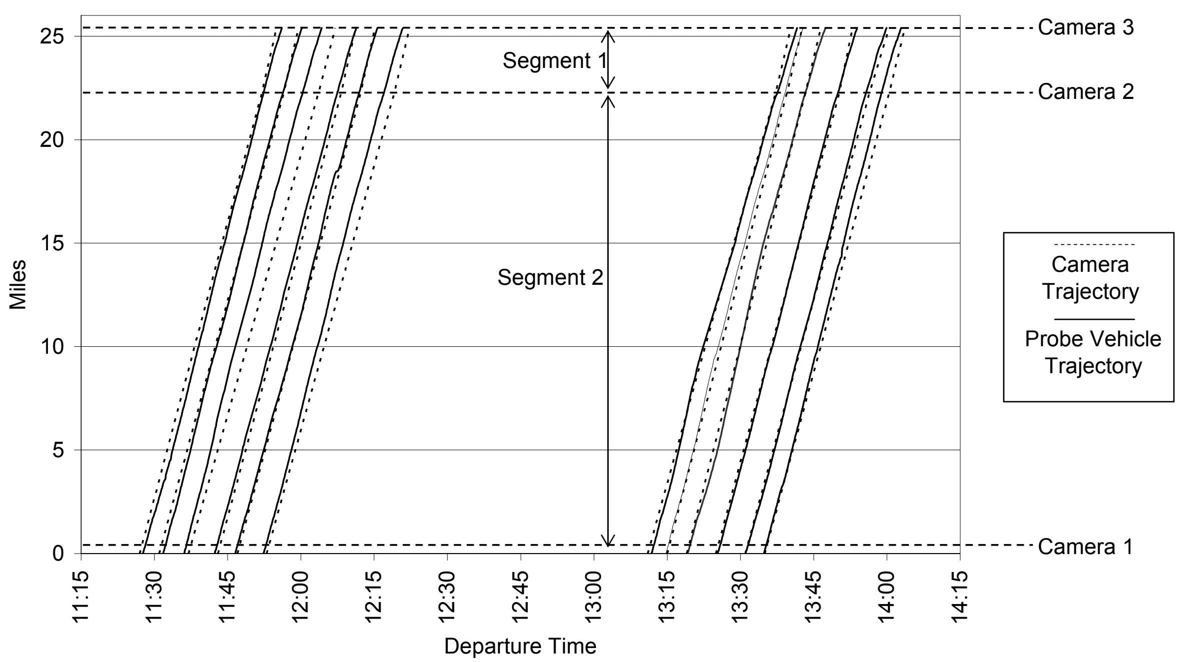


Figure 31 – Day 2: Comparison westbound, segment 1

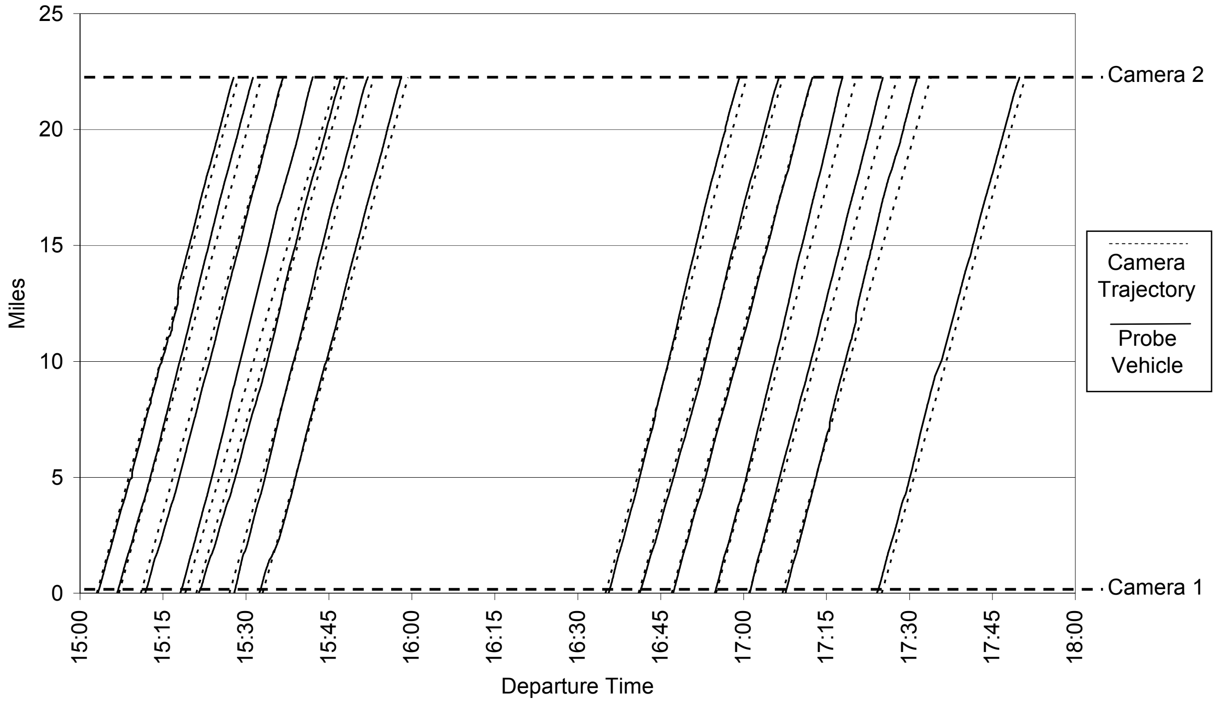


