EVALUATION OF A REAL-TIME TRAVEL TIME PREDICTION SYSTEM IN A FREEWAY CONSTRUCTION WORK ZONE

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ABSTRACT

A real-time travel time prediction system (TIPS) was evaluated 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 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 and a survey of the motoring public. 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. The data recorder in each crew also recorded the license plate numbers of private non-commercial vehicles with Ohio license plates. A total of 3177 different license plate numbers were recorded and a questionnaire was sent to each one. A total of 660 completed surveys were returned and analyzed. 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. Survey responses indicated that the motoring public does perceive a certain inaccuracy in the travel times. However almost 97% of surveyed motorists felt that a system to provide real-time travel time information in advance of work zones is either outright helpful or maybe helpful. 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 and appears to be perceived by the motoring public as helpful and useful.

ACKNOWLEDGEMENTS

A number of people have assisted Helmut T. Zwahlen, Russ Professor Emeritus at Ohio University, Athens, Ohio, in the field evaluation of the TIPS system. Thanks to David L. Holstein, P.E., Administrator, Office of Traffic Engineering, ODOT, for his support of the project. Special thanks to Rodger Dunn, Office of Traffic Engineering, ODOT, who assisted the author of this evaluation study in an excellent manner throughout the duration of the study and served as ODOT liaison. He also organized and supervised the ODOT crews who collected all the time and license plate information in the field. Thanks to the ODOT crew members: Arthur Garrett, Satya Goyal, Michael Keller, Donald Little, Tim Michael, Kamryn Ream, and Bobbie Williams. Thanks to Denise Butsko of the Ohio Department of Public Safety for providing all the vehicle registrants' addresses for the survey of the motoring public. Also, thanks to Dr. Prahlad D. Pant, Professor, Department of Civil Engineering, University of Cincinnati, who developed the TIPS system and provided technical information, as well as Ray Lindeman, University of Cincinnati, who provided the schematic of the experimental site.

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1 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. Currently, “Freeway construction work zones not only lead to traffic conditions that violate motorists' expectations but also expose construction workers hazardously close to fast moving vehicles. Currently, motorists are generally warned on traffic conditions in work zones through signs posted along the freeway. The typical signs display "Construction Ahead - Expect Delays" or "Possible Delay Ahead" - but for how long and why, nobody knows” [1]. For example consider the roadside announcement in Figure 1 [2].

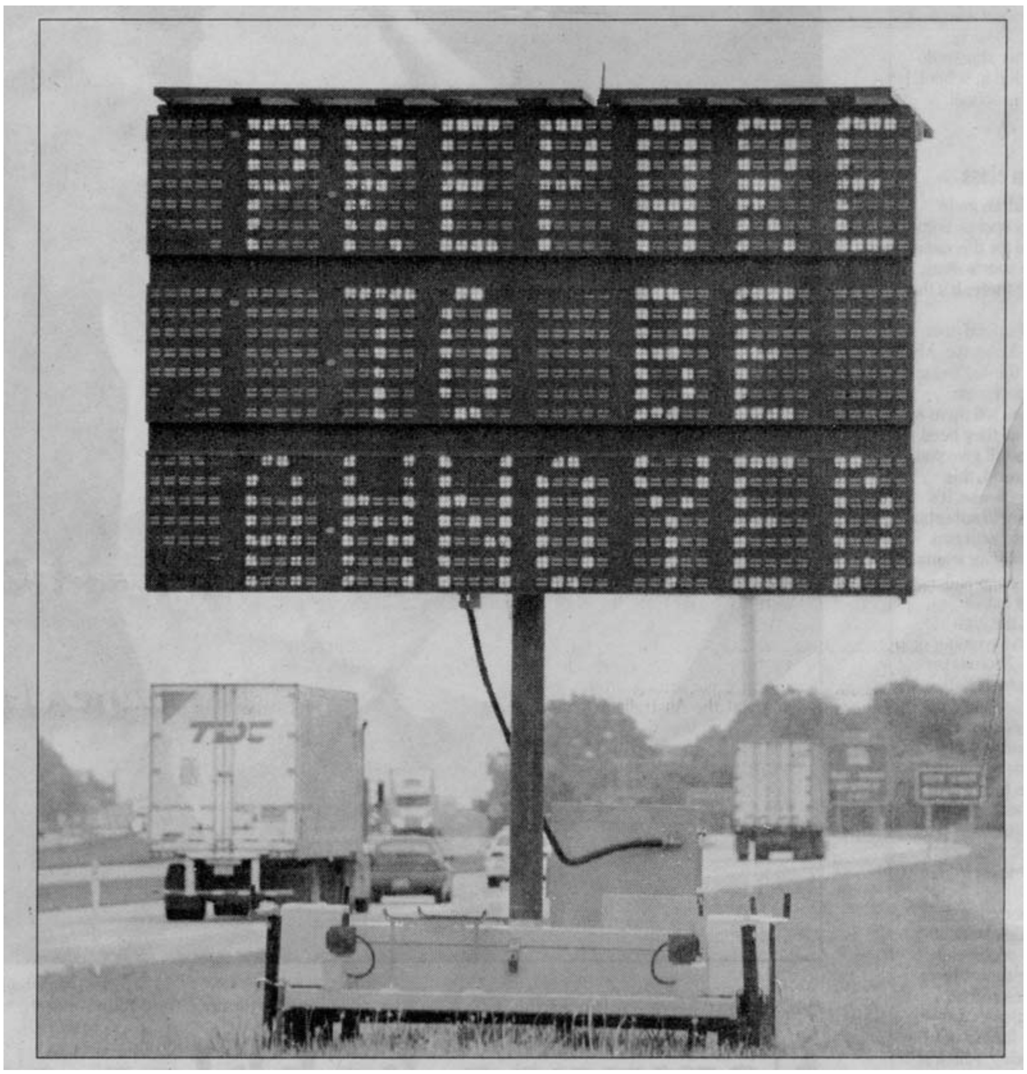


Figure 1. Photograph from *The Cincinnati Enquirer*. “The road to nowhere. The Missouri Department of Transportation warned drivers on I-44 about potential traffic snarls Monday.” [2].

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" [3]. In 1999 there were 868 work zone accident fatalities [4]. 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." [3]

To answer this need, the Travel Time Prediction System (TIPS) has been developed. 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 changeable message signs positioned at pre-determined locations along the freeway."

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 [5].

In addition to TIPS, a second somewhat similar system exists. Called Adaptir, it was developed by the Scientex Corporation. [3]

TIPS was implemented in a work zone on a 13 mile stretch of I-75 northbound in 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 and utility of TIPS were measured, both through field measurements and through a survey of motorists.

2 BRIEF DESCRIPTION OF TIPS

"The Travel Time Prediction System (TIPS) is a portable, real-time automated system that calculates travel times between different points in advance of and within a freeway work zone" [4]. It was developed to answer a need by drivers for more information regarding the delays they experience driving through work zones, specifically the time lost due to longer travel times. 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.

This configuration results in the following virtues for the TIPS system [5, 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 2 shows a sensor station trailer configured with traffic sensor, microwave antenna, and solar panel. Figure 3 shows a changeable message sign with information on the distance left to travel to the end of the work zone. Figure 4 shows the same sign with a message generated by the TIPS system predicting the travel time remaining to the end of the work zone. Figure 5 shows the radio base station with a personal computer.

3 OBJECTIVES OF STUDY

The first objective of this study was to determine the accuracy of the predicted travel times when compared to the actual travel times. The second objective of this study was to assess the perceptions of the motoring public about the usefulness, potential problems, and the perceived accuracy of such a system.

Figure 2. Sensor station trailer configured with traffic sensor, microwave antenna, and solar panel.

Figure 3. Changeable Message Sign in TIPS system displaying distance to the end of the work zone. This message alternates with the time of travel as shown in the following figure.

Figure 4. Changeable Message Sign in TIPS system displaying estimated time of travel to the end of the work zone. This message alternates with the distance message as shown in the previous figure.

Figure 5. The TIPS radio base station with a personal computer.

4 METHOD

4.1 Description of Test Site

Figure 6 illustrates the deployment of the TIPS system which was deployed on I-75 (north bound) in the Dayton area on July 14, 200 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.

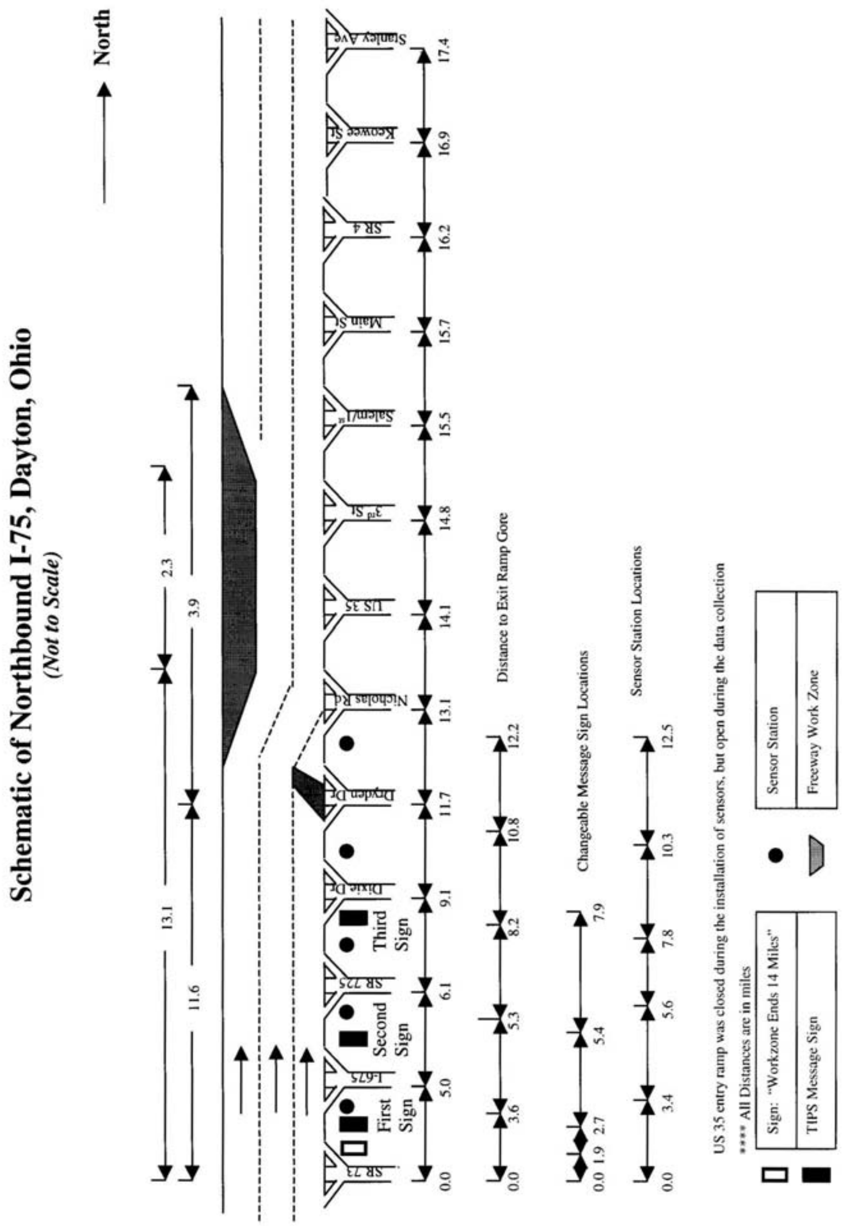


Figure 6. Schematic diagram of work zone on I-75 in Dayton, Ohio where TIPS was evaluated.

There were three Changeable Message (time/distance) Signs (CMS) as illustrated in Figures 3 and 4, and 5 sensor stations of the type illustrated in Figure 2. Each variable message sign was placed in the advance of an exit. Based upon the author's suggestion, these signs displayed alternately not only the predicted travel time to the end of the work zone (as initially configures) but also the distance in miles to the end of the work zone. There was an initial variable message sign in advance of the three time/distance message signs advising the motorists: "WORKZONE ENDS 14 MILES".

4.2 <u>Description of the Experimental Procedure</u>

Three 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 (see Figure 5).

The drivers and data recorders were given oral and written instructions (See Appendix A). 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. While driving northbound toward and through the work zone within the traffic stream, the data recorder recorded on a special data collection sheet (see Appendix A for an example) as many Ohio license plate numbers as possible from private vehicles. No license plate numbers from commercial or out-of-state registered vehicles were recorded. In addition, 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 (see Appendix A for an example). The actual time when the end of the work zone was reached was also recorded. A digital clock showing hours and minutes on a 3/4" (19mm) numeral height display, backlit to be readable in darkness mounted on each vehicle's dashboard was used to record the time values.

4.3 <u>Procedure for Survey of Motorist Responses</u>

The recorded license plate numbers were entered into a computer and multiple identical license plate numbers were subsequently eliminated. A questionnaire with ODOT letterhead, ODOT contact person address, return instructions, and thank-you note was sent to the survey participants through the Ohio Department of Transportation. The questionnaire contained a total of 7 questions (see Tables 9 through 15 and Appendix B). The questionnaire also contained two pictures showing a variable message sign displaying the distance to the end of the work zone information and the predicted travel time (See Figures 3 and 4 and Appendix B).

The first question dealt with how often a motorist drove through the work zone. The second question assessed to what degree and extent the motorist experienced traffic delays because of the work zone. The third question assessed whether or not and to what extent the motorist used the predicted travel time information to exit at an earlier than planned exit and travel an alternate route to get to the planned destination. The fourth question assessed whether or not the motorist felt that the presented real-time information was accurate and reliable. The fifth question assessed whether or not, based on the motorist's experience, the predicted travel times provided useful information. The sixth question assessed whether or not the provided distance/time information was easy to read. The seventh question asked the motorist whether or not such a travel prediction system in advance of work zones is helpful to the motoring public. Motorists were also asked at the end of the questionnaire for other comments.

The license plate number lists were then electronically transferred as an ASCII text file to the Ohio Department of Public Safety to get a computerized list of the names and addresses for all the recorded license plate numbers. The addresses were then transferred onto adhesive labels and attached to the survey envelopes. A survey envelope containing the two page survey questionnaire form and a self-addressed (ODOT address) stamped envelope was sent to each motorist. All survey questionnaire responses were collected by ODOT and subsequently forwarded to the author for the analysis. None of the returned survey questionnaires contained any respondent names or addresses and were, therefore, completely anonymous.

5 RESULTS

5.2 Accuracy of Predicted Travel Time Values

The recorded predicted and actual times obtained by each crew for each of three days are given in Appendix C. 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. Figures 7, 8, and 9 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. Figures 7, 8, and 9 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 95% confidence limits of the range of likely values for the population means as computed by Minitab [6] for the regression lines are given in the figures in Appendix D. 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.

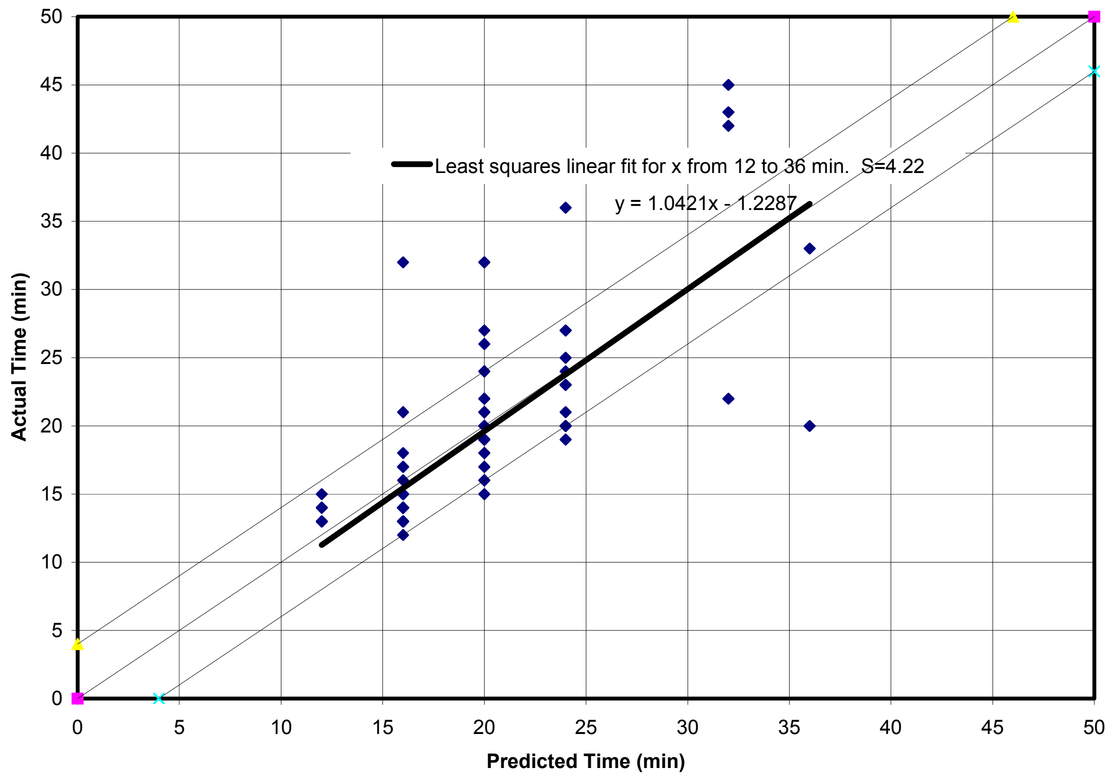


Figure 7. Actual travel times as a function of predicted travel times for the First CMS, showing linear least squares fit line, equation, and standard deviation *S* around the regression line. The three lighter lines in the drawing represent the equations *AT=PT*, *AT=PT+4*, and *AT=PT-4*.

