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Project Summary Report 0-4156-S
Project 0-4156: Integration of Point-Based and Link-Based Vehicle Detection Data

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PROJECT SUMMARY REPORT

Summary and Analysis: Integration of Point-Based and Link-Based Incident Detection and Traffic Estimation

The implementation of Intelligent Transportation Systems (ITS) carries the promise of more efficient use of already existing transportation networks. Advanced Traffic Management Systems (ATMS) assist operators of Traffic Management Centers (TMC) in managing traffic networks, and providing assistance to travelers to reach a particular destination via a private vehicle, public transportation or a combination of the two. ATMS rely mainly on real time traffic data collection for incident detection and traffic estimation. Most major U.S. cities house traffic management centers in a single location to facilitate communications and collaboration between agencies to detect and inform motorists about road conditions. To carry out their tasks, TMC agencies utilize several automated and non-automated methods to estimate the conditions on highways. Examples of automated methods are Inductive Loop Detectors (ILD) and Automated Vehicle Identification (AVI). Examples of non-automated methods include Police Patrols (PP), reports from motorists with cellular phones, and Closed-Circuit TVs (CCTV).

What We Did…

This study served three main objectives. First, it analyzes the information flow and architecture of traffic management centers in Texas; secondly, it proposes ways to integrate the data of the AVI and ILD systems for speed and travel time measurement; and thirdly, it develops a simulation model to integrate incident detection sensors. Additionally, the study compares the performance of AVI and ILD detector systems in terms of accuracy, reliability, range of use, and net benefits. It also develops guidelines to integrate the respective advantages of both systems, while compensating for their weaknesses. This study achieves its objectives primarily through the analysis of AVI and ILD field data made possible through the study corridor installation in San Antonio. Speed and the travel time over a highway section are among the most important information factors that affect the commute decision of motorists. Informed motorists are capable of making wise decisions regarding when to start a trip and which route to take to avoid delays when provided with good speed and travel time information.

Information Flow and Architecture:

The National ITS architecture provides a common framework for planning, defining, and integrating intelligent transportation systems. It is a mature product that reflects the contribution of a broad cross-section of the ITS community (transportation practitioners, systems engineers, system developers, technology specialists, consultants, etc). The National ITS architecture defines the functions that are required for ITS; the physical entities or subsystems where these functions reside; and the information flow and data flows that connect these functions and physical subsystems together into an integrated system (USDOT & Odetics 1996). The ITS architecture consists of four major physical subsystems: traffic management, roadside equipment, vehicles (passenger cars and commercial vehicles), and the traveling population.

What We Found…

The research study focused on parts of the Roadway and Traffic Management subsystems that are concerned with deployed traffic sensors on highways, the flow of data from these sensors to TMCs, and data processing and decision-making in the TMC. Various traffic sensors [Inductive Loop Detectors (ILD), Automated Vehicle Identification (AVI), and Video Image Processing systems (VIP)] are deployed on freeways to measure traffic parameters and detect incidents. Incidents are detected and verified and incident information is provided to the Emergency Management Subsystem, travelers (through Roadway Subsystem Highway Advisory Radio and Dynamic Message Signs), and to third party providers.

The project team conducted site visits to four of the main TMCs in Texas (San Antonio's Trans-

Guide, Houston's TranStar, Fort Worth's TransVision and Dallas' DalTrans) and documented the flow of information and the TMC architecture as well as the decision-making process within the TMCs. The information flow and architecture reflect the mission of the TMCs to inform motorists regarding the following four elements: (1) the presence of incidents, (2) current speed or travel time of certain segments of the highway, (3) construction warnings, and (4) congestion due to citywide events. The information flow and decision-making in Texas varies significantly from one traffic management center to another. This is primarily due to the different types of traffic sensors deployed, level of automation, and the size and demography of the metropolitan area served. The expanding, small size metropolitan areas in Texas could greatly benefit from the experience acquired by the large metropolitan areas to manage traffic. Our study focuses on the different system architectures already implemented in the state and the pros and cons of each system.

Investment decisions regarding the type of traffic sensors to be deployed in any metropolitan area should be carefully considered. For example, ILD systems seem to not perform as well and require more frequent maintenance in areas that have expansive soils, such as the City of Houston. Sharing information about performance of the existing AVI systems among Texas cities could help cities that are planning to implement toll systems, i.e., Austin and Dallas-Fort Worth. The types of incident detection sensors and methods currently deployed in major Texas cities are diverse. Conducting Benefit-Cost Ratio studies to justify further investment decisions for incident detection is essential.

