Transportation Northwest

PB98-135882

ESTIMATING LINK TRAVEL TIME WITH A VIDEO IMAGE TRACKING SYSTEM

Washington • Oregon • Idaho • Alaska

Final Report
TNW 98-03

ESTIMATING LINK TRAVEL TIME WITH A VIDEO IMAGE TRACKING SYSTEM

by

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April 1998

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. WA-RD ___ TNW 98-03 2. GOVERNMENT PB98-135882	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE ESTIMATING LINK TRAVEL TIME WITH A VIDEO IMAGE TRACKING SYSTEM	5.REPORT DATE April 1998 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Nancy L. Nihan and Scott S. Washburn	8. PERFORMING ORGANIZATION REPORT NO. TNW 98-03
PERFORMING ORGANIZATION NAME AND ADDRESS Transportation Northwest Regional Center X (TransNow) Box 352700, 123 More Hall University of Washington Seattle, Washington 98195-2700	10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. DTRS95-G-0010
12. SPONSORING AGENCY NAME AND ADDRESS United States Department of Transportation Office of the Secretary of Transportation 400 Seventh St. SW Washington, DC 20590	13. TYPE OF REPORT AND PERIOD COVERED Final Report 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with University of Washington.

16. Abstract

A new technology for measuring travel time that combines many of the advantages of other systems and eliminates their disadvantages was tested and evaluated by researchers at the University of Washington. This new technology is a video image detection system based on vehicle tracking, called Mobilizer. This system offers the promise of being able to track individual vehicles passively along any route monitored by video cameras. This system also provides all of the standard traffic measures reported by previous generation point processing video image systems, but is also capable of reporting link travel times, which cannot be measured by the point processing systems.

This report presents the results of the efforts to establish valid data collection equipment and methods for the Mobilizer system and the preliminary performance results of the Mobilizer system based on studies performed at local roadway segments within the Puget Sound region. These preliminary results indicated that the Mobilizer was capable of matching vehicles in successive fields-of-view with a high degree of accuracy and that the travel time estimates provided by the system were found to be statistically valid and accurate.

17. KEY WORDS video imaging, HOV, freeway traffic, travel time measurement	18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616

19. SECURITY CLASSIF. (of this report) None	20. SECURITY CLASSIF. (of this page) None	21. NO. OF PAGES: 39	22. PRICE $5.50

DISCLAIMER

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Travel time is currently believed to be one the best, if not best, indicators of the quality of flow and operation on a transportation facility. Travel time is such a good measure because it is easy for both commuters and transportation engineers to understand. The problem with travel time, however, is that historically it has been very difficult to measure accurately.

One of the best ways to measure travel time is directly, by timing individual vehicles from one point to another. Currently, very few systems are capable of providing this information in real-time. Automatic Vehicle Location (AVL), Automatic Vehicle Identification (AVI) and machine vision license plate matching systems offer this promise. AVL and AVI systems require in-vehicle equipment, while the license plate matching is a passive method. Each of these methods has varying advantages and disadvantages.

A new technology for measuring travel time that combines many of the advantages of these other systems and eliminates their disadvantages was tested and evaluated by researchers at the University of Washington. This new technology is a video image detection system based on vehicle tracking, called Mobilizer. This system offers the promise of being able to track individual vehicles passively along any route monitored by video cameras. This system also provides all of the standard traffic measures reported by previous generation point processing video image systems, but is also capable of reporting link travel times, which cannot be measured by the point processing systems.

This report presents the results of the efforts to establish valid data collection equipment and methods for the Mobilizer system and the preliminary performance results of the Mobilizer system based on studies performed at local roadway segments within the Puget Sound region. These preliminary results indicated that the Mobilizer was capable of matching vehicles in successive fields-of-view with a high degree of accuracy and that the travel time estimates provided by the system were found to be statistically valid and accurate.

INTRODUCTION

In today's information age, people have come to expect finding the kind of information they need to help them make many of the decisions they face everyday. One major area in which information is greatly lacking is the kind of information that would help commuters decide which route they want to take to their destination. Additionally, as arterial and freeway systems become more complex, methods of collecting more comprehensive and accurate traffic flow data are needed to support future IVHS applications intended to better manage and maintain these systems [Hughes and JHK 1994].

From both the planning and operational perspectives, link travel time is considered to be a key variable for real-time network information and for operational purposes. Travel time is currently believed to be one the best, if not best, indicators of the quality of flow and operation on a transportation facility. For the Washington State Department of Transportation (WSDOT), travel time savings and reliable trip time are included as required objectives for the high occupancy vehicle (HOV) system in the Puget Sound region (WSDOT, 1991). Travel time is such a good measure because it is easy for both commuters and transportation engineers to understand. The problem with travel time, however, is that historically it has been very difficult to measure accurately.

Currently, the Washington State Department of Transportation (WSDOT) makes available a map of the local freeway system that displays traffic volumes and speeds for many individual segments of the roadways around the Puget Sound region. While this system, and others like it, can usually provide estimates of travel time, these estimates are based on algorithms that use traffic flow measurements other than direct measurements of travel time. Unfortunately, this kind of information does not always provide an accurate "picture" of the actual travel time between two points.

A system for measuring travel time directly, the Mobilizer [Condition Monitoring Systems, Inc. 1997], is currently under development by Condition Monitoring Systems. This is a video image system that is capable of providing speed, density, volume, classification, and travel time data. Travel time data is provided directly by matching vehicles between successive field-of-views (FOV's).

RESEARCH PURPOSE

This research is a continuation of a previous project [Nihan, Leth, and Wong, 1995] that examined several of the above mentioned variables. Most notably, however, travel time evaluations were not performed due to inadequacies in the system development at the time. The previous project therefore focused on the other capabilities of the Mobilizer system, which were point processing type measurements in common with the previous generation of video image processing systems. Because of recent system enhancements, it was now possible to explore the issue of travel time determination. Aside from the direct enhancements to the Mobilizer system, a couple of fundamental changes were made to the data collection process that contributed to the improvements in the vehicle tracking performance (these will be discussed later in the report). This project focused exclusively on the issue of vehicle tracking and travel time measurement. While the accuracy of the other measurements have undoubtedly improved, the previous report showed satisfactory results with the standard measurements of volume and speed.

RESEARCH OBJECTIVES

Similar to the preceding project, this project was divided into two primary phases: 1) establish valid data collection equipment and methods, and 2) analysis of collected traffic data, reporting of the systems' accuracy and range of usefulness, and recommendation for further research. This report provides the results of both phases of the research and includes the following objectives:

1) Determine suitable video data collection locations for both freeway and arterial applications
2) Determine a suitable video data collection procedure, including
   – desirable camera placement,
   – desirable camera attributes, resolution, shutter speed, etc.
   – calibration distance marking method
3) Evaluate the ability of Mobilizer to accurately match vehicles in successive fields-of-view and the accuracy of reported travel time results
4) Assess the ability of Mobilizer to be used for comparing the differences in travel times between high-occupancy-vehicle (HOV) lanes and General-Purpose (GP) lanes.

