Demonstration of Alternative Traffic Information Collection and Management Technologies

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ABSTRACT

Many of the components associated with the deployment of Intelligent Transportation Systems (ITS) to support a traffic management center (TMC) such as remote control cameras, traffic speed detectors, and variable message signs, have been available for many years. Their deployment, however, has been expensive and applied primarily to freeways and interstates, and have been deployed principally in the major metropolitan areas in the US; not smaller cities.

The Knoxville (Tennessee) Transportation Planning Organization is sponsoring a project that will test the integration of several technologies to estimate near-real time traffic information data and information that could eventually be used by travelers to make better and more informed decisions related to their travel needs. The uniqueness of this demonstration is that it will seek to predict traffic conditions based on cellular phone signals already being collected by cellular communications companies. Information about the average speed on various portions of local arterials and incident identification (incident location) will be collected and compared to similar data generated by "probe vehicles". Successful validation of the speed information generated from cell phone data will allow traffic data to be generated much more economically and utilize technologies that are minimally infrastructure invasive. Furthermore, when validated, traffic information could be provided to the traveling public allowing then to make better decisions about trips. More efficient trip planning and execution can reduce congestion and associated vehicle emissions.

This paper will discuss the technologies, the demonstration project, the project details, and future directions.

Keywords: Intelligent Transportation Systems, Traffic Management, Cell-Phone, Wireless, Congestion Reduction

1. BACKGROUND/NEED

Traffic congestion in the US continues to be a chronic and worsening problem. In a hearing on “Congestion in the United States Transportation System” [1], it was stated that in 1997, of the nation’s 68 largest urban areas, traffic congestion was estimated to cost the traveling public more than $72B annually in wasted time and fuel and that in the 15 years just prior, traffic congestion increased by more than 225 percent. In addition, congestion was responsible for wasting more than 6.6 billion gallons of fuel, and there was a general recognition that adding more capacity by building more roads was an untenable solution to congestion. In the early 1990s, the US Department of Transportation initiated the Intelligent Transportation Systems (ITS) Program (then called the Intelligent Vehicle Highway System – IVHS). The ITS Program involves utilizing advanced computing, information systems and communications technologies that contribute to monitoring and managing traffic flow, reducing congestion, providing alternative routing to travelers, improving air quality, enhancing productivity, and saving lives, time and money [2].

Over the past decade, the ITS Program has generated numerous technologies dealing with traveler information, commercial vehicle operations, advanced traffic management systems, advanced public transportation systems, etc. Most recently, emphasis has been placed on enhancing the deployment of ITS technologies. Although these technologies had been shown to have the capability for saving lives and reducing congestion (see for example [3]),

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most of the deployment of ITS technologies has been centered on 78 major US metropolitan areas [4], the areas that were most likely able to afford more widespread deployment of such technologies. Outside of these metropolitan areas are medium to smaller cities that oftentimes do not have budgets for acquiring extensive ITS technologies.

One ITS area with a strong potential for reducing congestion is advanced traffic management. Advanced traffic management technologies involve a number of functions such as: active control of the flow of traffic on interstates and arterials; conveyance of timely information to travelers to enhance trip efficiencies; managing a mix of private, commercial and public vehicles; and efficient transfer between transportation modes. In many US states, management of highway transportation systems are accomplished through Transportation Management Centers whose purpose is "to facilitate the safe movement of people and goods, with minimal delay, throughout the roadway system"[5]. Active control through these centers involves ramp metering, signal control timing on arterials, changeable speed limits, utilization of High Occupancy Vehicle (HOV) lanes, etc. Communication with travelers in order to provide valid data and information on travel characteristics is another way that traffic flow can be managed. Valid information on traffic flow would allow more efficient travel decisions. Such communication can be achieved through: changeable/variable message signs; Highway Advisory Radio (HAR); pre-trip access to radio, television and Internet web-sites; and most recently through the nationwide 511 traveler information system. At the heart of all of these systems is the availability of valid and timely data and information on the quality of the transportation network. Such information is generated through a number of technologies including: traditional and advanced loop detectors, passive and advanced video-based monitoring and surveillance cameras, license plate reading technologies, weather and environmental sensors, GPS and automatic vehicle location technologies, microwave and laser-based sensors, probe vehicles, etc. Most of these technologies require a number of elements in order to assure that valid and robust data is collected. These elements include: field deployment of hardware and software, integration of the hardware and software into the infrastructure, provision of power, establishment of communication links, and providing calibration/maintenance resources. The costs associated with these requirements are considerable, and play an important role in decisions involving deployment of advanced traffic management technologies.