Integrating AVI and ILD Speed Data:

Reliable speed and travel time of a highway link are the most important information factors affecting motorist commute decisions. Inductive Loop Detectors (ILD) and Automated Vehicle Identification (AVI) are the main sensing systems deployed by most traffic management agencies to collect speed and travel time data. In the San Antonio, Texas Study Corridor, ILD, and AVI systems are deployed side-by-side to estimate and compare speed and travel time. The ILD system is capable of measuring the point speeds, while the AVI system is reliable in measuring average link speeds and travel time.

To investigate highway speed estimation approaches, the project team acquired AVI and ILD data collected from a previous study (Haynes 2001). The data was collected from the I-410/I-35 corridor in San Antonio, between the mile post 164.412 and 165.409. Site visits captured real boundary conditions of the corridor. The AVI and ILD data was checked for errors and processed before analysis. The AVI and ILD data was then analyzed separately to capture the underlying speed distribution trends before attempting integration. The analysis considered sensor accuracy and reliability and the level of penetration. After extensive investigation, the project team decided to utilize the Bayesian Updating and Weighted Average Methods to integrate the AVI and ILD data for speed estimation. Even at a low penetration of AVI, obtaining reliable travel time and space mean speed information was possible. One of the advantages of the AVI system is its capability to directly measure travel time and calculate average speeds.

Significant differences were found among the speeds recorded by ILD sensor stations on the study corridor. The average speed of the ILD at the milepost 164.909 was lower than that of mileposts 164.412 and 165.409 during the non-peak period. Estimating the average speed of a link by simply averaging the speed of the three ILD sensors was found to be misleading. Careful consideration of the local highway geometry is important to reliably estimate link speed. Exit and entrance ramps also cause fluctuation among speed measurements. It is, therefore, recommended to measure the speed of ILD sensors separately and then utilize engineering judgment to exclude sensor readings that are adversely affected by local geometry, construction and maintenance delays, or are not representative of the overall flow of traffic.

Generally, the AVI system is capable of estimating highway travel time with high reliability and traffic volume with limited reliability. The research team noted that due to the low penetration of AVI tagged vehicles and the penetration fluctuations during the day in San Antonio Study, in particular, the AVI system performed poorly in estimating traffic volume. The AVI system is not currently reliable enough to be implemented for Automated Incident Detection (AID) due to the low penetration levels. In contrast, the ILD system is very reliable in measuring traffic volume and has reasonable potential to automatically detect incidents. Deploying the AVI and ILD systems in the same link provides a better overall estimate of traffic parameters and incident detection. Table 1 below summarizes the conclusions for performance potentials of AVI and ILD when deployed separately or jointly to measure traffic parameters and detect incidents even in a system where AVI has a low penetration rate. When AVI penetration is dense, it has the potential for better estimation of traffic flow parameters than ILD's, but their respective performance for AID then depends largely on density of loops or AVI readers. While the fused performance of point-based (ILD) and link-based (AVI) systems for AID is demonstrated to be better than that of any system alone, the improvement in performance does not justify investment in a second parallel system. This reasoning could drive decisions about deployment and use of parallel link and point based systems. In summary, the results of the analysis suggest that the AVI system is reliable for speed and travel time estimation and the ILD system is reliable for occupancy and point-based speed measurement and for AID algorithm processing.

Modeling Incident Detection:

Various ways to simulate the combined performance of different link- and point-based sensing systems for incident detection were investigated. A Monte Carlo type simulation model was designed to model fusion sensors to detect traffic incidents. Models of the fused performance of different incident detection sources (sensors) were demonstrated that spanned the spectrum from simple arithmetic equations to the complete Monte Carlo simulation model. The arithmetic model based on simple probabilistic distribution equations was used to predict the combined hypothetical performance of three types of sensors. The arithmetic model predicted better performance from combined sensors than from any individual sensor. Applying simple arithmetic equations to predict the combined performance of incident sensors could not, however, properly address the performance impact of sensors' correlation. To resolve correlation issues and develop a single unified model that encompasses both detection rate and false alarm rate, the Monte Carlo Model is proposed.

The Monte Carlo technique works particularly well when the underlying probabilities are known but the results are difficult to derive deterministically. Monte Carlo simulation is essentially a numerical integration tool for conducting "what if" experiments. Three scenarios were investigated to predict the combined performance of detection sensors: (1) First vs. two or three corroborating alarms, (2) Correlated vs. independent (non-correlated) sensors, and (3) ideal 100% vs. less than perfect detection rate.

