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Title: Evaluation of the Accuracy of a Real-Time Travel Time Prediction System in a Freeway Construction Work Zone

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ABSTRACT

This is an investigation of the accuracy of the travel times displayed by a real-time travel time prediction system (TIPS) in a construction work zone. TIPS includes changeable message signs (CMSs) displaying the travel time and distance to the end of the work zone to motorists. The travel times displayed by these CMSs are computed by an intelligent traffic algorithm and travel-time estimation model of the TIPS software, which takes input from strategically placed microwave radar sensors that detect the vehicle traffic on each lane of the freeway. Besides the CMSs and the radar sensors, the TIPS system includes the computer and microcontroller computing the travel times, 220 MHz radios for transmitting data from the sensors to the computer and from the computer to the CMSs, and trailers with solar panels and batteries to power the radar sensors, CMSs, and radios. The evaluation included an accuracy analysis between the predicted and actual recorded travel times. Three crews driving independently of each other in the traffic stream recorded predicted and actual travel times at three CMSs to the end of the work zone for 12 hours each day for three consecutive days, resulting in 119 trial runs. Based on the regression analysis of actual times vs. predicted times, the system does on the average a reasonable job in predicting the travel times to the end of the work zone. About 88% of the actual times recorded for each sign, and for all the signs combined, were within a range of ±4 minutes of the predicted time. However, a few differences (actual-predicted) as great as 18 minutes were observed. In summary we may conclude that the real-time TIPS system represents a definite improvement over any static non-real-time display system. It provides, in general and most of the time, useful and relatively accurate travel time predictions to the motoring public.

INTRODUCTION

Lack of real-time travel time or delay information in freeway construction work zones is one of the main causes for motorist frustration today [1]. The need for better information for drivers in work zones is reinforced by the fact that "each year upwards of 1,000 fatalities occur in work zones alone" [2]. In 1999 there were 868 work zone accident fatalities [3]. In addition, there are many more injuries, accidents, and higher levels of stress associated with travel through work zones. "Major contributing factors to work zone accidents include exceeding safe speeds / speed limit and high travel speed differentials upstream of the work zone. In addition, major work zone operations inevitably produce congestion, which frustrates travelers whether they be commuters, commercial vehicle operators, or tourists. Furthermore, industry studies cite 'lack of credible information' as a key source of stress facing all travelers. Current static signs and stand-alone, preprogrammed Changeable Message Signs (CMS) do not adequately address the cited problems, because their messages are often obsolete and/or not detailed enough to be useful." [2]

To answer this need, the Travel Time Prediction System (TIPS) has been developed by P. D. Pant, Professor of Civil and Environmental Engineering at the University of Cincinnati, under the sponsorship of the Ohio Department of Transportation (ODOT) and the Federal Highway Administration (FHWA). Quoting from the TIPS website [1]: "The Travel Time Prediction System (TIPS) is a portable automated system for predicting and displaying travel time for motorists in advance of and through work zones, on a real-time basis. It collects real-time traffic flow data using roadside non-contact sensors, processes the data in an on-site personal computer, computes estimated travel time between different points on the freeway, and displays travel time information on several portable, electronic CMSs positioned at pre-determined locations along the freeway." These predetermined CMS locations along the freeway are usually before open exit ramps, allowing travelers familiar with the area to choose an alternate route to their destination when a long predicted travel time is displayed.

The TIPS website adds [1]: "The key advantage of TIPS is providing travel time information to motorists in advance of and through work zone, on a real-time basis. TIPS is designed to be portable from one work zone to another and to work with minimal human supervision. The system has been designed to incorporate features that make the system adaptable to different work zones, easily modifiable, and easy to use. TIPS allows motorists to make decisions about staying on the freeway or taking an alternate route, based on the travel time information displayed on the changeable message signs." More complete information on TIPS is available in the report *A Portable Real-Time Traffic Control System for Freeway Work Zones* by Prahlad D. Pant [4]. In addition to TIPS, a second somewhat similar system exists. Called Adaptir, it was developed by the Scientex Corporation. [2]

TIPS was implemented in a work zone on a 21 km (13 mile) stretch of I-75 northbound near downtown Dayton, Ohio that was regularly subject to traffic congestion, especially at peak times. The present study of TIPS was conducted during this implementation. The accuracy of TIPS was measured, both through field measurements and through a survey of motorists. The survey results will be presented separately.

BRIEF DESCRIPTION OF TIPS

The concerns associated with the development of TIPS include: mitigating driver frustration and rage, improving the safety of workers in zones, alleviating traffic congestion as drivers may choose alternate routes, and reducing the number of accidents in and around work zones.

A work zone can be divided into four parts: an advance warning area where motorists are notified of construction, a transition area where traffic is redirected into a suitable path, an activity area where the actual work occurs, and a termination area where normal driving is resumed. TIPS works by collecting traffic flow rate information throughout the zone to generate input for signs placed in the warning area, and perhaps additional areas as warranted.

According to [1], TIPS consists of the following components:

- Microwave radar sensors for vehicle detection on each lane of the freeway;

- Microcontroller with a specially-written program for calculating traffic volume and occupancy for each lane and responding to polling requests;

- 220 MHz radios for transmitting traffic flow data from each microcontroller to the on-site personal computer (PC);

- Intelligent traffic algorithm and travel-time estimation model residing in the specially-developed TIPS software in Windows NT environment;

- 220 MHz radios for transmitting travel time information from the PC to portable changeable message signs;

- Changeable message signs for displaying travel time information to motorists;

- Trailers for mounting sensors and radios, and solar panels for supplying electrical power for their operation.

The TIPS algorithm computes travel times based on weighted average lane occupancies [4, p50-55]. The velocity is modeled as a decaying exponential $v=v_0e^{-kOCCW}$, where v is velocity and *OCCW* is weighted average lane occupancy, and v_0 and k are parameters whose values depend on which of three regions the value of *OCCW* lies: 0-20%, 20-35%, or 35-90%. The travel time is computed by figuring out the travel time between stations as time = distance /v, and summing all the travel times to get a total travel time from a CMS to the end of the work zone. This procedure is executed every 30 seconds. The four most recent travel times, including the current one, are averaged to compute the message travel time. If this message travel time differs from the displayed travel time for a given period of time (the consistency time), the time displayed on the CMS is changed (3 minutes in this installation).