Almost three years ago, Oak Ridge National Laboratory, AirSage, Inc., and Intercode Technologies initiated discussions that focused on how ITS technologies might be more widely deployed. In particular, emphasis was placed how traffic management and associated technologies might be improved or utilized in ways that would allow such technologies to support smaller communities. It was determined that such technologies needed to: 1) be very cost effective, 2) build on technologies already deployed in the community, 3) be minimally infrastructure invasive, 4) provide information on arterials as well as freeways/interstates, and 5) should provide data and information with a quality that is equivalent to or exceeds current accepted technologies. Subsequently a partnership was formed that put together a proposal to demonstrate new and alternative traffic information collection technologies, and to assess their potential impact on local congestion and it's associated reduction in emissions. The proposal was eventually funded by Tennessee's Congestion Mitigation and Air Quality (CMAQ) program, and administered by the Knoxville (Tennessee), Transportation Planning Organization. The project is being conducted through NTRC, Inc., a 501(c) 3 corporation located in Knoxville, Tennessee.

2. OVERVIEW OF THE PROJECT

The demonstration project will test the integration of several technologies to estimate near-real time traffic information data and information that could eventually be used by travelers to make better and more informed decisions related to their travel needs. The uniqueness of this demonstration is that it will seek to predict traffic conditions based on cellular phone signals already being collected by cellular communications companies. Information about the average speed on various portions of selected arterials in Knoxville, Tennessee will be estimated and will be sent wirelessly to a data repository at the National Transportation Research Center (NTRC) for storage and analyses.

Additionally, 17 IPIX cameras will be deployed along the selected arterials in order to monitor for the occurrences of slow-downs and incidents. IPIX cameras generate 180-degree field-of-view digital video files that are capable of being accessed by multiple users without the need for dealing with camera control functions. Multiple users can effectively and simultaneously "look in different directions, with differing degrees of magnification." As a result, no panning or tilting capabilities are required. Cameras have no moving parts, require minimal maintenance, and are capable of providing real time streaming video. Images will be sent to a Traffic Information Center (TIC) located at the NTRC using wireless technologies.

Other information sent to the TIC will be probe vehicle-generated incident identification (incident location) and average speed information for various links on the arterials. Probe vehicles are vehicles that will be driven with the flow of traffic on the arterials during certain hours of the day to automatically report the average traffic speed, time of day and current location. Associated anecdotal information related to the traffic flow or incidents that are encountered will also be reported. Data from the probe vehicles will be reporting "ground truth" data. This data will be compared to the cellular estimates to determine whether their predicted values correspond to the "ground truth" values collected by the probes.

The TIC that will be located at the NTRC will provide a centralized location for the collection, storage, analysis, and GIS representation of the data collected in the project. The TIC will provide, on a big-board display, the real-time streaming video data being addressed by the IPIX cameras. This capability will allow a TIC operator to scan the video for the identification of slow-downs or incidents. Such data and information will be used to enrich the statistical comparison of probe-data to cell-phone data. In the event that the TIC operator identifies an accident or other event, appropriate authorities will be contacted. Also, as part of the TIC, a GIS display of the field-test geographic area will be developed. As traffic flow data is acquired from across the network, low-, medium-, and high-congestion will be displayed on the GIS in the form of arterials portrayed in green, yellow and red. The TIC operator, will, at a glance, be able to visually assess the condition of traffic flow on the network. For this test, and prior to validating the data generated in the test, this data will not be distributed to the public. It is being developed as a closed demonstration of how data and information might be displayed in a Traffic Management Center. Future phases of this project will consider dissemination of validated data to the public.