STATE OF THE ART

There are three primary areas for use of transportation data, whether for freeways or arterials. These areas can be classified as detection/operation, incident management, and planning. [Hughes and JHK 1994] Obtaining accurate and timely data for each of these areas is an important element in transportation professionals' strategies and plans for maximizing the efficiency of existing transportation facilities. Primary traffic measures for monitoring, operation, and management of transportation networks are flow/volume, occupancy/density, speed, and travel time.

Travel time measurement is the most important traffic parameter for congestion monitoring systems. The value of travel time measurements is that transportation facilities with differing operations (e.g., arterial vs. freeway, HOV lane vs. GP lane) can be effectively compared by utilizing this universal measure of effectiveness.

Many technologies currently exist for measuring traffic flow parameters. Of course, the most common is inductance loop detectors. This technology, like many others, is specifically designed for point measurements, such as speed and volume. However, very few technologies exist for automatically determining the travel time between two points on a roadway facility. The initial generation of video image systems were aimed at computing several traffic flow measurements, but these were still exclusively point measurements, and thus incapable of providing direct measurement of travel time.

Most current methods for evaluation of travel time are not automated. The more common methods include the floating car technique, license plate matching, and cellular telephone reporting [Hamm 1993].

However, for the long term needs of traffic management centers and the needs of future IVHS applications, it is apparent that automated methods of determining travel time will be necessary. Current technologies that are capable of providing automatic travel time measurements include video license plate matching (LPM), automatic vehicle location (AVL), automatic vehicle identification (AVI), and the newer generation of video image systems (tracking systems). Of course, each system has its specific set of advantages and disadvantages. These are summarized below (more information about LPM, AVL, and AVI technologies can be found in "Proceedings, National Traffic Data Acquisition Conference, Volume I". Albuquerque, New Mexico. 1996).

VIDEO LICENSE PLATE MATCHING (LPM)

Automatic license plate matching consists of processing video-taped images of license plates using machine vision. More specifically, cameras are placed that focus on a small area of either the front or rear end of a vehicle so as to capture the license plate within the field-of-view. The video tapes are then processed using computer algorithms designed to translate the license plate image into a unique set of characters. The system can then use these unique sets of characters to try to match these license plates in successive fields-of-view. In a nutshell, the machine vision simply automates the previously laborious task of using personnel to manually review the video tapes and enter license plates into the appropriate software program. The advantages of an LPM system are that it is capable of obtaining a high sample rate of license plates and dramatically reduces the post-processing time experienced with manual methods. License plate recognition accuracy rates in excess of 90% can be achieved. Studies have also shown good results in terms of statistical comparisons of travel time results using this method compared to more traditional methods. The disadvantages of this system are that the only other measurement it can provide is a lane volume count and a separate camera is needed for each lane of traffic.

AUTOMATIC VEHICLE LOCATION (AVL)

AVL systems rely on the use of an in-vehicle device to notify a traffic systems management center of the times at which it reaches certain positions. A vehicle operator manually reporting location information via a cellular phone is one example, but most current research is focusing on the potential of global positioning systems (GPS) to automatically report location information. GPS technology is based on signals sent from multiple satellites orbiting the earth, upon which an in-vehicle electronic device can be used to determine its precise position on the earth's surface. With the size and cost of portable GPS units decreasing substantially in the recent past, this technology is becoming more feasible. Since the sample size associated with this method is restricted to the size of the fleet for which vehicles are equipped with the GPS units, cost is a very significant issue. To obtain adequate coverage and statistically valid sample sizes, a very large number of vehicles need to be equipped with GPS units for most major metropolitan areas. This technology, however, is really not mature enough yet to be used practically in this environment. A couple of major issues, such as hardware and software standards, and the current practice of the Department of Defense of intermittently degrading the satellite signals, still need to be resolved. The major advantage of this technology is that location and time information for each GPS unit equipped vehicle can be very precise. The major disadvantage is the limited sample size, which in fact could have practical limits due to the general motoring public being reluctant to use these devices for fear of the "big brother" concept.

AUTOMATIC VEHICLE IDENTIFICATION (AVI)

Automatic Vehicle Identification (AVI) systems are similar in nature to AVL systems except that, rather than being able to determine a vehicle's position at any point in time, vehicle positions can only be reported at previously determined locations. An AVI system consists of some sort of in-vehicle device, or transponder, that emits signals that are received by roadside devices. Thus, only when a vehicle passes a point with a receiver can that vehicle's position be determined. These types of systems are already fairly popular in electronic toll collection applications, where vehicles equipped with special transponders get uniquely identified by equipment stationed at the toll facility and their toll accounts are automatically debited. Again, AVI systems are capable of providing very accurate measurements of travel time as the measurement data comes directly from uniquely identified vehicles. The main disadvantages are basically the same as with the AVL systems: limited sample size (except in areas with electronic toll collection facilities) and the "big brother" concept. Although certain types of agency and/or fleet vehicles (e.g., buses, taxis) could easily be equipped with these devices (for non-toll facilities), it is still likely that the sample size obtainable from any given traffic stream would be very small at best.

VIDEO IMAGE TRACKING SYSTEM

Previous generation video image processing systems were based on the "tripwire" approach, which determines vehicle passage through a video image when a vehicle passes a pre-selected band of pixels within the image. In effect, this technology provides a video emulation of loop detectors. The newer generation of video image processing is normally referred to as vehicle tracking. These systems are characterized by utilization of the entire video frame, focusing on the movement regions within each frame [Hockaday 1991]. Vehicle trackers utilize one of two processing schemes: identification of differences in successive video frames or analysis of differences between the entire video frame and a background frame (no vehicles present) [Hockaday 1991].

The Mobilizer is a tracking video image system. The advantage of this system is that it not only can provide travel time measurements, but also measurements of all other standard traffic flow parameters.

Additionally, it is a passive system; that is, the measurements can be taken without requiring any vehicles to be equipped with any special equipment.

Unlike previous generation video image systems that were capable of only processing specific points within the field-of-view (FOV), the Mobilizer can process individual vehicles as they traverse a FOV. The previous generation video image systems were only capable of providing rough classifications of vehicle length as the only unique vehicle identifying parameter. Thus, these earlier generation video image systems were incapable of determining whether a particular vehicle passed through more than one FOV. The Mobilizer system can extract details from the physical look of a vehicle and use these to give the vehicle a unique identification. If a vehicle in another FOV matches the ID given to a vehicle in an upstream FOV, the system determines that is has found a match and calculates the travel time between the successive FOV's.

