ASSESSMENT OF DYNAMIC MESSAGE SIGN TRAVEL TIME INFORMATION ACCURACY

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ABSTRACT

This paper describes a procedure for testing the accuracy of travel times displayed on dynamic message signs (DMSs) using GPS technology. The procedure relies on the capability of GPS receivers to time tag position observations automatically. It also relies on the capability of a traffic management center to generate electronic logs documenting DMS message updates throughout the day. The paper documents the use of the procedure to evaluate the accuracy of travel time information displayed on DMSs in San Antonio, Texas. The paper describes the data collection approach, the synchronization procedure used to match the GPS data with DMS travel time readings, and analysis of the results obtained.

KEYWORDS

Dynamic message signs, travel time, GPS, GIS

BACKGROUND

Like other major metropolitan areas in the U.S., San Antonio has a traffic management center. This center, called TransGuide, monitors traffic operations on a network of freeways and major arterial streets covering most of the metropolitan area (Figure 1). One of the main components of the monitoring system is a series of sensors (mainly loop detector pairs and sonic detectors) that provide the capability to measure point speeds. These detectors are roughly half a mile apart. Based on these point speeds, the system estimates travel times to specific landmarks and displays the estimated travel times on dynamic message signs (DMSs) that are roughly two-three miles apart (Figure 2).

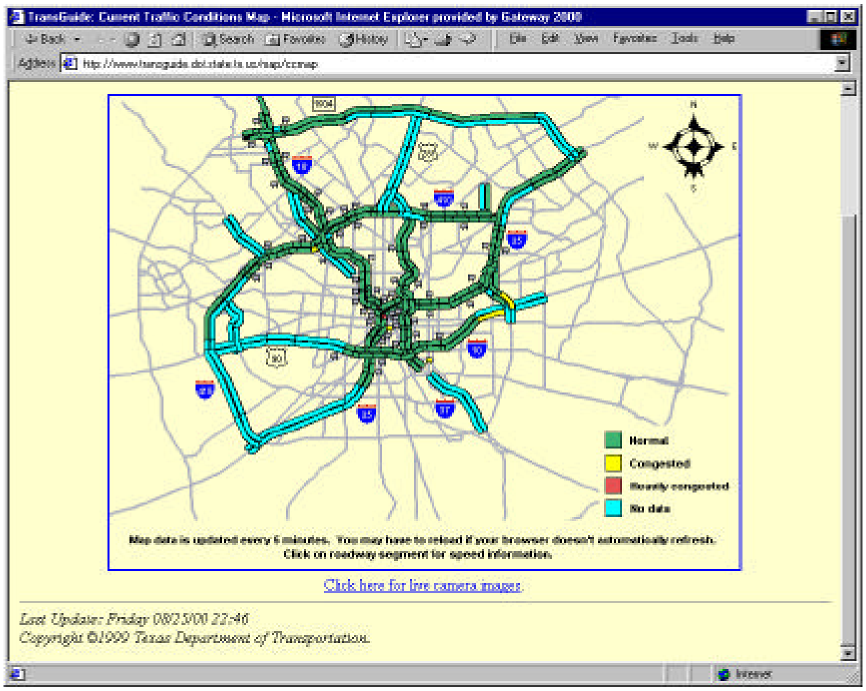


Figure 1. Freeway corridors monitored by TransGuide

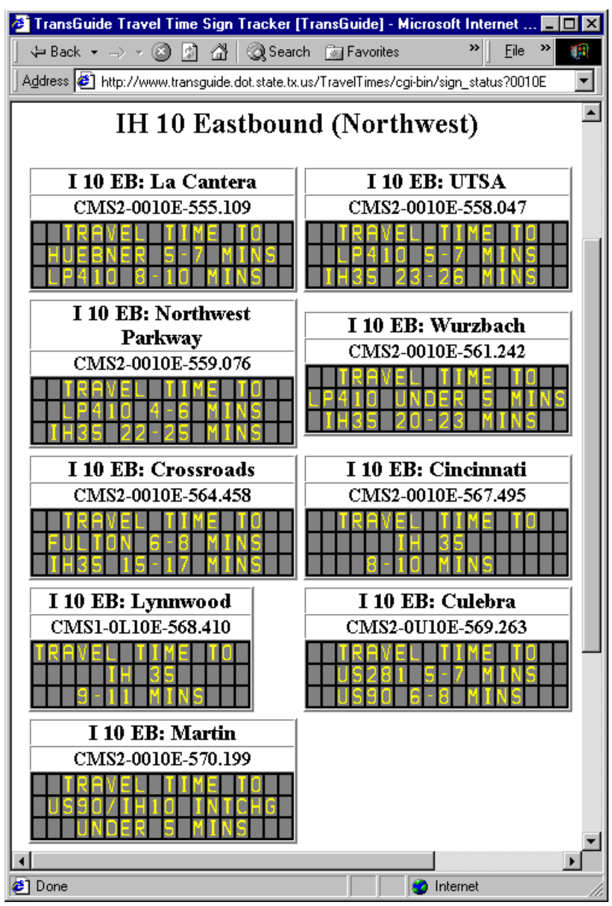


Figure 2. Sample travel times displayed on DMSs located on eastbound IH-10

In general, TransGuide uses the following rules for displaying travel times on the DMSs:

- Estimated travel time is less than 5 minutes: Displayed as "UNDER 5 MINS". For example, if the estimated travel time to IH-410 is 2 minutes and 37 seconds, the travel time is displayed as "TRAVEL TIME TO LP410 UNDER 5 MINS".
- Estimated travel time is between 5-20 minutes: Displayed as "Integer<travel time> - Integer<travel time>+2 MINS". For example, if the estimated travel time to IH-410 is 5 minutes and 45 seconds, the travel time is displayed as "TRAVEL TIME TO LP410 5-7 MINS". Notice that the travel time resolution is actually one minute. For example, if the estimated travel time to IH-410 is 6 minutes and 30 seconds, the travel time is displayed as “TRAVEL TIME TO LP410 6-8 MINS”.
- Estimated travel time is between 20-30 minutes: Displayed as "Integer<travel time> - Integer<travel time>+3 MINS". For example, if the estimated travel time to IH-410 is 21 minutes and 45 seconds, the travel time is displayed as "TRAVEL TIME TO LP410 21-24 MINS". Likewise, if the travel time to IH-410 is 22 minutes and 35 seconds, the travel time is displayed as "TRAVEL TIME TO LP410 22-25 MINS".
- Travel time is larger than 30 minutes: Displayed as "OVER 30 MINS". For example, if the estimated travel time to IH-410 is 34 minutes and 29 seconds, the travel time is displayed as "TRAVEL TIME TO LP410 OVER 30 MINS".

For estimating travel times, the system uses speeds measured with inductive loop detector pairs or sonic detectors that are roughly 0.5 miles apart (Figure 3). The general procedure for calculating travel times between a DMS location and a major interchange located down the road is as follows:

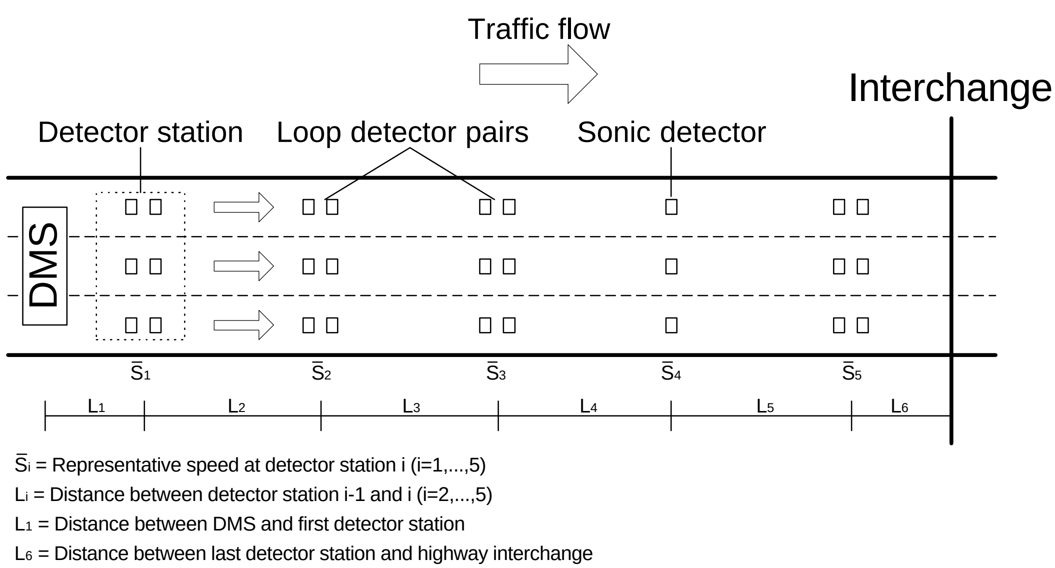


Figure 3. Typical detector and DMS configuration

- Every 20 seconds, the system polls detectors and produces point estimates of speed, volume, and occupancy. These data are stored on an ftp server and may be accessed at a later time for further analysis.
- Every minute, the system reads the most recent detector data off a memory pool and uses these data to estimate representative detector station speeds. At each detector station there may be three or four loop detector pairs (or sonic detectors), one for each lane. A representative speed for the detector station is obtained by averaging the point speeds associated with all of the detectors located at the detector station. For example, if there are three detector pairs at a detector station and the speed readings from the detector pairs are 45, 50, and 60 mph, the representative speed for the detector station is calculated as (45+50+60)/3 = 52 mph.
- The system determines the detector stations that are located between the DMS location and the major interchange. For each pair of adjacent detector stations, the system determines the lowest of the two detector station speeds and assigns that speed to the road segment that connects the adjacent detector stations. For example, if the speeds associated with two adjacent detector stations are 52 and 58 mph, the system assigns 52 mph to the road segment that connects the two adjacent detector stations. The main effect of using this approach for estimating road segment speeds is that the system tends to slightly underestimate speeds which, in turn, should result in slightly overestimated travel times.
- If the system does not receive a signal from a detector station, e.g. due to maintenance, construction, or technical problems at the station, the system uses other adjacent stations, beginning with the station closest to the non-functioning station, to estimate speeds. For example, if the system has the following speed data from three adjacent stations: 52 mph, n/a, and 58 mph, the system assigns 52 mph to the road segment that connects the first and third detector stations involved. If more than one adjacent station is non-functioning, the system simply tries to use the next adjacent detector station until it finds a station with data. Currently, the system does not provide an upper limit to the number of adjacent detector stations polled in case several adjacent stations are not accessible.
- For the road segment between the DMS and the first detector station, the segment speed is assumed to be the speed associated with the first detector station. Likewise, for the road segment between the last detector station and the major interchange, the segment speed is assumed to be the speed associated with the last detector station.
- The system converts each partial road segment speed into an equivalent travel time and adds all of the partial segment travel times to produce an estimate of the total travel time between the DMS location and the major interchange.
- The system converts the estimated travel time to a message following the rules described previously and checks whether the message is the same as the last message displayed at the DMS. If the message is the same, the system does not update the display. If the message is different, the system updates the display and generates a new entry in a log file.

