AN EVALUATION OF TRAVEL TIME ESTIMATION METHODOLOGIES

by

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SUMMARY

In the fight against traffic congestion, many agencies measure and monitor congestion levels on their freeways and arterial streets. Recent research has determined that travel time or travel rate is the best measure of congestion. Travel time is applicable for many different modes of travel, is able to be projected to predict future conditions, and is easy to measure. This report investigates several different travel time estimation methodologies in order to evaluate their advantages, limitations, accuracy, ease of measurement, and applicability for a variety of different uses.

The report is divided into two major sections. The first section describes four existing methods that are currently used to collect travel time data. These methods are the floating car technique, the license plate matching technique, the cellular telephone reporting technique, and the detector systems technique. The second major section identifies emerging technologies which will play a major role in travel time measurement in the near future. These technologies are automatic vehicle identification systems and global positioning systems.

The results indicate that all six travel time estimation methodologies provide an accurate representation of the actual average travel time of the traffic stream. Some methodologies do, however, have advantages over the others for different purposes. For example, for reporting real-time information, the emerging AVI technology will provide the best estimate of travel time assuming enough probe vehicles are in the traffic stream. The AVI technology will improve the estimates made by loop detectors and those reported by cellular telephones because it is measured automatically by the system and does not rely on vehicle length estimates or consistent human reporting. The AVI technology is also useful for measuring and monitoring congestion levels, incident management programs, and fleet tracking for the trucking industry.

However, due to the costs associated with this system, small metropolitan areas will not be able to install the AVI technology. With this in mind, the license plate matching technique proved to be the best method for measuring congestion on an annual basis. This technique provided about 15 times more data than the floating car technique for the same number of man-hours of work. In addition, the license plate technique samples random drivers from the actual traffic stream to produce a more representative sample of the driving population. The license plate matching technique, however, is only recommended for annual congestion measurement, and does not apply to collecting real-time information, incident detection programs, or for fleet tracking.

TABLE OF CONTENTS

INTRODUCTION

In the fight to combat congestion, many governmental agencies across the country measure and monitor congestion levels on their freeway system on a regular basis. Congestion levels are measured in many different ways, including Level of Service, delay, speed, volume, and travel time. Due to the passage of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), agencies will soon be required to evaluate more than just one mode of transportation. Agencies will need to measure congestion levels (i.e. mobility) across all modes. In response to this need, NCHRP recently sponsored a study that identified travel time as the preferred measure of congestion (1). Travel time is a measure which can relate to all modes of transportation, including automobiles, transit and ferries and can be collected and interpreted in a cost effective manner.

Several different methodologies are either currently in use or being developed to measure travel time. These methodologies include: using test vehicles or "floating cars" to physically measure travel times from one location to another; calculating travel times based on information supplied by vehicle detectors; using automatic vehicle identification (AVI); using a license plate matching technique; using global positioning systems; and by drivers who report travel times by cellular telephone after passing a checkpoint.

With several different methods available for measuring travel time, questions have arisen about the accuracy and reliability of each method. The AVI and global positioning methodology are relatively new and not utilized in most parts of the country. The other methodologies have been in use for many years, but are typically time consuming and expensive to use.

Purpose

The purpose of this project is to evaluate the different methodologies in measuring travel times in order to determine their differences, limitations, and ease of measurement. In addition, their applicability in measuring and monitoring congestion and in reporting real-time information will be analyzed. With regards to emerging technology, an investigation into the number of probe vehicles required and the technologies' applicability towards other purposes will be included.

Scope and Study Approach

This paper concentrates on the most common travel time estimation methodologies; namely, floating car measurements, detector measurements, license plate matching, cellular phone reports, AVI technology and GPS technology. Information about the existing methodologies was obtained from agencies that are currently using that methodology to evaluate travel time. These agencies include the Minnesota Department of Transportation, the California Department of Transportation, the Metropolitan Transportation Authority of Harris County (Houston), the Washington State Department of Transportation, and the Illinois Department of Transportation.

The evaluation of the emerging technologies was completed by obtaining information from several research projects currently in progress. These include the RTTIS project in Houston, the TRANSCOM project in New Jersey, and the ADVANCE project in Chicago. In some cases, adequate information is still not available for a complete methodology evaluation. Conclusions and recommendations will include the benefits and limitations of each method and the applicability of the travel time estimate for other uses.

EXISTING METHODOLOGIES

Overall travel time, as defined by the Transportation Research Board, is the "total elapsed time of travel, including stops and delays, necessary for a vehicle, or the average for a group of vehicles, to travel from one point to another over a specified route and under existing traffic conditions." (2, p.2) Over the years, different methods have emerged with improvements in technology in an effort to accurately measure travel time. Several methods are currently in use today, including some that have been used for many years, and some that are relatively new. This section investigates the existing methodologies and evaluates their accuracy, usefulness, and ease of measurement.

Floating Car Technique

The floating car technique is a form of the test car technique that is perhaps the oldest travel time estimation methodology. The floating car procedure involves driving a test vehicle through the normal traffic stream and recording the time it takes to travel between certain segments. The driver of the test vehicle tries to "float" in the traffic stream, passing as many vehicles as pass him, in order to obtain a representative travel time for the traffic stream (3).

Other test car techniques which are similar to the floating car technique are the average car technique and the maximum car technique. The average car technique requires the driver of the test car to travel at a speed which he feels is representative of the average travel speed of the traffic stream. The maximum car technique requires the driver to drive the test car at the posted speed limit unless impeded by actual traffic conditions (3).

Minnesota Department of Transportation

The Minnesota Department of Transportation in Minneapolis uses the floating car technique to measure travel time on a roadway segment whenever that segment must be evaluated. One staff member, usually a student technician, travels on the segment within the traffic stream. The operator uses a stop watch to measure time, and reads the time into a tape recorder when passing prearranged checkpoints. In addition, if the vehicle must come to a complete stop, the time that the vehicle was stopped is recorded along with the duration of the stop. Travel time is reported every 2 to 4 miles (4).

The reported travel times for each segment are converted to travel speeds for that segment for evaluation purposes. The travel times are not currently used to provide real-time information to motorists, nor are the travel time measurements considered to contain a high degree of accuracy (4). The measurements are collected for evaluation purposes, not on a continual basis, so continuous real-time information to motorists is not possible.

California Department of Transportation

The floating car technique is also used by District 4 of the California Department of Transportation (CALTRANS-4) located in the San Francisco Bay Area. CALTRANS-4 uses vehicles that are equipped with a computerized program that records the vehicle's speed and current time (5). The vehicles are driven by staff members who travel in the normal travel lanes and record times for each segment, which is 7 miles or less in length. Data collection only occurs during certain times of the year, such as the spring, for evaluation purposes of freeway segments.

During "full" data collection periods, at least three cars travel on each segment during the peak period (on weekdays only). The effects of minor accidents or other recurring delay is included in the travel time runs. Delays due to major accidents are excluded. A single car is used to check if travel times may have changed since the last full data collection period. If there is evidence that the travel time may have changed, a full data collection effort is completed. The travel time data is not reported in real-time, but it is available for local agencies to use for monitoring congestion levels on an annual basis.

Methodology Evaluation

Travel times measured by the floating car technique are only as accurate as the driver who is recording the data. A variation in travel times exists due to random human error. Other variations exist due to driver judgement as to whether he is "floating" in the traffic stream (i.e. passing the same number of vehicles that pass him).

One advantage of the floating car technique is that no special equipment is required to perform the study. Travel times can be determined using any vehicle, a stop watch, and a tape recorder or note pad.

The major disadvantage is the cost of labor in relation to the amount of data collected. The floating car technique is very labor intensive and is usually limited to a few measurements per day per staff member. Each staff member is limited to two or three travel time runs during the peak period due to time constraints. If the peak period lasts for three hours and each travel time run takes one hour (including time to return to the starting point), only three corridor travel times can be measured by the staff member. Therefore, if the evening peak period is included, only about six travel time runs can be measured along a corridor for an entire days worth of work for one staff member.

Despite the variation in accuracy and the cost of labor, the floating car technique can provide agencies with an indication of congestion levels on specified corridors on an annual or biannual basis. The floating car technique is not considered to be applicable for use in daily monitoring or real-time traffic reporting, but will provide a relatively inexpensive means of obtaining annual travel time data for measuring and monitoring congestion levels.

License Plate Matching Technique

This travel time estimation methodology requires personnel (or a video camera) to record the time and license plate number of vehicles passing a particular point on the roadway. Another staff member is recording the same data at a different location. The license plate numbers are later matched in order to determine a travel time from one point to the other.