This configuration results in the following virtues for the TIPS system [4, p. 5]:

- *Real-time*: Traffic flow data in TIPS are obtained and analyzed in real-time, providing frequently updated information for motorists.

- *Portability*: TIPS has been designed to be as portable as possible, hence allowing its installation (with only minor modifications) at different locations.

- *Flexibility*: The overall hardware design of TIPS is based on using readily available, current, off-the-shelf components in a way that allows replacement, should more advanced devices (e.g. traffic detectors or wireless communication devices) become available in the future.

- *Automation*: A principal objective of TIPS is to operate in an autonomous manner with as minimal supervision as possible by human operators.

- *Reliability*: TIPS has been designed to provide accurate and reliable information, keeping in mind the consequences of misinforming motorists in a work zone situation.

- *Modifiability*: In the future, TIPS can be custom modified to suit specific traffic management needs as in integrating TIPS with an already existing regional traffic management system (RTMS) or for automated information transfer to the Internet. It is not necessary that TIPS be used only in a work zone. It can be used on any congested stretch of normal freeway.

- *Adaptability*: Standardized components, installation, operation, and message display allow TIPS to be used anywhere in the United States. Different travel time prediction algorithms for different types of lane closures (part-width construction and crossovers) can be incorporated in the system making it comprehensive and adaptable to different situations.

Figure 1 shows a sensor station trailer configured with traffic sensor, microwave antenna, and solar panel. Figure 2 shows a changeable message sign with a message generated by the TIPS system predicting the travel time remaining to the end of the work zone alternating with a display of the distance.

OBJECTIVE OF STUDY

The objective of the first part of this study was to determine the accuracy of the predicted travel times when compared to the actual travel times. The results of a survey of driver acceptance of the TIPS system are presented separately [6, 7].

METHOD

Description of Test Site

Figure 3 illustrates the deployment of the TIPS system which was deployed on I-75 (north bound) in the Dayton area on July 14, 2000 and was in operation daily 7 days a week from 5 AM to 8 PM until November 4, 2000. On a few occasions, TIPS was operated until 12 Midnight and was run continuously 24 hours a day from September 22 to September 25 to facilitate nighttime construction and an additional lane closure during this period.

There were three Changeable Message (time/distance) Signs (CMS) as illustrated in Figure 2, and 5 sensor stations of the type illustrated in Figure 1. Each CMS was placed in the advance of an exit. These signs displayed alternately the predicted travel time to the end of the work zone and also the distance in miles to the end of the work zone. The predicted time message was displayed on the sign for 4.0 seconds before being switched to the remaining mileage message for 1.5 seconds. The time for switching messages was negligibly small [5].There was an initial CMS in advance of the three time/distance message signs advising the motorists: “WORKZONE ENDS 14 MILES”. The resolution of the system was 4 minutes; it predicted travel times through the work zone to the nearest multiple of 4 minutes. The consistency time was 3 minutes.

Description of the Experimental Procedure

Three ODOT crews consisting of one driver and one data recorder were used for three days (Thursday, October 12, 2000; Friday October 13, 2000; and Saturday, October 14, 2000). Each crew drove 12 hours each day and made between 11 and 17 runs through the work zone on I75 northbound from SR 73 to Stanley Avenue.

The drivers and data recorders were given oral and written instructions. The first crew started at 5 AM, the second at 6 AM, and the third started at 7 AM each day and drove within the traffic stream as instructed. At each of the three variable time/distance message signs the data recorder recorded the predicted travel time as stated on the sign and the actual time of the day at this point on a special data collection sheet. The actual time when the end of the work zone was reached was also recorded. A digital clock showing hours and minutes on a 19 mm (3/4”) numeral height display, backlit to be readable in darkness mounted on each vehicle’s dashboard was used to record the time values.

RESULTS

Accuracy of Predicted Travel Time Values

There were a total of 119 runs recorded by the three crews during the three-day period. Two observations for the Third CMS due to glare and difficult reading conditions resulted in 117 usable observations for this sign. Figure 4, Figure 5, and Figure 6 illustrate the actual observed travel times as a function of the predicted travel times. It should be noted that the predicted travel times could only assume values that are integer multiples of 4 minutes ranging between 8 minutes and 44 minutes (i.e. 8, 12, 16, etc.). Any of these displayed fixed values were also left constant for a time period of 3 minutes before a change, either up or down in multiples of 4 minutes, could be displayed. Figure 4 through Figure 6 also display the regression lines, the regression equations, and the standard deviations around the regression line, which indicate a fairly accurate least squares linear fit. The intercept value and the slope for each sign were statistically tested at the 0.05 level of significance and the hypothesis that the intercept value is 0.0 and that the slope value is 1.0 cannot be rejected based on the sample information provided. It should be noted that in Figure 4 through Figure 6 a displayed data point might represent more than one observation.

Figure 7 through Figure 10 indicate the differences between the actual recorded travel times and the predicted travel times (Actual-Predicted) in terms of frequencies and cumulative relative frequencies for each of the three CMSs and for the data of the three CMSs combined.

We computed the frequency and relative frequency for the absolute value of the time differences, in other words, those measurements where the predicted travel time equaled exactly the actual travel time, those which were off by ±1 minute, those off by ±2 minutes, and so on. Figure 11 through Figure 14 show how the cumulative percentages increase as the absolute value of the difference increases from zero to higher values.

A more detailed presentation and discussion of these results as well as a survey of motorists traveling through the site is presented in a report prepared for ODOT [6].

DISCUSSION AND CONCLUSIONS

The accuracy evaluation based on a total of 119 runs indicates that for each of the three CMSs, and for the data of all three CMSs combined, the cumulative relative frequency is very stable at ±4 minutes, staying at around 88% accuracy. This means that 88% of the readings taken for any CMS or for all three CMSs were accurate within ±4 minutes, which is also the resolution of the system. At half that range, ±2 minutes, the data are still pretty stable, ranging from just under 65% to something over 70%. Like beauty, accuracy is in the eyes of the beholder. For example, if one would require a ±2 minute range as an accuracy requirement for 90% of all observations, then the present TIPS system would fail, since the percentages for each sign and all signs combined is in the range from 65 to 71 percent. Also, a 4-minute difference for a predicted travel time of 8 minutes represents a 50% error. At a predicted time value of 12 minutes, a difference of 4 minutes still represents a 33% error.