For evaluating the accuracy of the travel time information displayed on the DMSs, a 15-mile corridor on eastbound (inbound) IH-10 on the northwest part of San Antonio was used (Figure 4). The following sections summarize the work completed. First, the paper describes the data collection approach. Second, it describes the procedure to ensure synchronization between the travel time data collected in the field and the travel time data displayed on the DMSs. Third, it provides a summary of the analysis completed.

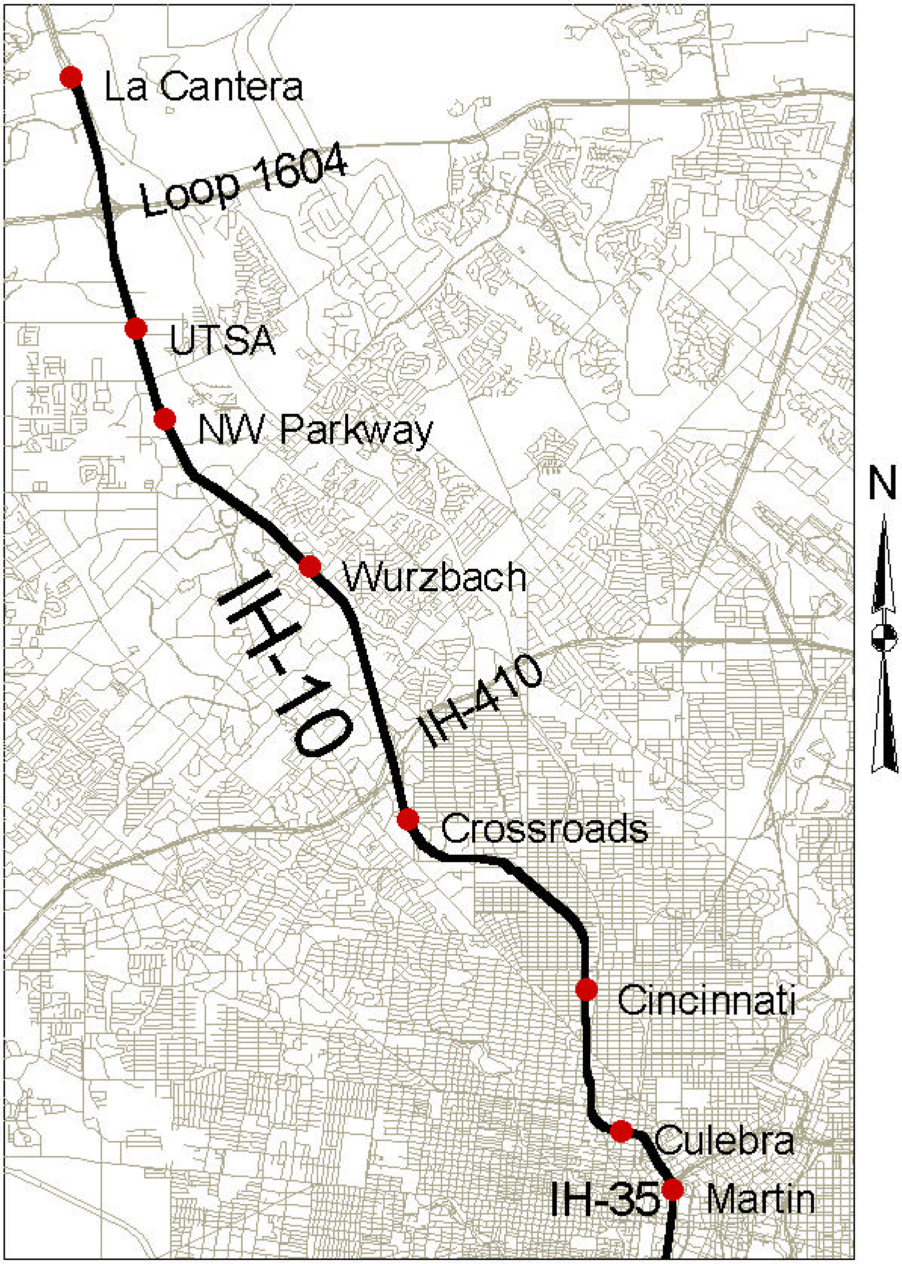


Figure 4. Dynamic message signs located on eastbound -inbound- IH-10 in San Antonio (not shown is a DMS located on a lower deck on IH-10 between Cincinnati and Culebra)

DATA COLLECTION APPROACH

To evaluate the accuracy of the travel time information displayed on the DMSs, a global positioning system (GPS)-based data collection approach was used [1]. For the data collection, there were 14 drivers who completed travel time runs on eastbound IH-10 and who used one of six available Trimble Placer 400 GPS receivers. On each travel time run, drivers collected GPS data automatically every one second. It should be noted that the DMSs and other landmarks had been inventoried previously using a Trimble Pro-XRS GPS receiver. Because the location of all of the DMSs and landmarks was known, drivers did not have to manually record the time they passed each DMS or landmark in the field. It should be noted that drivers did not have to manually record the travel times displayed on the DMSs either because these data were automatically recorded on an electronic data log at TransGuide. As a result, only one driver was needed in each of the vehicles, the driver only had to focus on driving (after the initial equipment setup), and all data synchronization and analysis could be done later in the office.