Seattle Study

A recent study in Seattle experimented with both the floating car technique and the license plate matching technique in collecting travel time data on arterial streets (6). Data collection personnel utilized lap top computers to record license plate numbers from vehicles passing several different points on the roadway. The internal clocks on each of the computers were synchronized and the time of entry was recorded for each entered license plate number. Staff members recorded the last three or four numbers of as many license plates as they could. License numbers for sequential data collection points were compared, and travel times were determined for all matches.

At the same time, study personnel were also measuring travel time using the floating car technique. Since the data were collected at the same time, direct comparisons could be made that help to identify the accuracy and reliability of each method. A statistical test was performed to compare the mean travel times obtained from the two methodologies, as shown in Table 1.

Table 1. Comparison of Floating Car and Computerized License Plate Travel Time Methods
SOURCE: Reference (6), p. 86.

	Mean Travel Times		Number of Travel Time Runs		t-statistic*
	Floating Car	License Plate	Floating Car	License Plate	
Bel-Red Road Eastbound PM	590	590	5	27	0
148th Avenue Southbound PM	453	487	3	45	-0.44
NE Eighth Eastbound PM	242	264	6	11	-0.40
148th Avenue Southbound AM	247	257	5	38	-0.27

* The Student's T statistic is used here to compare the mean travel times of the two travel time distributions. All t values are within the critical T value at the level of alpha=0.005, and the associated degrees of freedom for each test. This indicates that there is no statistical difference between the two travel time methodologies.

The license plate methodology produced results that are statistically the same as the floating car results. The larger number of observations in the license plate survey indicate that the license plate matching results produce a higher level of confidence in the mean travel time estimate than the floating car technique (6). In addition, the floating car technique was estimated to require 1.07 person hours for travel to the site, data collection, and converting the data to useable form. In comparison, the computerized license plate matching technique only required 0.07 person hours per travel time run. Thus, the license plate matching technique produces about 15 times more data than the floating car technique for the same amount of man-hours.

The study also compared estimates based on recording the first 3 numbers verses the first 4 numbers of every license plate. By recording four numbers, false matches are easier to detect because there are fewer of them, but recording four numbers takes longer to collect. However, statistical analysis determined that four-digit entries provided the best combination of ease of data entry and a low level of false matches (6).

Methodology Evaluation

The license plate matching technique provides about 15 times more data than the floating car technique per man hour of labor. In addition, the Seattle study proved that both methods produce identical results. However, the license plate matching technique does provide a larger sample base composed of different drivers and different vehicles operating in actual traffic conditions. The floating car technique typically uses only one or two drivers and one or two vehicles to collect its data over the peak period. On the other hand, the license plate matching technique measures travel times from many different drivers, each driving their own vehicle. This condition provides a more accurate estimation of the mean travel time for all drivers on the system. The license plate matching technique provides a more representative sample of the driving population.

One disadvantage of this technique is that portable computers are usually required. The methodology can be completed with hand written data, but it becomes much more time consuming and labor intensive. Another disadvantage is that the travel times collected are not applicable for reporting real-time information. The reported travel times are only applicable for measuring and monitoring congestion, not for providing information to motorists or transit operators.

Cellular Telephone Reporting Technique

As cellular telephones become more affordable, their existence among drivers increases. This valuable resource tool is a popular method for agencies around the country to obtain real-time traffic information such as incident locations. One such agency began utilizing cellular telephones for obtaining travel time information as part of a prototype traffic information system.

Houston Study

During Phase I of the development of Houston's Real-Time Traffic Information System (RTTIS), 200 drivers were identified through several corporations in the CBD and by newspaper advertisements and word of mouth. These participants were identified to travel one of three corridors daily from the north part of the Houston metropolitan area to the CBD. In return for their participation, the drivers were given a free cellular telephone which they could keep at the end of the study. Each driver agreed to participate for one full year. The study sponsors paid for all connection and monthly access fees for each cellular telephone. Two hundred probe vehicles and drivers were needed in order to provide adequate coverage of the routes during the time the system was operational (7).

The three corridors used in the study (IH-45, US-59, and the Hardy Toll Road) are each approximately 25 miles in length and link major residential communities in the suburbs to the CBD, as shown in Figure 1. These roadways also provide access to Houston's Intercontinental Airport, located about 13 miles north of the CBD. Reporting locations were identified along each corridor at approximately 3 to 5 mile intervals.

During system operation, drivers called a central communications center as they passed each reporting location. An operator at the center recorded the driver's identification number and location into the computer system. The system recorded the time the number was entered into the computer. Each call lasted less than 10 seconds because all the driver had to say was "driver 143 at point 4." (8) A travel time is automatically determined by the computer by monitoring successive calls by the driver. Travel time data were collected in the inbound direction from 6 to 10 AM and in the outbound direction between 3:30 and 7 PM. During the peak period, travel times were updated for each link segment about every five minutes. Each day, approximately 1500 calls were processed through the central communications center (7).

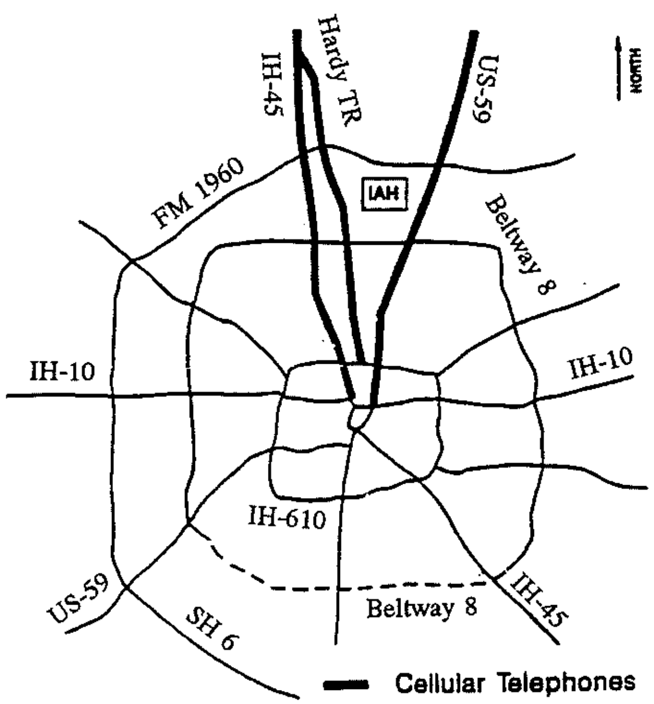

Figure 1. Study Area for Houston Cellular Phone Travel Time Study
SOURCE: Reference (7), p. 609.

Methodology Evaluation

Travel times obtained from the cellular phone reporting technique are considered accurate within a minute or two. A variation in travel times was experienced due to the way the drivers collected the data. Times were recorded by the computer when drivers reported their location to the communications center. Therefore, if the line was busy when the driver attempted to report his location, he would have to call again. By the time he connected with the operator, the driver may have been 1/4 or a 1/2 mile downstream of the actual reporting point, thereby altering the true travel time.

Other problems with this technique occurred with drivers who would exit the freeway to get gasoline and then return to the freeway and report at the next reporting location. These travel times were obvious outliers to other reported times, so they could be eliminated. In addition, some drivers would forget to call at one location, but remember to call at a following location. Thus, their calculated travel time was for a combination of two segments instead of for one segment.

Despite these problems, the cellular telephone reporting technique does allow more data to be collected than the floating car technique with approximately the same degree of accuracy. In addition, the cellular telephone technique permitted data collection every day of the week without many additional expenses. Major investments were required to install the computer center and provide free cellular telephones. However, the only regular costs beyond installation are computer maintenance, personnel to operate the phone lines, and monthly phone bills. These costs are considerably cheaper per travel time run than with the floating car technique. The cellular telephone technique can provide more data than the floating car technique on a daily basis.

Vehicle Detection Systems Technique

This travel time estimation methodology involves calculating travel times along roadway segments based on information provided by vehicle detectors. Vehicle detectors provide information such as detector occupancy and traffic volume which are then converted to average travel speed for the traffic stream. The speed values are then converted to travel time based on the assumption that the detector data collected at one location represents traffic conditions along the section of roadway to the next detector zone.

Chicago System

An extensive vehicle detection system exists in the Chicago, Illinois area. Approximately 2,000 induction loop detectors along 130 miles of the Chicago area freeway system report data 24 hours a day to the Illinois Department of Transportation Traffic Operations Center. The Chicago area network is shown in Figure 2.