In Figure 1, the layered processing architecture of the linktime system is shown. At the lowest (Physical Sensor) level, there are multiple roadside sensors, each providing an origin or destination sensor input. These sensors can be smart loops, radar sensors, video cameras, or other types of sensors which provide fingerprints of the vehicles. In this study, we used video cameras because at the present time, video offers more unique signature information about vehicles than other technologies.

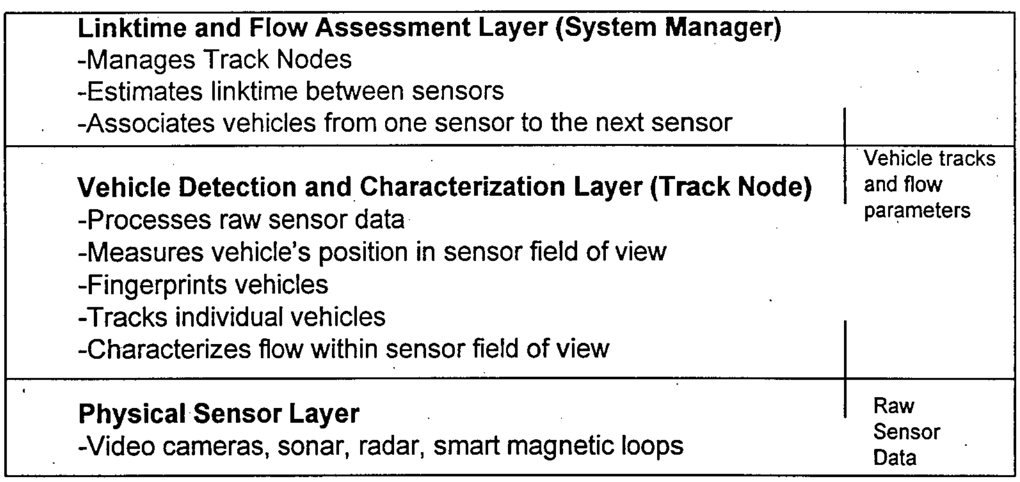

Figure 1. Multi-layered architecture for linktime estimation system

At the second level, the Track Node module processes the raw sensor inputs. It detects vehicles and performs a local tracking function which extracts the vehicle fingerprints and the local traffic statistics from the scene. Up to four Track Nodes may be installed in a single computer, depending on how many camera video inputs are located at that computer.

The third layer, the System Manager, receives the output fingerprints and time/velocity information (tracks) for vehicles from theTrack Nodes and performs the functions of linktime estimation between the origin and destination inputs. As many as four Track Node inputs may be processed by one System Manager computer. The System Manager also performs other functions such as managing and monitoring the Track Node functions, providing snapshots from the individual Track Nodes, logging all Track Node and linktime statistics to files, providing numerous real time displays for the operator, and sending data outputs to other computers for ATMS network and Internet functions.

The sampling speed of the Mobilizer Track Node is usually set to between 2 and 4 samples per second. This allows the system to obtain information about the vehicle's fingerprints every 250-500 milliseconds as it moves through the field of view. The most reliable fingerprint matching information is obtained when the vehicle is close to the camera, so the sample rate must be fast enough to detect a vehicle with a speed of 70 mph in an area near the camera. The specialized image processing hardware installed in a PC for this project was capable of processing two camera inputs with a 233 Mhz Pentium processor at 4 samples per second, or one camera input with a 133 Mhz processor at about 3.5 samples per second.

The primary consideration with cpu speed is the sampling rate of vehicles from the FOV. Since the Mobilizer is a tracking system, it gathers its information by taking multiple "looks" at each vehicle as it travels within the FOV. The more "looks" the system can get at a vehicle within the FOV, the more information it obtains for use in identifying the vehicle in later FOV's. Obviously, to obtain more "looks" (i.e., greater sampling rate), it requires more computing speed. Additionally, the faster the speed of the traffic within the FOV, the faster the sampling rate required.

A critical piece of hardware is the video digitizing card. This is necessary to process the live or recorded video into the appropriate format that the system software can process. With a very fast cpu, it is possible to use one video card to process two streams of independent video simultaneously. While the system can function with some off-the-shelf video digitizing cards, the video card specified and built specifically for the Mobilizer system will achieve better results than off-the-shelf video digitizing cards.

Video cameras are of course a necessary piece of equipment in the data collection. The quality of the camera image is a significant variable in the video imaging process. The cameras must be capable of providing high-resolution, good signal to noise ratio, high dynamic range (able to pick up both very bright and very dim objects), and high shutter speed to prevent the CCD (Charge-coupled device) focal plane from smearing the data from rapidly moving vehicles.

The software currently runs on a DOS platform, but future plans include upgrading to a Windows NT platform.

Previous documented studies on the Mobilizer system are still limited, but a study by Dermer, Nasburg, and Lall [1995] can be consulted for more background information, as well as the predecessor report [Nihan, Leth, and Wong, 1995] to this study.

RESEARCH DESIGN

INTRODUCTION

As previously mentioned, the sole intent of this project was to evaluate the ability of the Mobilizer system to accurately track vehicles from one field-of-view to another; thus allowing an evaluation of the system's ability to provide reliable travel time measurements. Because of recent system enhancements, it was now possible to explore the issue of travel time determination. Aside from the direct enhancements to the Mobilizer system, a couple of fundamental changes were made to the data collection process that contributed to the improvements in the vehicle tracking performance. These changes are discussed below.

EQUIPMENT CONSIDERATIONS

The biggest fundamental change in the data collection procedure versus the previous research on this system was the video cameras used. As previously mentioned, the video camera image quality is a key variable to the success of the Mobilizer system. In the previous Mobilizer study [Nihan, Leth, and Wong, 1995], WSDOT surveillance video cameras were utilized. It was eventually determined that these cameras were inadequate, not just in terms of location, but also because of video image quality. As the WSDOT cameras are currently used for surveillance purposes only, maintaining the cameras to the highest video image performance levels is not an issue. As long as WSDOT personnel can still see the freeway and vehicles through the camera, they have no reason to inspect the camera or adjust its performance. This is clearly inadequate for video imaging. Additionally, while many of the WSDOT cameras probably have the capability of using high shutter speeds, there is no guarantee that the camera is set to use a high shutter speed, as the camera operators never look at still image captured from the video camera. There is also no guarantee that the camera is properly focused because significant differences in the focus level are difficult to perceive to the passive eye. However, small differences in the focus level can make large differences in the image clarity obtained from capturing a still frame of video.