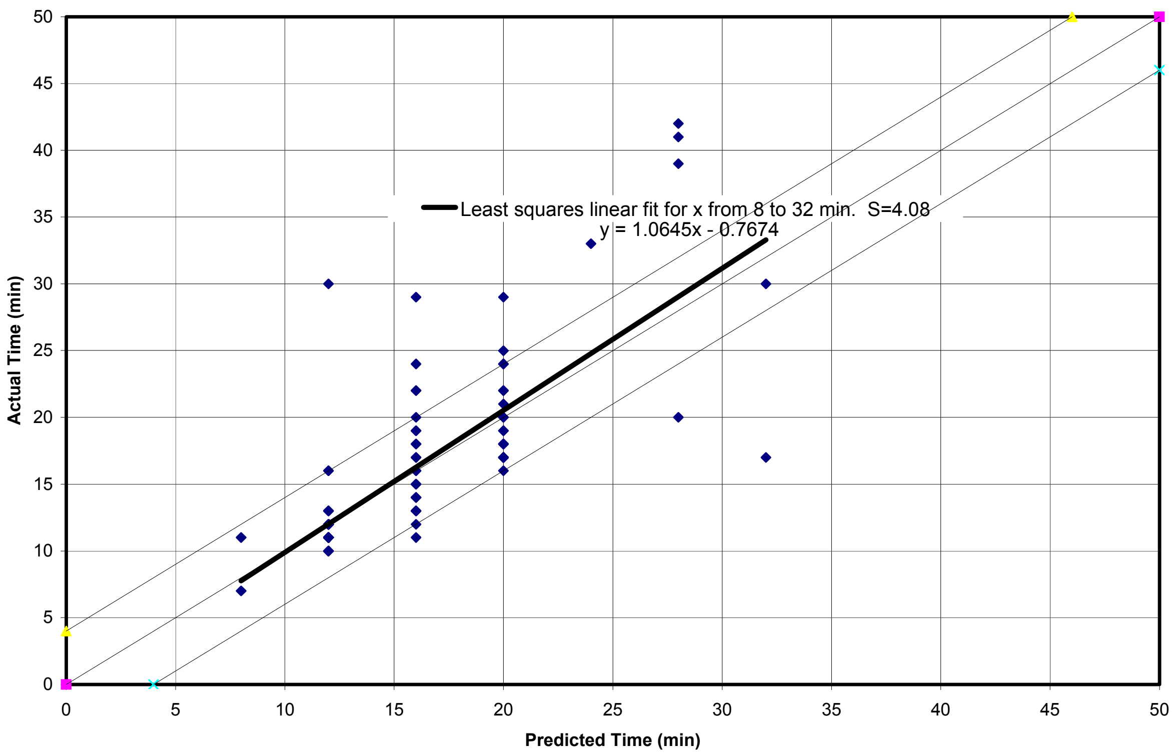


Figure 8. Actual travel times as a function of predicted travel times for the Second CMS, showing linear least squares fit line, equation, and standard deviation *S* around the regression line. The three lighter lines in the drawing represent the equations *AT=PT*, *AT=PT+4*, and *AT=PT-4*.

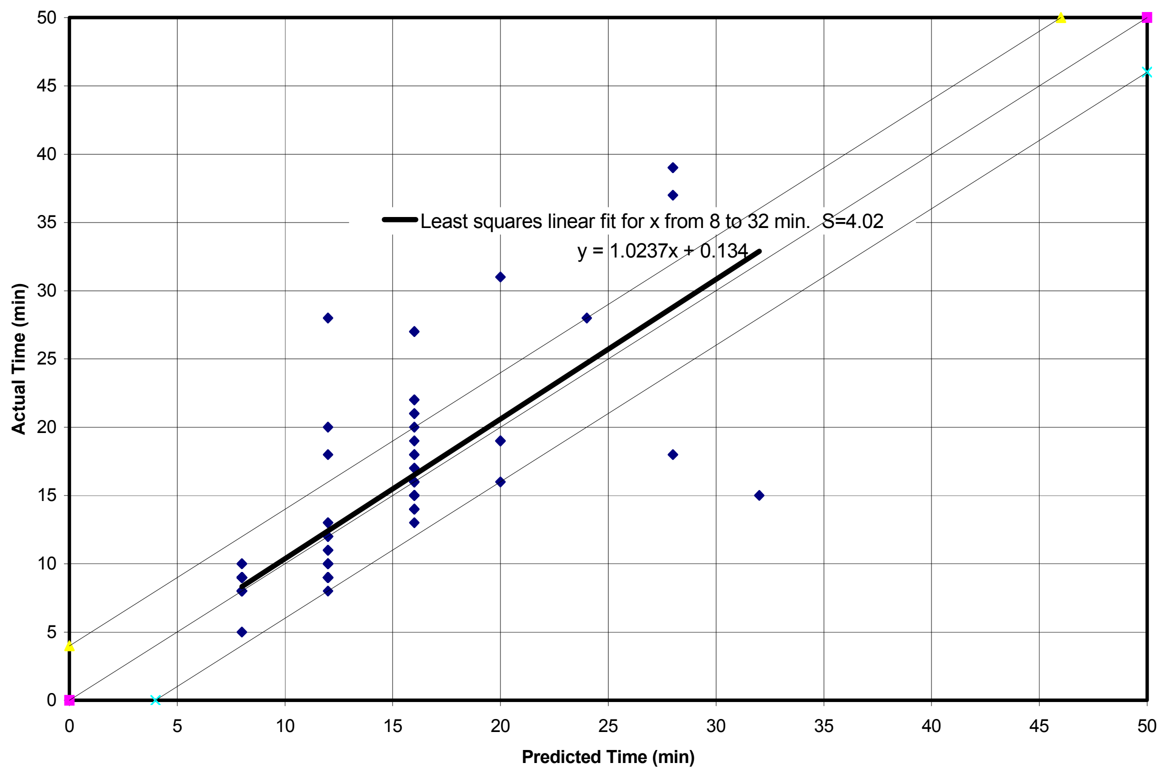


Figure 9. Actual travel times as a function of predicted travel times for the Third CMS, showing linear least squares fit line, equation, and standard deviation *S* around the regression line. The three lighter lines in the drawing represent the equations *AT=PT*, *AT=PT+4*, and *AT=PT-4*.

It should be noted that in Figures 7, 8, and 9, a displayed data point might represent more than one observation. Figures 10, 11, and 12 show the distribution of actual recorded times for each predicted time value. These figures provide additional information regarding how the actual recorded travel times are distributed, as well as provide the average and the standard deviation of the actual recorded travel times for each observed predicted time value.

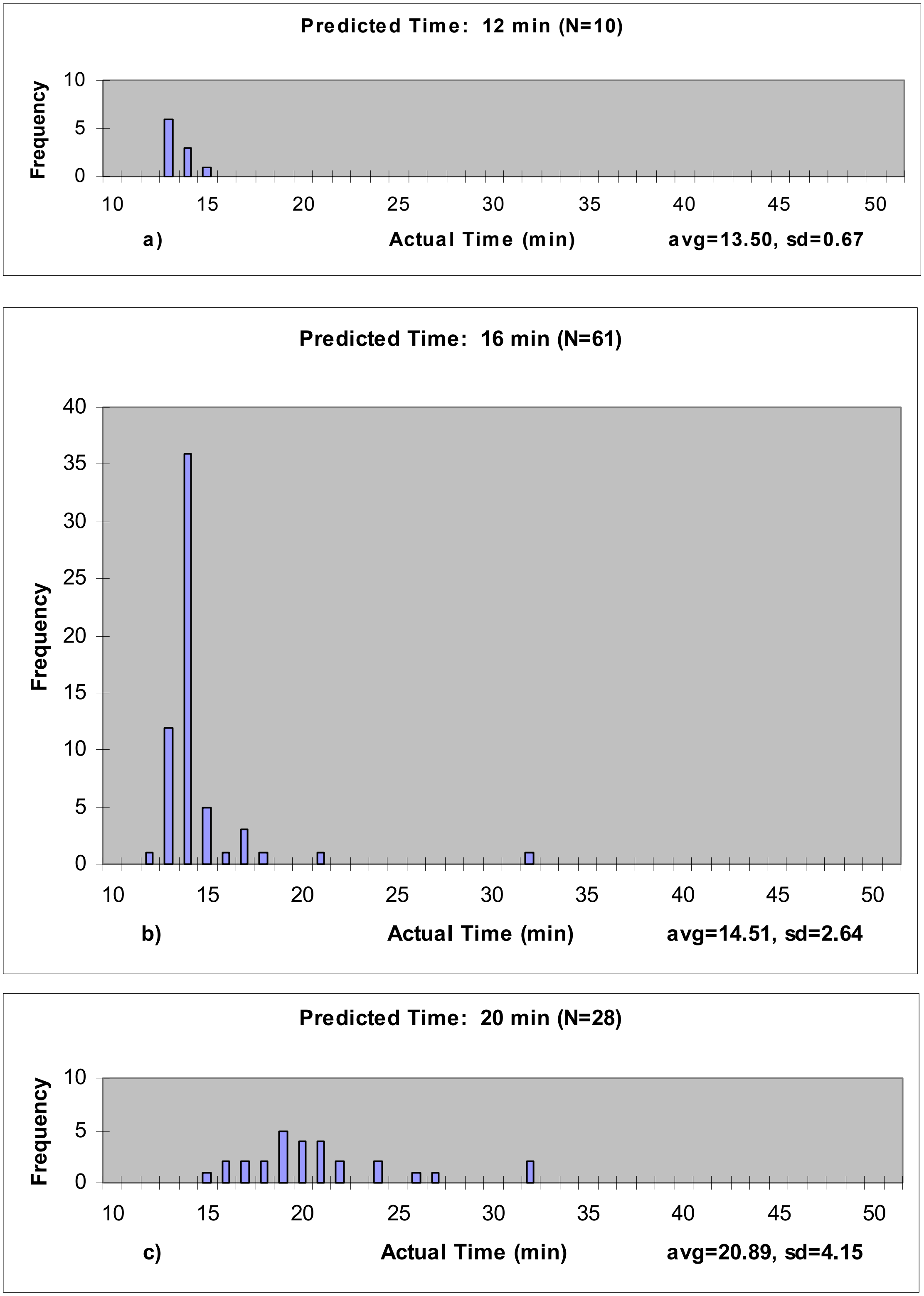
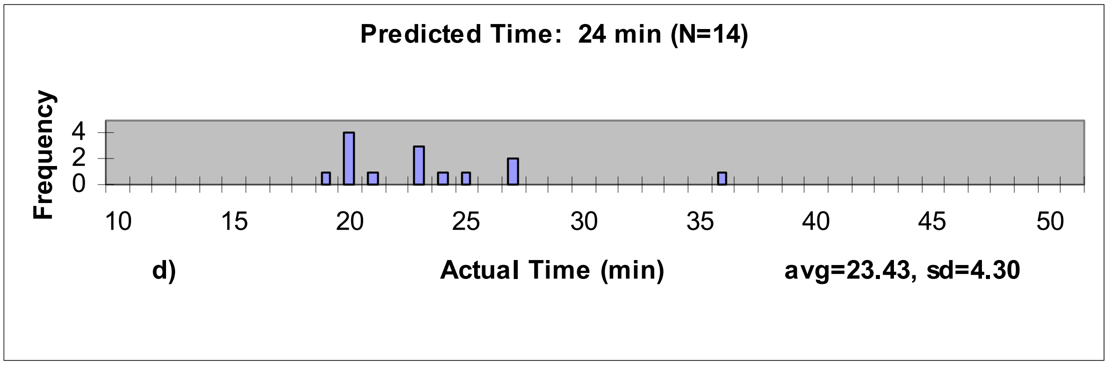
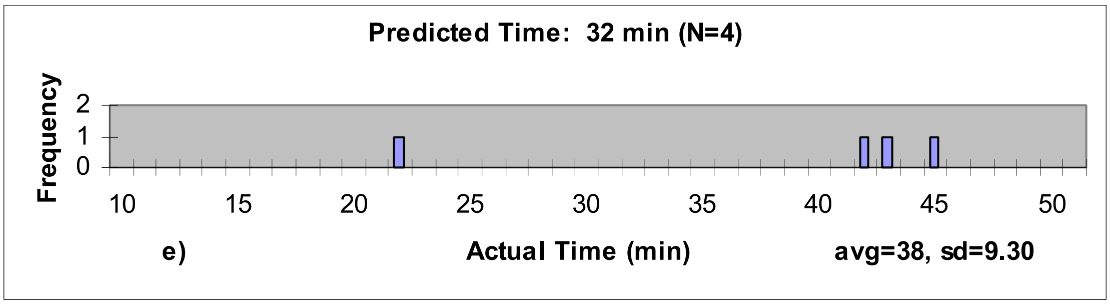


Figure 10. Parts a-c. Continued on next page.