Based on the regression analysis, the system does a reasonable job in predicting on the average the travel times to the end of the work zone. Based on the analysis of the time differences between the actual and the predicted travel times, there exists a certain variability which appears to increase somewhat with increasing predicted travel times. Some of the observed higher differences between the actual and the predicted travel times could possibly have been avoided by placing one of the microwave traffic sensor stations at a different location, which might suggest that proper strategic placement of the microwave traffic sensor stations is important.

A further evaluation and possible refinement of the prediction time steps (presently 4 minutes), the holding time for a predicted time value (presently 3 minutes), as well as the prediction time algorithm would seem to be beneficial in order to possibly further increase the prediction accuracy and the motoring public's confidence into the accuracy and reliability of the time prediction system. It is, however, not clear whether or not such an effort would actually result in significantly more accurate predicted travel times, considering that the traffic flow process is a stochastic process with a certain inherent non-predictable variability. Further, to demonstrate any improvement in the predicted travel time accuracy, additional field tests to assess the accuracy of predicted travel times such as were carried out in this study would need to be conducted.

In summary we may conclude that the real-time TIPS system represents a definite improvement over any static non-real-time display system, assuming proper placement of the microwave radar traffic sensors. It provides, in general and most of the time, useful and relatively accurate travel time predictions to the motoring public.

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REFERENCES

[1] Prahlad D. Pant, “Introduction to TIPS”, http://www.pptips.com/intro.htm.

[2] The Scientex Corporation, “Adaptir Home page”, http://www.scientexcorp.aa.psiweb.com/ad-main.htm.

[3] Federal Highway Administration, “National Work Zone Awareness Week 2001”, http://safety.fhwa.dot.gov/fourthlevel/nwzaw01.htm.

[4] Prahlad D. Pant, *A Portable Real-Time Traffic Control System for Freeway Work Zones*, Report No. FHWA/OH-2000/011, July 2000.

[5] Prahlad D. Pant, personal communication Oct. 17, 2001.

[6] Helmut T. Zwahlen, *Evaluation of a Real-Time Travel Time Prediction System in a Freeway Construction Work Zone*, Final Report, Prepared for David L. Holstein, P.E., Administrator, Office of Traffic Engineering, Ohio Department of Transportation, 1980 East Broad Street, Columbus, Ohio, 43223, March 2001.

[7] Helmut T. Zwahlen and Andrew Russ, “Evaluation of the Motoring Public’s Acceptance of a Real-Time Travel Time Prediction System in a Freeway Construction Work Zone”, Paper prepared for Presentation at the 81st Annual Meeting of the Transportation Research Board, January 13-17, 2002, National Academy of Sciences, Washington DC, Paper No. 02-2372.

LIST OF FIGURES

Figure 1. Sensor station trailer configured with traffic sensor, microwave antenna, and solar panel.

a) b)

Figure 2. Changeable Message Sign in TIPS system displaying time (a) and distance (b) to the end of the work zone in alternating messages.

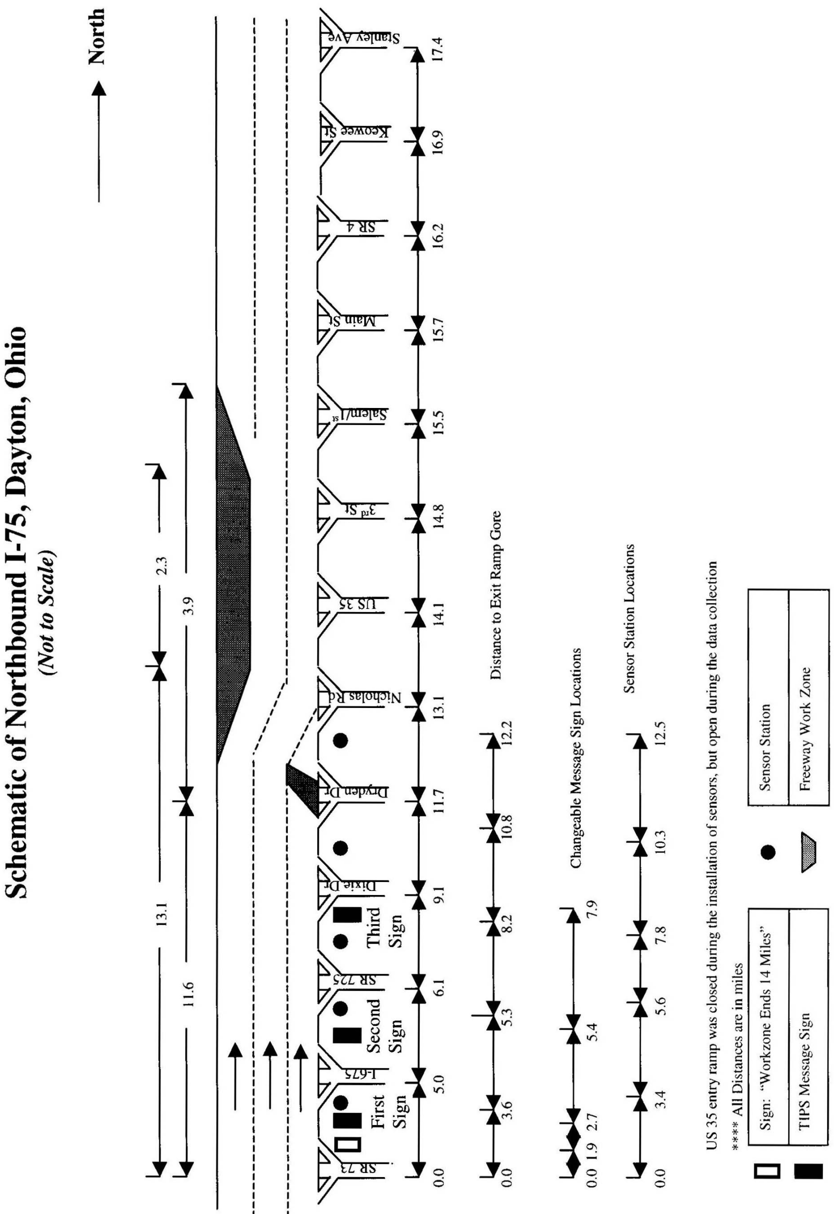

Figure 3. Schematic diagram of work zone on I-75 in Dayton, Ohio where TIPS was evaluated.