Figure 32 – Day 2: Comparison westbound segment 2

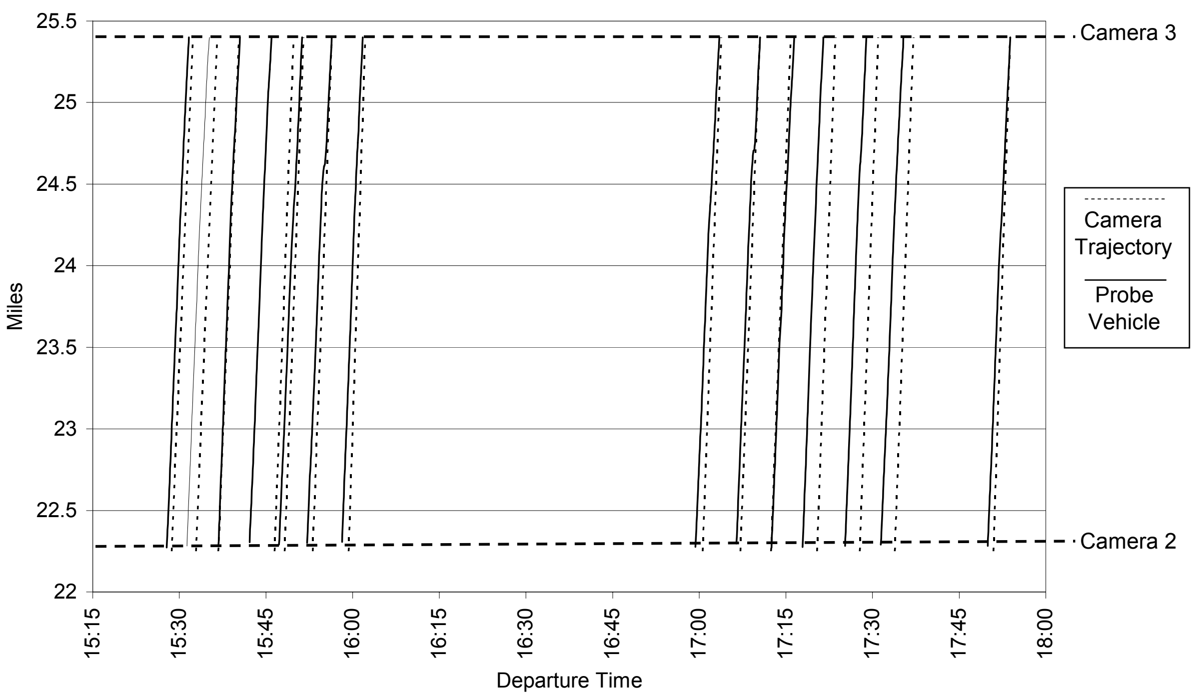
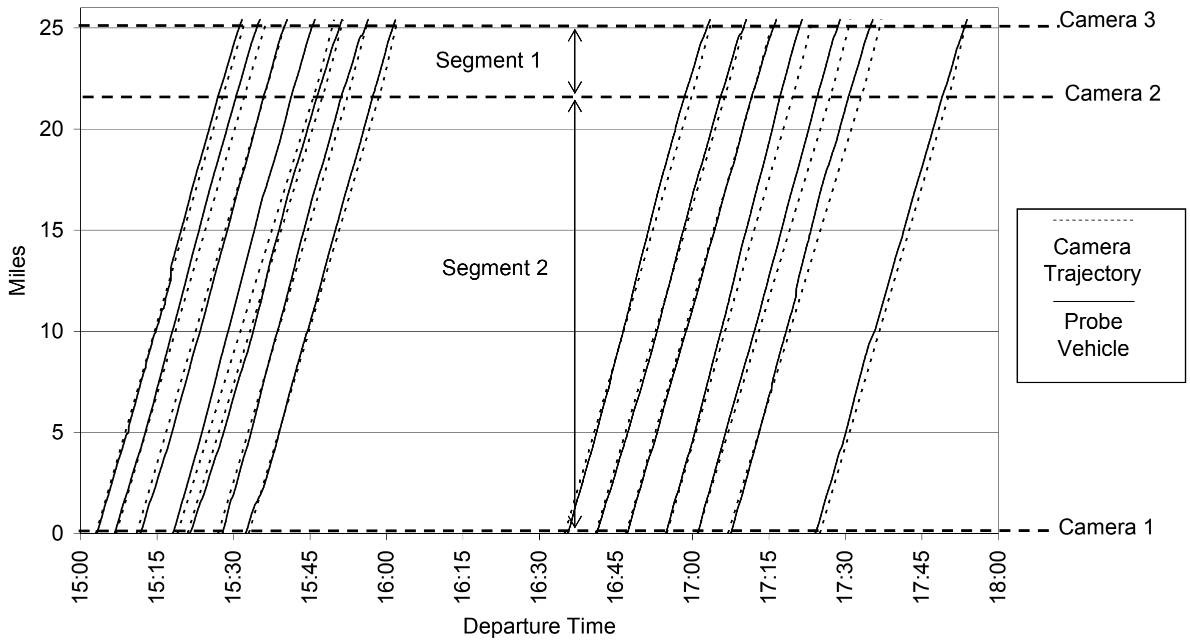