Induction loop detectors are located nearly every half mile in the center lane of three lane roadways or the left-center lane of four lane roadways. At every three mile point, loop detectors are located in every lane. In addition, one loop detector is also located on every entrance and exit ramp throughout the system.

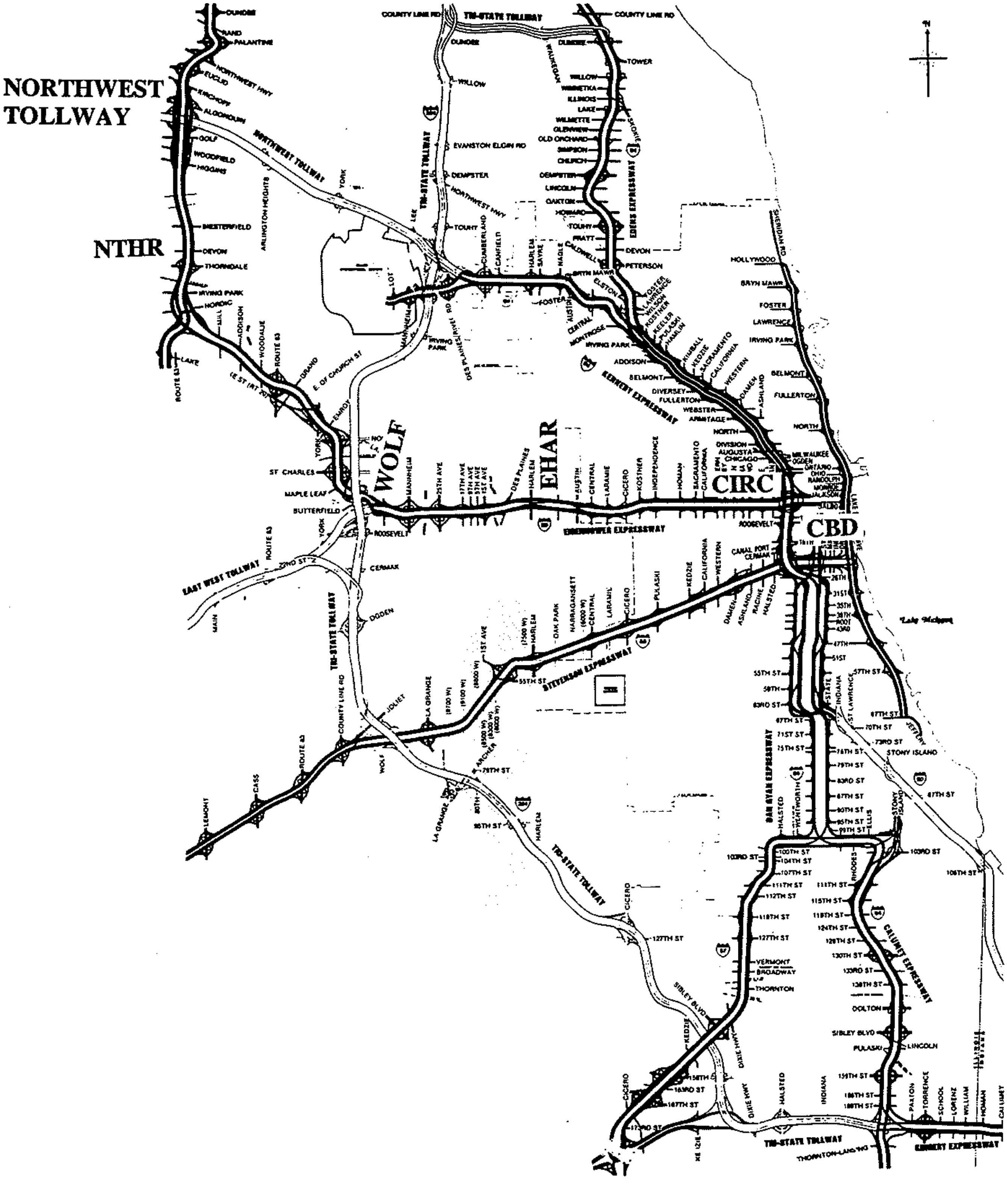

Figure 2. Chicago Area Surveillance Network.

Each detector is connected to a tone transmitter located in a roadside control cabinet which transmits the signal from the roadside to the Traffic Operations Center. A surveillance digital computer in the Traffic Operations Center receives each signal. The computer continuously scans for the status of each mainline loop detector 60 times per second and each ramp detector 12 times per second (9).

Each loop detector operates in the presence mode of operation, which means that the detector unit senses that a vehicle is present on top of the loop and identifies when the vehicle leaves the loop area. By operating the loop detectors in presence mode, the computer is able to determine each loop's occupancy rate. Loop occupancy is the percentage of time that the loop area is occupied by a vehicle. Loop occupancy is the basic form of measurement used at each surveillance point throughout the entire system.

The relationship between loop occupancy, average travel speed, volume, and congested conditions is shown in Figure 3 (10). A loop occupancy less than 20% indicates free flow conditions on the freeway segment. Between 20 and 30%, conditions on the freeway begin to deteriorate. Speeds are decreasing due to fewer and shorter gaps between vehicles, restrictive flow conditions, and an increased difficulty in changing lanes. These flow conditions are referred to as impending congestion (9). Once loop occupancy passes 30%, conditions are considered to be congested. Speeds continue to deteriorate and throughput volume decreases, as indicated by Figure 3.

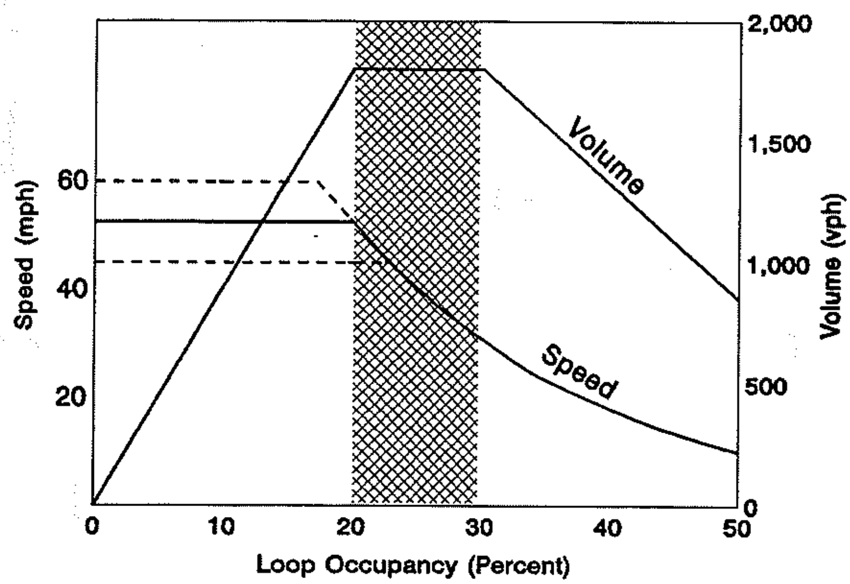

Figure 3. Generalized Freeway Traffic Flow Characteristics (one lane, at a point). SOURCE: Reference (10), p. 12.

By assuming a standard vehicle length (21.5 feet) and determining the current lane volume on the freeway, an average travel speed at the location of the detector can be determined. Speeds are determined by the computer program every minute by the following formula:

$$SPEED\ (mph) = \frac{\dfrac{Volume * 21.5\ feet}{Loop\ Occupancy}}{40.9}$$

Speeds are calculated for each mainline detector using a five-minute data base which is updated every minute. Each loop detector is assumed to represent conditions for the section of roadway from the halfway point to the downstream detector to the halfway point to the next upstream detector. For example, with the detectors spaced at every half mile, each detector is assumed to represent conditions for the quarter mile segments both upstream and downstream of the detector, for a total distance of a half mile, as shown in Figure 4. From this estimated distance, travel time can be computed based on the estimated speed as follows:

$$Travel\ Time\ (seconds) = \frac{Distance\ (miles)}{Speed\ (mph)} * 3600$$

The computed travel times for each half mile segment are calculated every 5 minutes and summed together to determine the total travel time over a given section of roadway, as shown in Figure 5. The travel times are summed for predetermined sections of roadway and reported by the central computer at the IDOT traffic control center. A sample printout from the IDOT computer is shown in Figure 6.