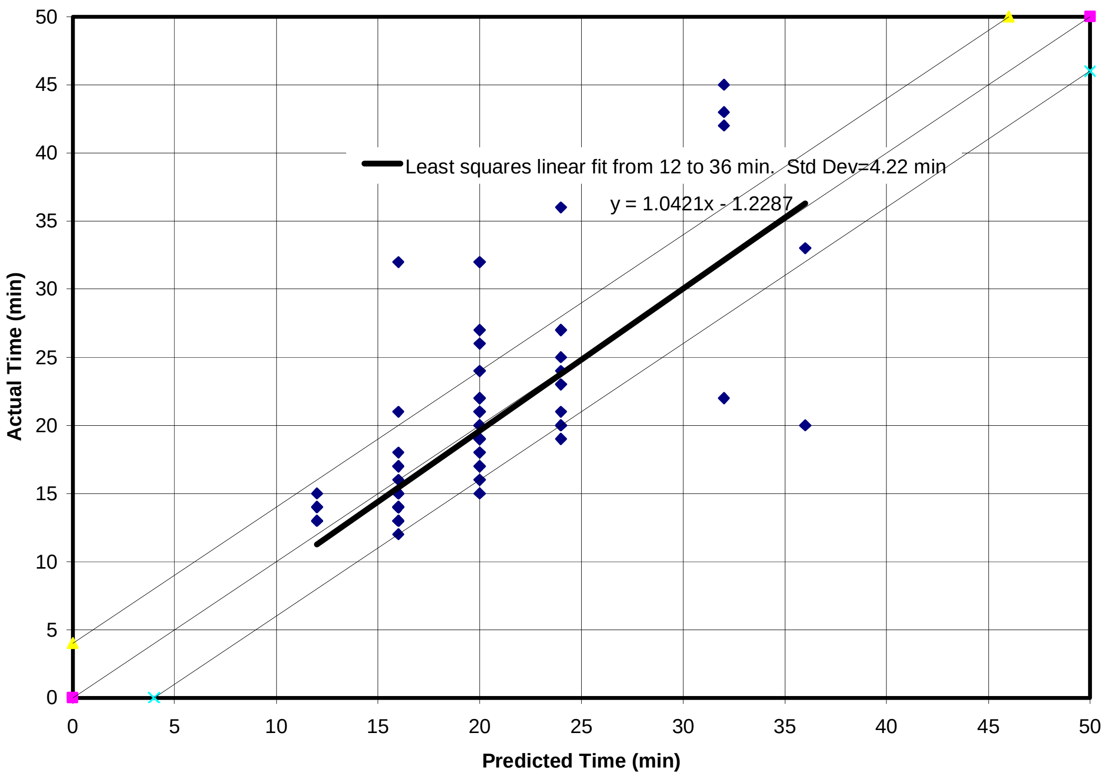

Figure 4. Actual travel times as a function of predicted travel times for the First CMS, showing linear least squares fit line, equation, and standard deviation around the regression line. The three lighter lines in the drawing represent the equations Actual Time = Predicted Time, Actual Time = Predicted Time + 4 minutes, and Actual Time = Predicted Time – 4 minutes.

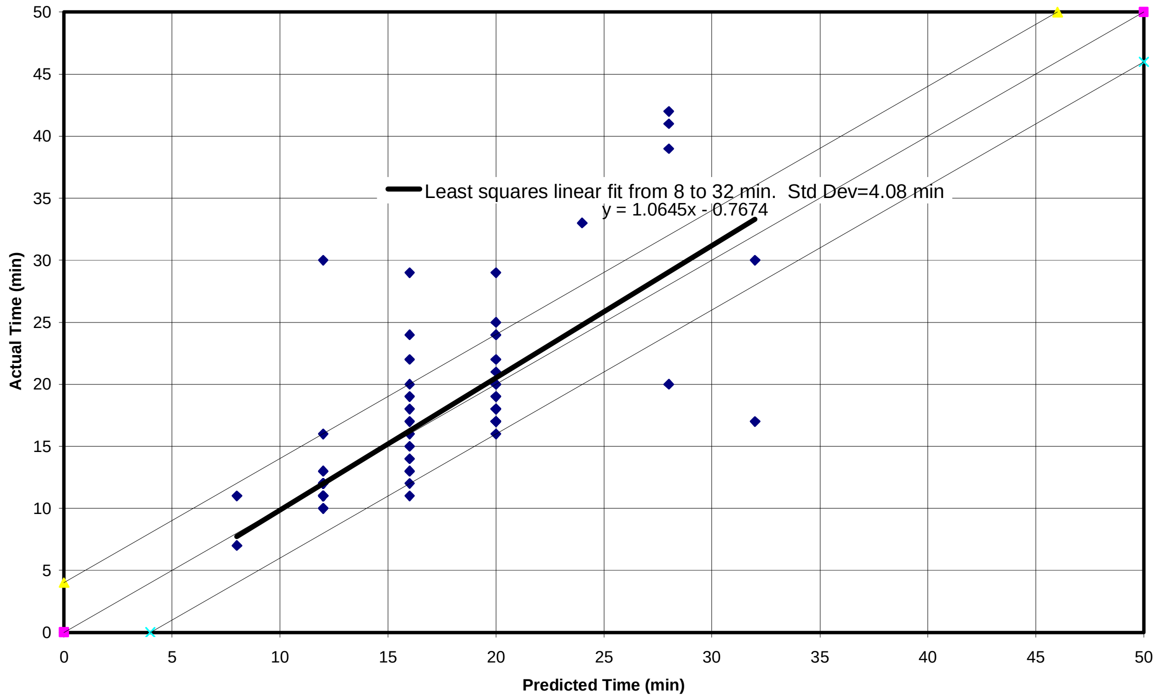

Figure 5. Actual travel times as a function of predicted travel times for the Second CMS, showing linear least squares fit line, equation, and standard deviation around the regression line. The three lighter lines in the drawing represent the equations Actual Time = Predicted Time, Actual Time = Predicted Time + 4 minutes, and Actual Time = Predicted Time – 4 minutes.