Additionally, the automatic gain control feature (AGC) is often enabled on the WSDOT surveillance cameras. Previous studies [Hockaday 1991, Hughes and JHK 1993] have mentioned that image quality from cameras that have automatic iris and gain control (AGC) tends to deteriorate for periods of time in reaction to intense light changes. This type of camera darkens the light level in the video image in response to the intense light.

Thus, for this project, the decision was made to purchase and use separate high-performance video cameras for data collection. This change was made for two reasons: 1) Ability to place cameras in a more optimal position, and 2) Ability to ensure video image quality would always be at its best. More details will be provided on these issues in the sections that follow. The cameras purchased for this research were Canon L2 high-quality 8mm video cameras. These cameras provide excellent image resolution and are capable of capturing high quality images under high traffic speeds and varying light conditions.

DATA COLLECTION CONSIDERATIONS

Camera Placement/Perspective

Another fundamental change aside from the camera equipment itself, was the positioning the cameras for data collection. Departments of Transportation have traditionally placed surveillance cameras in locations that provide good wide-area coverage of all freeway lanes in both directions. However, these locations are generally less than ideal for vehicle tracking purposes.

For successful tracking of vehicles from one camera location to another, it is essential that the fields-of-view (FOV's) of each camera "look" as similar as possible. Since the tracking algorithms rely on the vehicles "looking" as similar as possible between successive FOV's, the best way to ensure this is to set the cameras up such that vehicles maintain as constant geometry as possible. For the data collection done for this project, the video cameras were positioned on overpasses directly over the center of the lanes used for analysis. As an illustration, you can see in Figure 2 and Figure 3 how two adjacent surveillance cameras positioned near Interstate 5 provide completely different vehicle perspectives.

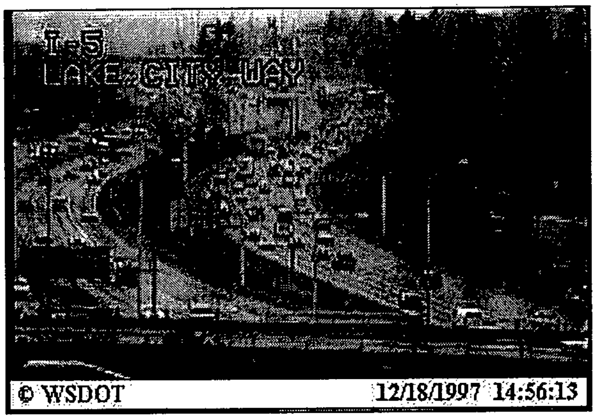

Figure 2. Surveillance camera image looking south.

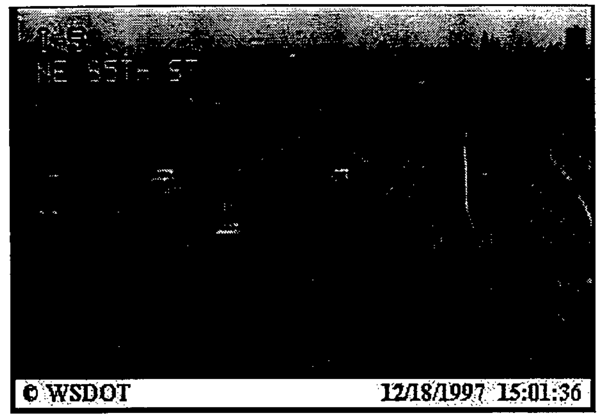

Figure 3. Surveillance camera image looking south.

Additionally, lane occlusion due to tall vehicles has often been cited as a problem for video image systems that use images from cameras positioned to the side of the travel lanes, rather than over them analyzed [Hockaday 1991, Hughes and JHK 1993]. With the camera placement used for this project, this problem was also eliminated. Use of cameras directly over the roadway also gives the ability to place cameras at a lower height than those mounted on high poles offset from the roadway.

Camera Spacing

In this project, the distance between successive camera locations was generally in the ¼ mile to ½ mile range. This was done for two reasons: 1) the shorter distances mean there is less probability of a given vehicle changing lanes within that distance, and 2) there is less chance of a vehicle entering the traffic stream between the two camera stations that looks similar to one identified in the upstream FOV.

One of the requirements of the Mobilizer system to identify a match is that the vehicle is in the same lane in the downstream FOV as it was in the upstream FOV. While this may seem like a restrictive requirement, allowing matches from different travel lanes opens up a greater propensity for mismatches because of the general lack of variety of vehicle types in the traffic stream.

While the number of different motor vehicle models manufactured today is greater than it has ever been, it seems as though the average vehicle composition on any given roadway segment at any given time is becoming more homogeneous than ever. This can probably be explained by the extreme popularity of certain types of vehicles. For example, mini-vans and sport utility vehicles are beginning to dominate the average traffic stream. While the Mobilizer had good success and discerning between multiple models of these vehicle types over the short distances used in this study, it is obvious that using large spacings between cameras can yield inaccurate travel times. Large as used in this context is a relative term that depends on the specific area. Areas that have many departure and entry points between the camera locations for a specific roadway facility will have a greater chance of matching two vehicles that look the same but are really not the same.

Shutter Speed

It is necessary to use a shutter speed which is capable of providing unblurred images of the vehicles during a "frozen" camera image. The appropriate shutter speed will depend on the speed of vehicles. The following images demonstrate the difference in image clarity. Figure 4 shows an image from a portion of video shot using a shutter speed of 1/60 second. Figure 5 shows an image from another portion of the same video that used a shutter speed of 1/1000 second. Both videos were of freeway traffic traveling between 55 and 65 mph.

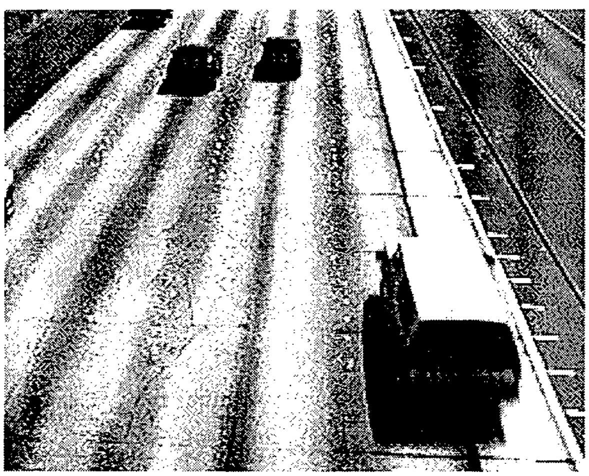

Figure 4. Video image snapshot using slow shutter speed

Figure 5. Video image snapshot using fast shutter speed

Generally, shutter speeds in excess of 1/500 second should provide adequate results for freeway free-flow speeds. Video images taken of slower traffic on arterials can probably use shutter speeds of 1/250 second and still obtain adequate results.