The TIC will also function to support the data analysis conducted within the project. A series of statistical tests will be conducted to determine the accuracy with which the proposed cell-phone technology is able to assess traffic conditions on arterials. Specifically, paired t-test and chi-square statistics will be used to compare ground truth measurements of travel time between given points within the study area, at randomly selected times, against travel time reported for the same segments and time by the algorithms processing the cell-phone information.

Lastly, because of the need to demonstrate the potential impact of these technologies on the reduction of emissions, a computer simulation model will be developed that will emulate the traffic flow on the arterials, and will estimate the impact on total vehicle emissions based on assumptions of how drivers might respond if they were given near-real-time traffic information (e.g., selecting less congested routes). The results of these emulations will provide insight to the value of near-real-time traffic information in congestion management and emission reductions.

3. LOW-COST: MINIMALLY INVASIVE TECHNOLOGIES

The generation of traffic flow information and the operation and maintenance of associated hardware and software to gather such information involves significant resources. AirSage, Inc., of Atlanta, Georgia has developed software that aggregates signaling from cellular networks to estimate speed and travel information for urban and rural highways and arterials. AirSage provides this capability through proprietary software that uses signaling data from cellular networks to monitor the movement of mobile devices. This signaling data is aggregated from one or more wireless service providers, converted into speed and travel time information, and packaged for real-time access via XML-based web services or archived for data file transfer processes.

AirSage works with cell phone carriers to access existing information collected by cellular networks. Such information does not involve the content of the cell-phone communications, only information related to the movement of a cell phone through an associated coverage area. Additionally, the cell phone carriers are not providing access to any information involving the identity of the cell phone owner/user. No information concerning individual privacy is available to AirSage, and anonymity of the owner/user is maintained.

Once a cell phone is powered on, a carrier tracks its movement throughout its particular coverage area. This is done by collecting call processing data during inbound and outbound calls and through periodic off-line communication between the phone and the network. As such, the data that all carriers utilize today to be able to properly route and hand off calls is leveraged and aggregated by AirSage to produce estimates of how long cell phones that are identified as moving, stay within a particular cell zone.

As a cell phone registers with its network provider and calls are placed, signaling information is captured in real time and mapped as an anonymous data point. Multiple, anonymous data points are cached and compared to earlier registrations and call data, and calls and phones that show movement, are selected for processing into traffic information. AirSage's software takes these data points, converts them into GIS information, and overlays them on a road system map. AirSage generates a plot of where each individual trip started and stopped and how long it took to make the trip. The data points are then averaged and converted into an estimate of the average miles-per-hour on specifically defined road segments, and the average travel times between major intersections. Data can be provided in near real-time updates and can be archived and catalogued in 15-minute intervals.

Since the initiation of licensing of Personal Communications Services (PCS) providers, and the rollout of Enhanced Specialized Mobile Radio Services (ESMR) by Nextel and other ESMR providers, the number of wireless service providers has multiplied across the country. The wireless services that began in 1983 with two licensees per market were further expanded in 1995 to provide for up to nine carriers per market. Today, more than 241 million Americans can choose between 3 and 8 wireless service providers.

At the end of 2002, there were 140 million cell phone subscribers in the US and that number is expected to grow to over 200 million by the end of 2007. With 200 million licensed drivers, the percentage of vehicles with cell phones in them is currently in the range of 70% and will be approaching 100% in just a few years. If all carriers were to participate in the program, this would provide a near 100% sampling of all vehicles. Such sampling is far more than enough to accurately measure traffic flow.

Earlier studies [6] have shown that a 5% sampling rate would be sufficient to derive average speeds and travel times if the location accuracy were within 1/10 mile. Using AirSage’s approach, the location accuracy is variable; however, the sample sizes are much higher. The current project will quantify the variability of the location measurements and determine the associated sample size required under the various circumstances.