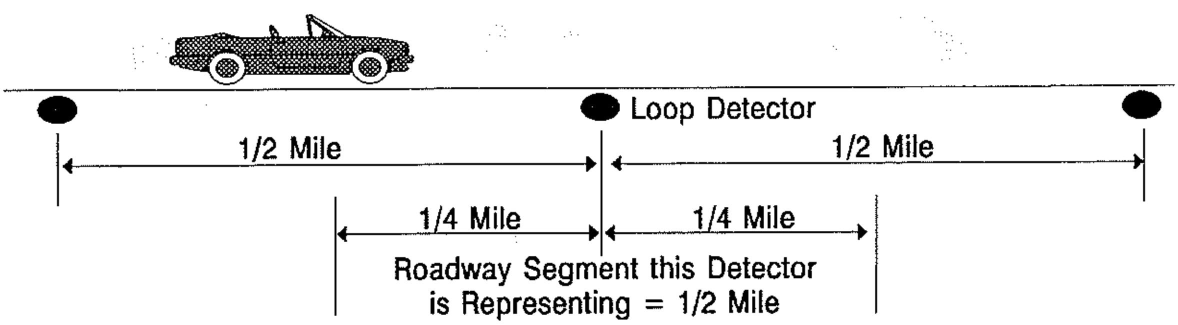

Figure 4. Schematic of Roadway Segment Represented by Each Loop Detector

The reported travel time information is used by various radio and television reporters to broadcast real-time travel information to the motoring public. The travel time information is reported for given sections of the freeway system, such as the 16 mile section along IH-290 from the Northwest Tollway to Wolf Road (just past the Tri-State Tollway). The reported travel times for this segment are circled on Figure 6. These detector locations are indicated on Figure 2 with NORTHWEST TOLLWAY and WOLF. The highest travel time for this segment was at 7:50 AM when the travel time was about 45 minutes. The best time to travel was at 9:30 AM when the travel time was only 25 minutes. Other reported travel times along IH-290 on Figure 6 correspond to detector locations on Figure 2, such as EHAR, CIRC and NTHR. Each of these reported times is from the NORTHWEST TOLLWAY detector location to the indicated detector location. This type of real-time information gives motorists the opportunity to make educated decisions in selecting an appropriate route to or from work (avoiding IH-290), altering their mode of travel, or changing the time they leave work.

Seattle Study

The Washington State Department of Transportation currently operates an inductance loop system on the freeways in the Puget Sound Region around Seattle. At the present time, none of the information collected from the loop detectors is used to determine travel times (11), but work is underway to determine an effective method of travel time estimation. A recent study at the University of Washington evaluated the effectiveness of using loop detector information to estimate travel time (12,13).

The basic theories and principles used in the Chicago system are similar to the basic methodology proposed for Seattle. The study recognized that the foundation for estimating travel time from loop detectors relies on the speed estimate. Therefore, the research effort has concentrated on improving the speed estimate. Speed is typically estimated from the volume/capacity information reported by the loop detector. The study reported that speed estimates could be improved, thereby improving the travel time estimate, by using a cross correlation technique.

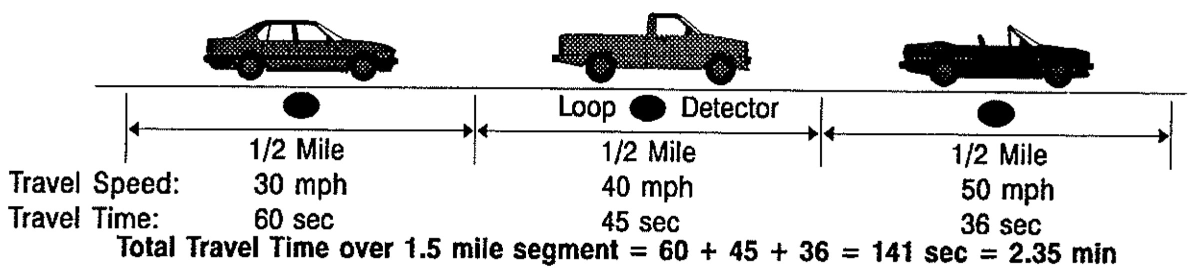

Figure 5. Schematic of Travel Time Estimation for a Roadway Section

INBOUND AM AVERAGE TRAVEL TIMES IN MINUTES

TIME	I-290				EDENS		REV	KENNEDY		DR-E	DR-L
END	NTHR	WOLF	EHAR	CIRC	NDEM	MONT	OHIO	MONT	VANB	VANB	29TH
05:05	7.7	27.3	34.3	45.9	15.2	23.2	10.5	13.[illegible]	28.9	12.3	9.8
05:10	8.3	28.9	34.7	45.5	13.1	21.3	13.3	14.7	29.4	12.5	8.5
05:15	7.9	30.5	36.1	45.2	13.2	22.1	8.5	16.3	30.8	13.1	9.8
05:20	7.0	29.5	35.1	44.2	12.9	21.3	10.6	11.5	26.0	12.9	9.4
05:25	7.2	26.4	32.0	41.0	12.9	21.1	10.0	14.0	28.6	12.8	8.9
05:30	7.5	27.6	33.0	42.3	12.7	20.9	9.3	11.1	25.8	13.1	8.2
05:35	7.2	26.2	31.6	40.7	12.5	20.7	10.9	14.4	28.9	12.9	8.6
05:40	6.9	26.2	31.5	40.4	12.2	19.9	8.7	11.1	25.8	13.1	8.5
05:45	7.0	26.0	31.4	40.5	12.1	19.5	8.5	11.1	25.6	13.6	8.6
05:50	6.8	23.1	28.5	37.6	11.8	19.2	8.4	12.6	27.2	14.9	8.1
05:55	6.7	22.7	28.1	37.1	11.7	19.0	8.4	11.1	25.6	15.4	8.3
06:00	[illegible].4	27.3	33.0	42.3	12.3	20.0	[illegible].7	11.4	26.0	15.7	9.3
06:05	7.4	27.7	33.9	43.0	11.9	19.8	8.6	10.9	25.5	16.2	7.9
06:10	7.0	26.0	34.9	44.4	11.8	19.8	8.7	11.8	26.3	20.0	7.3
06:15	6.6	26.6	35.5	45.3	11.8	20.0	9.0	9.9	24.4	21.2	7.4
06:20	7.1	28.4	39.3	49.0	12.0	21.7	8.4	10.4	24.8	21.5	7.8
06:25	6.3	27.6	41.6	51.6	12.0	22.5	8.7	11.9	26.4	20.3	7.8
06:30	6.8	29.0	44.7	55.1	12.0	23.2	8.8	13.0	27.4	22.6	9.2
06:35	6.9	28.1	42.4	52.2	12.0	22.9	8.7	11.6	26.1	24.5	8.8
06:40	6.9	28.0	43.4	53.0	12.1	21.9	8.4	10.6	25.1	23.5	9.8
06:45	6.9	26.6	48.3	57.8	12.0	22.8	8.9	10.6	25.3	22.4	10.6
06:50	7.1	28.9	50.9	61.6	11.8	21.2	8.6	12.3	26.9	22.2	11.3
06:55	7.2	27.5	45.9	57.7	11.7	21.2	[illegible].8	12.0	26.5	21.9	13.3
07:00	8.1	28.6	46.1	58.5	11.9	20.4	8.6	12.1	26.6	22.6	10.4
07:05	8.2	29.6	43.8	56.5	12.0	21.1	9.0	10.5	25.0	23.4	10.9
07:10	8.9	30.8	46.3	60.3	12.0	20.9	8.6	12.4	27.0	24.8	8.8
07:15	10.4	31.5	48.2	64.9	12.1	20.9	9.4	12.1	26.6	25.1	8.2
07:20	12.6	35.1	51.4	67.9	12.2	21.4	9.3	10.7	25.2	25.0	8.3
07:25	13.6	34.6	54.2	72.5	12.1	22.0	9.2	11.5	26.0	24.5	8.9
07:30	14.1	34.9	57.8	74.9	11.8	23.0	9.1	10.7	25.2	24.6	9.8
07:35	14.9	35.3	61.0	79.3	11.8	23.1	8.7	11.8	26.4	26.3	10.3
07:40	14.7	36.0	65.3	80.6	11.8	23.6	8.8	12.1	26.6	27.9	11.8
07:45	17.2	37.7	66.3	84.1	12.1	23.1	8.9	12.5	27.0	26.3	11.5
07:50	16.1	44.9	69.3	88.1	12.3	23.7	9.8	11.4	26.0	26.5	12.2
07:55	15.0	36.6	62.3	83.9	11.9	24.3	8.7	10.3	24.8	29.4	11.6
08:00	16.1	38.1	58.8	80.1	11.6	22.4	8.6	12.2	26.6	27.4	10.5
08:05	11.7	33.2	55.3	78.4	11.6	23.2	8.8	10.9	25.5	26.0	10.4
08:10	10.7	33.4	62.9	82.5	11.8	23.6	8.6	11.9	25.5	26.2	9.6
08:15	12.0	34.3	58.3	78.0	11.9	24.1	8.5	12.4	27.1	27.4	9.1
08:20	10.6	33.1	57.3	75.7	11.7	24.4	8.6	12.5	27.1	28.9	9.8
08:25	10.2	30.5	55.4	74.4	12.0	26.3	8.9	10.4	24.9	23.9	8.6
08:30	9.4	31.2	58.0	78.9	12.4	26.0	9.1	11.4	26.0	25.4	8.6
08:35	9.2	30.8	57.6	77.7	12.3	25.7	9.2	11.7	26.3	27.0	9.8
08:40	7.9	32.0	54.9	75.8	12.1	25.9	9.2	10.8	25.3	27.8	9.6
08:45	7.4	30.3	52.1	72.5	12.0	25.0	8.9	11.1	25.7	27.3	9.5
08:50	7.2	30.6	53.0	71.8	12.1	25.1	9.1	10.7	25.3	26.0	8.9
08:55	7.1	30.7	52.7	71.8	12.3	25.4	9.1	10.7	25.4	26.2	9.3
09:00	7.3	30.1	50.2	67.0	12.1	25.3	9.2	13.4	28.2	24.5	8.9
09:05	7.3	28.3	48.2	64.2	12.2	24.0	9.4	11.1	25.8	21.3	9.3
09:10	7.6	31.6	48.2	62.7	12.6	24.9	10.0	11.7	26.4	18.5	9.1
09:15	7.3	26.1	45.1	58.6	12.2	24.0	9.0	13.7	29.5	19.5	8.7
09:20	7.3	26.1	46.4	58.2	12.5	24.0	9.0	11.6	26.4	15.9	9.2
09:25	7.2	26.2	47.6	58.7	12.2	24.6	9.3	10.4	25.1	16.3	9.5
09:30	7.2	25.5	45.3	56.0	12.6	25.0	9.1	10.9	25.6	16.7	9.6
09:35	7.2	27.4	44.6	54.9	12.7	24.9	9.1	12.9	27.6	15.4	8.6
09:40	11.5	34.5	46.3	56.9	12.6	24.2	9.1	11.4	26.1	13.8	9.4
09:45	15.1	35.7	44.8	55.8	12.7	23.9	9.2	12.1	26.9	13.6	9.6
09:50	16.2	36.2	43.6	55.2	12.6	25.5	9.4	15.7	30.5	14.1	10.0
09:55	16.8	36.7	45.5	57.6	12.6	25.6	9.3	12.2	27.1	13.6	9.6
10:00	18.5	40.3	50.8	61.8	12.9	25.6	9.8	12.8	27.7	13.6	9.4
AVERG	9.6	30.6	46.7	60.5	12.2	22.9	9.1	11.9	26.5	20.8	9.3