Figure 5 shows a sample travel time run using GPS data. The points overlay a vector representation of the eastbound upper deck section on IH-10 near Culebra. Using geographic information system (GIS) spatial neighborhood operations and time interpolation, it was possible to determine the time stamp associated with the moment the probe vehicle passed the DMS location. For example, in Figure 5 assume the time stamp for the GPS point immediately before the DMS was 7:30:21 and the time stamp for the point immediately after the DMS was 7:30:22. Using a linear interpolation technique, the time stamp associated with the DMS was 7:30:21.7.

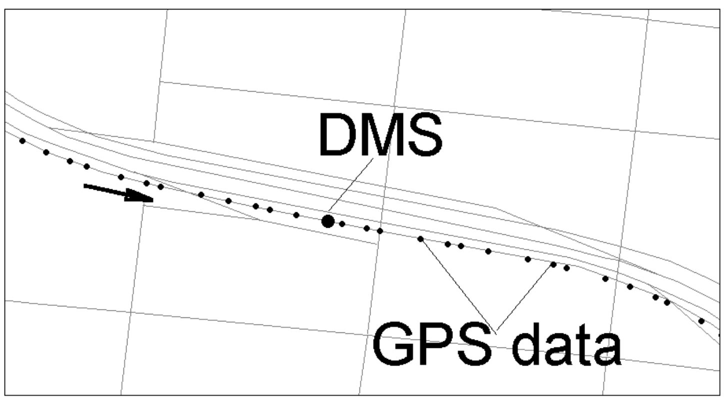


Figure 5. Sample GPS data on eastbound (inbound) IH-10 in San Antonio

DATA SYNCHRONIZATION

A critical component of the data reduction process was synchronizing the GPS-based travel time data and the TransGuide-based DMS travel time data. An analysis of time stamps produced by the GPS receivers indicated a fairly constant offset of about 11 seconds with respect to the Official U.S. Time published by the National Institute of Standards and Technology (NIST) and the U.S. Naval Observatory (USNO) [2]. For example, when the GPS receiver indicated 17:02:00, the reading at the Official U.S. Time web site was 17:01:49, i.e. 11 seconds behind. It may be worth noting that the Official U.S. Time web site readings were made using a high speed Internet connection.

Previous to May 10, 2000, TransGuide relied on the clock in one of its computers for the purposes of synchronizing all system operations. An analysis of the TransGuide system time indicated that the system time had an offset of more than two minutes with respect to the Official U.S. Time and that the offset was growing at a rate of about one second per day. For example, on April 26, 2000, when the Official U.S. Time was 13:56:00, the TransGuide system clock indicated 13:53:57, i.e. 2 minutes and 3 seconds behind. The following day, the offset had grown to 2 minutes and 4 seconds.

On May 10, 2000, at 14:30:00 (Official U.S. Time) or 14:32:17 (TransGuide system time), TransGuide implemented a new algorithm that effectively tied the TransGuide system time to the Official U.S. Time. As a result, all DMS time stamp data after May 10, 2000 at 14:30:00 had an essentially zero offset with respect to the Official U.S. Time.

For simplicity, all time stamps were synchronized with the time stamps provided by the GPS receivers. This meant that all DMS time stamps were modified by adding to the DMS time stamp data 11 seconds plus whatever offset was measured between the Official U.S. Time and the TransGuide system clock. For example, for the DMS time stamp data of April 26, 2000, a total of 2 minutes and 14 seconds were added to the DMS time stamps to ensure synchronization with the GPS data collected that day. For the DMS time stamp data after May 10, 2000 at 14:30:00, only 11 seconds were added to the DMS time stamp data to ensure synchronization with the GPS data.

Once the DMS data and the GPS data were on the same time domain, a procedure was developed to scan the DMS daily log files and extract the messages that were displayed at the time the vehicles passed the DMS locations. The procedure also extracted the corresponding display update time stamps and estimated travel times to facilitate the matching between estimated travel times and ground truth, GPS-based travel times. For example, Table 1 shows the time stamps associated with the travel time run that started on May 5, 2000 at 7:10 am. Table 1 also shows the messages that were displayed when the vehicle passed each DMS location, the time stamps associated with the latest DMS message update, and the corresponding estimated travel time to IH-35.