The other major technologies being evaluated within this demonstration are IPIX cameras, its associated Internet camera technology, and video delivery systems. The IPIX Internet camera uses a fish-eye lens that bends the light as it enters the optics and creates “warped” frames in the video stream. Though the use of a plug-in for the browser, the image is “de-warped” on the client side and creates a navigable image steam that has a 180-degree field of view. The interesting feature about this process is that many people can be viewing this video stream and looking in many different directions at the same time. This is possible because the “de-warp” process and the navigation of the images are being done at the client level after the “warped” stream has left the server. In effect, the user has a dedicated, private view of the video stream that can be manipulated, as the user wants. The video stream, as it leaves the cameras, is already encoded for the Internet so the need to encode, transport, decode and re-encode for the Internet is no longer necessary. As such, this alleviates the need for expensive encoder/decoder networks. The camera streams can be transmitted across traditional, lower cost network systems such as 802.11 wireless, DSL, T1 and ATM networks as TCP/IP packets.

The project will involve the deployment of 17 IPIX cameras over a 12-mile grid. A mixture of broadband DSL connections and 1 MB to 11 MB wireless connections to lower the amount of landline connection to support the system will be used. The cameras will be mounted to existing billboard structures that have close proximity to roadways as well as pre-installed electrical systems to lower the installation and maintenance requirements. Once the cameras are operational, they will transmit data across the network to a central hosting site to allow for a serving point of the information for both the travel time data provided by the cellular monitoring, as well as the video streams for future consumer use (for the current project, no traffic flow information will be disseminated to the public). The TIC will have a separate dedicated network for viewing the camera information so that access will always be available. This will enable a video information system that can be stable in performance for both the public (in a future test or application) and the TIC, and ensure proper reporting of the information.

4. SIMULATION MODEL OF THE NETWORK

A traffic simulation model of the network under analysis, including the freeway portion, will be built to study the effects on pollution emissions of congestion reduction strategies, such as diverting travelers to alternate roads (i.e., the freeway or the other parallel arterial). The eventual deployment of these strategies can only be achieved if three elements are present: a reliable source of accurate traffic information, a way of communicating this information to the public, and the ability to change the settings of traffic signals at intersections and on-ramp meters.

While the former (i.e., the cell-phone technology) constitutes the crux of this project, the other two are not present in the current test. The simulation model will provide the means to synthetically add these two components allowing a study of the impacts of distributing the travel time information to the public (so they can make better decisions about routing and departure times) while providing the ability to change the traffic signal settings to accommodate the excess traffic that could result from route diverting strategies. The FHWA CORSIM (CORridor SIMulation) traffic simulation model will be used for such analysis. Figure 1 below shows the topology of the simulation network for the study area. (Note: this is an actual representation of the CORSIM network that will be used in this part of the project; the grid separation is 1 mile.)