Figure 6. IDOT Computer Printout of Measured Travel Times.
SOURCE: Illinois Department of Transportation, June 9, 1993.

However, the technique is only reliable for loop occupancies in the range of 0 to 15%. Unfortunately, the most critical travel time data needed by the public is for the peak period where loop occupancies are typically well above 20%. Therefore, the improved speeds from the cross correlation technique are not useful for the loop detector travel time estimation methodology. Researchers in Seattle are beginning to investigate different techniques, such as the Kalman Predictor, to help further improve the speed estimate (13).

Methodology Evaluation

The travel times estimated from loop detectors along the Chicago freeway system permit real-time information to be given to the motoring public. The information permits motorists to make educated decisions about their travel route in order to minimize their travel time.

One disadvantage of the loop detector estimation technique is its reliance on loop detectors for data. Loop detectors require frequent maintenance to maintain their reliability. Studies have shown that loop detectors only provide accurate information when maintained on a regular basis (14). Pavement movements, high volumes of traffic, and construction work all effect loop operations. Operating characteristics of loop detectors are also different with odd-sized vehicles, especially high profile trucks and motorcycles.

However, some of these problems can be overcome. A good routine maintenance program can help keep the loop detectors operating effectively. In addition, the system designed in Chicago is primarily concerned with the characteristics of the entire traffic stream, not with individual vehicles. When determining traffic characteristics, if the loop detector does not detect an odd-sized vehicle, such as a motorcycle, the travel time estimation will not be greatly affected. The traffic stream characteristics will not change much because the detector did not detect a single vehicle.

Another disadvantage is that the speed estimate is based on an average vehicle length of 21.5 feet. This value represents both high profile trucks and standard automobiles. This standard assumption raises the question of the accuracy of these travel time estimates. Times reported on days with high truck traffic will be high due to the increase in loop occupancy rate caused by the trucks. Similarly, on days with low truck volumes, reported travel times will be lower than actual due to the decrease in loop occupancy rate. The speed estimate could be improved by using speed traps composed of a pair of loop detectors rather than a single loop in the center lane. In this case, speeds are directly determined from the loop detector data and are not based on an average vehicle length.

With regards to travel time estimation, this methodology does have some advantages for reporting real-time information. Measured travel times represent actual roadway conditions since they are based on real-time information. By using the floating car technique, reported travel times are for the segment of roadway just traveled on. This measured travel time will not help the driver who is just starting his trip. For example, if the floating car technique measures a travel time of 50 minutes on a 25 mile segment, the reported time of 50 minutes does not apply to a driver just beginning the 25 mile segment. Traffic conditions at the beginning of the segment have changed since the floating car technique was started. This driver's travel time will either be better or worse than what was measured by the floating car technique, depending on the time of the peak hour. However, the travel times estimated with loop detectors are estimated over small segments and update conditions every five minutes.

In providing real-time information, the times reported by loop detectors are clearly preferred over travel times estimated by the floating car technique, the cellular phone technique or the license plate matching technique because they are being determined every few minutes based on current traffic conditions and can assist the motorist in making a route or mode change decision. However, all four of these existing techniques provide an adequate estimate of travel time for use in measuring and monitoring congestion.

EMERGING TECHNOLOGIES

Over the years, different methods have emerged with improvements in technology in an effort to accurately measure travel time. With the beginning of the IVHS era a few years ago, a few new technologies have emerged on the scene; namely, automatic vehicle identification (AVI) and global positioning systems (GPS). Several research projects in different areas of the country have recently begun utilizing this promising technology to measure travel time as part of real-time motorist information systems. This section investigates these emerging technologies and evaluates their accuracy, usefulness, and ease of measuring travel time. In addition, the required number of probe vehicles will be discussed along with applicability of AVI to other motorist or industry services.

Automatic Vehicle Identification

Automatic vehicle identification (AVI) is a definite improvement in technology over the current travel time estimation methodologies. The technique involves placing a device in a vehicle which transmits the vehicle's identification number. Receiving units placed along the roadway receive the signal when the vehicles pass by. The receiving unit then transmits the signal to a central computer or communications center. By monitoring several receiving units, the computer can determine a travel time by noting the time it takes a vehicle to pass two sequential receivers. This technology has the advantage of being able to determine travel times continuously, assuming many vehicles in the traffic stream are equipped with the transmitting device. The methodology is still in the developing stage in different parts of the country so an evaluation of actual travel time data is not possible. However, a review of the proposed methodology will follow, including a look at other applications of AVI.

RTTIS Project

During Phase II of Houston's RTTIS project, AVI technology will replace the cellular telephone reporting technique previously discussed. Beginning in the Fall of 1993, 5 corridors of the Houston freeway system will be equipped with AVI readers spaced every 3 to 5 miles, as shown in Figure 7. This is an expansion of the previous system utilizing cellular telephones. Approximately 1,000 probe vehicles equipped with AVI transmitters will travel the corridors during the peak period to/from the CBD/suburbs. Drivers of probe vehicles will again be selected based on their work location, their home location, and their work hours in order to evenly spread the probe vehicles throughout the peak period (7).

The AVI readers will be installed as close as possible to the reporting locations used during the cellular telephone test. The readers used in this study will be placed above the travel lane. In order to save installation costs, they will be placed on existing structures such as overhead sign supports and bridges. In some cases, these structures do not exist at the existing cellular telephone reporting locations (8).