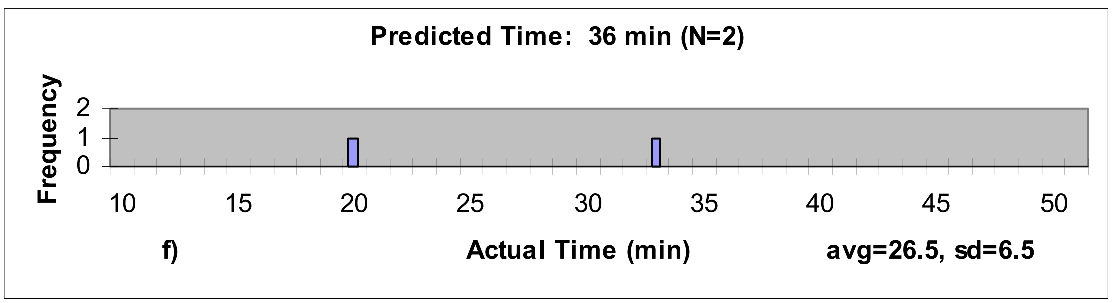
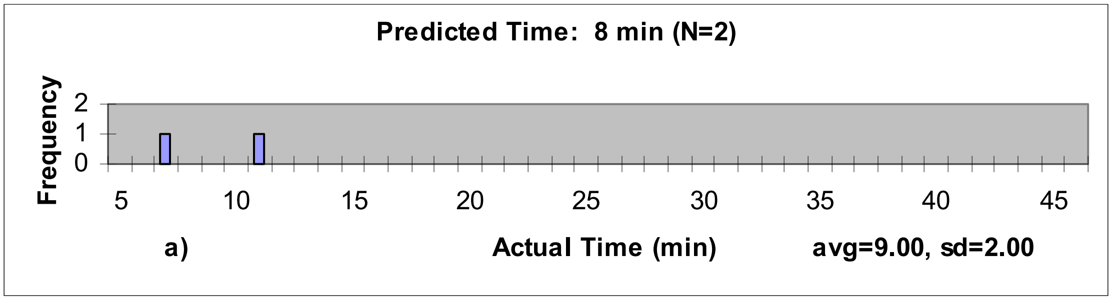
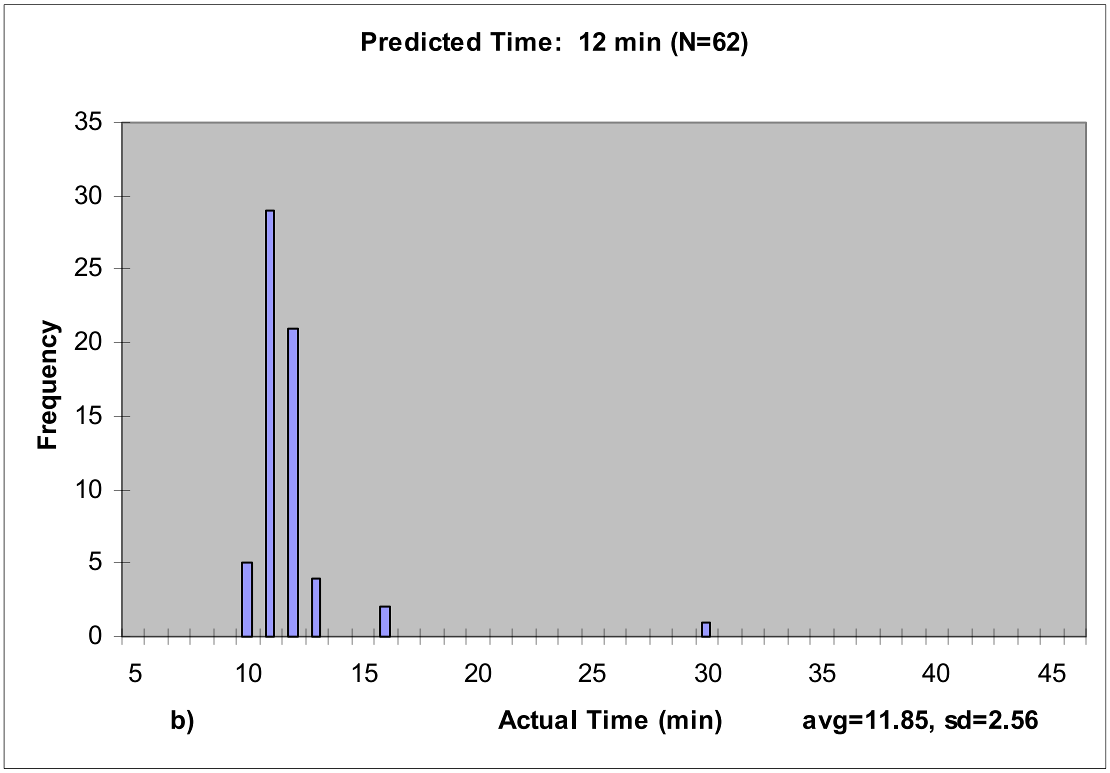


Figure 10. Histograms of actual travel times for particular values of predicted travel times displayed by the First CMS: a) 12 minutes, b) 16 minutes, c) 20 minutes, d) 24 minutes, e) 32 minutes, f) 36 minutes. There were no observations of the first CMS predicting travel times of 28 minutes. The average and standard deviation from each histogram is located in the lower right of each graph.





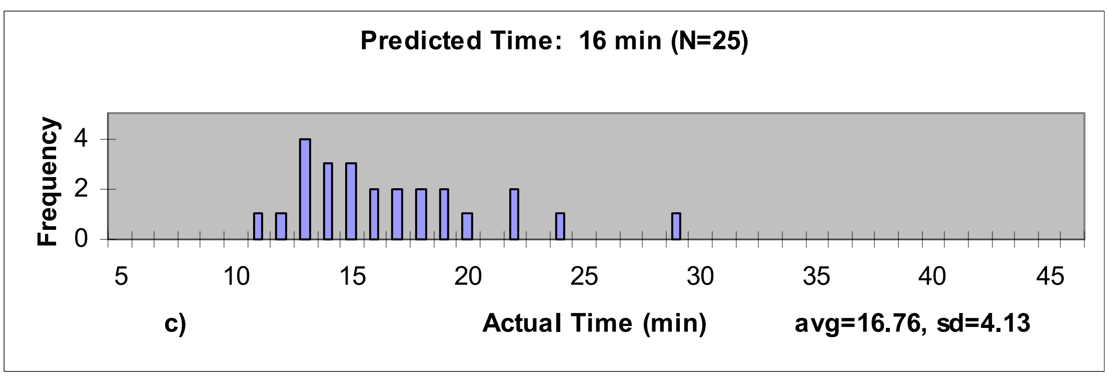


Figure 11. Parts a-c. Continued on next page.

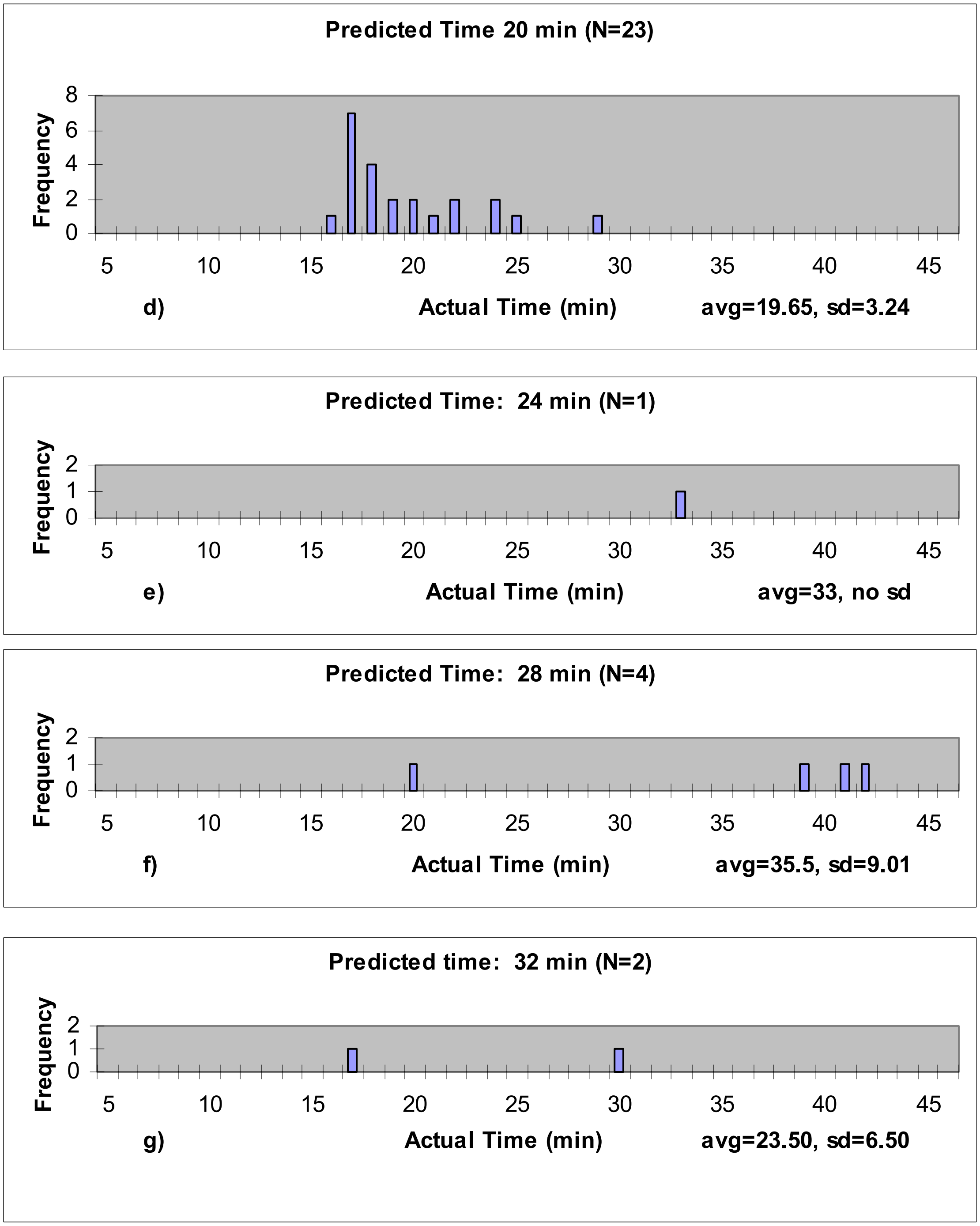


Figure 11. Histograms of actual travel times for particular values of predicted travel times displayed by the Second CMS: a) 8 minutes, b) 12 minutes, c) 16 minutes, d) 20 minutes, e) 24 minutes, f) 28 minutes, g) 32 minutes. The average and standard deviation from each histogram is located in the lower right of each graph, however for predicted time of 24 minutes there is no standard deviation as there was only one observation.

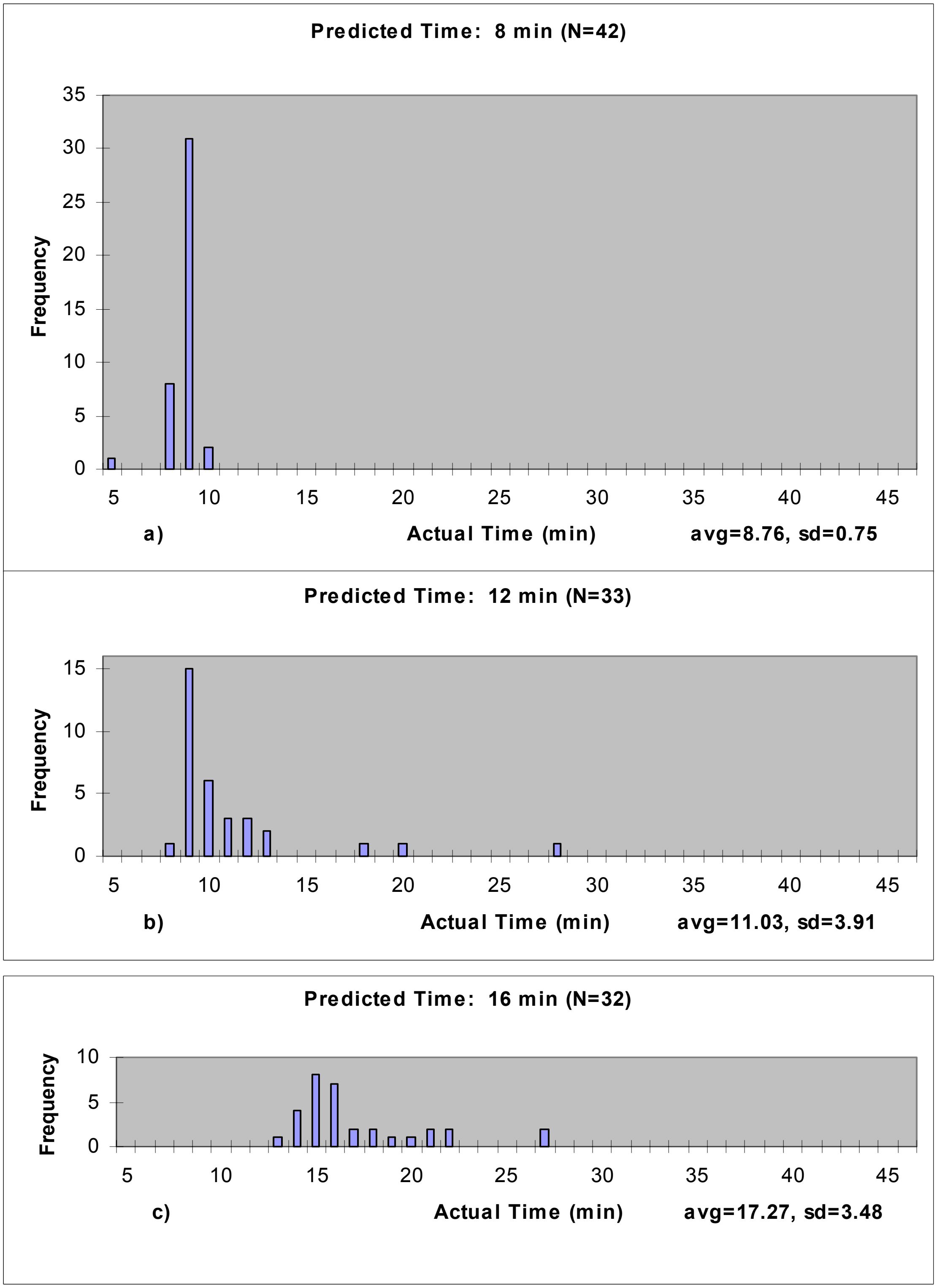


Figure 12. Parts a-c. Continued on next page.

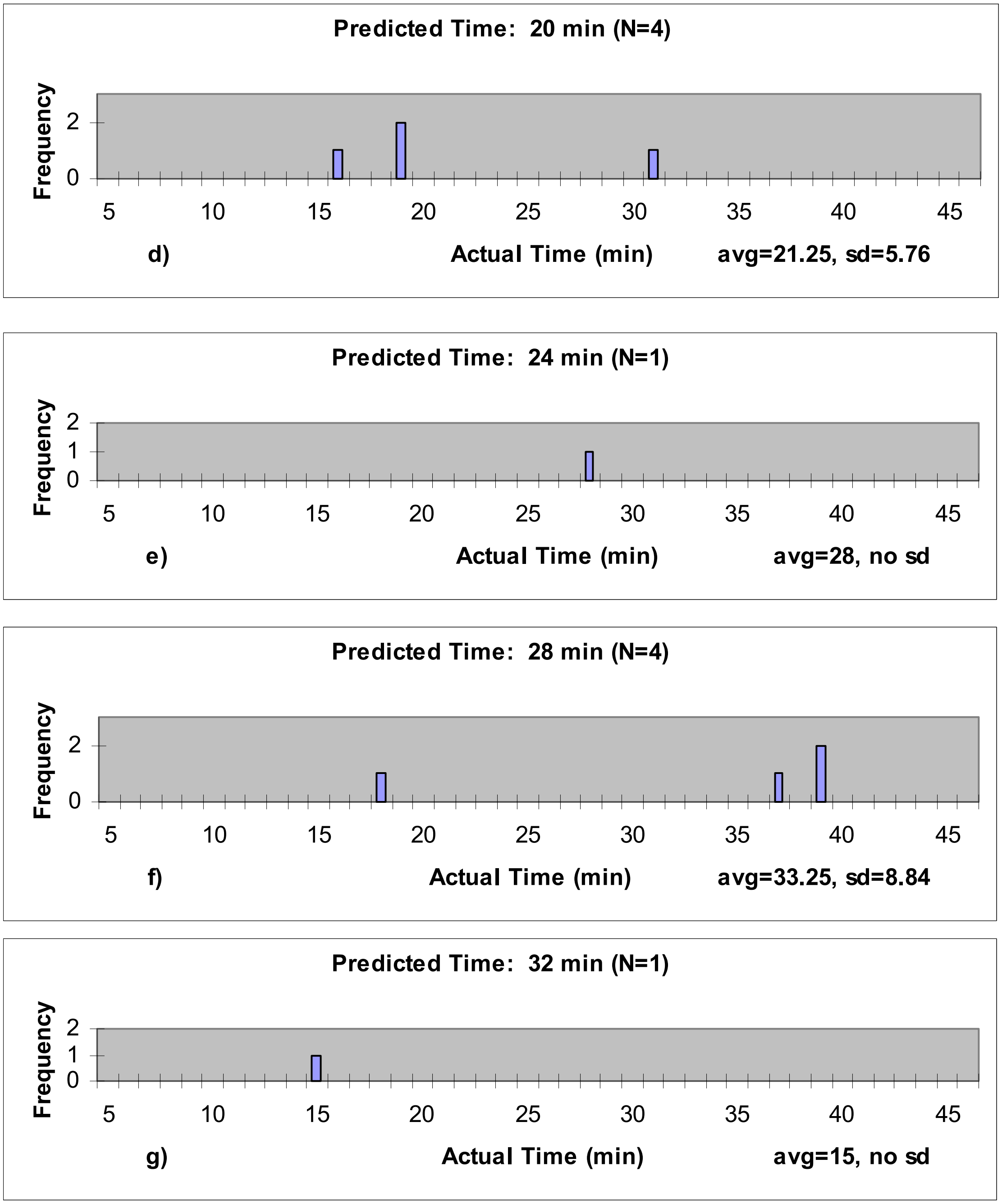
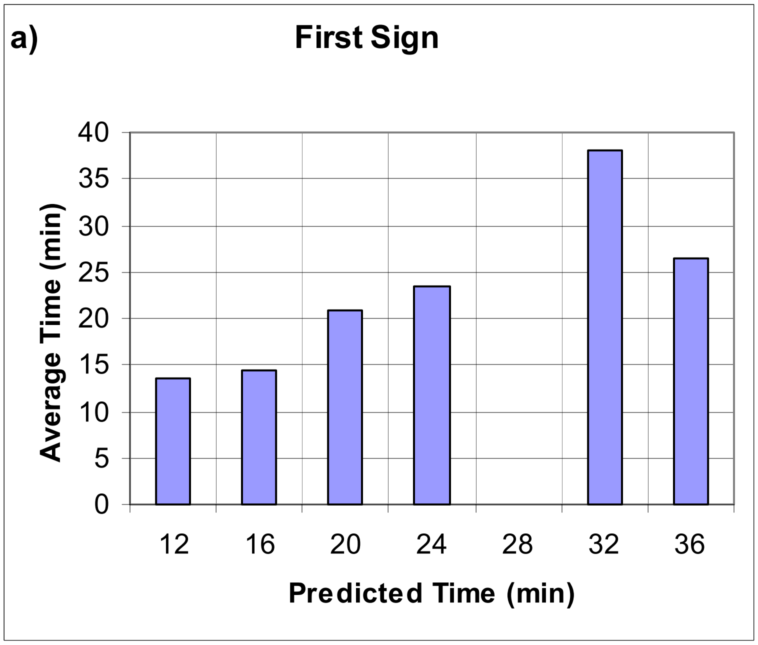


Figure 12. Histograms of actual travel times for particular values of predicted travel times displayed by the Third CMS: a) 8 minutes, b) 12 minutes, c) 16 minutes, d) 20 minutes, e) 24 minutes, f) 28 minutes, g) 32 minutes. The average and standard deviation from each histogram is located in the lower right of each graph, however for predicted times of 24 and 32 minutes there is no standard deviation as there was only one observation.