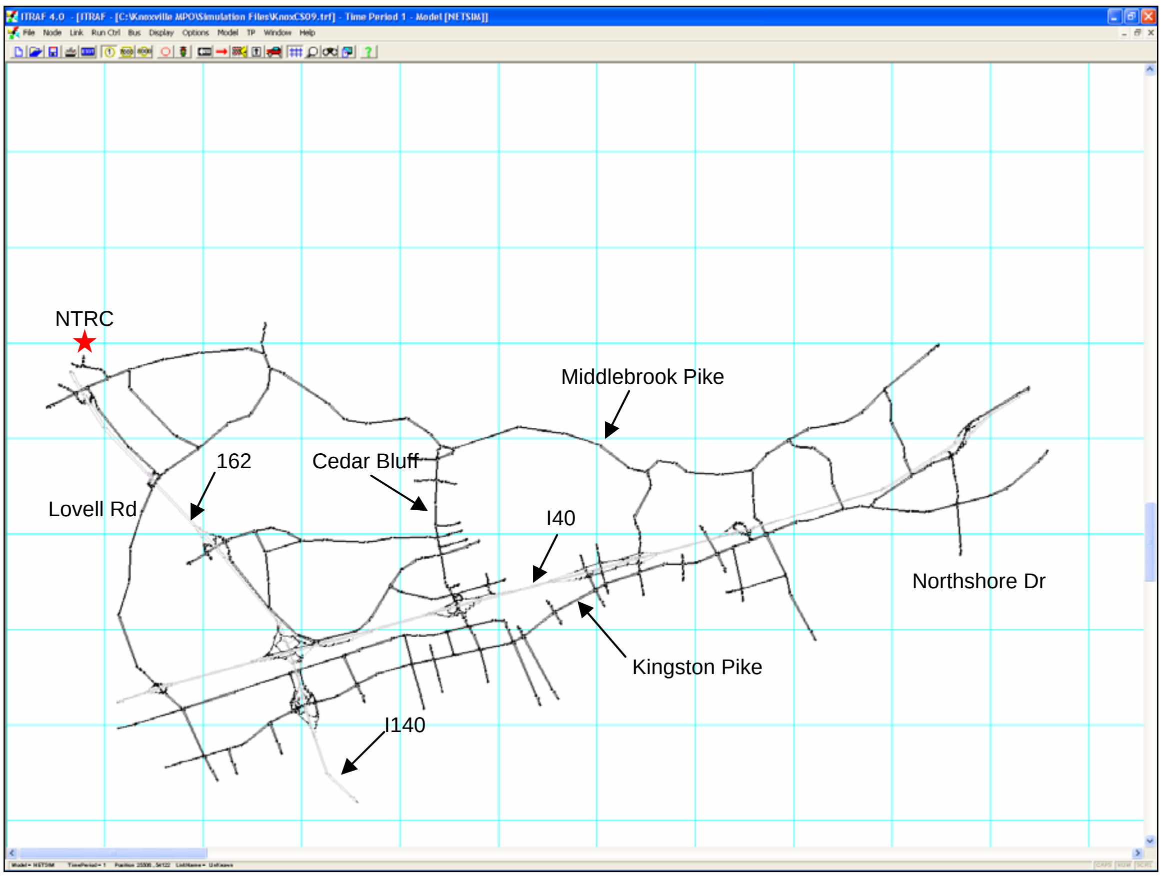

Figure 1. CORSIM Traffic Simulation Network Topology

Once all the relevant information (i.e., geometric characteristics, traffic parameters, and traffic signal settings) have been input to the simulation model, the information collected from the field through the probe vehicles will be used to calibrate the model. Several scenarios, which will be developed using information collected for this project, will be developed using the simulation model and will serve as the “do-nothing” alternatives. For those alternatives, the simulation model will provide information related to pollutant emissions, including HC, CO, and NO.

Emulation of the distribution of information to the public will be accomplished by assuming that some percentage of the drivers (***pd***) will divert to alternative routes to avoid congestion (i.e., longer travel times than usual). The simulation model will be used to represent these new routes and also to change the settings of the traffic lights along those routes to accommodate the extra traffic volumes. A new set of the measure of effectiveness (i.e., HC, CO, and NO levels) will be produced and compared, through statistical analysis, to those of the corresponding “do-nothing” alternative to determine if there is a statistically significant reduction in pollutant emissions. A sensitivity analysis will also be conducted on the ***pd*** to evaluate the impacts of the public response rate to the traffic information provided.