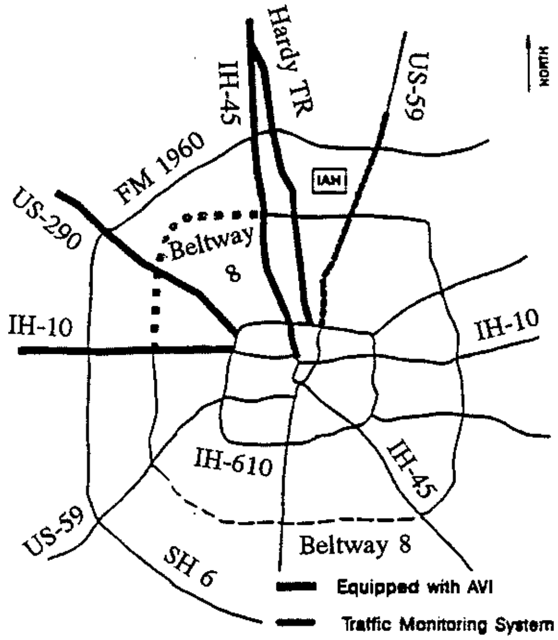

Figure 7. Study Area for Houston AVI Travel Time Study.
SOURCE: Reference (7). p. 611.

Travel time information will be determined at the central communications center by a computer system. At the present time, the primary user of the information will be the Motorist Assistance Patrols to try and identify incident locations. Eventually, the information will be used by other local agencies (such as METRO for use in bus routing) and commercial vehicle companies (such as Federal Express).

TRANSCOM Project

The TRANSCOM Electronic Toll and Traffic Management (ETTM) IVHS Operational Field Test is studying the feasibility of an incident detection system for the New Jersey to Staten Island corridor. The measurement of travel time using the AVI technology is the proposed methodology for detecting incidents. The project feasibility study was completed in February 1993 and implementation is expected before the beginning of 1994 (15).

The ETTM (same as AVI) tags will be placed in selected vehicles traveling on the study corridors in northeastern New Jersey, as shown in Figure 8. The system is scheduled to be installed in three phases. Reader units placed along the roadway will identify tagged vehicles and transmit vehicle identification, reader arrival time, current reader ID lane number, and reader status information to the central computer. The computer will calculate vehicle travel times based on two sequential readers that have identified the same vehicle.

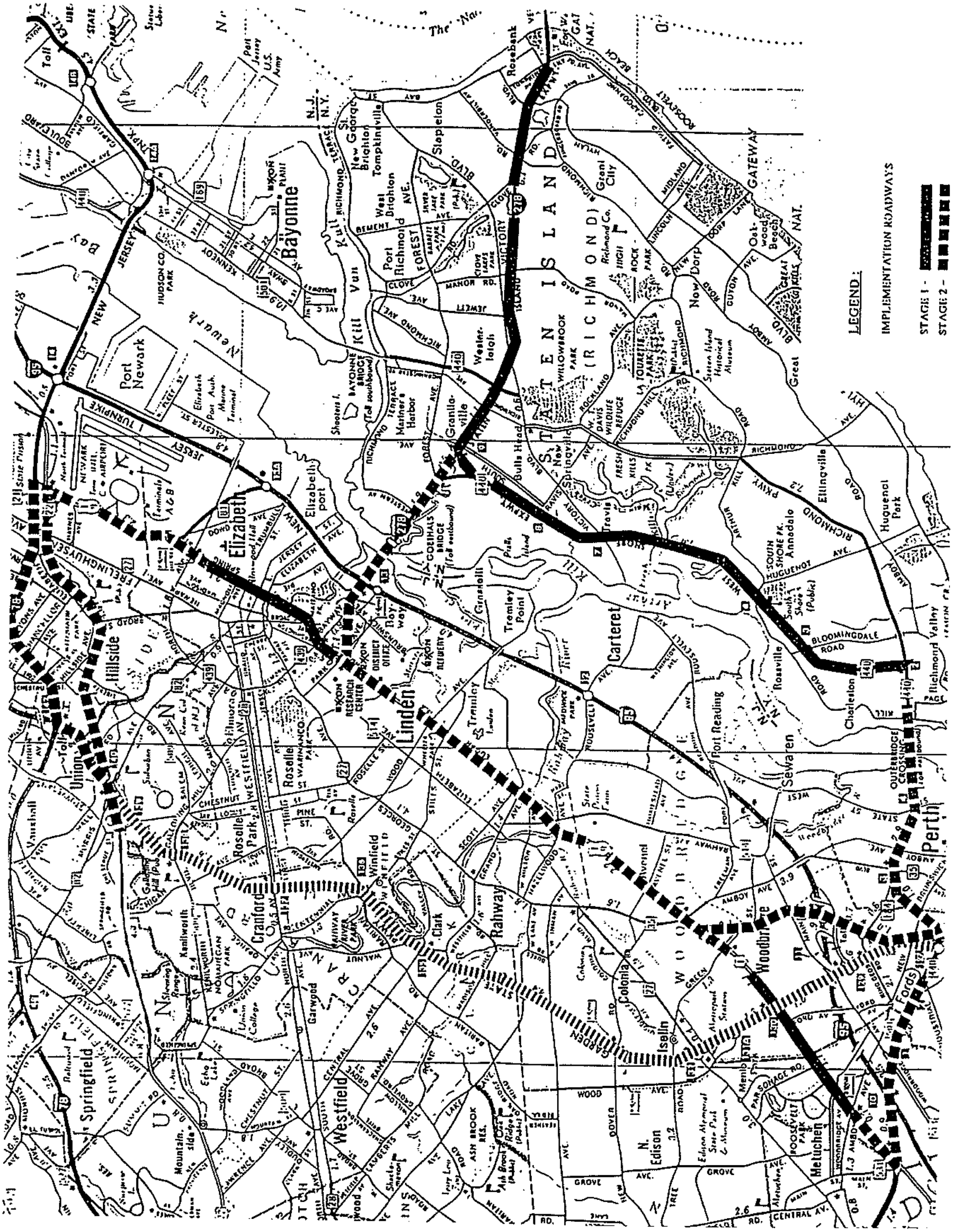

Figure 8. TRANSCOM ETTM Implementation Corridor Locations.
SOURCE: Reference (16), p. 144.

For incident detection purposes, the measured travel times will be converted to average travel speed. The incident detection algorithm uses the speed distribution for each location and individual time periods to project the vehicle's path to the next ETTM detector. The probability of the vehicle's arrival at the next detector is continuously calculated so the probability of an incident can be determined (16). The only travel time data which will be stored by the computer are those which are beyond the expected arrival time (i.e. those which indicate an incident). Travel times which are within the expected range will be discarded.

If the false alarm rate is kept below two percent, incident detection time can be held below five minutes. Therefore, in order to accomplish this task, readers must be placed less than or equal to 1.5 miles apart. The 1.5 mile spacing will permit fewer readers than a 0.5 or 1.0 mile spacing and keep costs to a minimum. However, in some cases due to topography or roadway geometries, readers may need to be placed closer together. Closer spacing of readers will reduce the incident detection false alarm rate, but it will also increase capital costs.

Methodology Evaluation

The emerging AVI technology appears to be a vast improvement over traditional travel time estimation methodologies. The AVI system under construction in Houston will eliminate the majority of the problems discovered with the cellular phone reporting technique. Consistent reporting of vehicle location and time of day by the AVI readers will eliminate the human errors in reporting and recording the vehicle's location. The system is also completely automated, so operating costs will be lower with the elimination of the telephone operators.

In theory, the AVI readers should be capable of reporting real-time traffic information assuming enough probe vehicles are in the traffic stream. Travel times for each segment can be updated frequently with an adequate number of probe vehicles detected. The AVI real-time estimation is an improvement over the current loop detector estimation procedures. The AVI technology can measure travel times over small segments of roadway and then sum the data to estimate a travel time over the entire section. Similarly, the loop detector systems estimate travel time over 1/2 mile segments and sum the data to estimate travel times over the entire section. The major improvement with the AVI technology is that travel times are actually measured by probe vehicles traveling in the traffic stream. Loop detector systems estimate travel times based on loop occupancy, lane volume, and an assumed vehicle length. Problems previously identified with these estimations are eliminated by using the AVI technology.

In addition, the AVI technology provides accurate data for use in measuring and monitoring congestion levels along both freeways and arterial streets. The technology provides daily travel time measurements for monitoring overall travel conditions on the roadway, including buses, other transit vehicles, and the use of HOV lanes. The data collected will eliminate the need for annual or biannual congestion measurements using the floating car or license plate matching techniques.