Figure 33 – Day 2: Comparison westbound, total



Further statistical analysis was conducted to test the similarities between the mean trip time for each group of probe vehicle trips with the mean of the system predicted travel time using all times between the first and last probe vehicle departure. The summary statistics for westbound trips are shown in Table 1 and eastbound in Table 2. Since the Frontier system's output occurs about every 3 seconds, the *n* value for the system is larger than for the probe vehicles. The means were then plotted with each 95% confidence interval as shown in Figure 34. The various trips are defined by the groupings of probe vehicle departures. For example, in Figure 34 all probe vehicles departing from 15:00 to 15:30 are considered a trip. The results show that in all cases except for Day 2, Trip 1, the means are not significantly statistically different because there is some overlap between the probe vehicle and Frontier system travel time confidence intervals. Although there are some differences in the system's ability to predict shorter trips as mentioned below, the system is effective predicting the total 25.4 mile corridor trip.

Closer examination of the differences between the Frontier system predicted travel times and probe travel times reveals that errors for the shorter and longer segments are different. The plot in Figure 35 (a) shows travel time difference (predicted – probe vehicles) that the Frontier system generally predicted longer travel times than observed by the probe vehicles for the segment 1 (3.15 miles). The Frontier system predictions were a maximum of 56 seconds greater than the probe vehicle times and were consistent longer for all probe comparisons. However, for the longer segment 2 (22.25 miles), the system predicted a shorter time than all but one of the probe vehicle trips (Figure 35 (b)). For segment 2, the maximum difference of the system predicted times and the probe was 58 seconds.