For the Mobilizer system, there is really no disadvantage to using a high shutter speed in all cases; thus, it makes sense to use a shutter speed of at least 1/1000 second in all cases. For normal video viewing, the main disadvantage to a high shutter speed is that the video can sometimes appear jerky in continuous motion. Since the Mobilizer system is really only looking at very frequent snapshots of the video image, it is better to have the still images look as sharp (unblurred) as possible. Since the Mobilizer system is only sampling a fraction of all possible video frames anyway, the digitized video will still look jerky even using the slowest shutter speed.

Distance Calibration

In addition to the field of view, the other critical component to successful operation of the tracking system is the accurate setup of the calibration lines within the FOV. Since an important parameter in identifying a particular vehicle is its length, it is necessary to have points of reference within the FOV for which specific distances are known. For the arterial data, this was accomplished by measuring distances between raised pavement markers. For the freeway data, this was accomplished by painting reference lines on the shoulder at specific distances. Since the Mobilizer system gathers most of its information at the near end of the FOV, it is best to have calibration lines more closely spaced in the first 50 feet of the FOV. In the previous study, the calibration lines were only placed at 50 foot intervals. The Mobilizer development team later determined that calibration line spacings that large were totally inadequate.

Figure 6 shows the calibration lines on the right side of the image, in the shoulder area. The first seven stripes are spaced five feet apart, the next two are spaced ten feet apart, the next four are spaced 25 feet apart, and the remaining stripes are spaced 50 feet apart. The distance from the first calibration mark to the edge of the overpass in this FOV is 55 feet.

Figure 6. Example calibration line setup

The process of placing the calibration lines requires considerable effort. It is generally necessary to first set up a camera and determine the field-of-view. From this FOV, you can find a reference mark on the pavement to determine where to start the calibration lines. The material used for the calibration marks is also important. There are industrial brands of pavement tape available, but the environmental conditions must be considered. The initial pavement marking effort used pavement striping tape. Following two solid days of rain, there were almost no perceptible traces that the tape had ever been placed on the pavement. Thus, it was obvious that another striping material would be needed. After obtaining permission from the WSDOT, the next pavement marking effort used pavement marking spray paint. These marks have withstood the local environmental conditions and still remain on the pavement today. The process of putting markings down on the pavement is in itself a challenging prospect. Even with the assistance of a WSDOT safety truck, the person placing the tape or paint puts themselves in jeopardy because of working so close to the travel lanes and high-speed traffic. Since this method of determining calibration distances was not very practical for repeated test sites, it was decided that another method should be investigated in the interest of time efficiency and safety. Another method was tested that involved the use a Total Station typically used for surveying purposes. More detail about this procedure is described in the Appendix.

Background Level Estimation (AGC region)

In selecting a data collection site and corresponding FOV, it is necessary to ensure that at least some small portion of the image will not be traversed by vehicles nor their shadows. The user must define such an area within the FOV during setup for the processing of the video. This area is monitored by the Mobilizer system to constantly determine how the background luminance levels are changing with respect to the pavement. In order to maintain a continually accurate background level, this area must not be affected by crossing vehicles or their shadows. Unfortunately, there are many possible sites that this type of area may not be present in the FOV. Figure 7 below shows such a site.

Figure 7. Site without adequate AGC region (I-5/NE 145th)

DATA COLLECTION SETUP

The factors discussed in the previous section were found to be important through many various attempts at data collection. With the knowledge obtained through several data collection efforts, the preferred procedure for collecting the video data will now be described.

1. Find an Adequate Site

   A suitable site for data collection will consist of a section of roadway in which at least two video cameras (one per station) can be placed directly over the roadway travel lanes with a spacing not greater than one-half to one mile. Additionally, the height of the overpass (or similar structure) used for locating the camera must not be too low. It was found that a camera height of about 23 feet was probably a practical minimum.

2. Determine Calibration Distances

   The calibration distance determination is a very important step, and can be accomplished in one of two ways. One method involves placing physical marks on the roadway that can be seen within the camera FOV, such as painted lines. Another method involves accurately measuring points in the roadway that can discerned within the FOV, such as raised pavement markers or similar items. Care must be taken, however, because items that are just barely perceptible from the camera FOV may not be distinguishable once the video is digitized without color and at lower resolution.

3. Video Camera Set-Up

As previously mentioned, the cameras were positioned directly over the middle of the travel lanes used for data collection. Standard tripods were used to mount the cameras. Due to the typically short time that power is provided by the factory camera batteries, heavy-duty marine 12-volt batteries were usually used for data collection. Adapters were attached to the battery terminals that provided a standard cigarette style power converter.

The cameras were set to a manual mode so that focus and gain control would not be change during the data collection from the initial set up values. The shutter speed was set to an appropriate level for the traffic conditions. Also, different lenses (e.g., polarized, UV) could be utilized depending on the ambient light conditions. The microphone was also installed on the camera to record important information spoken by the operator, such as time stamps.

4. Collecting the Data

Before starting the data collection, the watches of the camera operators are synchronized. Once the video recording is started, a time-stamp from the synchronized watch is spoken into the microphone. The Canon L2 cameras also place a digital time-stamp on the video; thus, it can be determined what the actual clock time is at any point on the video. This makes for easy determination of the relative time offset between successive videos from the same data collection trial.

For these test data collection efforts, it was found that being able to communicate with the other data collector(s) was invaluable. Two-way radios (i.e., walkie-talkies) were purchased and used extensively during the data collection efforts. The two-way radios were useful for coordinating the starting and ending of the video recording, coordinating the changing of any video settings (e.g., shutter speed), and alerting each other to any items of note.

Preliminary investigation has been conducted utilizing data from two study sites. One location is a major arterial, the other a major freeway site. The initial studies have utilized two camera sites on each roadway facility, with short spacing between the cameras. The camera spacing was on the order of about a ¼ mile in each instance. This initial short spacing was used to limit the loss of vehicles between the two points and the number of lane changes; thus having a greater proportion of vehicles for which to test the matching algorithms within the Mobilizer system.

The arterial site consisted of two lanes in each direction, with the video cameras being located directly over the middle of the two northbound lanes on pedestrian overpass bridges. Figure 8 and Figure 9 show the upstream and downstream FOV's, respectively.