5. GEOGRAPHIC INFORMATION SYSTEM (GIS)

The GIS to be utilized within the TIC will be focused on providing a visualization of the data and information addressed within this project. Appropriately displayed data can allow an integrated and easily discernable visual profile of transportation network conditions. However, data collection for the development of a GIS can be an expensive task. For a project with limited resources, efforts were made to find existing local GIS data layers, which were suitable for the project. After preliminary searching, the project found that the most up-to-date Knoxville-Knox county GIS data layers had been collected and was being maintained by The Knoxville-Knox County - Knoxville Utilities Board (KUB). It was determined that all of the Knox County digital geographic data was maintained in their system. Furthermore, permission to use their GIS for this project was granted. For the current project, roadway centerline and geo-coded aerial photo layers from will be utilized. Other related GIS layers that will be used have been previously developed internally by ORNL. Figure 2 shows roadway centerline data and a geo-coded aerial photo of the study area.

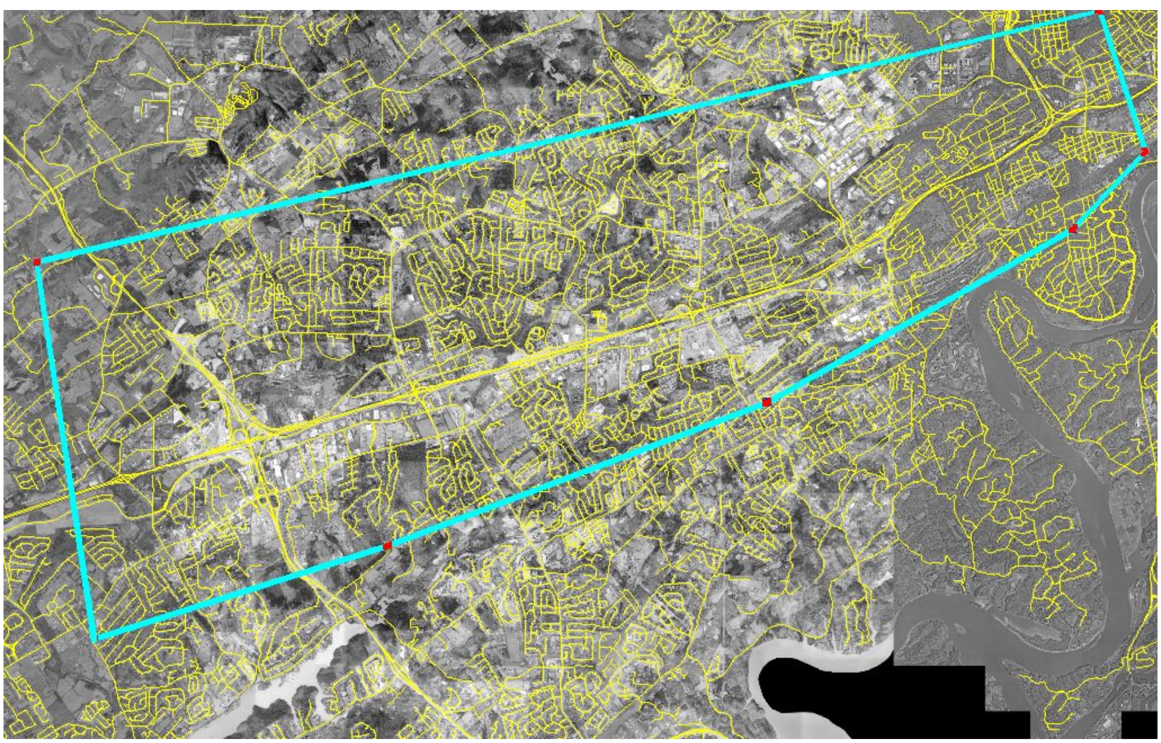

Figure 2. Roadway Centerline and Geo-Coded Aerial Photo of the Study Area

6. EXPERIMENTAL DESCRIPTION

During the data collection period, AirSage will continually generate estimates of the average speed on all links associated with the arterials of interest in the study region. In consultation with AirSage, the two main east-west arterials in the study area will be divided into segments that run between north-south transversal streets. The coordinates of the starting and exit points of these segments will be calibrated using the GPS in the field and the GIS system that will be developed for this project. During the data collection period, AirSage will provide ORNL with travel time (***tt***) information that will be defined by the arterial segment id (***sid***) and a time (***ts***) and date (***ds***) stamp. A typical traffic information data point will be (***sid, ds, ts, tt***).