Figure 13 illustrates the average actual travel time as a function of the predicted travel time for each CMS, using the averages shown on Figure 10 through Figure12. For each CMS, the average actual travel times increase as expected with the predicted travel times, except for the greatest predicted travel times, which for each sign were observed only once or twice.



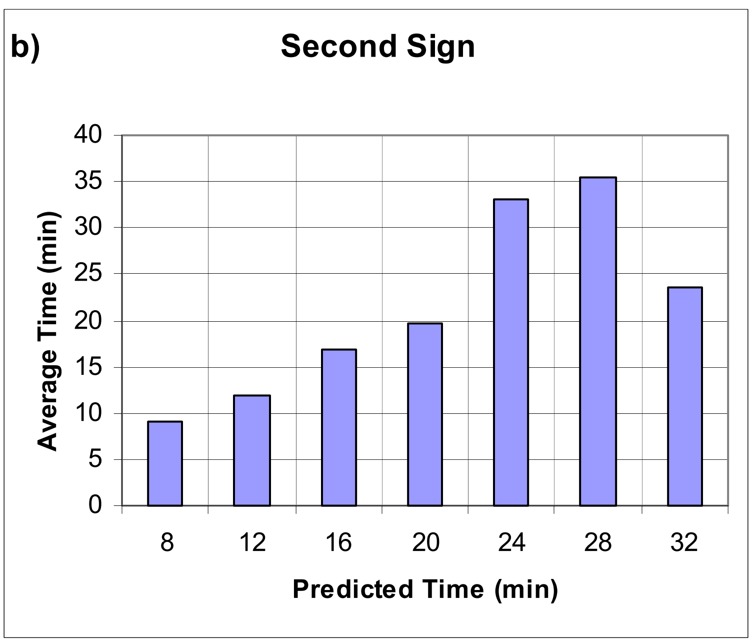


Figure 13. Parts a-b. Continued on next page.

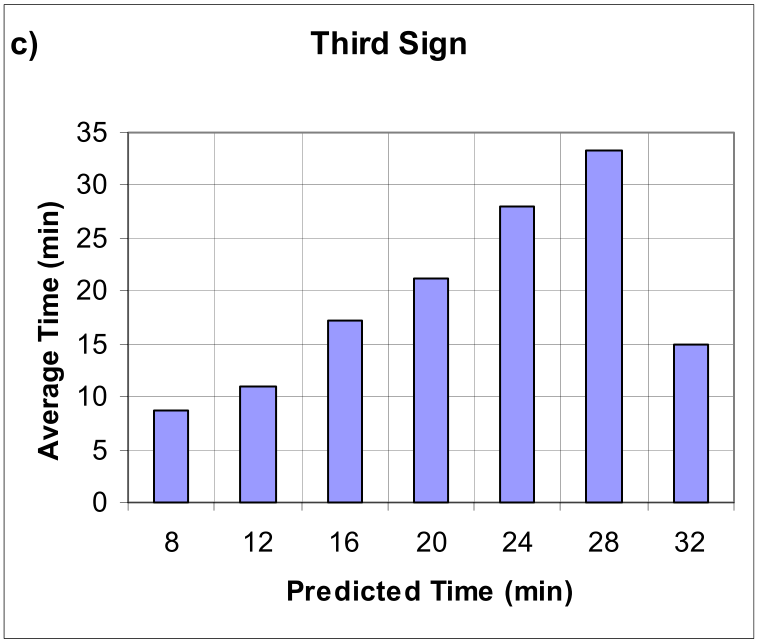


Figure 13. Average travel time as function of predicted travel time for the TIPS CMSs. a) First sign. b) Second sign. c) Third sign.

Figures14, 15, and 16 display the standard deviations of the actual times for each sign as a function of the predicted time, both in minutes and as a percentage of the predicted time. For all three signs there appears to exist a general trend to greater standard deviations at longer predicted times. Note that in some cases there was only one observation of a particular predicted time, thus in Figures 15 and 16 these are not represented since the standard deviation is zero in such a case. The standard deviations expressed as a percentage of the predicted times appear not to increase as much (if at all), since the larger predicted times hold down these values.

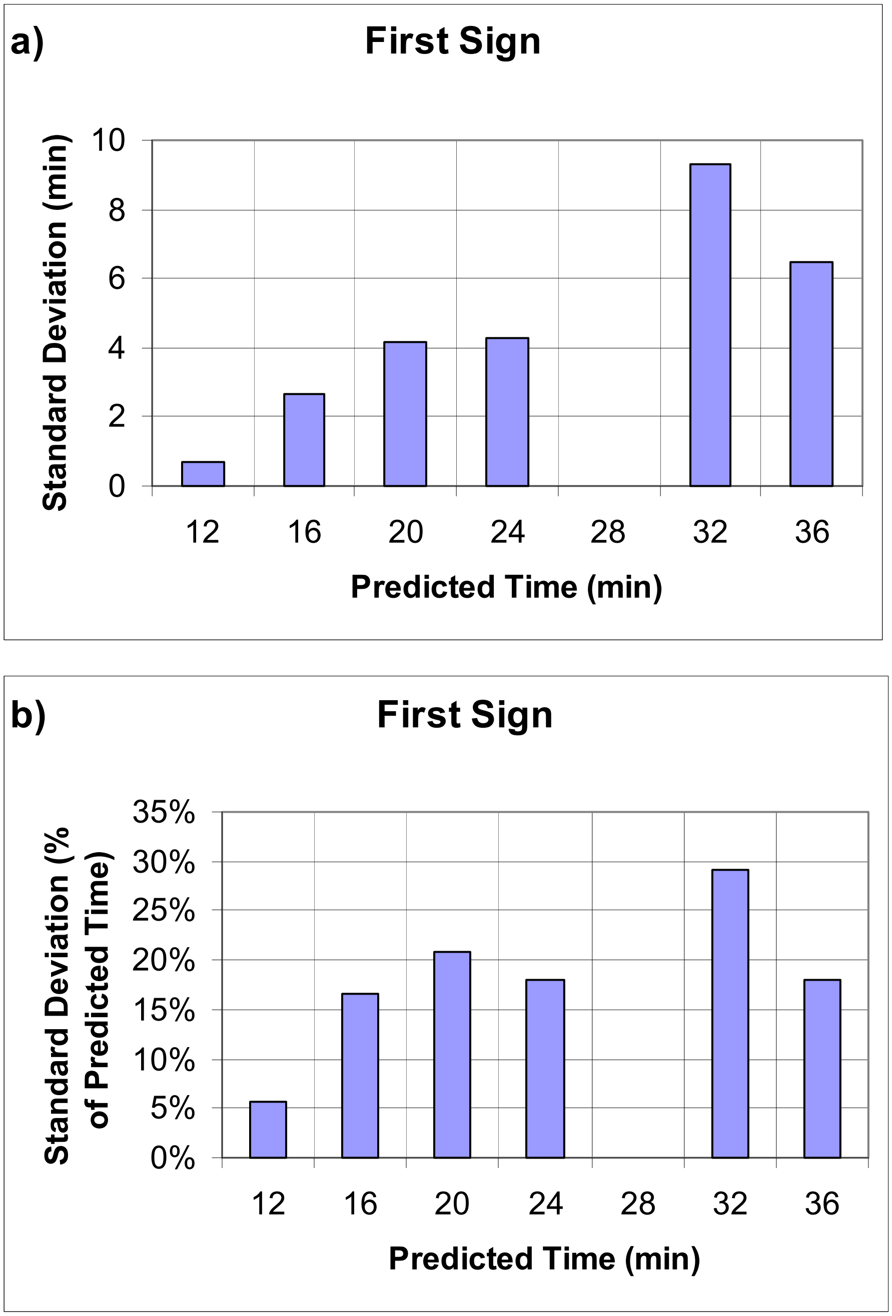
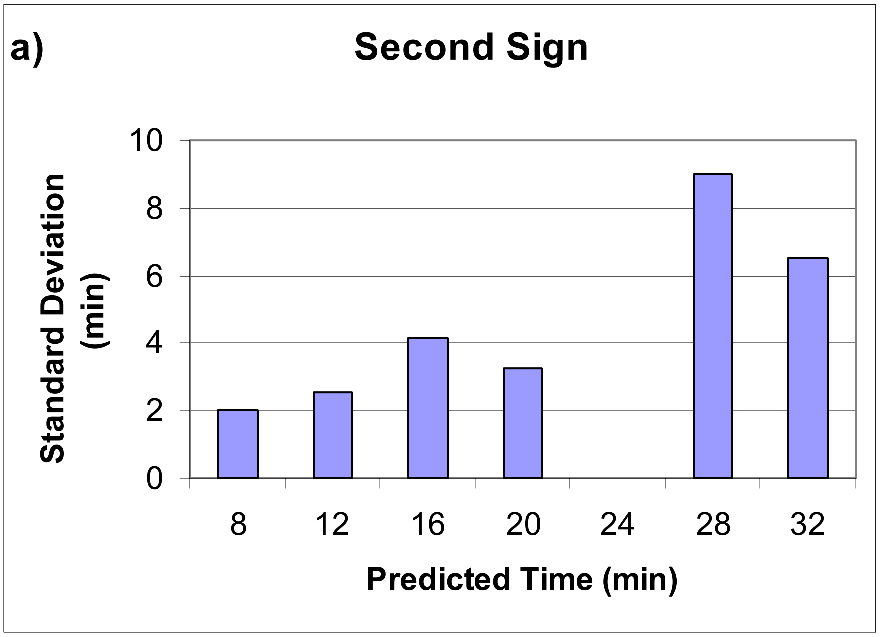


Figure 14. Standard Deviation of actual time values as a function of the predicted travel time displayed by the First CMS. a) standard deviation in minutes. b) relative standard deviation, as a percentage of the predicted time.



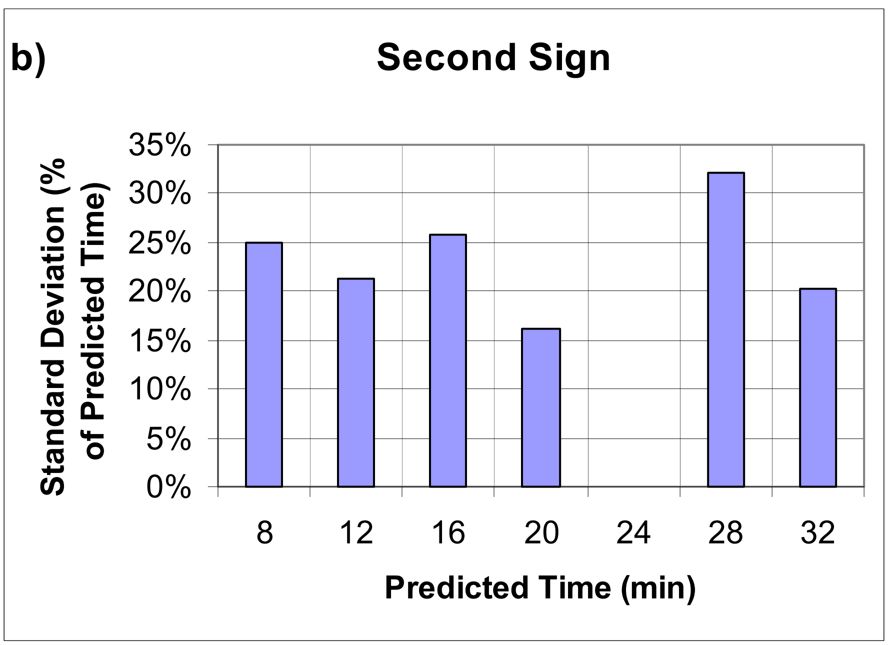
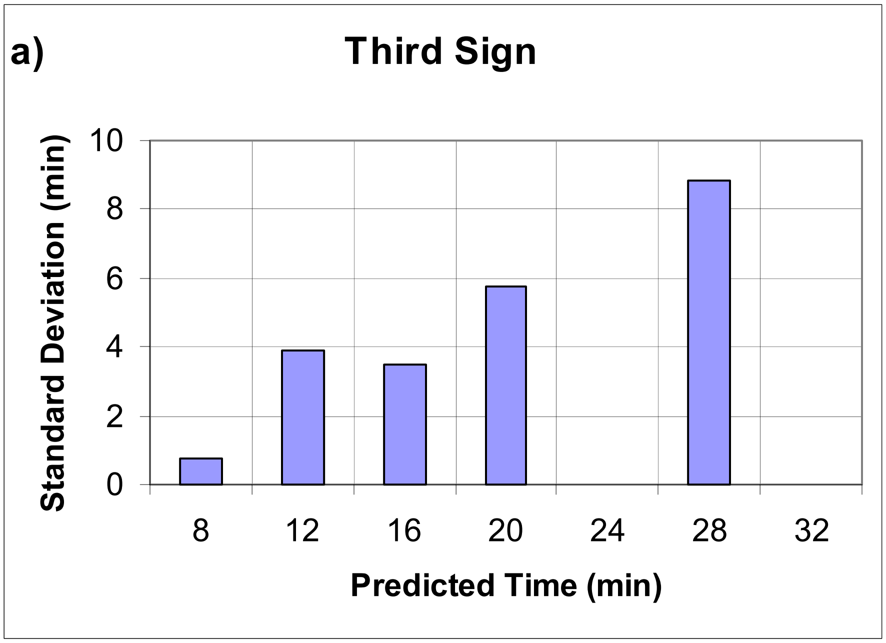


Figure 15. Standard Deviation of actual time values as a function of the predicted travel time displayed by the Second CMS. a) standard deviation in minutes. b) relative standard deviation, as a percentage of the predicted time.