Table 1 Summary Statistics Westbound

	Westbound							
	Day 1				Day 2			
	Trip 1		Trip 2		Trip 1		Trip 2	
	Probe Vehicles	Cameras	Probe Vehicles	Cameras	Probe Vehicles	Cameras	Probe Vehicles	Cameras
n	7	16	7	26	6	14	6	13
Mean	28:42	29:39	28:19	29:12	28:34	28:43	28:32	28:21
Standard Deviation	00:38	00:37	01:06	00:26	00:23	00:36	00:40	00:45
Confidence Interval	00:28	00:18	00:49	00:10	00:18	00:19	00:32	00:25

Table 2 Summary Statistics Eastbound

	Eastbound			
	Day 1			
	Trip 1		Trip 2	
	Probe Vehicles	Cameras	Probe Vehicles	Cameras
n	6	13	6	12
Mean	28:26	28:40	28:45	28:59
Standard Deviation	00:19	00:50	00:35	00:22
Confidence Interval	00:15	00:27	00:28	00:12

Figure 34 - Means and Confidence Intervals For Probe Vehicle And Predicted Travel Times

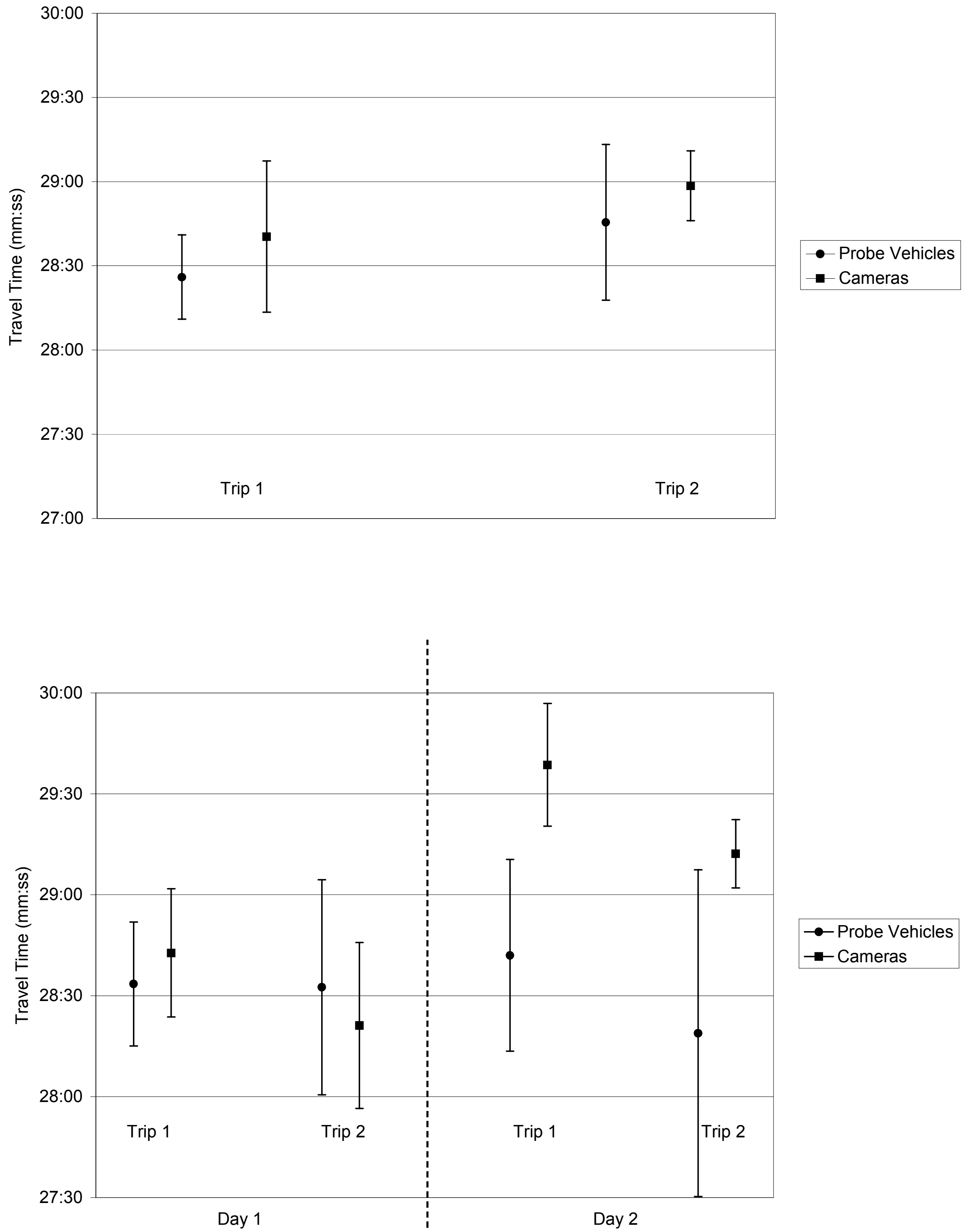
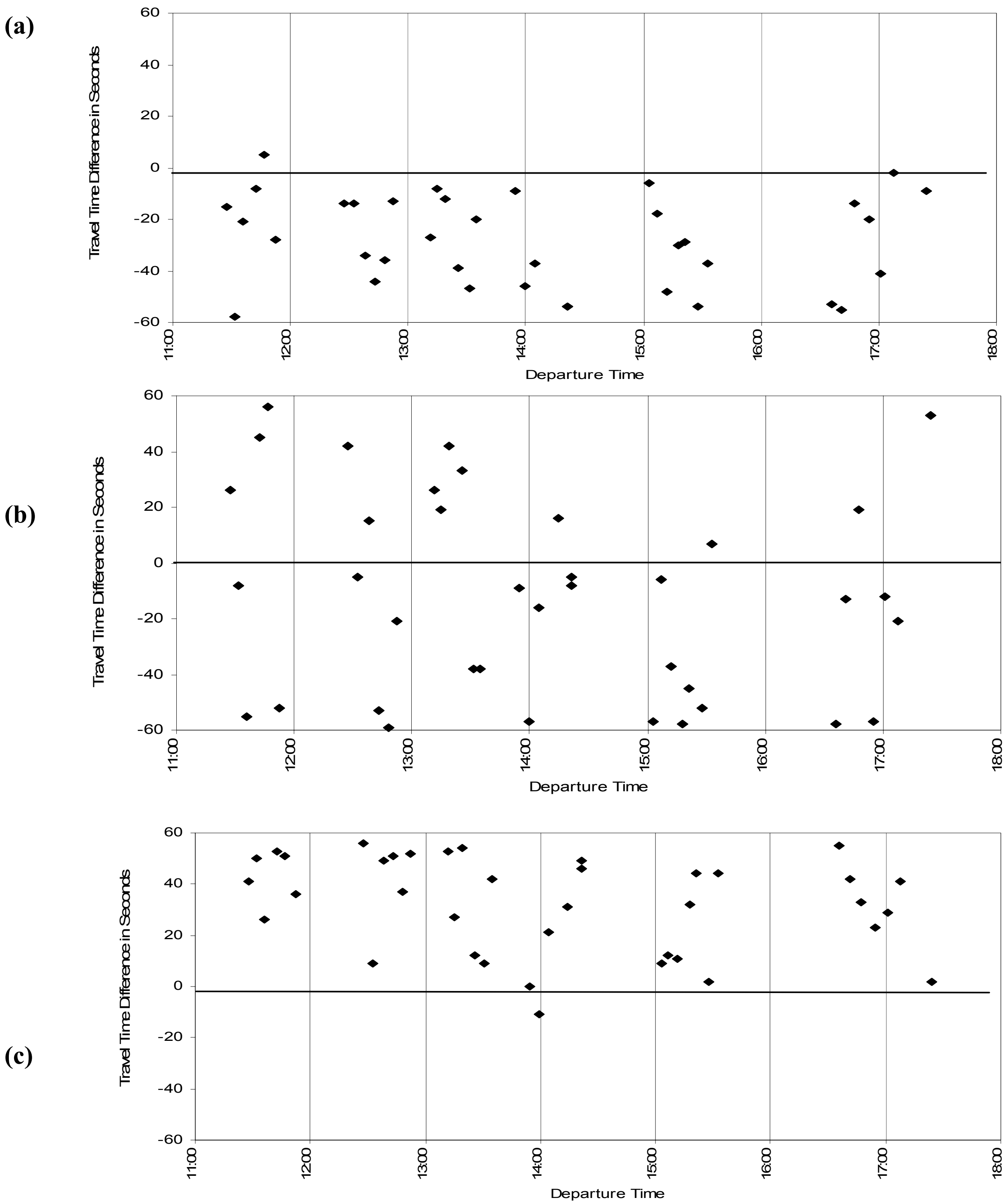