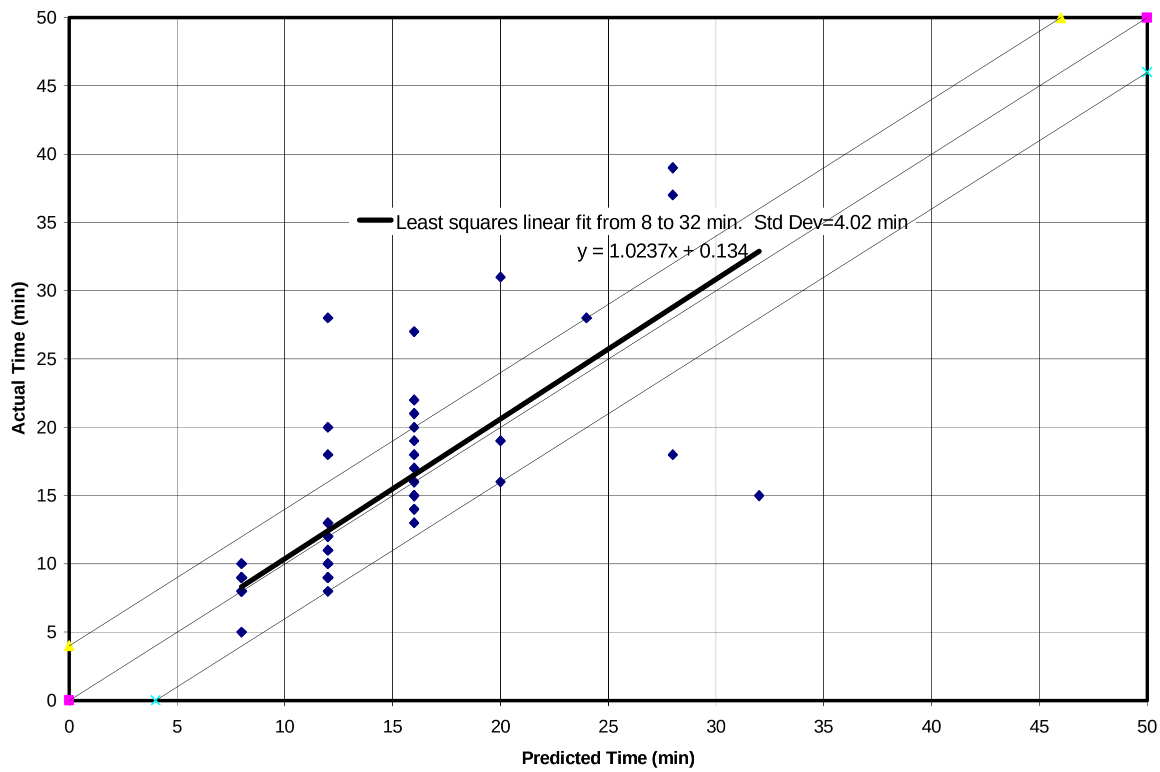

Figure 6. Actual travel times as a function of predicted travel times for the Third CMS, showing linear least squares fit line, equation, and standard deviation around the regression line. The three lighter lines in the drawing represent the equations Actual Time = Predicted Time, Actual Time = Predicted Time + 4 minutes, and Actual Time = Predicted Time – 4 minutes.

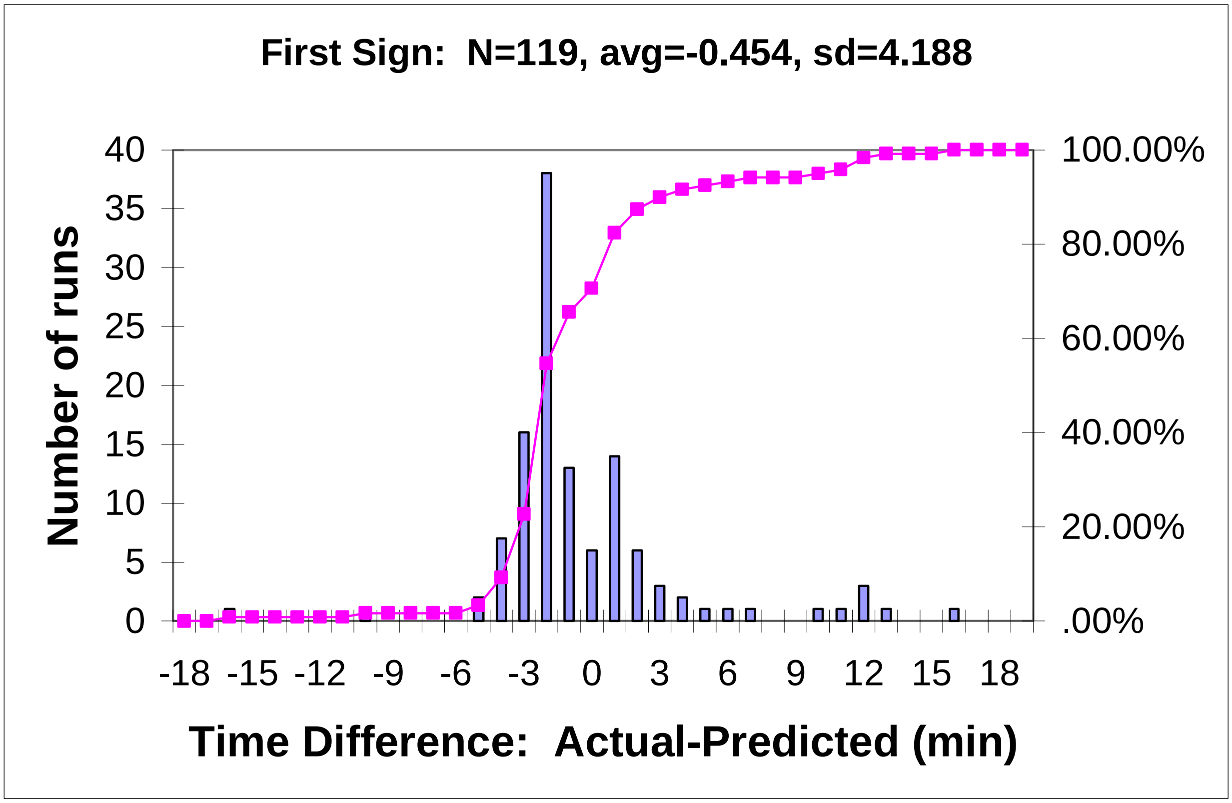

Figure 7. Histogram of discrepancy between actual travel time and predicted travel time for the First CMS, including cumulative percentages (axis at right).