Other Benefits of AVI Technology

The same AVI technology that can provide accurate travel time data for congestion monitoring activities has other benefits as well. Throughout the United States, Europe, and Japan, AVI technology has been applied to automatic toll collection, traveller information systems, road pricing, and fleet management. Automatic toll collection systems permit tagged vehicles to pass through the toll plaza without having to stop and manually pay a toll. The AVI system automatically reads the tagged vehicle's ID number and deducts the toll from the appropriate account. Traveller information systems provide motorists with information relative to the driver's location on the roadway, which is determined by the AVI technology.

With regards to road pricing, AVI technology can permit charging for using certain roadways during peak time periods in a similar manner as with automatic toll collection systems. A demonstration project using AVI technology for road pricing in Hong Kong ran for about 2 years. The project was considered a success, but it was abandoned due to political unpopularity. For fleet management applications, the AVI technology permits fleet operators to track the locations of their vehicles to increase efficiency. The AVI technology allows delivery companies to identify the locations of their vehicles and report arrival times to their customers, automate driver log information, or for driver access control.

Global Positioning Systems

Global positioning systems (GPS) involve using a satellite system to continuously track a vehicle's location. Vehicles are equipped with a receiving device and a screen which displays a map of the area and the vehicles exact location. Most GPS systems can pinpoint the accuracy of a vehicle to around 50 to 100 feet (17). This technology may have the advantage of being able to determine travel times continuously assuming many vehicles in the traffic stream are equipped with the receiving device. The methodology is still in the developing stage in different parts of the country so an evaluation of actual travel time data is not possible. However, a review of the proposed methodology will follow including an investigation into the proposed number of probe vehicles needed to operate effectively.

ADVANCE Project

The Advanced Driver and Vehicle Advisory Navigation Concept (ADVANCE) is a joint public-private venture in the northeastern Illinois suburbs near Chicago. ADVANCE will provide real-time traffic information to drivers to help reduce congestion and travel time. Each vehicle will be equipped with a navigation and route guidance system consisting of a video screen, a microcomputer, a data communications radio, and a global positioning satellite receiver. The satellite receiver will help determine the vehicle's exact location in order for proper navigational instructions to be given.

Current traffic information will be gathered from and transmitted to the vehicles over a dedicated frequency communications system. The vehicles themselves will be functioning as traffic probes, and will calculate their own travel times with the on-board computer. Any travel time which is computed to be abnormal (i.e. longer than expected) is reported back to the Traffic Information Center. This information, along with information from police reports and other sources, will allow the computer system to determine the best possible route to suggest to the driver (18). The transfer of information in ADVANCE is illustrated in Figure 9.

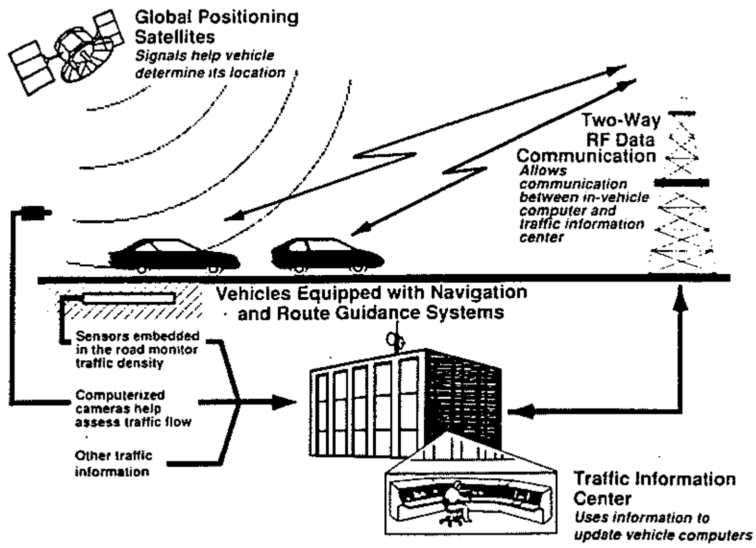

Figure 9. The ADVANCE Data Transmission Concept.
SOURCE: Reference (18).

Probe Vehicle Sample Size

For the ADVANCE project, researchers estimate that 5,000 probe vehicles will be required for enough data to be available for the system to operate effectively. The probe estimate was developed by solving a static, user-optimal route choice model for the road network under consideration during the morning peak period. The total number of trips expected during the peak hour is about 185,000. Thus, the 5,000 probe vehicles would comprise about 2.7% of the traffic stream. During a 20 minute time period, these probe vehicles will traverse about 75% of arterial links in the network. It is anticipated that this percentage will provide sufficient information to evaluate current traffic conditions (19). The proportion of links traversed based on the number of probe vehicles is shown in Figure 10.

At the time of this analysis, the network comprised 200 square miles, and 4,000 probe vehicles were recommended for use in the project. Since the time the report was published, the network has been expanded to cover 250 square miles and the number of required probe vehicles has been increased to 5,000.

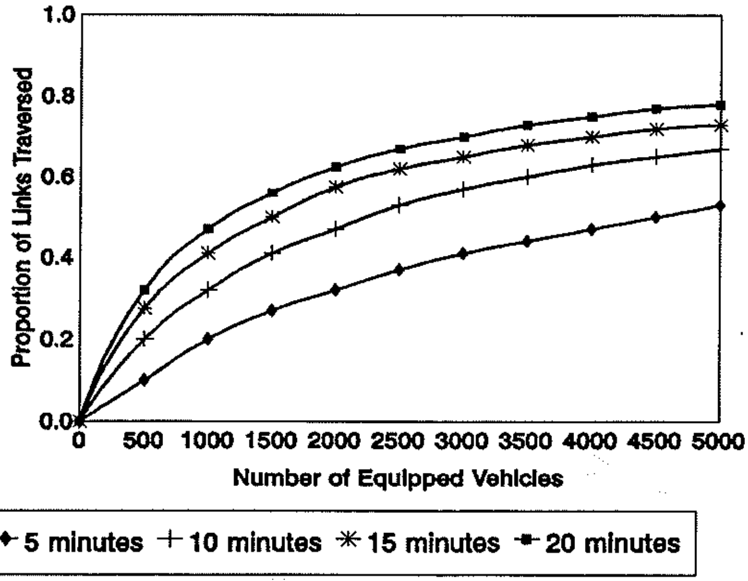

Figure 10. Link Coverage of North Shore Network - All Arterial Links.
SOURCE: Reference (19), p. 20.

In addition, the information transfer process between the probe vehicles and the traffic information center was designed based on the number of probe vehicle reports expected during a short time period. Assuming a worst case scenario and each probe vehicle reported a travel time following a link traversal (each intersection), 3,170 probe reports would be transmitted during a 10 minute period. Therefore, the system had to be designed to accommodate at least 317 probe reports every minute (20). The amount of data that could be transferred during a given time period was a major factor in selecting the probe vehicle sample size.

Due to this process of information transfer from the probe vehicles to the traffic information center, travel times are only reported by the vehicles if they deviate from normal conditions. Therefore, it is possible, although highly unlikely, that all 5,000 probes are travelling within the network and nothing is being reported to the traffic information center. More information regarding the estimation of the required number of probes will be released by the project staff in the near future.

Methodology Evaluation

In theory, GPS technology should be capable of reporting real-time traffic information assuming enough probe vehicles are in the traffic stream. Travel times for different segments of the network are calculated continuously by probe vehicles travelling on that segment. However, only travel times which are unusually long are reported to the traffic information center due to the restrictions on the amount of data that can be transmitted between the vehicles and the traffic information center. This limitation decreases this methodologies applicability for collecting historical travel time data for monitoring congestion. The only data that will be obtained is data for congested conditions.

The major improvement made by using GPS technology is that travel times are actually measured by probe vehicles traveling in the traffic stream. Loop detector systems estimate travel times based on loop occupancy, lane volume, and an assumed vehicle length. Problems previously identified with these estimations are eliminated by using the GPS technology since travel times are measured and not estimated.

In addition, problems exist with the willingness of the public to install the navigation, route guidance, and computer systems in their vehicles. The travel times calculated by GPS technology will not exist without properly equipped probe vehicles travelling in the traffic stream. Despite these problems, the GPS technology appears to be a promising technology that will provide many benefits, such as route guidance and navigation, to motorists in the near future.