When processing a hypothetical scenario using the proposed Monte Carlo model, the average TTD for the three sensors was lower than any individual sensor. The standard deviation of the time to detect was also lower producing more consistent TTD values. For example, when waiting for a second corroborating (or confirmatory) alarm, the average time-to-detect from the three sensors was larger than when detecting at first alarm. This model could be used by decision makers to not only decide which detection sensor to deploy (if the option exists), but, also, whether to detect at first or second alarm. These results were supported by running numerical scenarios. When hypothetically assuming the average TTD for AVI is 6 minutes, ILD is 5 minutes, and CCTV is 4 minutes, the model was able to reliably predict the combined performance of approximately 3.3 minutes and 4.8 minutes at first and second alarms, respectively.

Table 1: Performance Potential of AVI and ILD, Jointly or Separately for a Low AVI Penetration Situation

	TRAVEL TIME	SPEED	VOLUME	AID
AVI	H	M	L	L
ILD	L	L	H	H
AVI & ILD	H	M	H	H

L = Low Performance
M = Medium Performance
H = High Performance

The results of the simulation when considering no correlation between sensors and hypothetical detection rates of the CCTV, ILD, and AVI systems are 85%, 70%, and 55% respectively. The first alarm scenario provided a combined performance of 98% DR, compared to 81% at second alarm. This result suggests that the combined performance at second alarm is lower than the highest performing sensor (i.e. CCTV). This result should not be taken in isolation, however, since the false alarm rate of the combined sensors performance is lower when detecting at second alarm.

The proposed Monte Carlo model was validated using traffic and incident data from San Antonio's TransGuide. When the proposed model is subjected to the results that Zhou (2000) concluded in an earlier study; the results reflected a highly accurate performance prediction. With good parameter data, the model can be utilized as a performance prediction tool useful in deciding what combination of types of algorithms or sensors would provide the highest performance. Accurately estimating each individual sensor parameter that the model requires is a challenging task, since it is difficult to assign an exact start time for each incident with the experimental data available. Ultimately, however, with good data and derived sensor performance parameter values, the proposed model can be used as a performance predictor that supports decision making for traffic sensor system investment.

The Researchers Recommend...

The results of the analysis support the reliability of the AVI system for speed and travel time estimation, the ILD system for occupancy, point-based speed measurement, and the Automatic Incident Detection (AID) for algorithm processing. Additionally, the Monte Carlo simulation model was designed to model sensor fusion to detect traffic incidents. The Monte Carlo model provided promising results when validated using traffic and incident data from the San Antonio network. It can also be used as a performance predictor in the planning phases of implementing traffic sensing systems investment decisions.

For More Details...

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The research is documented in the following reports:

0-4156-1 *Integration of Point-Based and Link-Based Incident Detection and Traffic Estimation* October 2002, Rev. March 2004

To obtain copies of a report: CTR Library, Center for Transportation Research,
(512) 232-3126, email: ctrlib@uts.cc.utexas.edu

TxDOT Implementation Status
March 2005

The objectives of this research project were threefold: 1.) to analyze the information flow and architecture of traffic management centers in Texas; 2.) to propose ways to integrate the data of Automated Vehicle Identification (AVI) and Inductive Loop Detector (ILD) systems for speed and travel time measurement; and 3.) to develop a simulation model to integrate incident detection sensors. Four products were required for this project: 1.) Analysis of comparative benefits of point data and link data; 2.) Strategy for combining the benefits of point data and link data from different sources; 3.) Blueprint for implementing an integrated data usage system at specific Texas locations; and 4.) Model for simulating and investigating the effectiveness of levels of implementation. This research has determined the strengths and weaknesses of link-based (AVI) and point-based (ILD) detection systems through analysis of traffic flow parameters (travel time, speed, volume, and automated incident detection) when deployed separately. When the two systems are integrated, there is a potential for better estimation of the traffic flow parameters. Further research should be conducted to determine the combined performance of point-based and link-based systems at various levels of deployment. One of the ways this can be achieved is by estimating the benefit-to-cost ratios of installing a system when on system is already in place versus installing a completely new combined system.

For more information, contact Wade Odell, P.E., Research and Technology Implementation Office, at (512) 465-7403 or email: wodell@dot.state.tx.us.

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