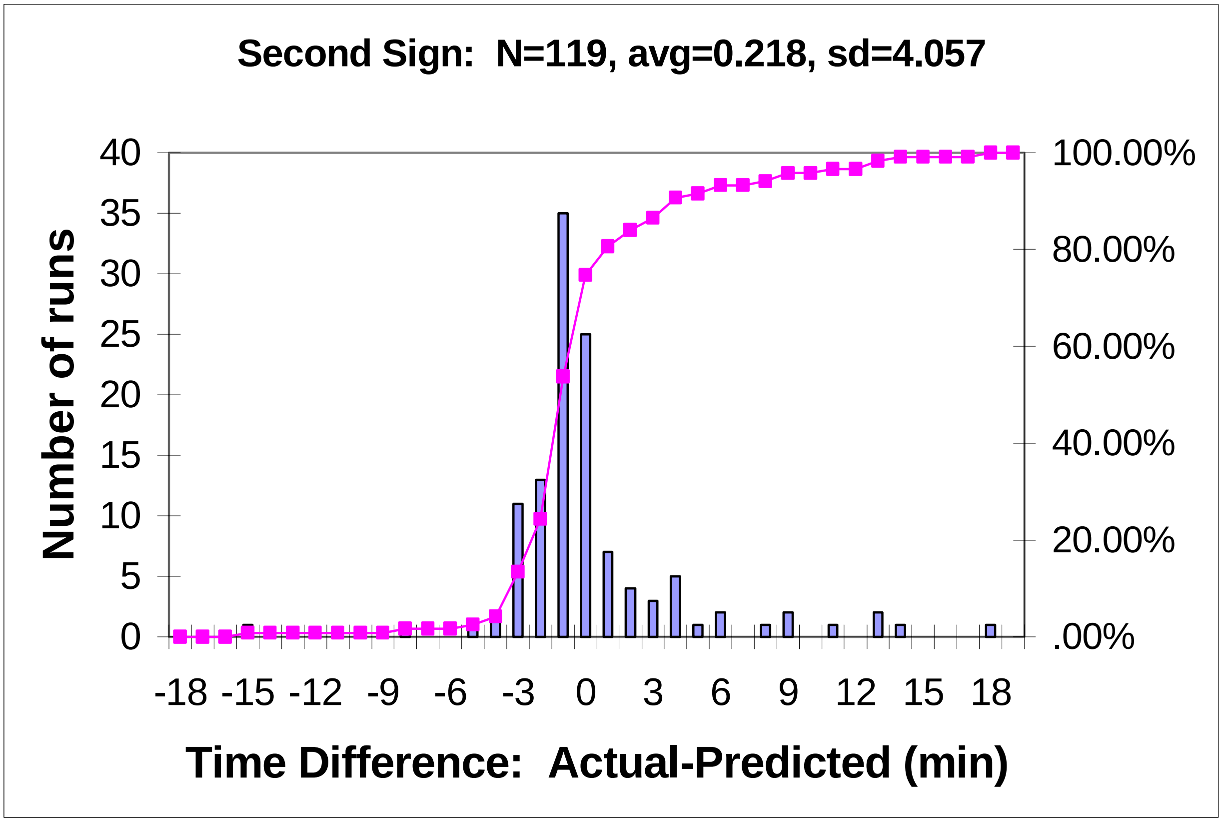

Figure 8. Histogram of discrepancy between actual travel time and predicted travel time for the Second CMS, including cumulative percentages (axis at right).

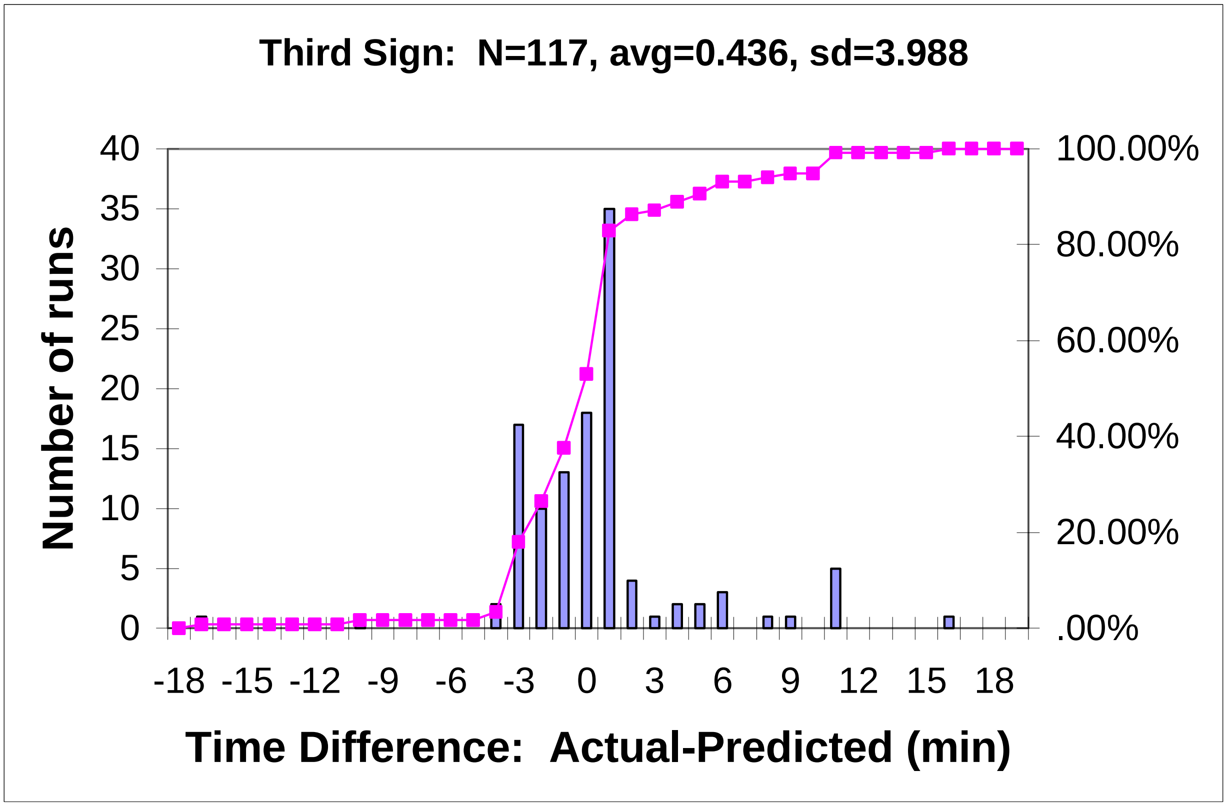

Figure 9. Histogram of discrepancy between actual travel time and predicted travel time for the Third CMS, including cumulative percentages (axis at right).