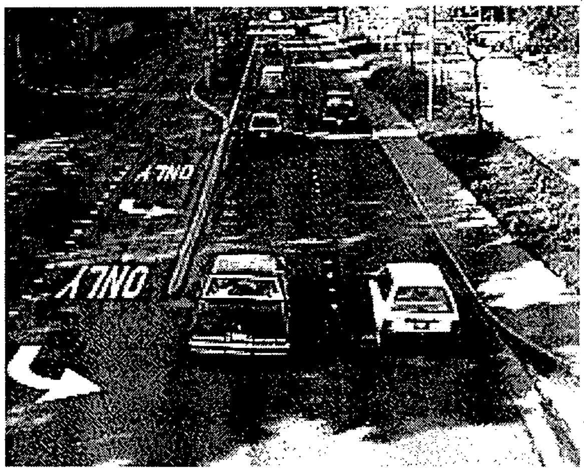

Figure 8. Montlake Blvd. (Upstream)

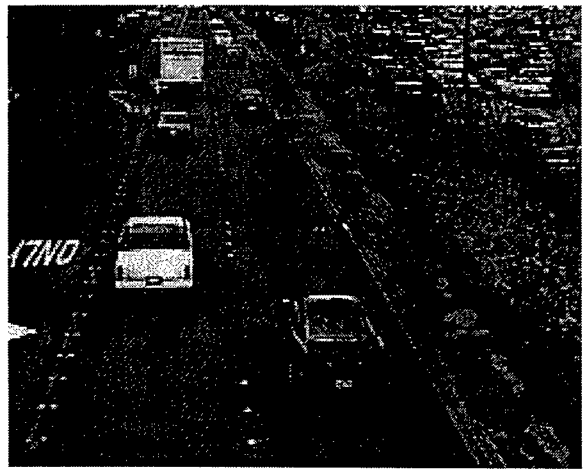

Figure 9. Montlake Blvd. (Downstream)

The height of the camera on the upstream overpass was just over 23 feet. The downstream camera height was slightly higher.

The freeway site consisted of four general purpose lanes in each direction. For this site, data were collected from just the two outside lanes, with the video cameras being located directly over the middle of these two lanes on adjacent interchange overpass structures. Figure 10 and Figure 11 show the data station locations.

Figure 10. I-5/NE 50th Ave (Origin)

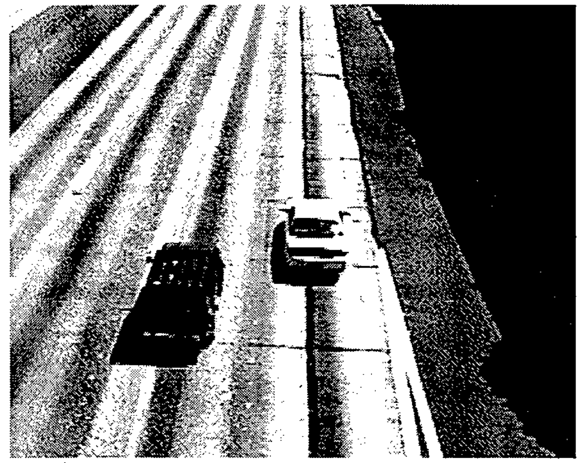

Figure 11. I-5/NE 45th Ave (Destination)

For both of these data collection efforts, a departing FOV was used. That is, the vehicles were moving away from the camera, rather than approaching it. The camera heights from these overpass locations were about 35 feet.

Previous data collection efforts utilized a couple of WSDOT surveillance cameras. While the Mobilizer system is still capable of providing fairly reliable site specific data such as volume and speed, these cameras and their location were found to be totally inadequate for performing vehicle tracking for travel time measurement. While these WSDOT cameras were of lower video quality than those utilized for later data collection, the main factor affecting the vehicle tracking was the location. These cameras were both offset from the freeway lanes, but at different distances and angles from the travel lanes. Thus, the vehicle profiles provided by the two FOV's were not very similar.

REFERENCE DATA

The tools provided by the Mobilizer system for data evaluation have also improved since the previous report. Mobilizer system enhancements over the previous version have reduced the difficulty for obtaining ground-truth data and have also increased the researchers' degree of confidence in the accuracy of this data.

After processing the video streams with the Mobilizer system, the System Manager outputs a report that details every vehicle sighted in both FOV's. It also outputs graphics files that can be overlayed on the video image files, showing a unique ID number for each vehicle sighted in the traffic stream. With this information, the video image files can be visually reviewed and compared with the detailed output report to determine whether the correct vehicles in each FOV were matched. Due to the better placement/perspective of the cameras for this project and the better resolution provided by the Canon L2 cameras, visual confirmation of matched vehicles from the digitized image files was a easy process, albeit a time consuming one. The system allows the image files to be searched by frame or vehicle ID; thus, each FOV image file can be searched for matching vehicle ID's based on the output file results, and a quick visual confirmation can be made as to whether or not the vehicles are a true match. This process was the primary basis for the ground truth data.

RESULTS AND INTERPRETATION

ARTERIAL

A fifteen minute piece of video was used for analysis from the arterial video. This video was shot during the late afternoon and contained many shadows (both vehicle and street) at both stations (upstream and downstream) due to the angle of sun and many trees bordering the edge of arterial. The presence of shadows was intermittent throughout the video because of clouds intermittently blocking the sun. It was initially thought by the developer that the height of the camera on the pedestrian overpasses might not be high enough, but it turned out this was not a problem. The camera height is important because if it is too low, it will be impossible to obtain a long enough FOV (for multiple looks at vehicles) while still obtaining a reasonable vehicle profile that contains not only the tops to of the vehicles, but also the rear ends of the vehicles. The traffic flow during this time period varied from about 23 mph to 40 mph (free-flow).

During the fifteen-minute period, a sample of 130 vehicles were matched from the traffic stream, which represents a sample rate of about 18 percent from this data set. That corresponds to a total of about 720 vehicles traveling this section during the fifteen-minute period. It should be pointed out that the actual number of vehicles from which matches could be found would be less than 720, because some vehicles exit between the two stations, and some vehicles enter between the two sections.

Of these 130 vehicles matched, 100 of them were matched correctly. This corresponds to a match accuracy of 76.9 percent. A t-test was performed to determine if the average travel time for all vehicle matches was significantly different from the average travel time obtained from just the correct vehicle matches. The following tables summarize these results, as well as the general descriptive statistics.

Table 1. Arterial Summary Statistics

Time Period (minutes)	Total Volume (vehicles)	Number of Matches	Percent Matches	Number Matches Correct	Percent Matches Correct
15	720	130	18	100	77

Table 2. Arterial Travel Time Results

	Minimum	Average	Maximum
Travel Time (seconds)	21.5	28.0	37.1
Travel Speed (mph)	23.0	30.5	39.7

Table 3. Arterial Travel Time Accuracy Results

	All Matches	Correct Matches
Average Travel Time	27.41	27.96
Standard Deviation	3.47	3.01
n	130	100
t-stat	1.24	
t-ref (95%)	1.96	
p-value	0.215	

As can be seen from the above table, at the 95 percent level of confidence, the difference in travel times between all matches and just the correct matches is not statistically significant.