Table 1. Time corrections added to DMS time stamps to ensure synchronization with GPS-based time stamps

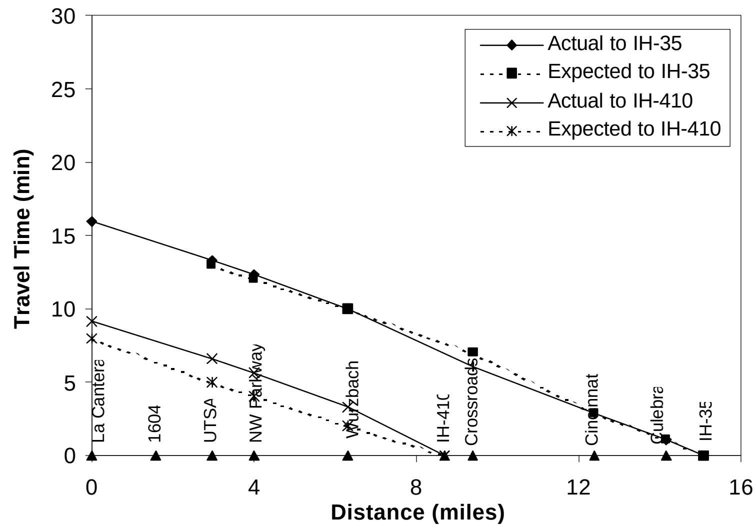
Checkpoint	GPS time stamp	Travel time to IH-35 (mm:ss)	DMS update time stamp	DMS message text	DMS travel time to IH-35 -first value- (min)
La Cantera	7:10:14 am	18:45	6:03:23 am	TRAVEL TIME TO|HUEBNER 5-7 MINS|LP410 8-10 MINS	
Loop 1604	7:11:39 am	17:20			
UTSA	7:12:53 am	16:06	6:59:24 am	TRAVEL TIME TO|LP410 5-7 MINS|IH35 13-15 MINS	13
NW Parkway	7:13:55 am	15:04	7:03:25 am	TRAVEL TIME TO|LP410 4-6 MINS|IH35 12-14 MINS	12
Wurzbach	7:16:13 am	12:46	7:14:42 am	TRAVEL TIME TO|LP410 UNDER 5 MINS|IH35 10-12 MINS	10
IH-410	7:21:08 am	07:51			
Crossroads	7:21:52 am	07:07	7:20:52 am	TRAVEL TIME TO|FULTON 6-8 MINS|IH35 9-11 MINS	9
Cincinnati	7:26:46 am	02:13	7:00:51 am	CONGESTION|ON EXIT TO I-35 N|2 1/2 MILES	
Culebra	7:28:33 am	00:26	7:00:47 am	CONGESTION|ON EXIT TO I-35 N|1/2 MILE	
IH-35	7:28:59 am	00:00			

Once the DMS data and the GPS data were synchronized, it was possible to compare estimated travel times with actual travel time data. For example, Figure 6 shows estimated travel time data and actual travel time data during the AM peak on May 5, 2000. Figure 7 shows estimated travel time data and actual travel time data during the off peak on May 8, 2000. In Figures 6 and 7, the estimated travel time profiles represent travel times displayed on each DMS when the driver passed the DMS while traversing the 15-mile corridor. The actual travel time profiles represent actual travel times spent by the driver traversing the corridor. For example, in Figure 6a, the estimated travel time from UTSA to IH-35 when the driver passed the DMS at UTSA was between 13 and 14 minutes (the actual message read "TRAVEL TIME TO IH 35 13-15 MINS"). Likewise, the estimated travel time from Crossroads to IH-35 when the driver passed the DMS at Crossroads was between 7 and 8 minutes (the actual message read "TRAVEL TIME TO IH 35 7-8 MINS"). By comparison, the actual travel times from UTSA and Crossroads to IH-35 were 13 minutes and 22 seconds and 6 minutes and 3 seconds, respectively.

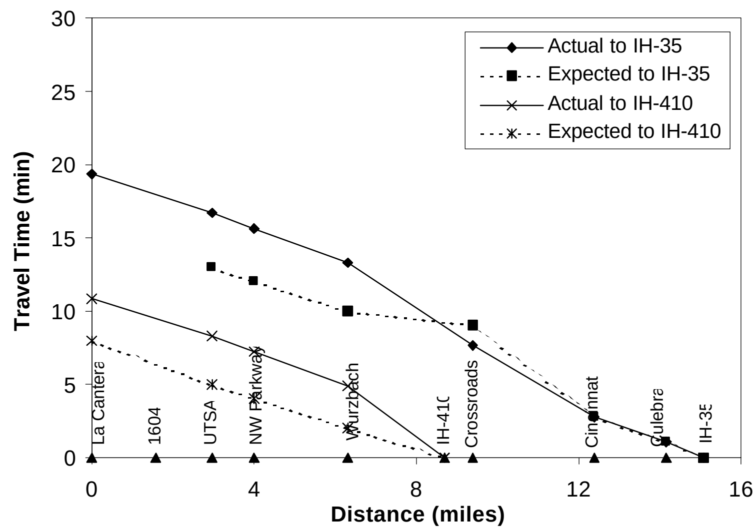
At 7:00 am, when the first vehicle started its travel time run, congestion still had not built up on the corridor and the vehicle was able to traverse the 15-mile corridor in about 15 minutes, i.e. under essentially free flow speed conditions. Ten minutes later when the second vehicle started its travel time run, the system was still predicting free flow speed conditions when in reality the vehicle was already experiencing congestion. Notice that only when the vehicle passed Crossroads the system had started to update the DMS displays to reflect more recent traffic conditions. For the vehicle that started the travel time run at 7:30 am, the system had already updated the displays on all the DMSs, however, because the system uses a snapshot approach for estimating travel times, the system still did not adequately replicate the travel time experienced by the probe vehicle. In contrast to the AM peak runs, traffic conditions during the off-peak period remained essentially uniform both in space and time. As a result, the estimated travel times were very close to those experienced by the probe vehicles. Similar differences in estimated vs. actual travel times were observed for many other travel time runs during the study.