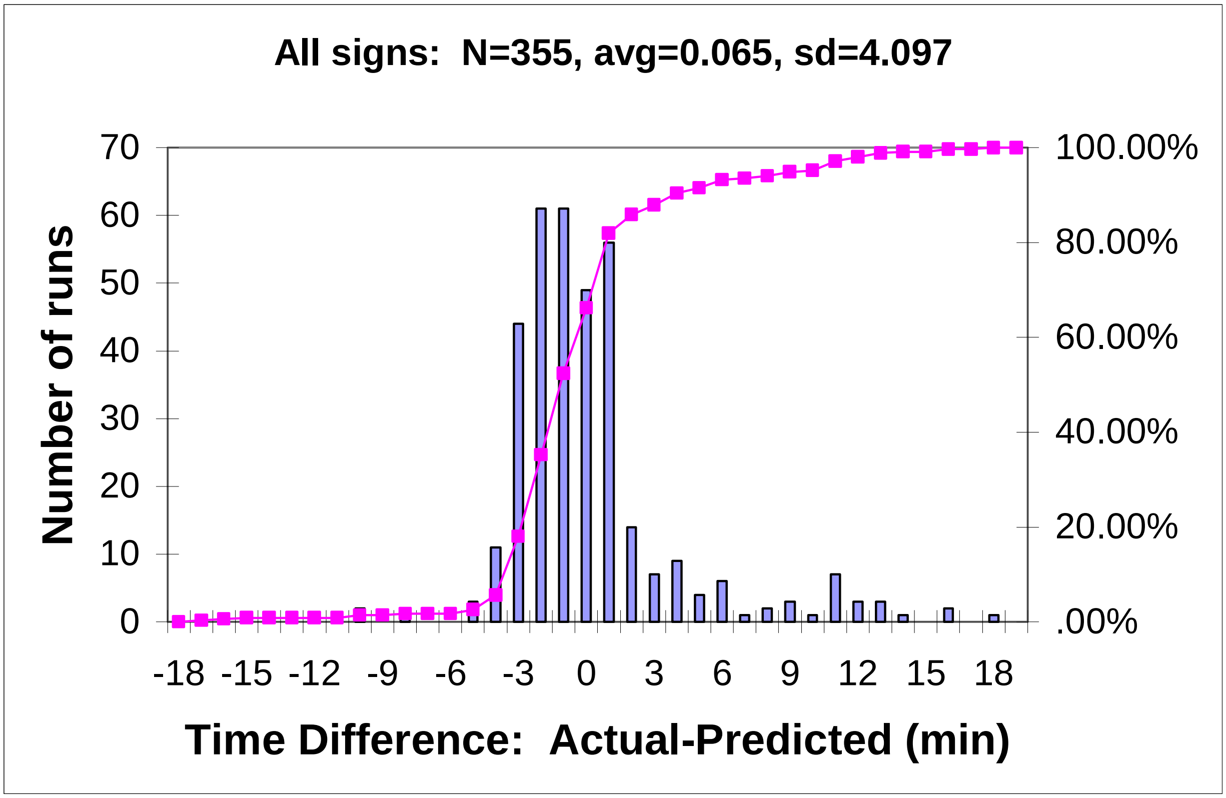

Figure 10. Histogram of discrepancy between actual travel time and predicted travel time for all three CMSs, including cumulative percentages (axis at right).

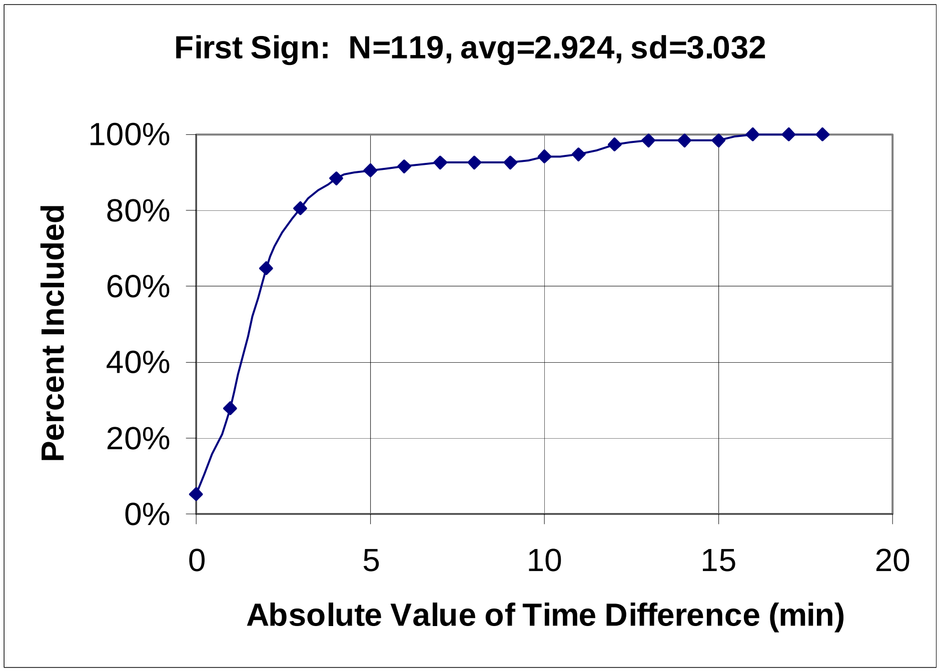

Figure 11. Relative Frequency observations included by selected ±Time Value (in minutes) of actual recorded time value from the predicted time value for the First CMS.