The question also arises as to whether the match rate is adequate to determine the true travel time between the two stations. After removing the incorrect matches, the match rate becomes 14 percent. A general formula can be applied to determine if this match rate is adequate.

$$N = \left(S\frac{K}{E}\right)^2 = \left(3.01\frac{1.96}{1}\right)^2 = 34.8 \rightarrow 35$$

where N = minimum number of matches

S = estimated sample standard deviation, seconds

K = constant corresponding to desired confidence level (1.96 = 95%)

E = permitted error in the average travel time estimate, seconds

In this case, the 100 correct matches greatly exceeds the minimum number of 35 matches to be 95 percent confident that the measured average travel time is within 1 second of the true average travel time.

Additionally, we can compute a 95 percent confidence interval for which the true average travel time is likely to fall.

$$28.0 - \frac{1.99 \times 3.01}{\sqrt{100}} < \mu < 28.0 + \frac{1.99 \times 3.01}{\sqrt{100}} = 27.4 < \mu < 28.6$$

where μ = mean of the population

FREEWAY

A fifteen minute piece of video was used for analysis from the freeway video. This video was shot during the mid afternoon and contained many significant vehicle shadows due to the angle of sun. The height of these overpasses was considerably higher than those on the arterial. The traffic flow during this time period varied from about 50 mph to 68 mph (free-flow).

During the fifteen-minute period, a sample of 46 vehicles were matched from the traffic stream, which represents a sample rate of about 11 percent from this data set. That corresponds to a total of about 420 vehicles traveling this section during the fifteen-minute period.

Of these 46 vehicles matched, 36 of them were matched correctly. This corresponds to a match accuracy of 78.3 percent. A t-test was performed to determine if the average travel time for all vehicle matches was significantly different from the average travel time obtained from just the correct vehicle matches. The following tables summarize these results, as well as the general descriptive statistics.

Table 4 . Freeway Summary Statistics

Time Period (minutes)	Total Volume (vehicles)	Number of Matches	Percent Matches	Number Matches Correct	Percent Matches Correct
15	420	46	11	36	78

Table 5. Freeway Travel Time Results

	Minimum	Average	Maximum
Travel Time (seconds)	14.0	16.0	19.25
Travel Speed (mph)	49.6	59.8	68.2

Table 6. Freeway Travel Time Accuracy Results

	All Matches	Correct Matches
Average Travel Time	16.19	15.95
Standard Deviation	1.46	1.12
n	46	36
t-stat	0.81	
t-ref (95%)	1.99	
p-value	0.419	

Again, to get an idea adequacy of the sample size of 36 for this data set, the following calculation is performed:

$$N = \left(S\frac{K}{E}\right)^2 = \left(1.12\frac{1.96}{0.5}\right)^2 = 19.3 \rightarrow 20$$

This result shows that minimum number of 20 matches were required to have a 95 percent level of confidence that the maximum error in the travel time estimate is 0.5 seconds. This calculation offers a similar level of precision to the previous data set as the vehicles on the freeway were moving about twice as fast as those on the arterial for a similar distance.

Another six minute piece of video was analyzed from the same freeway video; but this portion of video was shot using the default shutter speed of the camera, 1/60 second. These results are presented to illustrate the difference due to the shutter speed. While the traffic stream may have been slightly different, for all practical purposes, everything was the same from this piece of video as the previous one shot with a shutter speed of 1/1000 second, as they were just minutes apart on the same video tape.

During the six-minute period, a sample of 58 vehicles were matched from the traffic stream, which represents a sample rate of about 32 percent from this data set. That corresponds to a total of about 183 vehicles traveling this section during the six-minute period.

Of these 58 vehicles matched, 42 of them were matched correctly. This corresponds to a match accuracy of 72.4 percent. While the sample rate was considerably higher for this portion of video, the match accuracy was considerably lower. As pointed out in a previous section, the vehicles in this portion of video are slightly blurred due to the slow shutter speed. This results in more vehicles looking similar than they otherwise would; therefore resulting in the greater number of matches. But as the match accuracy shows, a greater percentage of these matches are incorrect because, in fact, many of these blurry vehicles that look similar to the system are not the same vehicles. The following tables summarize these results.

Table 7 . Freeway Summary Statistics

Time Period (minutes)	Total Volume (vehicles)	Number of Matches	Percent Matches	Number Matches Correct	Percent Matches Correct
6	183	58	32	42	72

Table 8. Freeway Travel Time Accuracy Results

	All Matches	Correct Matches
Average Travel Time	15.36	15.74
Standard Deviation	1.89	1.02
n	58	42
t-stat	1.18	
t-ref (95%)	1.99	
p-value	0.239	

Matching Parameter Settings

There are several parameters that can be varied by the analyst that will affect the vehicle matching results. These parameters are proprietary information of CMS and cannot be discussed in detail in this report. These parameters can be adjusted for each unique pair of FOV's. For the purposes of the analyses in this report, it was decided to utilize the same set of parameter settings for each video data set. Thus, the parameter settings chosen for use in these analyses were general settings that will achieve good results under a wide variety of conditions. However, it is possible to improve upon the results discussed in this report by tailoring the parameter settings specifically for each data set.

CONCLUSIONS AND RECOMMENDATIONS

The test results described in this report show very good potential for this technology to be effective in matching vehicles in successive fields-of-view. For both the arterial and freeway tests with a high shutter speed, the match accuracy rates were in excess of 75 percent. Even factoring in the incorrect matches, however, the travel time was not found to be statistically significantly different from the travel time of just the correct matches. A key reason for this is because the system can be "told" to not consider matches that fall outside of the established travel time range (this is initially set by the user, but then is adjusted in real-time by the system). The most common type of mismatch error is usually a very similar type of vehicle (e.g., sport-utility) being in the same vicinity (one or two vehicles away) of the correct vehicle. Very similar generally means the same brand, model, year, and color intensity (light or dark), as it was confirmed by the researchers on numerous occasions that the system is very good at distinguishing between similar vehicles with slight differences, such as license plates in different locations, different taillight locations, and other small differences. Even the presence of an item in view through the rear window can be used to distinguish between two otherwise identical vehicles. Unfortunately (for this system), there are a tremendous number of identical looking sport-utility vehicles (e.g., Honda Passport) and mid-sized sedans (e.g., Honda Accord) on the roadway. Given this fact, it will make it very difficult to ever achieve match accuracy rates approaching 100 percent; however, for travel time purposes, it is unlikely that this high an accuracy rate will ever be necessary.