Figure 35 - Difference Between Probe Vehicles' Trip Times And Cameras' Predicted Trip Times



RESULTS

Based on a comparison of the mean travel times for the days examined, the Frontier Travel Time system on OR-18 and on US-101 between Lincoln City and Valley Junction predicts trip times effectively for the total 25.4 mile trip based on only one of the six comparisons being significantly statistically different. As for the short segments 1 and 2, the cameras were also effective from a practical perspective.

CONCLUSION

The results of the field validation indicate that the Frontier Travel Time system is sufficiently accurate in predicting corridor travel times. Since all probe vehicle tests were performed while generally free flow traffic conditions prevailed, the results of this field test have limited application. In general, it is shown here that the Frontier system can reliably predict travel times within a minute, which is robust considering the length of the corridor. With this in mind, it is suggested that the system's predicted trip times be displayed on several VMS at key junction points upstream of the point where drivers enter the corridor. This would be particularly useful in the case of incidents, which are known to occur along the corridor (but did not occur on either of the study days). Given additional travel information would allow drivers to change their route, destination, or travel mode.

Additional field tests comparing probe vehicle trips to the Frontier system predicted trip time could only improve this research. Based on these results it is likely that the system will perform well during freely flowing conditions. One issue with all travel time reporting systems is the latency of the data. In all travel time systems that measure actual vehicles' travel times over a highway segment can only report that travel time at the end of the trip across the segment. In urban areas where segments are short, this is usually not a major concern. However, along a rural corridor with long segments such as this, a travel time that would be reported to a driver entering the corridor could be 30 minutes old or older. This would be exacerbated at the beginning and end of congested periods. Therefore it is conceivable that some motorists could receive information predicting freely flowing conditions along the corridor as they begin their trip, but would actually experience substantial delay due to an incident or congestion. The opposite would also be true, whereby motorists would be given information predicting very long travel times but would actually experience freely flowing conditions due to queue dissipation. These experiences (particularly the first condition) would likely cause users to doubt the reliability of the travel time prediction system. As such, this should be the subject of further research.

Also, linking the results from this study with other research that looks at the amount of delay time drivers are willing to accept before choosing alternative routes would also benefit this research. Finally, we recommend that ODOT test the actual travel time reporting system and conduct a user survey to determine how drivers use the travel time information. It is possible that such a system could be extended to other key corridors around the state, so some consideration of criteria for implementing such a travel time measurement system should also be the subject of further work.

REFERENCES

1. Western Transportation Institute. Rural ITS Pooled Fund Research Project: Frontier innovative ITS Applications for the Rural Environment. Bozeman, Montana
2. 2002 Volumes for Highway(s) 33-42: Salmon River Highway No. 39. Oregon Department of Transportation. http://www.odot.state.or.us/tdb/traffic_monitoring/. Accessed on July 28, 2004.
3. Bertini, R.L. and McGill, G. Analysis Of Oregon's Rural Incident Response Program Using Archived ITS Data, Ninth World Congress on Intelligent Transport Systems, Chicago, Illinois, October 14-18, 2002.
4. Who We Are. Telematica, http://www.tmsl.com/about.htm. Accessed on July 28, 2004
5. Western Transportation Institute. Frontier: Rural Travel Time Estimation Project Evaluation Plan. February 2002.
6. Institute of Transportation Engineers. Manual of Transportation Engineering Studies. ITE, Washington, D.C., 2000.
7. Turner, S. M., W. L. Eisele, R. J. Benz and D. J. Holdener. Travel Time Data Collection Handbook. Publication FHWA-PL-98-035. FHWA, U.S. Department of Transportation, 1998.
8. Distance Calculation, Meridian World Data, Inc. [Online], Available: http://www.meridianworlddata.com/Distance-Calculation.asp