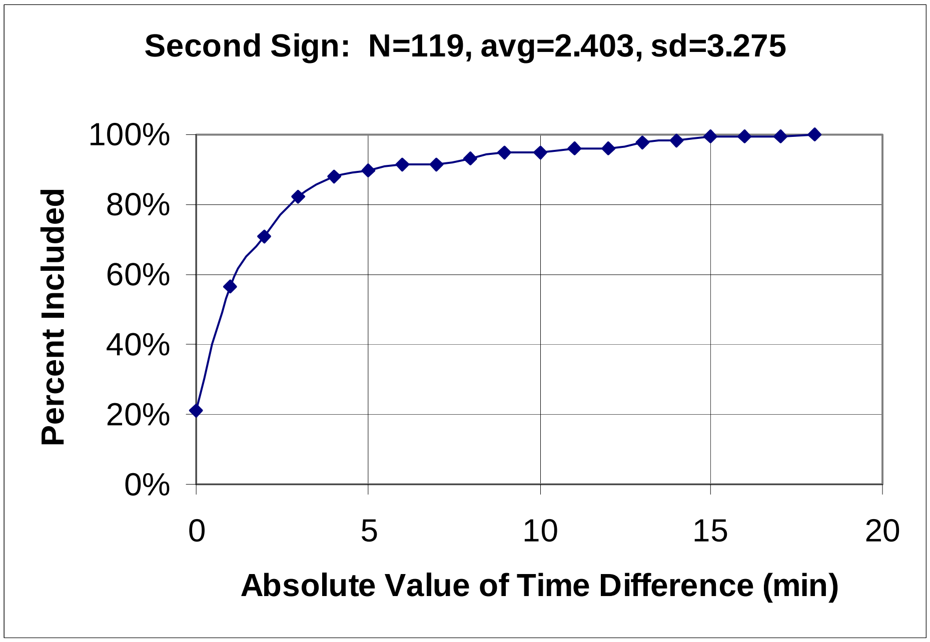

Figure 12. Relative Frequency observations included by selected ±Time Value (in minutes) of actual recorded time value from the predicted time value for the Second CMS.

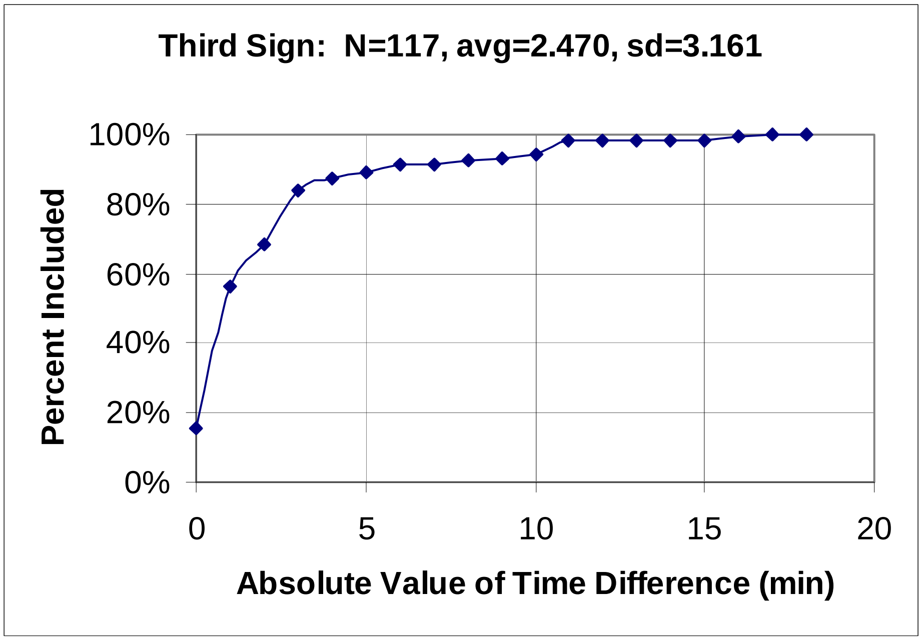

Figure 13. Relative Frequency observations included by selected ±Time Value (in minutes) of actual recorded time value from the predicted time value for the Third CMS.

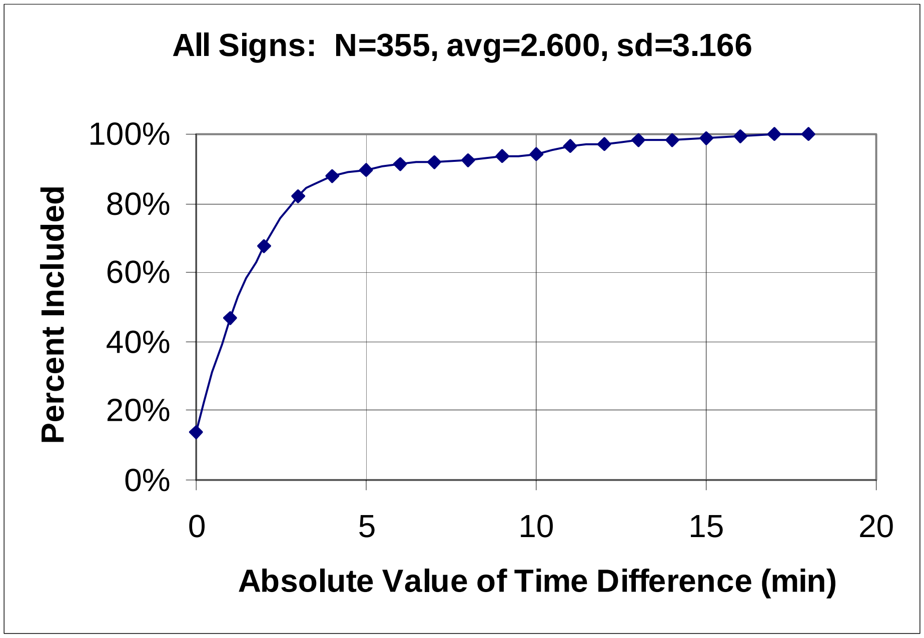

Figure 14. Relative Frequency observations included by selected ±Time Value (in minutes) of actual recorded time value from the predicted time value for all three CMSs.