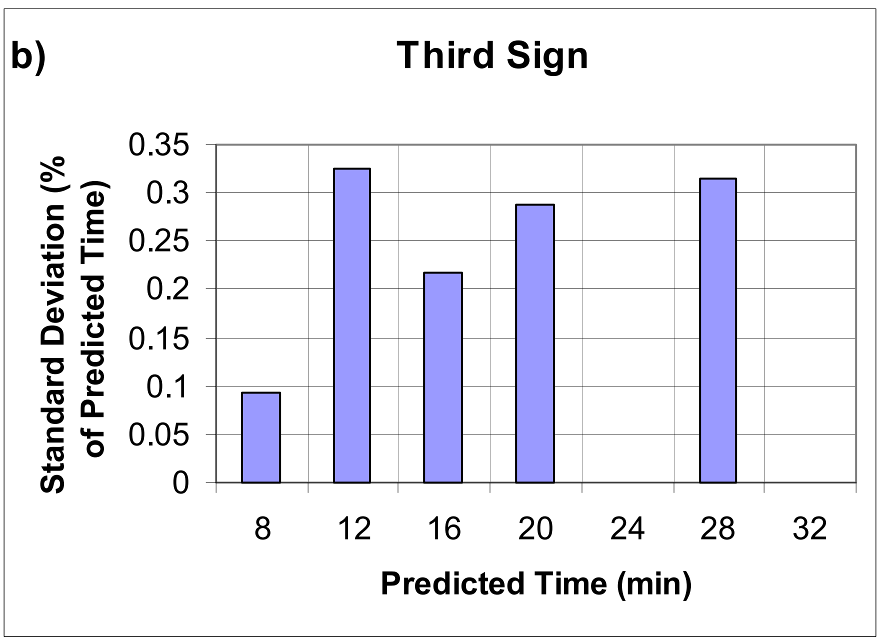
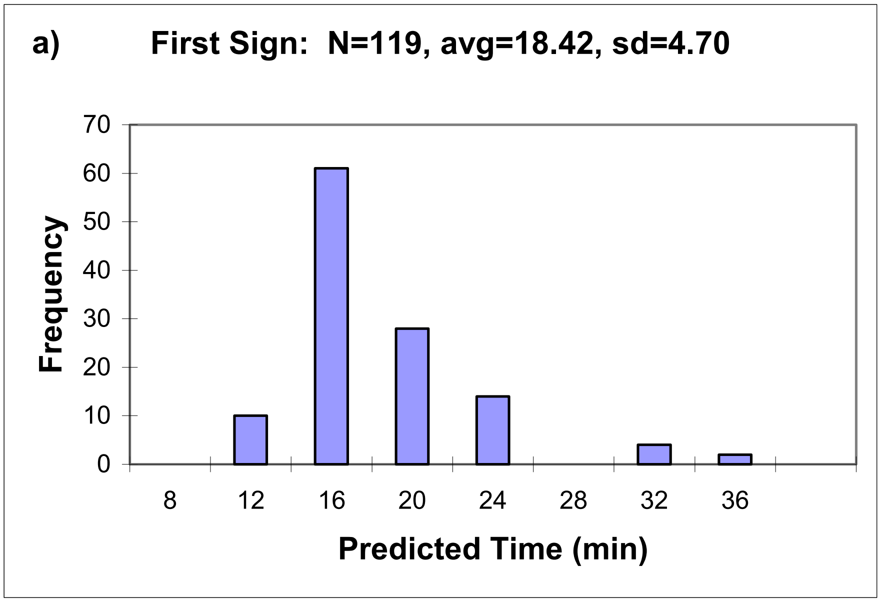


Figure 16. Standard Deviation of actual time values as a function of the predicted travel time displayed by the Third CMS. a) standard deviation in minutes. b) relative standard deviation, as a percentage of the predicted time.

Figure 17 indicates how many times a particular predicted time value was observed at each CMS. These figures also indicate the average and the standard deviation in terms of the central tendency and the variability of the predicted time values. The mode for the First CMS (Figure

17 a) is at 16 minutes, the mode for the Second CMS (Figure 17 b) is at 12 minutes, and the mode for the Third CMS (Figure 17 c) is at 8 minutes.



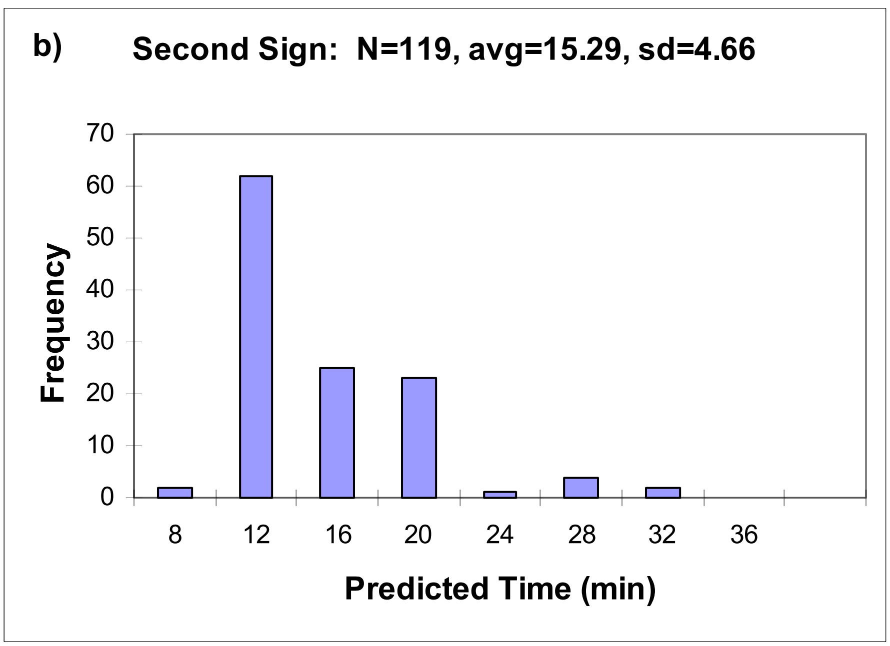


Figure 17. Parts a-b. Continued on next page.

Figure 18 shows the average predicted and actual travel times observed as a function of the distance to the end of the work zone. The average values on the two graphs match fairly well, however the standard deviations of the actual values are noticeably greater than those for the predicted values.

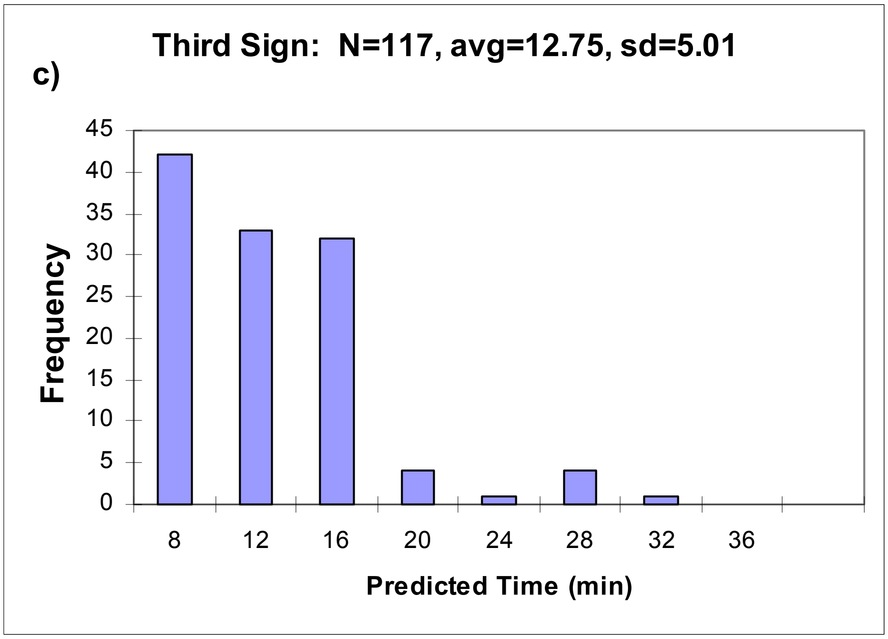


Figure 17. Histograms of predicted travel times observed on each CMS. a) First CMS. b) Second CMS. c) Third CMS.

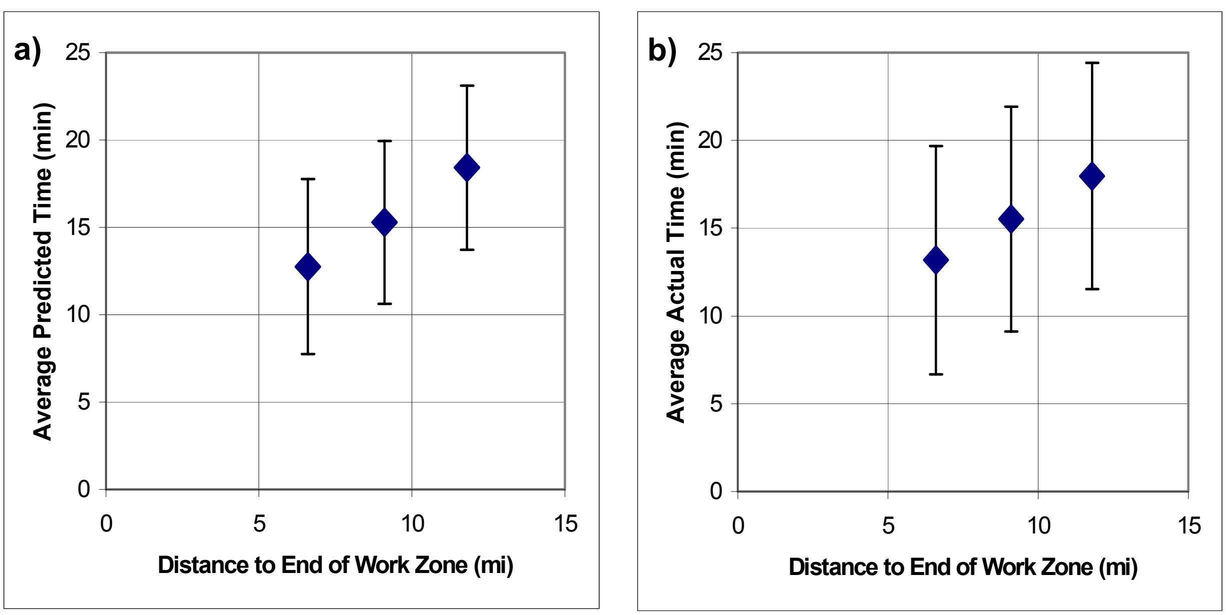


Figure 18. a) Average predicted travel time for each CMS as function of distance to the end of the work zone. b) Average actual travel time for each CMS as function of distance to the end of the work zone. In both figures, note 0 is the end of the work zone, thus the first CMS is to the right in the graph. The error bars represent the corresponding standard deviations.

Figures 19, 20, 21, and 22, and Tables 1, 2, 3, and 4 indicate the differences between the actual recorded travel times and the predicted travel times (Actual-Predicted) in terms of frequencies, cumulative frequencies, relative frequencies, and cumulative relative frequencies for each of the three signs and for the three signs combined.

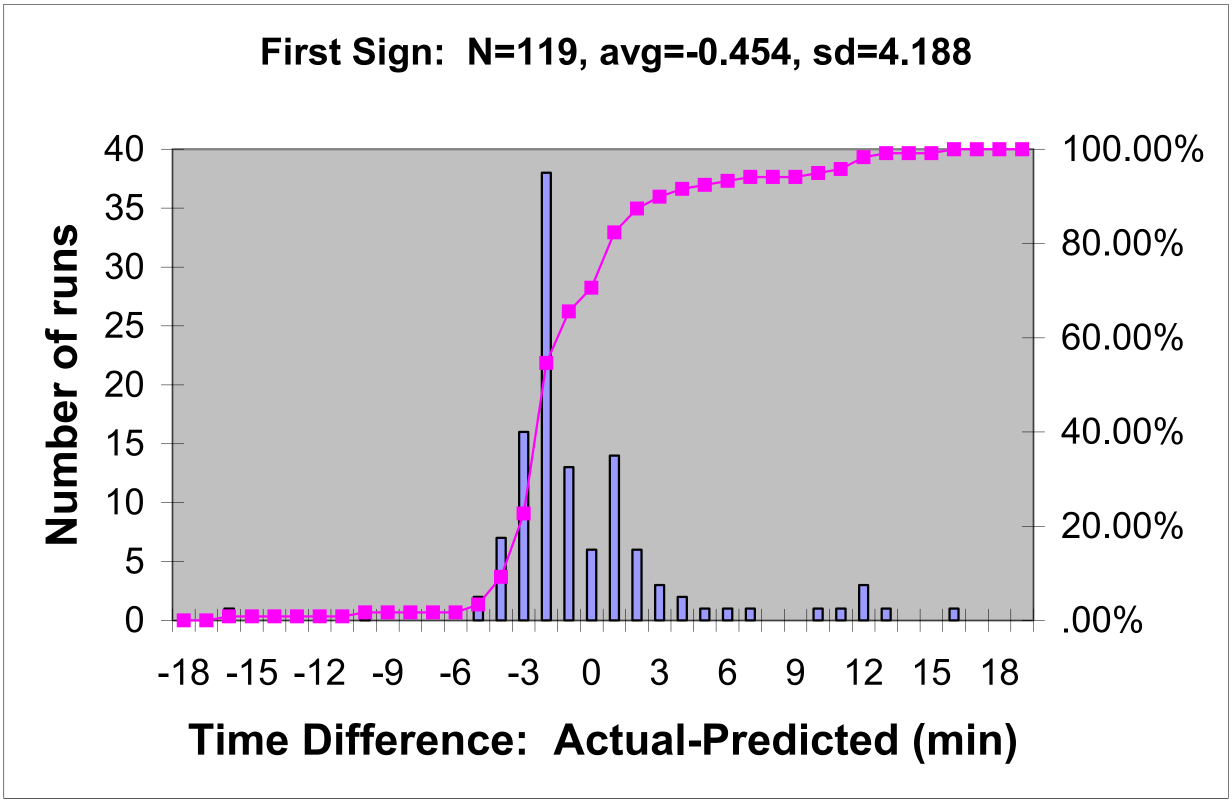


Figure 19. Histogram of discrepancy between actual travel time and predicted travel time for the First CMS, including cumulative percentages (axis at right).

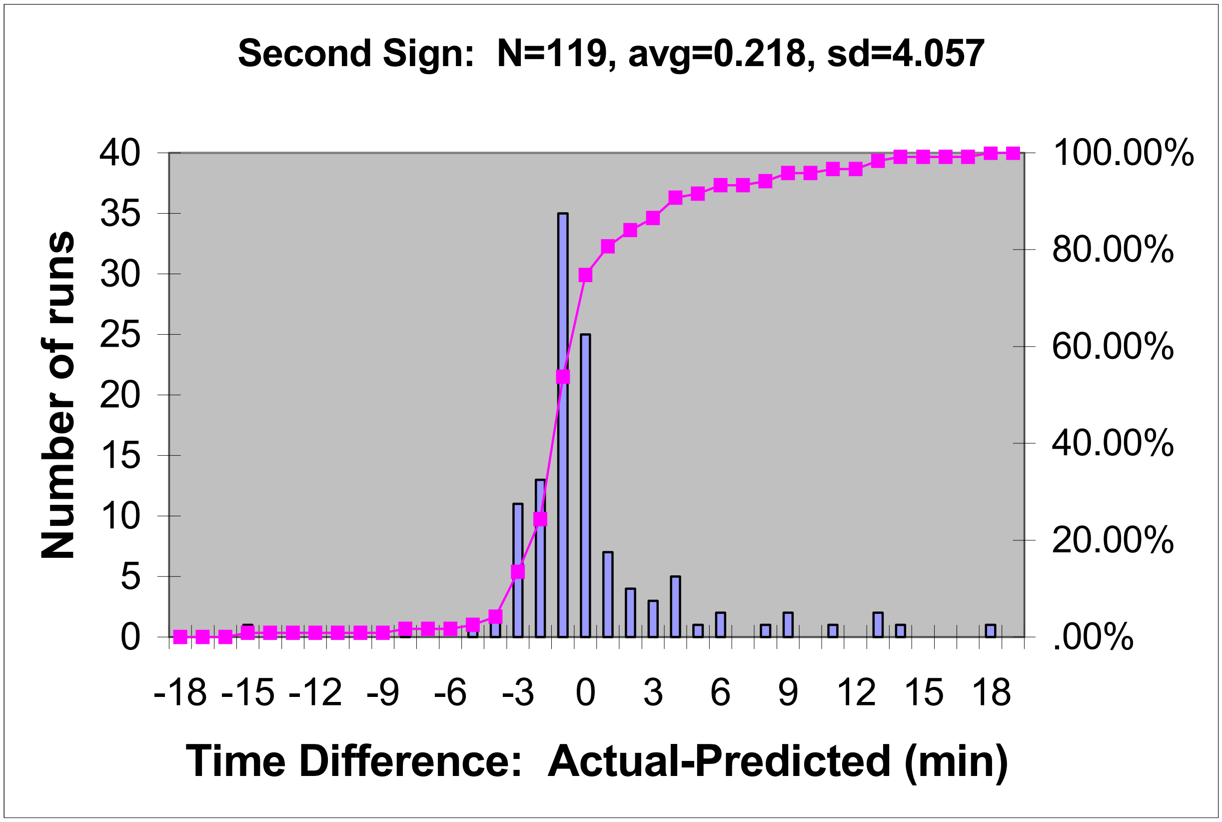


Figure 20. Histogram of discrepancy between actual travel time and predicted travel time for the Second CMS, including cumulative percentages (axis at right).