The field data will be gathered by means of three probe-vehicles that will travel the selected arterials collecting location and time information. They will be equipped with the Battelle GPS Leader system [7], a cell phone to communicate with the TIC (in case the probe vehicles need to be re-directed to specific areas), and a voice recorder so that the driver can take notes of any relevant traffic information as the trip evolves. Once a day, the data collected by and stored in the GPS Leader system will be downloaded to a dedicated computer located in the TIC. Weekly backups of the data will be made and stored in CD-ROMs.

The probe-vehicles will provide ORNL with points described by (X, Y) coordinates, time, and date. With the entry and exit point coordinates of each arterial segment, it will be then possible to determine travel time (***ttf***) on that segment by subtracting the entry time ***to*** from the exit time ***te*** for that particular segment of arterial (i.e., ***ttf*** = ***te*** – ***to***). This will constitute one observation that will be paired to the observation ***tt*** provided by AirSage for the same segment ***sid*** at the same time of the day (***ts*** and ***ds***).

For each segment of arterial, randomly selected field observations will be made to build a distribution of travel times that will be paired to a similar distribution of observations provided by AirSage for the same segment, time, and date. A paired t-test statistic will be used to test the hypothesis that the two distributions have the same means and a chi-square statistic to determine the goodness of fitting of the AirSage distribution against the probe-vehicle data. Confidence intervals will be built for these measurements providing information on the accuracy with which the cell-phone technology is able to assess travel times on arterials.

Under certain circumstances, the quality of the estimated data should be addressed within the context of the intended usage. The tolerance of deviations of the estimated data away from the measured data depends on its usage. For example, if the estimated travel time information will be used for the travel advisory purposes, the average travel time for a 10 miles stretch of roadway segment should not be off by more than one minute. On the other hand, if the estimated travel time information is to be used to select a pre-defined traffic signal control plan for a computer-controlled arterial signal network, then the errors introduced by the estimation procedure should not be so large that a “sub-optimal” traffic signal plan is selected.

A total of 25,000 miles of probe vehicle data will be collected over a four-month period of time. Data will be collected during morning and afternoon peak travel times, in both directions of the arterials, and during clear and rainy weather. Data will be collected by students from Pellissippi State Technical Community College located in Knoxville, Tennessee who will also provide TIC operations support.

Regarding incident detection, the operators in the TIC will use AirSage information (which will be provided in real-time) to determine abnormal increases in travel time on any segment, and will use the IPIX cameras to determine the cause of this increase. Notes will be taken and subsequently compared to accident reports to determine how effective the IPIX cameras were for surveillance purposes.

7. FUTURE DIRECTIONS

Data collection will be carried out in the spring and early summer, 2004. A report detailing the validity of the cell phone data as compared to probe vehicle data will be prepared at the conclusion of the test. If validated, such a data collection approach could have a profound effect on traffic management. Data on a whole network could be generated relatively easily. Such data will not require the deployment of additional sensors into the infrastructure saving both the cost of the sensors but also associated calibration and maintenance costs. As such, smaller communities could afford to collect such data and information not only for transportation planning purposes, but also to assist in local congestion management.

A second phase of this project is currently being planned which involves closing the loop with the traveling public and extension of the methodology to a wider regional area. Regarding communication with the public: validated data could be provided to travelers via the traditional modes mentioned earlier such as changeable message signs, commercial radio, internet, etc. As the electronic revolution continues, access to such data may be via PDAs premium cell phone services, or other devices not yet developed. Regarding more regional applications, there is interest in looking at applications that involve a transportation corridor that could involve larger geographic areas.
Such an application would allow higher level transportation management including traffic management for special events, regional weather events, emergency evacuation, etc. Such a system could also be important for the national 511 Program.

Data collection methods that free the state DOTs from the tethers of infrastructure based sensors would allow enhanced DOT services resulting in more efficient and safer highways.

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