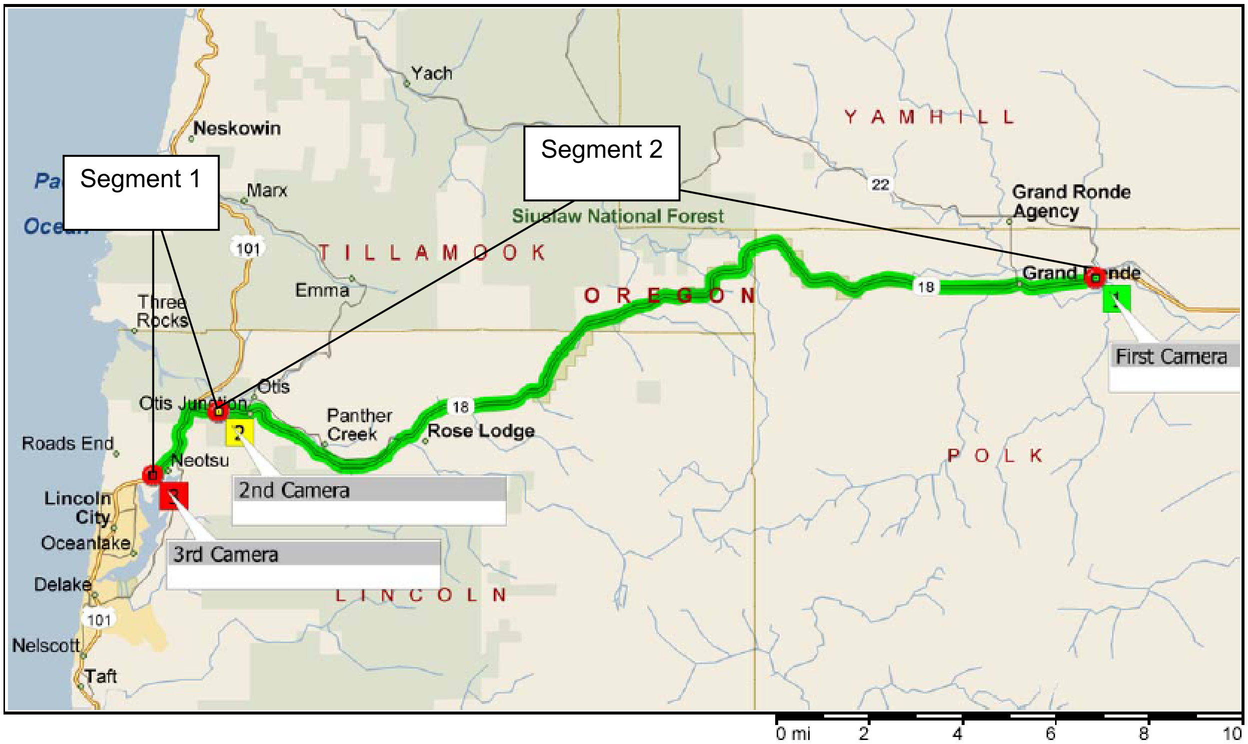


Figure 1 – Map of Study Area

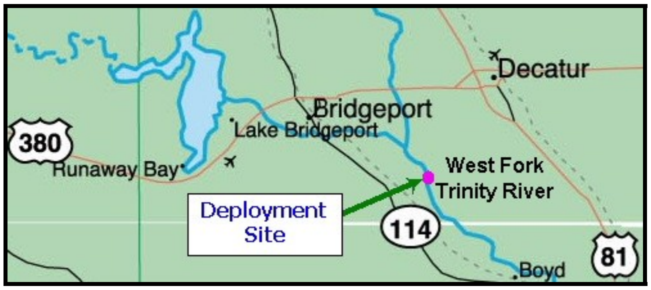
FRONTIER TRAVEL TIME SYSTEM

The Frontier Travel Time system consists of six license plate recognition cameras mounted on poles above the roadway placed at two locations on OR-18 and one location on US-101 just north of Lincoln City as shown in Figure 1. Each installation consists of two cameras, one for each direction. The distance between cameras 2 and 3 (Segment 1) is 3.15 miles and the distance between cameras 1 and 2 (Segment 2) is 22.25 miles. The total corridor length is 25.4 miles.