The evaluation of the accuracy of the travel times displayed on the DMSs was made from the point of view of user perception. As a result, a statistical analysis was conducted by using travel time as the primary variable and by measuring how close the system replicated actual travel time conditions. For the analysis, actual travel time data from each DMS to IH-410 (if the DMS was located north of IH-410) or IH-35 were grouped into one-minute estimated travel time bins (5-6 minutes, 6-7 minutes, 7-8 minutes, and so on), and each bin was treated as an independent population. This grouping provided a very convenient way of comparing actual travel times with estimated travel times. It is acknowledged, though, that there is a spatial and temporal correlation among travel time values associated with individual travel time runs that would be lost by treating each travel time value independently. However, as a whole, the methodology used provides a measure of what typical users of the system -mainly regular commuters- would perceive as the accuracy associated with travel time postings on the DMSs.

(a) Run started at 7:00 am



(b) Run started at 7:10 am



(c) Run started at 7:30 am

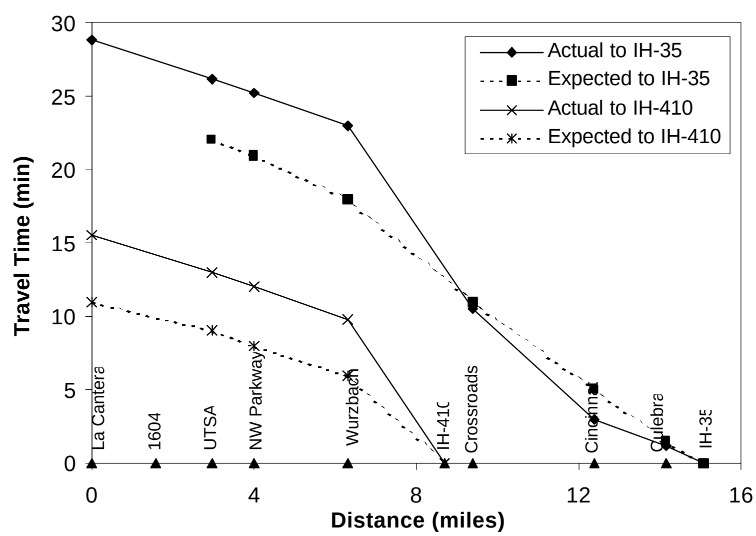
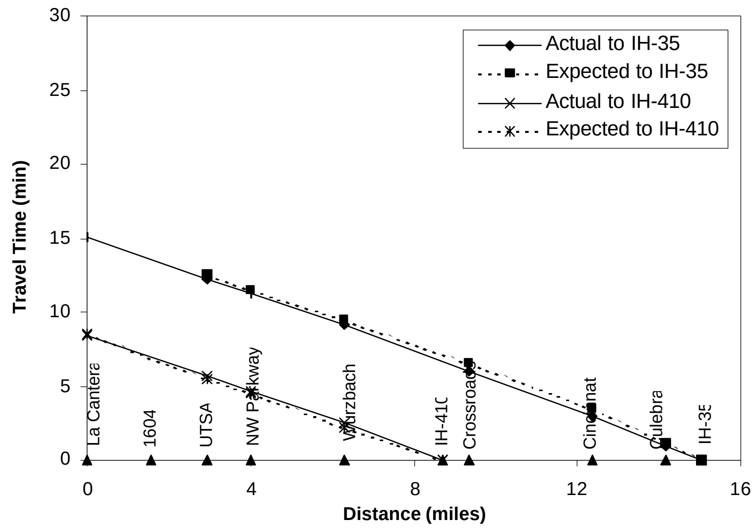
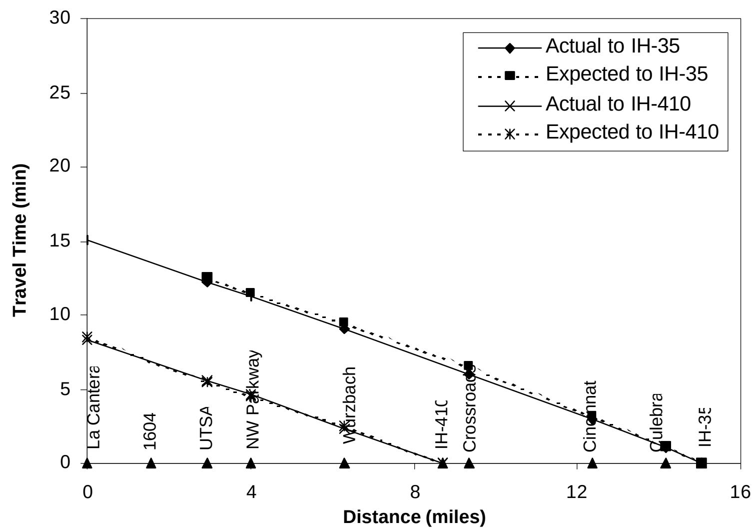


Figure 6. Travel time from specific DMS locations to IH-410 and IH-35 on IH-10 (travel time runs made during the AM peak on May 5, 2000)