CONCLUSIONS

Each of the evaluated travel time methodologies has certain advantages and disadvantages for different applications and for overall effectiveness and reliability. Table 2 identifies general information regarding costs, labor, equipment and proven reliability. Table 3 identifies the applicability of the travel time estimate for different uses, including congestion measurement and monitoring activities, incident detection, and for providing real-time information.

Of the six travel time estimation methodologies evaluated, only three (the floating car technique, license plate matching technique, and detection systems technique) have been completed field tested. The cellular telephone reporting technique is still under evaluation and the AVI and GPS systems are just beginning to be implemented. However, from the available information, several comparisons could be made between the estimation techniques.

Table 2. Comparison of Travel Time Estimation Procedures

	Floating Car Method	License Plate Matching	Cellular Phone Reports	Traffic Detec-tor Data	AVI Tags	GPS System
Methodology Completely Field Proven	Yes	Yes	Some-what	Yes	No	No
Accuracy of Estimate	Good	Good	Fair	Good	Great	Great
Methodology Labor Intensive	Yes	Yes	Somew-hat	No	No	No
Special Equipment Required	No	Some-what	Yes	Yes	Yes	Yes
Comparable Cost of Initiation	Low	Low	Med	High	High	High
Operating Cost/Travel Time Run	Med	Low	Med	Low	Low	Low
Cost of Routine Maintenance	None	None	Med	High	?	?

Table 3. Applicability of Travel Times Computed from Various Methodologies

Computed Travel Time Applicable for	Floating Car Method	License Plate Matching	Cellular Phone Reports	Traffic Detector Data	AVI Tags	GPS System
Annual Congestion Measurement	Y	Y	Y	Y	Y	Y
Daily Congestion Monitoring	P	P	Y	Y	Y	Y
Providing Real-Time Information	N	N	P	Y	Y	Y
Daily Incident Detection	N	N	Y	Y	Y	Y
Evaluating Incident Detection Effectiveness	P	P	Y	Y	Y	Y
Private Business Use (i.e. trucking industry)	N	N	P	P	Y	Y

Y = Yes P = Possible but not recommended N = No

The accuracy of the travel time estimate is one important factor to consider. The floating car technique and license plate matching technique estimates were proven to be reliable and identical estimations of the average travel time along a segment. The detector systems methodology also provides a good travel time estimate providing that the actual average length of vehicles is near the 21.5 feet used in the estimation procedure. The cellular phone technique provides an estimate which is not as accurate, primarily due to the variability in driver reporting times. The two emerging technologies are expected to improve the travel time estimate, due to the automated characteristics, but the techniques have not been completely implemented yet.

The floating car and license plate matching techniques are the most labor intensive compared to the other four methods. The cellular phone method requires some degree of labor to operate the phone system. The other methods rely on electronics and computer systems to automatically collect and record data, thereby eliminating the reliance on manual labor.

An advantage of the floating car technique is that no special equipment is required for implementation. Travel times can be determined with any vehicle and a stopwatch. The license plate matching technique works best when portable computers are used to collect data, but it is possible (but not recommended) to utilize this technique without them. The remaining methods all require specialized equipment, including such items as cellular phones, computer systems, vehicle detectors, and navigation systems.

In respect to investment, operating, and maintenance costs, specific data were not available for each method as to their exact costs. However, general cost comparisons could be made based on each technique's procedures and operating and maintenance requirements. On an annual basis, the floating car and license plate matching techniques' costs are low compared to the other methods. The AVI, GPS, and detector system methodologies require a large investment for equipment installation and equipment maintenance. The cellular phone reporting technique is probably somewhere in between. The only costs associated with installation of this technique are the purchases of many cellular telephones, the installation of a computer system, and the hiring of a phone operator.

Cost per travel time run is low for all methodologies, with the exception of the floating car technique. For each man-hour of labor with the floating car technique, you get only one completed travel time run. However, for the license plate matching technique, about 15 travel time runs are recorded for each man-hour of labor. The cellular telephone reports and detector systems travel time estimations are assumed to be comparable, since many travel time runs are reported every hour by motorists or the loop detector system. Even though the AVI and GPS systems have not been field tested, it is assumed that their performance per man-hour will be similar to the detector systems technique.

Maintenance costs for the detection systems technique will be the highest due to the problems associated with maintaining loop detectors. The floating car and license plate matching techniques do not require routine maintenance since they are not used on a daily basis. The cellular phone reporting technique requires routine costs for monthly phone usage and for operating the traffic control center, but these costs are not as high as those for maintaining nearly 2,000 loop detectors. Unfortunately, it is currently unknown as to the amount of maintenance that will be required for the AVI and GPS systems since they are still in the developing stages.

As indicated in Table 3, the travel times determined from the various methodologies have a wide variety of applications, from congestion measurement to incident detection. All six methodologies are applicable for measuring congestion on an annual basis for use in a congestion management system. However, the floating car method and the license plate matching technique are not recommended for use for daily congestion measurement. The costs associated with using these techniques daily far outweigh the benefits. The other four methodologies would provide daily congestion monitoring information more effectively.

The traffic detector systems, AVI systems, and GPS systems are the only three travel time estimation techniques recommended for providing real-time information to motorists. The other three methodologies are not accurate enough for real-time reporting, and typically are not reported soon enough to be of use to a motorist just beginning his trip.

For incident detection, the reported travel times for the last four methodologies are applicable for both detecting incidents and evaluating incident detection response times. In order for the floating car method and the license plate matching technique to be effective for incident detection, they would have to be done on a continual basis, which makes their use impractical. Incident detection strategies require real-time data about traffic conditions, which the floating car technique and the license plate matching technique are not able to provide. If the final four methodologies are operating effectively, they can be used for evaluating the effectiveness of incident detection procedures. Travel times measured on days before and after the implementation of an incident management program can help to quantify the effect the program has had on traffic conditions.

For travel times to be effective for private industry use, they must be reported in real-time. Package delivery services and the trucking industry need current travel times in order to gain a benefit. By having real-time data, the industry is able to predict arrival times for their customers and help drivers select the quickest route to their destination. The most effective methodologies for this use are the AVI and GPS systems. Both of these methodologies provide real-time data and have vehicle tracking capabilities. Truck locations can be determined from the vehicle identification numbers used in measuring travel times. The other four methods do not have this capability, and therefore, would not provide as large a benefit to the trucking industry.

RECOMMENDATIONS

For measuring and monitoring congestion, providing real-time information, detecting incidents, and assisting the trucking industry, the travel time estimation technique using the automatic vehicle identification technology is preferred over all other methods. The AVI technology accurately measures travel time, and, assuming enough equipped vehicles are in the traffic stream, the data can be reported in real-time. The GPS technology also accomplishes these tasks, but evaluations from several different field tests have not yet been released. Problems are also apparent with the GPS technology in data transfer from individual vehicles to the communications center. If every vehicle using a roadway will be someday be equipped with a GPS system, the data transfer portions of the system must be improved.

The other methodologies, however, are not without merit. For annual congestion measurements, small metropolitan areas can obtain accurate travel time estimates using the license plate matching technique. This method is preferred over the others because of the amount of accurate data that can be collected per man-hour of labor. In small towns, personnel and labor requirements are very important due to the limited transportation staff available. The other methodologies are either too costly or do not provide as much accurate data as the license plate matching technique. Small metropolitan areas are typically not equipped with sophisticated and expensive detection systems to use for travel time estimation.

For cities with established traffic detection systems, the detector systems technique will provide accurate travel time estimates for congestion monitoring and incident detection purposes. However, this methodology is not recommended for cities implementing a new system. The AVI system is preferred because of the degree of accuracy of the travel time estimate.

The cellular telephone matching technique can be used in areas that cannot afford elaborate detection systems if enough volunteers are available who own cellular telephones. The travel times reported are accurate within about a minute, on average, and do provide an adequate picture of the status of congestion or the effectiveness of an incident management program.

Thus, the automatic vehicle identification technique is the preferred travel time estimation methodology for those agencies which want to reap all of the benefits of measuring travel time, such as congestion monitoring, real-time traffic information, incident detection, and fleet tracking. For agencies only interested in annual congestion measurement, the license plate matching technique is preferred over the other methodologies based on its accuracy, cost per travel time run, and ease of implementation.

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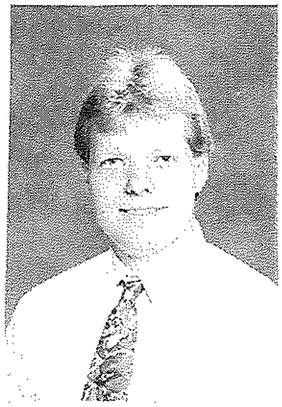

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