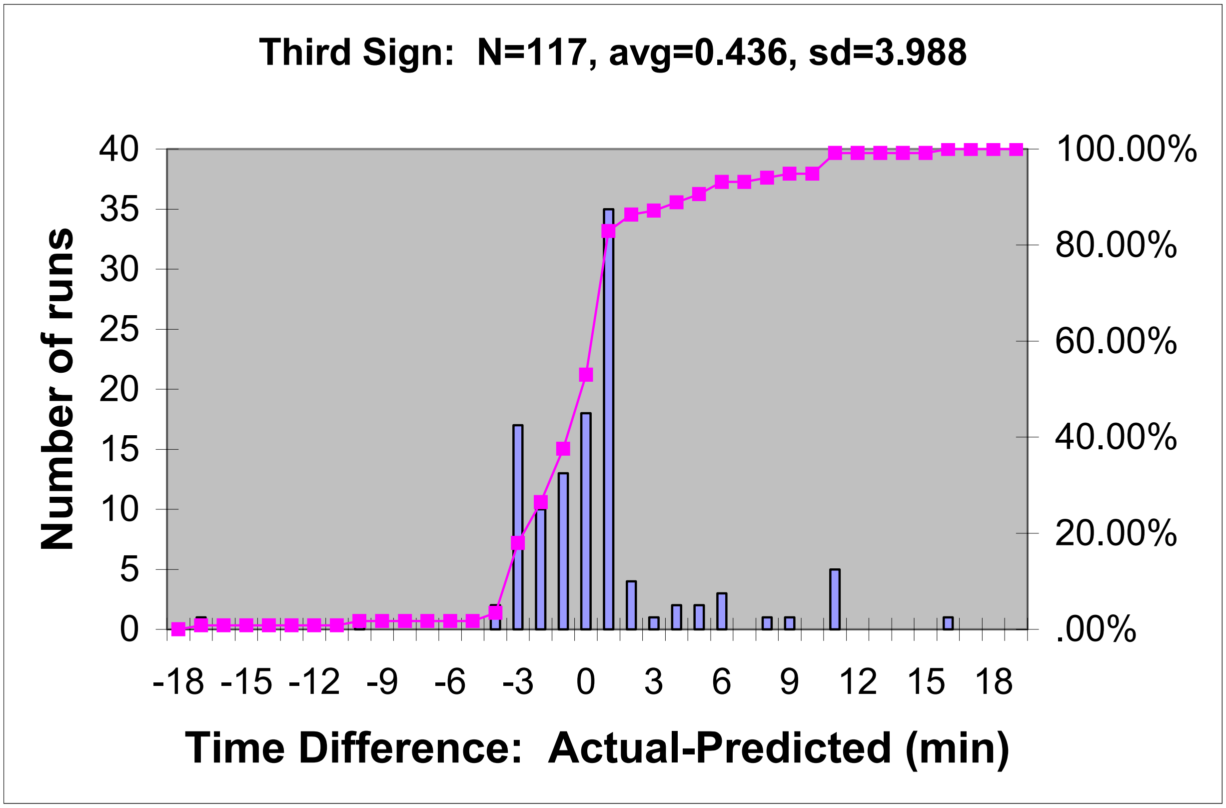


Figure 21. Histogram of discrepancy between actual travel time and predicted travel time for the Third CMS, including cumulative percentages (axis at right).

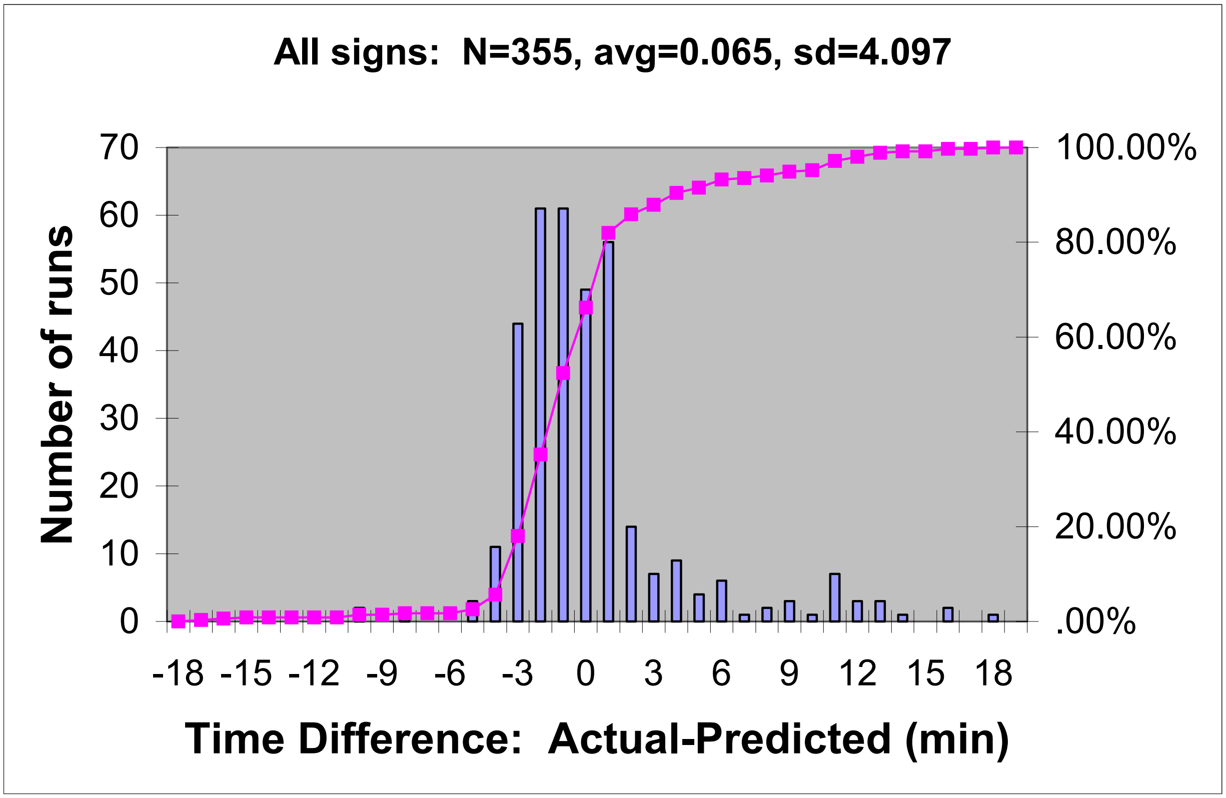


Figure 22. Histogram of discrepancy between actual travel time and predicted travel time for all three CMSs, including cumulative percentages (axis at right).

Table 1. Time difference histogram data for the First CMS, with frequency and cumulative values expressed as both numbers and percentages.

Minutes off	*Frequency*	*Rel. F %*	*Cumulative*	*Rel. Cum. %*
-18	0	0.00%	0	.00%
-17	0	0.00%	0	.00%
-16	1	0.84%	1	.84%
-15	0	0.00%	1	.84%
-14	0	0.00%	1	.84%
-13	0	0.00%	1	.84%
-12	0	0.00%	1	.84%
-11	0	0.00%	1	.84%
-10	1	0.84%	2	1.68%
-9	0	0.00%	2	1.68%
-8	0	0.00%	2	1.68%
-7	0	0.00%	2	1.68%
-6	0	0.00%	2	1.68%
-5	2	1.68%	4	3.36%
-4	7	5.88%	11	9.24%
-3	16	13.45%	27	22.69%
-2	38	31.93%	65	54.62%
-1	13	10.92%	78	65.55%
0	6	5.04%	84	70.59%
1	14	11.76%	98	82.35%
2	6	5.04%	104	87.39%
3	3	2.52%	107	89.92%
4	2	1.68%	109	91.60%
5	1	0.84%	110	92.44%
6	1	0.84%	111	93.28%
7	1	0.84%	112	94.12%
8	0	0.00%	112	94.12%
9	0	0.00%	112	94.12%
10	1	0.84%	113	94.96%
11	1	0.84%	114	95.80%
12	3	2.52%	117	98.32%
13	1	0.84%	118	99.16%
14	0	0.00%	118	99.16%
15	0	0.00%	118	99.16%
16	1	0.84%	119	100.00%
17	0	0.00%	119	100.00%
18	0	0.00%	119	100.00%
More	0	0.00%	119	100.00%

Table 2. Time difference histogram data for the Second CMS, with frequency and cumulative values expressed as both numbers and percentages.

Minutes off	*Frequency*	*Rel. F %*	*Cumulative*	*Rel. Cum. %*
-18	0	0.00%	0	.00%
-17	0	0.00%	0	.00%
-16	0	0.00%	0	.00%
-15	1	0.84%	1	.84%
-14	0	0.00%	1	.84%
-13	0	0.00%	1	.84%
-12	0	0.00%	1	.84%
-11	0	0.00%	1	.84%
-10	0	0.00%	1	.84%
-9	0	0.00%	1	.84%
-8	1	0.84%	2	1.68%
-7	0	0.00%	2	1.68%
-6	0	0.00%	2	1.68%
-5	1	0.84%	3	2.52%
-4	2	1.68%	5	4.20%
-3	11	9.24%	16	13.45%
-2	13	10.92%	29	24.37%
-1	35	29.41%	64	53.78%
0	25	21.01%	89	74.79%
1	7	5.88%	96	80.67%
2	4	3.36%	100	84.03%
3	3	2.52%	103	86.55%
4	5	4.20%	108	90.76%
5	1	0.84%	109	91.60%
6	2	1.68%	111	93.28%
7	0	0.00%	111	93.28%
8	1	0.84%	112	94.12%
9	2	1.68%	114	95.80%
10	0	0.00%	114	95.80%
11	1	0.84%	115	96.64%
12	0	0.00%	115	96.64%
13	2	1.68%	117	98.32%
14	1	0.84%	118	99.16%
15	0	0.00%	118	99.16%
16	0	0.00%	118	99.16%
17	0	0.00%	118	99.16%
18	1	0.84%	119	100.00%
More	0	0.00%	119	100.00%

Table 3. Time difference histogram data for the Third CMS, with frequency and cumulative values expressed as both numbers and percentages.

Minutes off	*Frequency*	*Rel. F %*	*Cumulative*	*Rel. Cum. %*
-18	0	0.00%	0	.00%
-17	1	0.85%	1	.85%
-16	0	0.00%	1	.85%
-15	0	0.00%	1	.85%
-14	0	0.00%	1	.85%
-13	0	0.00%	1	.85%
-12	0	0.00%	1	.85%
-11	0	0.00%	1	.85%
-10	1	0.85%	2	1.71%
-9	0	0.00%	2	1.71%
-8	0	0.00%	2	1.71%
-7	0	0.00%	2	1.71%
-6	0	0.00%	2	1.71%
-5	0	0.00%	2	1.71%
-4	2	1.71%	4	3.42%
-3	17	14.53%	21	17.95%
-2	10	8.55%	31	26.50%
-1	13	11.11%	44	37.61%
0	18	15.38%	62	52.99%
1	35	29.91%	97	82.91%
2	4	3.42%	101	86.32%
3	1	0.85%	102	87.18%
4	2	1.71%	104	88.89%
5	2	1.71%	106	90.60%
6	3	2.56%	109	93.16%
7	0	0.00%	109	93.16%
8	1	0.85%	110	94.02%
9	1	0.85%	111	94.87%
10	0	0.00%	111	94.87%
11	5	4.27%	116	99.15%
12	0	0.00%	116	99.15%
13	0	0.00%	116	99.15%
14	0	0.00%	116	99.15%
15	0	0.00%	116	99.15%
16	1	0.85%	117	100.00%
17	0	0.00%	117	100.00%
18	0	0.00%	117	100.00%
More	0	0.00%	117	100.00%

Table 4. Time difference histogram data for all three CMSs combined, with frequency and cumulative values expressed as both numbers and percentages.

Minutes off	*Frequency*	*Rel. F %*	*Cumulative*	*Rel. Cum. %*
-18	0	0.00%	0	.00%
-17	1	0.28%	1	.28%
-16	1	0.28%	2	.56%
-15	1	0.28%	3	.85%
-14	0	0.00%	3	.85%
-13	0	0.00%	3	.85%
-12	0	0.00%	3	.85%
-11	0	0.00%	3	.85%
-10	2	0.56%	5	1.41%
-9	0	0.00%	5	1.41%
-8	1	0.28%	6	1.69%
-7	0	0.00%	6	1.69%
-6	0	0.00%	6	1.69%
-5	3	0.85%	9	2.54%
-4	11	3.10%	20	5.63%
-3	44	12.39%	64	18.03%
-2	61	17.18%	125	35.21%
-1	61	17.18%	186	52.39%
0	49	13.80%	235	66.20%
1	56	15.77%	291	81.97%
2	14	3.94%	305	85.92%
3	7	1.97%	312	87.89%
4	9	2.54%	321	90.42%
5	4	1.13%	325	91.55%
6	6	1.69%	331	93.24%
7	1	0.28%	332	93.52%
8	2	0.56%	334	94.08%
9	3	0.85%	337	94.93%
10	1	0.28%	338	95.21%
11	7	1.97%	345	97.18%
12	3	0.85%	348	98.03%
13	3	0.85%	351	98.87%
14	1	0.28%	352	99.15%
15	0	0.00%	352	99.15%
16	2	0.56%	354	99.72%
17	0	0.00%	354	99.72%
18	1	0.28%	355	100.00%
More	0	0.00%	355	100.00%

Tables 5, 6, 7, and 8 indicate 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. Figures 23, 24, 25, and 26 show how these percentages increase as the absolute value of the difference increases from zero to higher values. Note that for each of the three CMSs, and for 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 sign or all signs 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%.

Table 5. Frequency and Relative Frequency observations covered by selected ±Time Value (in minutes) of actual recorded time value from the predicted time value for the First CMS.

Selected ±Time Value (min)	Frequency	Relative Frequency %
0	6	5.04%
1	33	27.73%
2	77	64.71%
3	96	80.67%
4	105	88.24%
5	108	90.76%
6	109	91.60%
7	110	92.44%
8	110	92.44%
9	110	92.44%
10	112	94.12%
11	113	94.96%
12	116	97.48%
13	117	98.32%
14	117	98.32%
15	117	98.32%
16	119	100.00%
17	119	100.00%
18	119	100.00%
More	119	100.00%

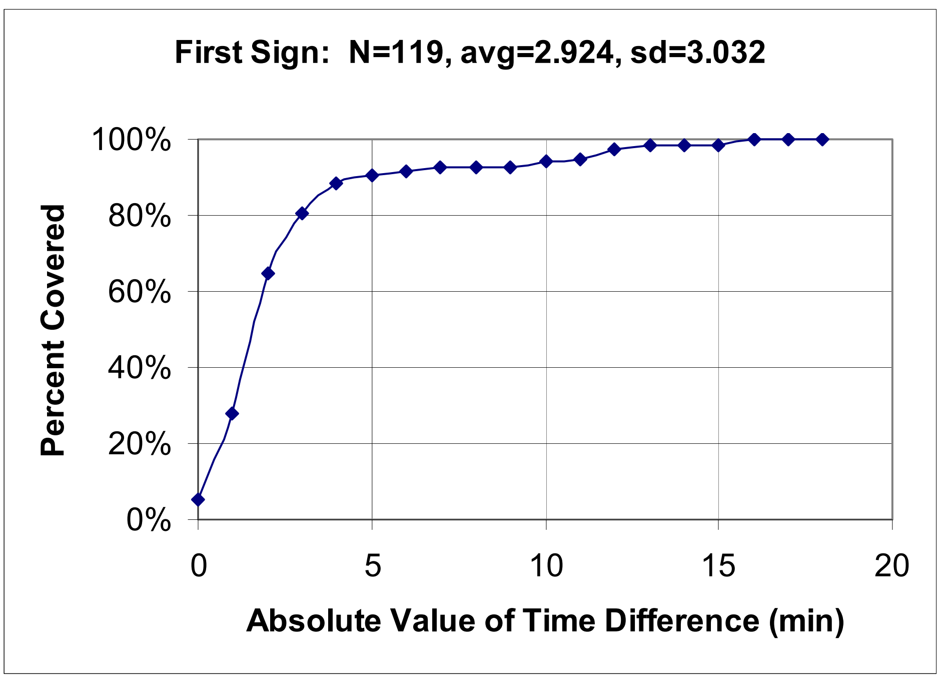


Figure 23. Relative Frequency observations covered by selected ±Time Value (in minutes) of actual recorded time value from the predicted time value for the First CMS.