The Frontier Travel Time system logic is shown in Figure 2. The license plate reading cameras used for this research are made by Telematica Systems Limited (TSL); TSL is an associate company of the Trafficmaster group and describes the system as Passive Target Flow Measurement (PTFM) (*4*). The system uses infra-red technology to read license plates for travel time measurement. Similar to the London Congestion Charging system, the cameras along the corridor are calibrated to recognize the license plates of passing vehicles. The license plate numbers are privacy-protected number with encryption and time-stamped tags are sent via telephone communications network to the central server (*5*). The server matches the time-stamped tags collected at different checkpoints to identify vehicles that have passed between two

APPENDIX H

HIGH-WATER WARNING SYSTEM MAINTENANCE STAFF SURVEY



1. Did you access the real-time water level information? ❑ Yes ❑ No

2. How did you access the real-time water level information?
   a) Did you personally look at it? ❑ Yes ❑ No
   b) Did co-workers look at it and give you information? ❑ Yes ❑ No
   c) Did your supervisor look at it and give you information? ❑ Yes ❑ No

3. How useful did you find the real-time water level information?

   ❑ Very ❑ Somewhat ❑ Not at all

4. What did you do with the real-time water level information?

	Frequently	Sometimes	Rarely	Never
a) It helped me be alert when the water is within two feet of reaching the roadway surface.	4	3	2	1
b) It helped me determine when to close the road to avoid the “water-over-the-roadway” situation.	4	3	2	1
c) It made the high-water signing more timely.	4	3	2	1
d) It changed the order in which I drove the routes.	4	3	2	1
e) It helped me cover my routes more efficiently (i.e. avoid “wasted trips”).	4	3	2	1
f) It made staffing decisions more efficient.	4	3	2	1

Comments:____

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When did you use the real-time water level information?

	Frequently	Sometimes	Rarely	Never
▪ Daytime hours	4	3	2	1
g) Nighttime hours	4	3	2	1
h) Currently stormy weather	4	3	2	1
i) Forecast stormy weather	4	3	2	1
j) “Bluebird weather” (no current storm, no forecast storm)	4	3	2	1
k) During flood-season operations	4	3	2	1
l) During off-season operations	4	3	2	1
m) When a supervisor was on-duty	4	3	2	1
n) When no supervisor was on-duty	4	3	2	1

Comments:____

5. How frequently would you look at the real-time water level information during different conditions?

	Frequently	Sometimes	Rarely	Never
a) Daytime hours	4	3	2	1
b) Nighttime hours	4	3	2	1
c) Currently stormy weather	4	3	2	1
d) Forecast stormy weather	4	3	2	1
e) “Bluebird weather” (no current storm, no forecast storm)	4	3	2	1
f) During flood-season operations	4	3	2	1
g) During off-season operations	4	3	2	1
h) When a supervisor was on-duty	4	3	2	1
i) When no supervisor was on-duty	4	3	2	1

Comments:____

How accurate is the real-time water level information compared to other sources?

	More accurate		Equally accurate		Less accurate
a) Verbal reports from other maintenance staff (on- or off-duty)	5	4	3	2	1
b) Verbal reports from motorists	5	4	3	2	1
c) Weather forecasts	5	4	3	2	1
d) Reports from other agencies	5	4	3	2	1

Comments:____

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8. Is this high-water warning system easy to use?

	Very easy		Medium		Not easy
a) Overall hardware	5	4	3	2	1
b) Signing control software	5	4	3	2	1
c) Center computer user interface	5	4	3	2	1
d) Pager notification system	5	4	3	2	1
e) Data storage and analysis	5	4	3	2	1
f) Other: ________________________	5	4	3	2	1

Comments:____

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9. How reliable is this high-water warning system?

	Very reliable		Medium		Not reliable
a) Solar power systems	5	4	3	2	1
b) Water level sensors	5	4	3	2	1
c) Signing control hardware/Controllers	5	4	3	2	1
d) Signing control software	5	4	3	2	1
e) Communications system	5	4	3	2	1
f) Mechanical changeable message signs	5	4	3	2	1
g) Center computer user interface	5	4	3	2	1
h) Pager notification system	5	4	3	2	1

i)	Data storage and analysis	5 4 3 2 1
j)	Other: ______________________	

Comments:____

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10. Did you receive any comment from the general public or other drivers about the high-water warning signs? If so, what were they?