(a) Run started at 12:50 pm



(b) Run started at 1:30 pm



(c) Run started at 1:50 pm

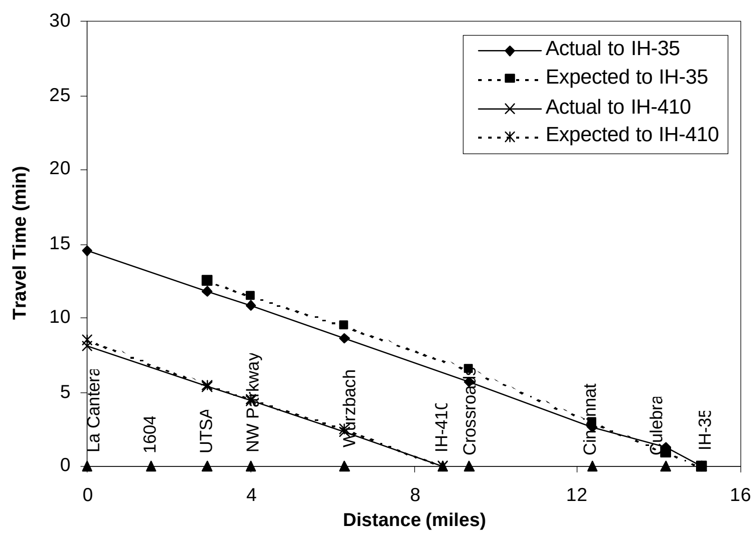
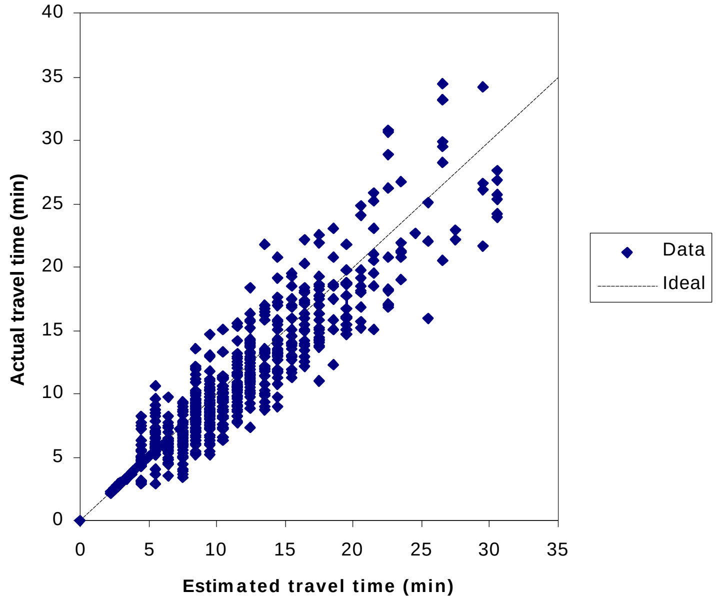


Figure 7. Travel time from specific DMS locations to IH-410 and IH-35 on IH-10 (travel time runs made during the off-peak on May 8, 2000)

ANALYSIS

During the April 25 - May 31, 2000 time period, 200 travel time runs on eastbound IH-10 were made: 102 travel time runs during the AM peak (mainly 7 - 8 am), and 98 travel time runs during the off-peak (mainly 1-3 pm). The 200 travel time runs resulted in 1,967 travel time data points (actual travel time vs. estimated travel time): 968 data points during the AM peak and 999 data points during the off-peak. These points are shown in Figure 8. In total, 14 drivers operating a total of 6 GPS receivers were involved. For consistency, drivers were instructed to use the floating car technique and to stay on the middle lane as much as possible.

(a) AM peak traffic conditions (968 travel time data points)



(b) Off-peak traffic conditions (999 travel time data points)

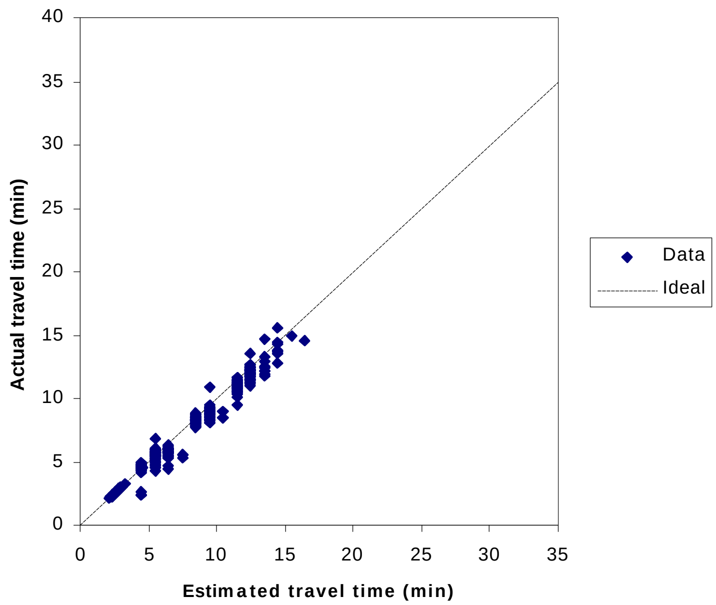


Figure 8. Estimated vs. actual travel time

An analysis of the trends shown in Figure 8 indicates the following:

- As expected, the trends show a noticeable discrepancy between actual travel times and estimated travel times during the AM peak runs. In contrast, there was a much closer agreement between actual travel times and estimated travel times during the off-peak runs. During the AM peak runs, traffic conditions varied greatly over time along the 15-mile corridor. As a result, the traffic conditions that characterized the corridor when the probe vehicles started their travel time runs were no long valid as the vehicles traversed the corridor. The travel time profiles shown in Figure 6 provide a clear indication of this situation.
- In contrast to the AM peak runs, traffic conditions during the off-peak period remained essentially uniform both in space and time. As a result, the estimated travel times were very close to those experienced by the probe vehicles. This is a good indication that the algorithm for estimating travel times is at least appropriate to handle off-peak traffic conditions.
- The data points in Figure 8 appeared to be aligned along vertical lines. This is the result of the grouping done on the data points according to the one-minute estimated travel time bins mentioned previously.
- Both during the AM peak and off-peak periods, the trends shown in Figure 8 suggest that estimated travel times tend to be slightly larger than actual travel times. To measure this effect, a power function was generated for each travel time distribution [3]. In most cases, the power percentage was high with the average observed travel time being lower than the bin mid-value. This is an indication that the algorithm tends to slightly overestimate travel times.

Figure 9 shows two sample distributions of actual travel times. Figure 9a shows the actual travel time distribution associated with the AM peak 12-13 minute estimated travel time bin. Figure 9b shows the actual travel time distribution associated with the off-peak 11-12 minute estimated travel time bin. An analysis of the travel time distributions shown in Figure 9 and all of the other distributions associated with the data points shown in Figure 8 indicates the following:

(a) AM peak

(b) Off-peak

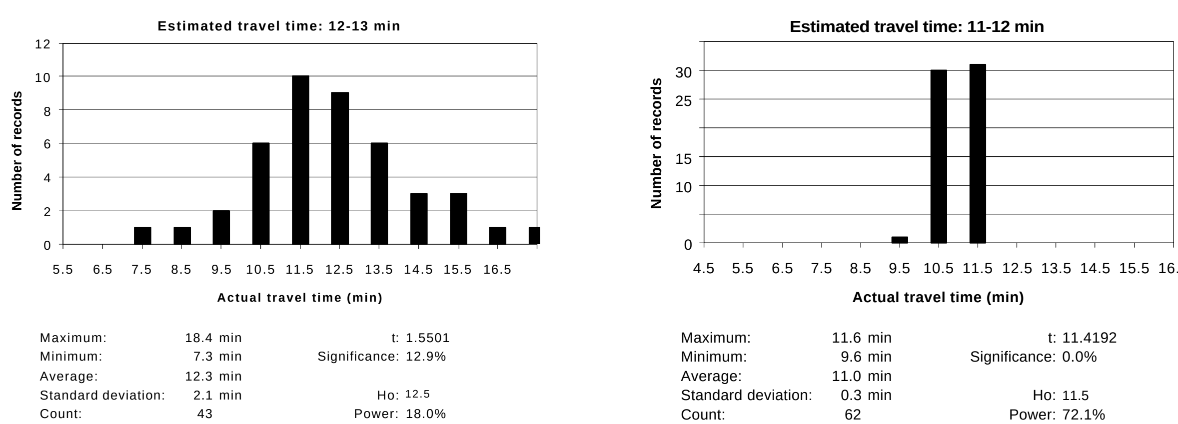


Figure 9. Sample actual travel time distributions

- For the AM peak runs, the standard deviation of the travel time distributions varied from 1.5 to 3 minutes. Assuming a normal distribution, this observation would indicate that actual travel times tend to fluctuate 1.5 - 3 minutes around the mean roughly 68% of the time (or 3 - 6 minutes 95% of the time). This is an indication that the 2-minute window used for the DMS displays may be exceeded more than 30% of the time.
- For the PM peak runs, the standard deviation of the travel time distributions varied from 0.3 to 0.9 minutes. As before, assuming a normal distribution, this observation would indicate that actual travel times tend to fluctuate 0.3 - 0.9 minutes around the mean roughly 68% of the time (or 0.6 - 1.8 minutes 95% of the time). This is an indication that the 2-minute window used for the DMS displays is exceeded less than 5% of the time.

CONCLUSIONS

This paper describes a procedure for testing the accuracy of travel times displayed on dynamic message signs (DMSs) using GPS technology. The procedure relies on the capability of GPS receivers to time tag position observations automatically. It also relies on the capability of a traffic management center to generate electronic logs documenting DMS message updates throughout the day. The paper emphasizes the need to accurately synchronize DMS travel time data with GPS-based travel time data.

The procedure was tested using data collected on a section of freeway monitored by TransGuide in San Antonio, Texas. For the evaluation, 200 travel time runs were made, roughly half of them during the AM peak and the remaining half during the off-peak. An analysis of AM peak results indicates a significant discrepancy between travel times displayed on the DMSs and actual GPS-based travel times. In contrast, during the off-peak discrepancies between travel times displayed on the DMSs and actual travel times were very small. These results are consistent with the snapshot approach currently used by TransGuide for estimating travel times and suggest that a more accurate predictive algorithm would result in lower discrepancies between travel times displayed on the DMSs and actual travel times experienced by drivers.

ACKNOWLEDGEMENTS

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