Table 6. Frequency and Relative Frequency observations covered by selected ±Time Value (in minutes) of actual recorded time value from the predicted time value for the Second CMS.

Selected ±Time Value (min)	Frequency	Relative Frequency %
0	25	21.01%
1	67	56.30%
2	84	70.59%
3	98	82.35%
4	105	88.24%
5	107	89.92%
6	109	91.60%
7	109	91.60%
8	111	93.28%
9	113	94.96%
10	113	94.96%
11	114	95.80%
12	114	95.80%
13	116	97.48%
14	117	98.32%
15	118	99.16%
16	118	99.16%
17	118	99.16%
18	119	100.00%
More	119	100.00%

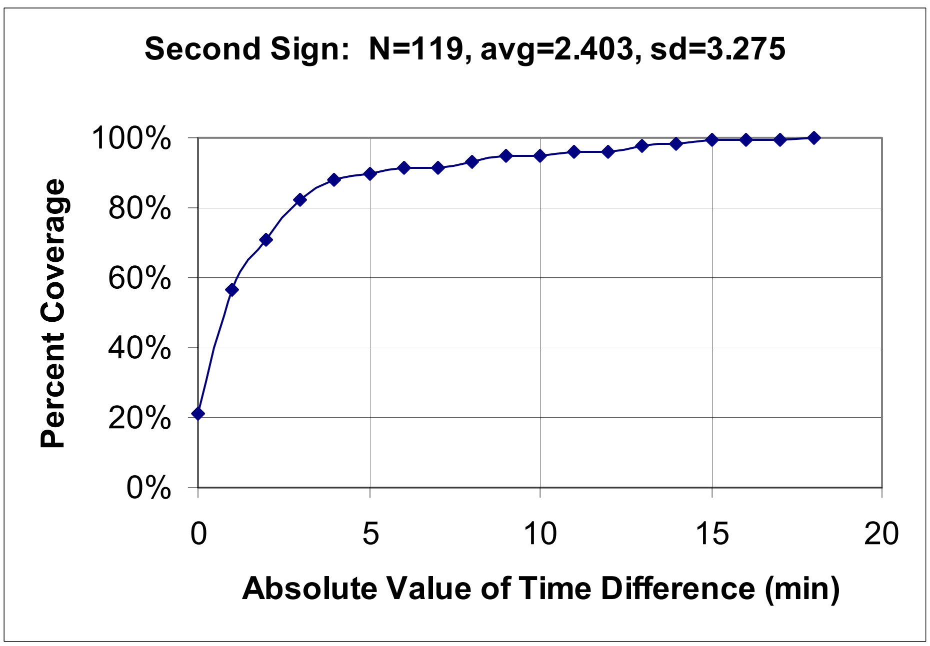


Figure 24. Relative Frequency observations covered by selected ±Time Value (in minutes) of actual recorded time value from the predicted time value for the Second CMS.

Table 7. Frequency and Relative Frequency observations covered by selected ±Time Value (in minutes) of actual recorded time value from the predicted time value for the Third CMS.

Selected ±Time Value (min)	Frequency	Relative Frequency %
0	18	15.38%
1	66	56.41%
2	80	68.38%
3	98	83.76%
4	102	87.18%
5	104	88.89%
6	107	91.45%
7	107	91.45%
8	108	92.31%
9	109	93.16%
10	110	94.02%
11	115	98.29%
12	115	98.29%
13	115	98.29%
14	115	98.29%
15	115	98.29%
16	116	99.15%
17	117	100.00%
18	117	100.00%
More	117	100.00%

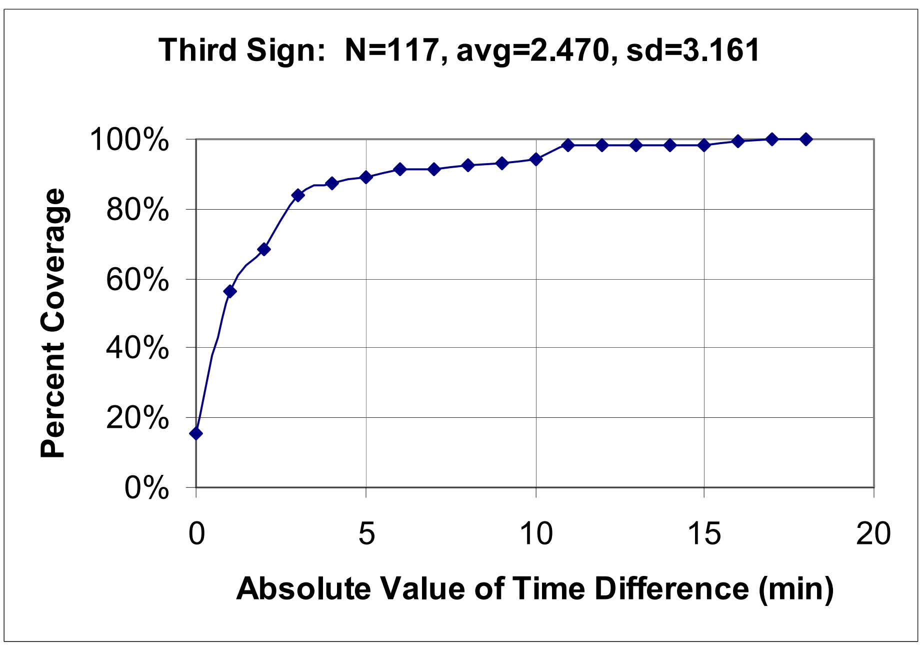


Figure 25. Relative Frequency observations covered by selected ±Time Value (in minutes) of actual recorded time value from the predicted time value for the Third CMS.

Table 8. Frequency and Relative Frequency observations covered by selected ±Time Value (in minutes) of actual recorded time value from the predicted time value for all three CMSs.

Selected ±Time Value (min)	Frequency	Relative Frequency %
0	49	13.80%
1	166	46.76%
2	241	67.89%
3	292	82.25%
4	312	87.89%
5	319	89.86%
6	325	91.55%
7	326	91.83%
8	329	92.68%
9	332	93.52%
10	335	94.37%
11	342	96.34%
12	345	97.18%
13	348	98.03%
14	349	98.31%
15	350	98.59%
16	353	99.44%
17	354	99.72%
18	355	100.00%
More	355	100.00%

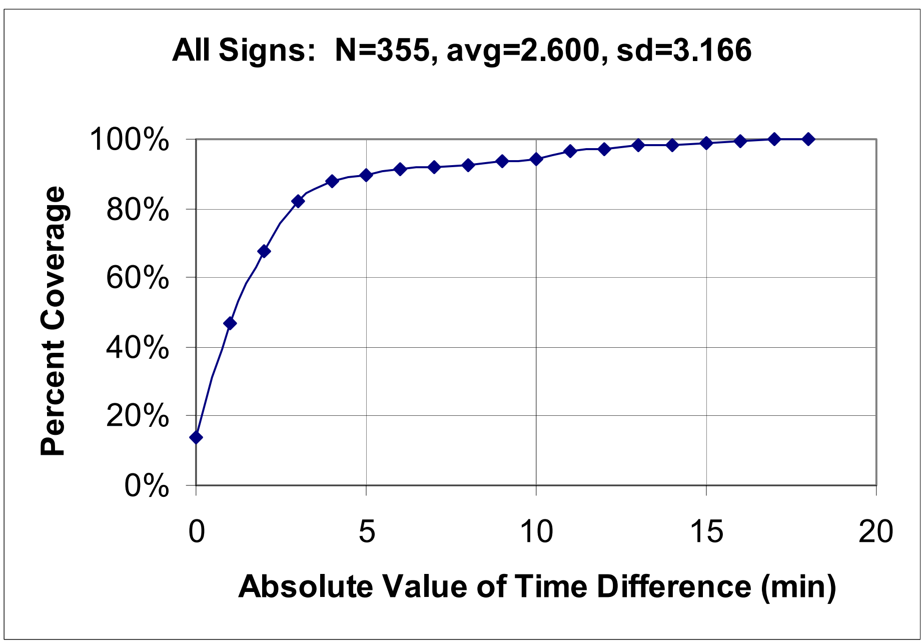


Figure 26. Relative Frequency observations covered by selected ±Time Value (in minutes) of actual recorded time value from the predicted time value for all three CMSs.

5.3 Analysis of the Survey Questionnaire Responses

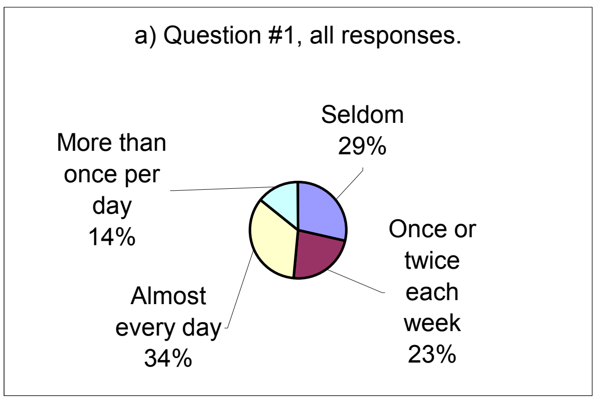
The responses to the motorist survey questionnaire responses are presented as a function of motorist exposure to the work zone in Table 9 through Table 15 and in Figure 27 through Figure 33. Overall, 3270 Ohio license plate numbers were recorded. After eliminating 93 duplicate license plate numbers, a sample of 3177 numbers remained, and the corresponding car registrants were each sent a survey questionnaire. Of these, 809 survey questionnaires were returned, which included 149 (18.4%) marked with “don’t remember driving through the work zone.” A number of these “don’t remember” returns might be explained by the fact that the registrant was not the same person driving the car when it was observed. Out of the 809 returned survey questionnaires, 660 were analyzed (20.8% return rate).

The analysis of Question #1 (see Table 9 and Figure 27) indicates that 29% of the responding motorists seldom drove through the work zone, while 23% drove through the work zone once or twice per week. Another 34% drove through the work zone almost every day, while 14% drove through the work zone more than once per day. Thus it appears that almost half (48%) of the responding motorists drove through the work zone almost every day or more often, and therefore could qualify as heavy users of the road who would be expected to have a pretty solid experience with the TIPS system on which to base their questionnaire responses.

Table 9. Responses to Question #1 of the survey, N=660.

Question #1: During summer and fall 2000, how often did you drive northbound on I-75 south of Dayton through the work zone? Please mark one.

Exposure		Total
Seldom	Number	189
Seldom	Percentage	28.6%
Once or twice each week	Number	151
Once or twice each week	Percentage	22.9%
Almost every day	Number	226
Almost every day	Percentage	34.2%
More than once per day	Number	94
More than once per day	Percentage	14.2%
Total	Number	660
Total	Percentage	100.00%



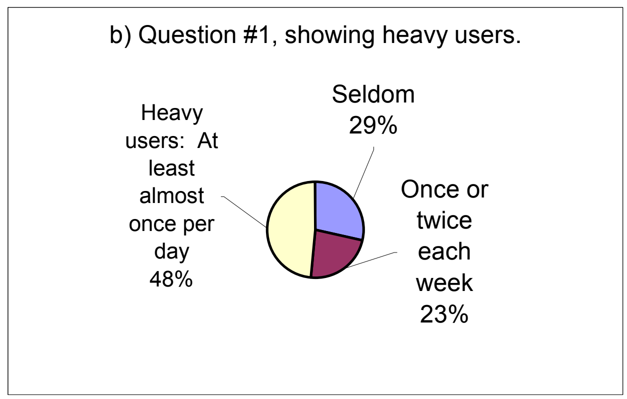


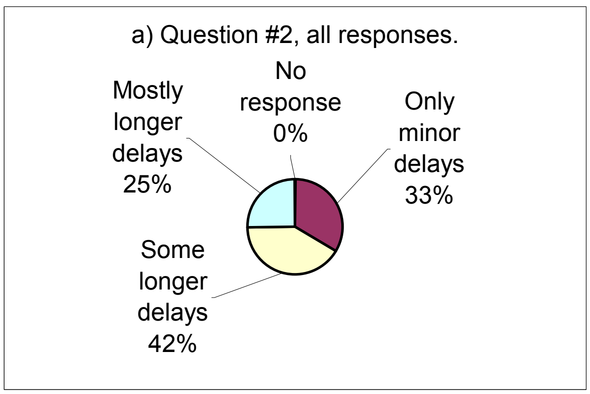
Figure 27. Pie graphs of responses to Question #1 of survey. a) all responses. b) all responses, with "Almost every day" and "More than once per day" responses grouped together as "Heavy users." There were 320 heavy users, 48.4% of respondents.

The responses to Question #2 (Table 10 and Figure 28) indicate that overall about 2/3 of the motorists experienced some longer or mostly longer traffic delays. Looking at the heavy users ("almost every day" and "more than once per day"), the corresponding percentage is, as expected, even higher at about 80%.

Table 10. Responses to Question #2 of the survey, broken down by categories from Question #1 regarding frequency of travel through the work zone.

Question #2: While Driving northbound on I-75 south of Dayton in advance of the work zone and through the work zone, what type of traffic delays have you experienced? Please mark one.

Exposure (Question #1)		Total	No response	Only minor	Some longer	Mostly longer
Seldom	Number	189	2	109	62	16
Seldom	Percentage	28.6%	1.1%	57.7%	32.8%	8.5%
Once or twice each week	Number	151	0	50	75	26
Once or twice each week	Percentage	22.9%	0.0%	33.1%	49.7%	17.2%
Almost every day	Number	226	0	42	104	80
Almost every day	Percentage	34.2%	0.0%	18.6%	46.0%	35.4%
More than once per day	Number	94	0	18	32	44
More than once per day	Percentage	14.2%	0.0%	19.1%	34.0%	46.8%
Total	Number	660	2	219	273	166
Total	Percentage	100.00%	0.30%	33.18%	41.36%	25.15%



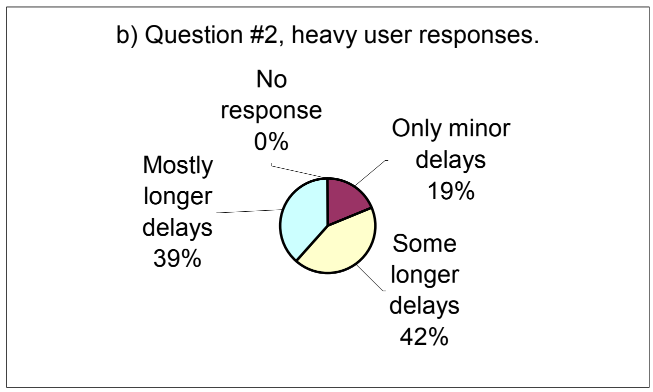


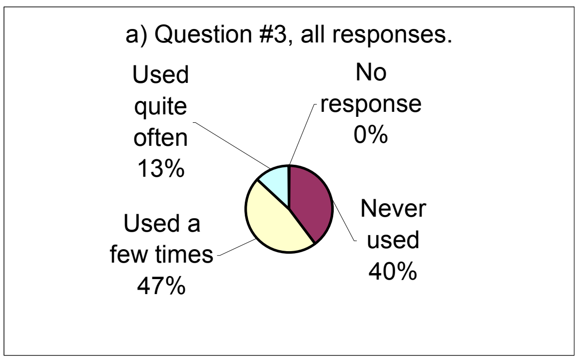
Figure 28. Pie graphs of responses to Question #2 of survey. a) all responses. b) heavy user responses ("Almost every day" and "More than once per day" responses to Question #1). Percentages in b) are of the heavy user group only, not all the respondents.

The responses to Question #3 (Table 11 and Figure 29) indicate that overall about 60% have used the predicted travel time information to exit I-75 at an earlier than initially planned exit. Looking at the heavy users, the corresponding percentage is, as expected, even higher at about 72%.

Table 11. Responses to Question #3 of the survey, broken down by categories from Question #1 regarding frequency of travel through the work zone.

Question #3: Have you used the predicted real-time travel time information presented on the three changeable message signs to exit I-75 at an earlier than initially planned exit and selected an alternate route to get to your destination? Please mark one.