In all of the tests, the weather conditions were fairly benign (except for cold). However, significant shadows were present in several of the video segments. The system showed a good ability to adjust to shadow conditions—although some data are temporarily lost during the adjustment process, the transition is fairly quick (within 10 or 15 seconds). The presence of heavy shadow conditions did not appear to adversely affect the performance of the Mobilizer system. It is possible that prolonged rapidly fluctuating shadow conditions could have an adverse effect, but this condition was not encountered during testing, thus no conclusions can be drawn at this time.

The Mobilizer system appears to be an effective tool for comparing HOV lane and GP lane travel times. From the tests conducted for this report, the system is currently capable of matching vehicles in adjacent FOV's with reasonable success. Since this is the key element to determining travel time, comparisons in travel time can be made between any lanes captured within the FOV's. This is actually easily facilitated since the system currently does not consider matches of vehicles that have changed lanes; therefore, the travel time results are lane dependent. There are however a couple of considerations to take into account when collecting travel time data for lane comparison. As previously mentioned, you can only compare travel times between lanes that are captured within the FOV's. For freeway segments with 4 lanes or more, the camera set-up may be such that the accuracy rates will be less than optimal due to the level of zoom and perspective needed to capture that much width of roadway. In the tests performed for this report, a maximum of three lanes of data were captured at any one time. If only wanting to compare an inside HOV lane travel time to two adjacent GP lane travel times, for example, then the main consideration will be the calibration distance set-up. Since most of the available area for placing calibration marks is often on the outside edge of the roadway, it may be difficult to place calibration marks in the median area; thus, it may be necessary to use a technique such as the Total Station method described in the Appendix.

ADDITIONAL IMPROVEMENTS

The Mobilizer system is currently not utilizing color information in its tracking algorithms. While the results are still very promising despite the lack of color information, adding color identifying information to the algorithms will undoubtedly improve the results. This will become especially apparent in situations when two otherwise identical vehicles (e.g., same model of mini-van or sport-utility vehicle) can be distinguished based on their color. The current algorithms utilize shades of gray, so light colored vehicles can be distinguished from dark colored vehicles; however, a blue vehicle cannot be distinguished from a black vehicle, nor a white vehicle from a yellow vehicle.

The Mobilizer system currently digitizes the video stream at a resolution of 320 x 200 pixels. While this still affords good resolution, provided an adequate shutter speed was used, eventually the system will digitize at a higher resolution. The developers have confidence that the latest generation of pentium II processors will allow them to digitize at twice the resolution without any loss in processing performance currently realized from the previous generation of pentium processors. Certainly, the greater the resolution, the more detail that can be extracted from vehicles, and thus even better results can be obtained, both a higher match rate and greater match accuracy.

The addition of color recognition and increased resolution to the Mobilizer system should make significant strides toward distinguishing between similar vehicles because other unique items (e.g., patches of dirt) could then be used as identifying information.

While the match rates were not very high (10 – 20 percent for the non-blurry video), they were still found to be statistically adequate for these tests. However, these rates will only increase with the future improvements in computer hardware.

RECOMMENDATIONS FOR FURTHER RESEARCH

These results demonstrate the viability of this technology under non-congested flow conditions. It is desired to evaluate the system next under congested flow conditions. It is actually anticipated that results would get even better under many congested flow conditions, short of stop-and-go, as the slower speed of traffic would allow the system to get even more "looks" at a vehicle within each FOV. Certainly, stop-and-go conditions should be investigated as well. It is unknown at this point how the system would react to extremely small vehicle gap conditions.

Additionally, a more inclusive set of environmental conditions typical to this region should be investigated. In particular, the Mobilizer system should be tested with conditions of heavy rain and even fog.

ACKNOWLEDGEMENTS

A special thanks to TransNow (U.S.D.O.T. University Transportation Center, Region 10) for sponsoring this research.

Thanks to Mike Mansfield and Mark Leth of the Washington State Department of Transportation for their assistance with data collection and calibration marking.

Thanks to Kamal Ahmed, Department of Civil Engineering survey instructor, for his help in testing the measurement method with the Total Station.

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Appendix – Distance Calibration using a Total Station

As previously discussed, it was desired to find an alternative method of determining calibration distances other than having to be near the freeway travel lanes and physically place markings on the pavement. As Figure 12 below illustrates, it sometimes can be impossible to place these marks without closing a lane of traffic. For this particular FOV, the stripes would need to be placed in the median area, and there is not enough room to work there without closing the HOV lane.

Figure 12. FOV for which placement of calibration marks would be difficult at best

A notable feature about this FOV are the dark lines (pavement section joints) running perpendicular to the travel lanes. Since these show up very well on the digitized image, knowing the distances between these lines is a good calibration reference. Additionally, the raised pavement markers provide good measurement points. With the use of a Total Station, these points could just be measured from the overpass above the freeway. For situations like this, the Total Station can be a very effective tool. The only limitation is that you can only measure what is there; unlike the physical placement of markings, where you can place them anywhere you like, with the Total Station method, you have to measure existing things in the roadway that can be seen within the FOV. Care must also be taken, however, because items that are just barely perceptible from the camera FOV may not be distinguishable once the video is digitized without color and at lower resolution.

The Total Station is a sophisticated piece of surveying electronics. The Total Station allows you to focus on distant and small objects and measure very precise angles from a reference point to those objects. It also allows you to measure the distance between the Total Station and a reflector.

The general method for using the Total Station to measure distances for the test sites is as follows:

1. Setup the Total Station on a tripod at one end of the overpass and a tripod mounted reflector at the other end (for our test sites, there were sidewalks present that we could use to setup on; thus not interfering with arterial traffic either). When determining the position to place both the Total Station and the reflector, it is better to place them as far apart as practicable, as that will contribute to the overall accuracy. However, it is also necessary that the Total Station will be able to "see" all the objects that need to be measured on the roadway surface from both tripod locations.
2. Measure the horizontal distance between the Total Station and the reflector. Once the Total Station is properly aimed at the target (reflector), this is an automatic and immediate process.
3. With the Total Station still aimed at the reflector, set the horizontal angle to zero.
4. Rotate and aim the Total Station at every object you want to measure the distance for, and then obtain the horizontal angle reading for each object.
5. Move the Total Station to the other tripod (the one with the reflector previously mounted on it) and repeat the angle measurements for each of the objects measured from the other location.
6. The final step just involves using all the measurements and simple trigonometry to compute distances between objects. Essentially, every measured object forms a triangle between itself and the two tripod locations, and since you know the distance of one side of the triangle (the distance between the two tripods) and two angles (one measured to each object from both tripod locations), you have all the information you need to solve for the distances to each object.

This procedure was tested for one of the arterial locations, for which distances had already been measured, and the results matched.