Exposure (Question #1)		Total	No response	Never	A few times	Quite often
Seldom	Number	189	2	114	66	7
Seldom	Percentage	28.6%	1.1%	60.3%	34.9%	3.7%
Once or twice each week	Number	151	0	56	79	16
Once or twice each week	Percentage	22.9%	0.0%	37.1%	52.3%	10.6%
Almost every day	Number	226	0	64	118	44
Almost every day	Percentage	34.2%	0.0%	28.3%	52.2%	19.5%
More than once per day	Number	94	0	27	48	19
More than once per day	Percentage	14.2%	0.0%	28.7%	51.1%	20.2%
Total	Number	660	2	261	311	86
Total	Percentage	100.00%	0.30%	39.55%	47.12%	13.03%



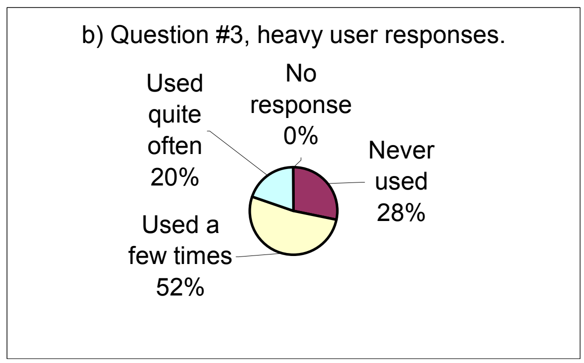


Figure 29. Pie graphs of responses to Question #3 of survey. a) all responses. b) heavy user responses ("Almost every day" and "More than once per day" responses to Question #1). Percentages in b) are of the heavy user group only, not all the respondents.

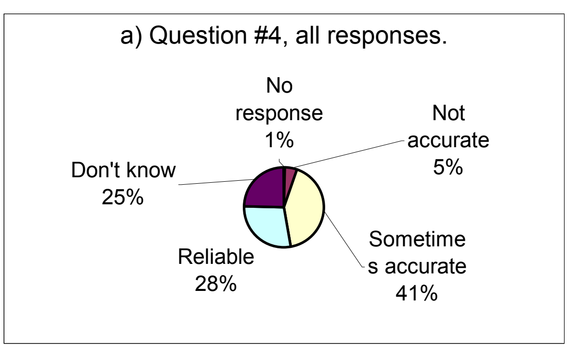
The responses to Question #4 (Table 12 and Figure 30) indicate that overall about a quarter of the respondents don't know whether or not the displayed predicted travel times were accurate or not. The corresponding percentage for the heavy users indicate that about 1/6 of these motorists don't know whether the predicted travel times are accurate or not. It is interesting to note that only about 28% of the responding motorists indicate that the predicted travel times are accurate and reliable enough for them. About 30% of the heavy users gave the same answer, which is fairly close and consistent with regard to the overall percentage. It should be noted that overall about 42% of the responding motorists indicate that the predicted travel time information is sometimes accurate and reliable and sometimes not accurate and reliable. Again, the corresponding percentage for the heavy users group is about 45%, which is again fairly close and not much different with regard to the overall percentage. This result would indicate that almost one half of the respondents are aware that the predicted travel times are sometimes accurate and sometimes not, which may lead motorists to second guess the system and take chances with regard to their selection of a plan of action (either selecting an earlier exit or stay on the freeway until reaching the initially planned exit). It appears that overall only about 5% of the responding motorists indicated that the predicted travel times are not accurate and reliable enough for them.

Table 12. Responses to Question #4 of the survey, broken down by categories from Question #1 regarding frequency of travel through the work zone.

Question #4: Based on your driving experience, when driving northbound on I-75 in advance and through the work zone, do you feel that the presented real-time travel times to the end of the work zone were accurate and reliable? Please mark one.

Exposure (Question #1)		Total	No response	Not accurate
Seldom	Number	189	4	4
Seldom	Percentage	28.6%	2.1%	2.1%
Once or twice each week	Number	151	0	5
Once or twice each week	Percentage	22.9%	0.0%	3.3%
Almost every day	Number	226	0	15
Almost every day	Percentage	34.2%	0.0%	6.6%
More than once per day	Number	94	0	9
More than once per day	Percentage	14.2%	0.0%	9.6%
Total	Number	660	4	33
Total	Percentage	100.00%	0.61%	5.00%

Exposure (Question #1)		Sometimes	Always Accurate	Don't know
Seldom	Number	59	52	70
Seldom	Percentage	31.2%	27.5%	37.0%
Once or twice each week	Number	65	39	42
Once or twice each week	Percentage	43.0%	25.8%	27.8%
Almost every day	Number	113	63	35
Almost every day	Percentage	50.0%	27.9%	15.5%
More than once per day	Number	38	31	16
More than once per day	Percentage	40.4%	33.0%	17.0%
Total	Number	275	185	163
Total	Percentage	41.67%	28.03%	24.70%



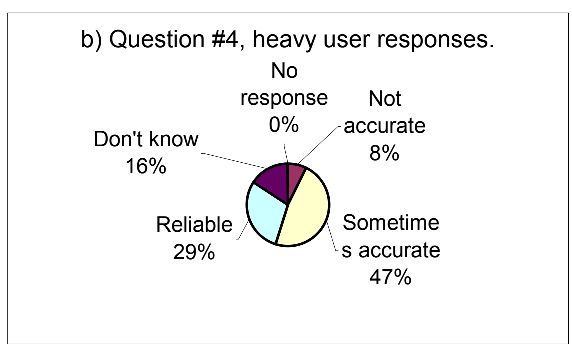


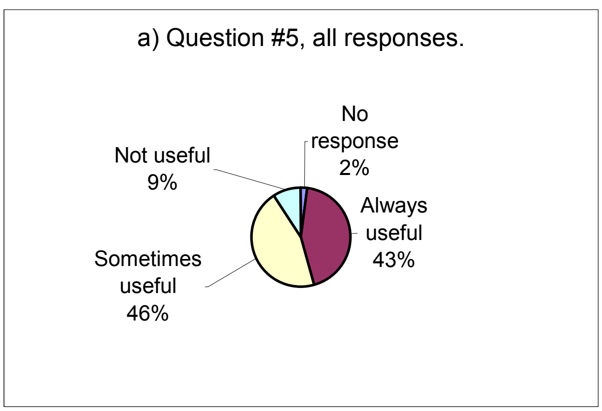
Figure 30. Pie graphs of responses to Question #4 of survey. a) all responses. b) heavy user responses ("Almost every day" and "More than once per day" responses to Question #1). Percentages in b) are of the heavy user group only, not all the respondents.

The responses to Question #5 (Table 13 and Figure 31) indicate that overall about 90% of the motoring public thinks that the predicted travel times are sometimes or always useful. For the heavy users, the corresponding rate is about 86%, or just slightly less than the percentage of the overall responses. It appears that 10% of the motorists think that the predicted travel time information is not useful, which is about twice the approximately 5% of the respondents who responded "not accurate or reliable enough for me" to Question #4.

Table 13. Responses to Question #5 of the survey, broken down by categories from Question #1 regarding frequency of travel through the work zone.

Question #5: Do you think that, based on your experience, the presented real-time travel times provided you with useful information, even if you couldn't exit earlier to avoid traffic delays? Please mark one.

Exposure (Question #1)		Total	No response	Always	Sometimes	Not useful
Seldom	Number	189	5	86	83	15
Seldom	Percentage	28.6%	2.6%	45.5%	43.9%	7.9%
Once or twice each week	Number	151	2	62	76	11
Once or twice each week	Percentage	22.9%	1.3%	41.1%	50.3%	7.3%
Almost every day	Number	226	3	99	102	22
Almost every day	Percentage	34.2%	1.3%	43.8%	45.1%	9.7%
More than once per day	Number	94	4	40	38	12
More than once per day	Percentage	14.2%	4.3%	42.6%	40.4%	12.8%
Total	Number	660	14	287	299	60
Total	Percentage	100.00%	2.12%	43.48%	45.30%	9.09%



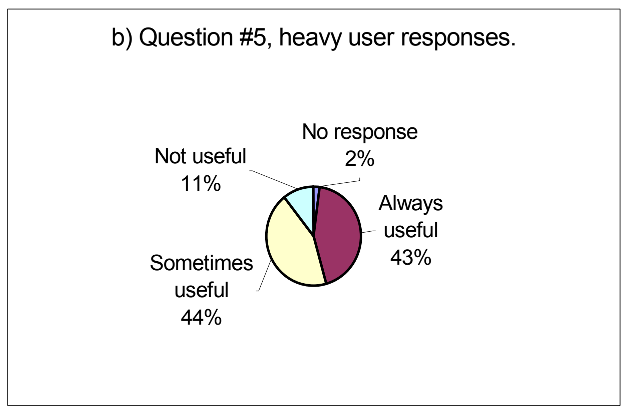


Figure 31. Pie graphs of responses to Question #5 of survey. a) all responses. b) heavy user responses ("Almost every day" and "More than once per day" responses to Question #1). Percentages in b) are of the heavy user group only, not all the respondents.

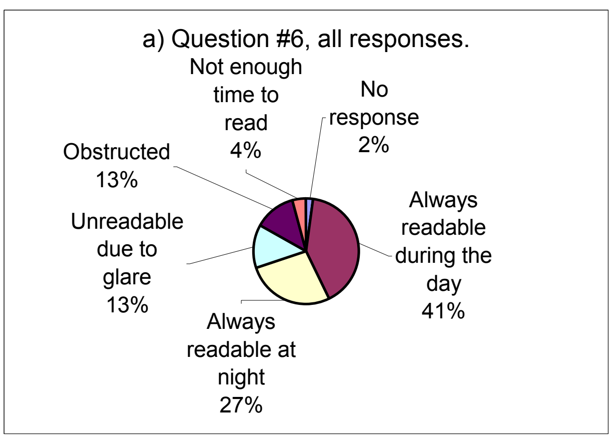
The responses to Question #6 (Table 14 and Figure 32) indicate overall that the information was not always easy to read due to glare (13.3%), obstructions or other traffic (12.65%), or not enough time (4.22%). On the other hand, about 41% indicated that the predicted travel time information was always easy to read during daytime, and about 27% indicated the information was always easy to read during night time. The corresponding percentages for the heavy users are very similar when compared to the overall percentages.

Table 14. Responses to Question #6 of the survey, broken down by categories from Question #1 regarding frequency of travel through the work zone.

Question #6: Was the presented real-time travel time information to the end of the work zone easy to read? Please mark those that are applicable.

Exposure (Question #1)		Respondents	Total	No response	Always, day	Always, night
Seldom	Number	189	266	9	111	71
Seldom	Percentage	28.6%	100.0%	3.4%	41.7%	26.7%
Once or twice each week	Number	151	227	4	85	60
Once or twice each week	Percentage	22.9%	100.0%	1.8%	37.4%	26.4%
Almost every day	Number	226	340	4	142	94
Almost every day	Percentage	34.2%	100.0%	1.2%	41.8%	27.6%
More than once per day	Number	94	139	4	57	38
More than once per day	Percentage	14.2%	100.0%	2.9%	41.0%	27.3%
Total	Number	660	972	21	395	263
Total	Percentage	100.0%	100.00%	2.16%	40.64%	27.06%

Exposure (Question #1)		Glare	Obstruction	Not enough time
Seldom	Number	32	32	11
Seldom	Percentage	12.0%	12.0%	4.1%
Once or twice each week	Number	33	35	10
Once or twice each week	Percentage	14.5%	15.4%	4.4%
Almost every day	Number	48	40	12
Almost every day	Percentage	14.1%	11.8%	3.5%
More than once per day	Number	16	16	8
More than once per day	Percentage	11.5%	11.5%	5.8%
Total	Number	129	123	41
Total	Percentage	13.27%	12.65%	4.22%



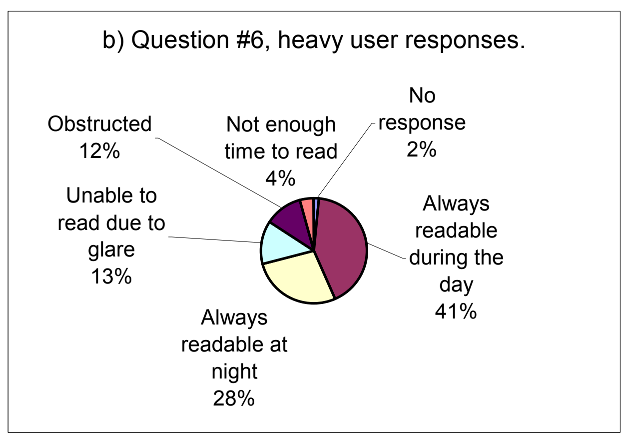


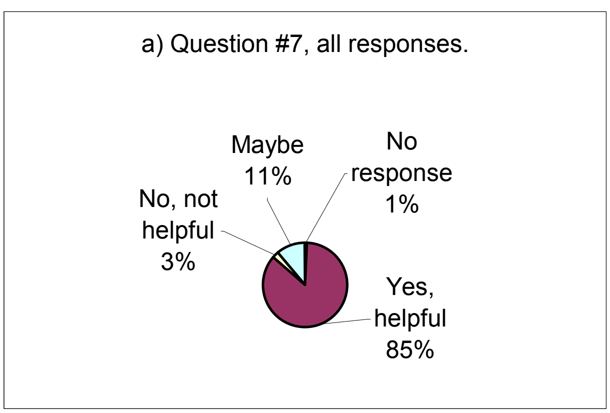
Figure 32. Pie graphs of responses to Question #6 of survey. a) all responses. b) heavy user responses ("Almost every day" and "More than once per day" responses to Question #1). Percentages in b) are of the heavy user group only, not all the respondents.

The responses to Question #7 (Table 15 and Figure 33) indicate that overall about 86% of the surveyed motoring public think that such a travel time prediction system is helpful to the motoring public, while only about 2.5% indicate that the system would not be helpful. Another 11% indicate that such a system could, maybe, be useful to the motoring public. Again, the responses for the heavy user group are fairly close to those of overall surveyed motorists. Combining the "Yes' and "maybe" responses to Question #7 indicates that almost 97% of the responding motorists think that such a system is either outright helpful or maybe helpful. This endorsement for a real-time travel time prediction system is really not surprising considering the responses to some of the earlier survey questions.

Table 15. Responses to Question #7 of the survey, broken down by categories from Question #1 regarding frequency of travel through the work zone.

Question #7: Do you think that such a travel time prediction system in advance of work zones and in advance of exits on heavily traveled freeways where drivers could select an alternate route in situations where long travel times to the end of the work zone are predicted is helpful to the motoring public? Please mark one.

Exposure (Question #1)		Total	No response	Yes	No	Maybe
Seldom	Number	189	4	166	4	15
Seldom	Percentage	28.6%	2.1%	87.8%	2.1%	7.9%
Once or twice each week	Number	151	0	131	2	18
Once or twice each week	Percentage	22.9%	0.0%	86.8%	1.3%	11.9%
Almost every day	Number	226	1	193	7	25
Almost every day	Percentage	34.2%	0.4%	85.4%	3.1%	11.1%
More than once per day	Number	94	0	75	4	15
More than once per day	Percentage	14.2%	0.0%	79.8%	4.3%	16.0%
Total	Number	660	5	565	17	73
Total	Percentage	100.00%	0.76%	85.61%	2.58%	11.06%



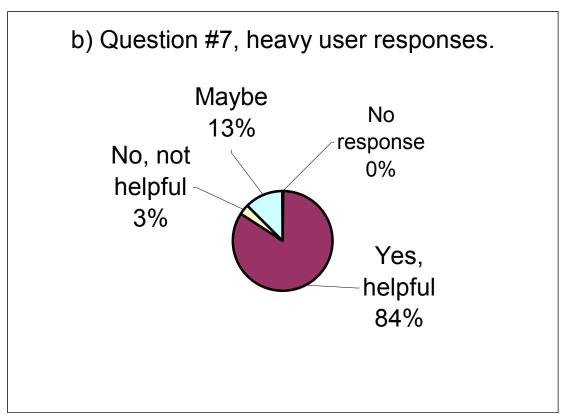


Figure 33. Pie graphs of responses to Question #7 of survey. a) all responses. b) heavy user responses ("Almost every day" and "More than once per day" responses to Question #1). Percentages in b) are of the heavy user group only, not all the respondents.

6 DISCUSSION AND CONCLUSIONS

The accuracy evaluation based on a total of 119 runs indicates that the percentage of actually recorded travel time values which are within a ±4 minute range of the predicted time value are closely around 88% for each of the three signs and when all signs are combined. 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. Again, 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.

The survey responses to Question #4 (42% of the responding motorists indicate that the predicted travel times are sometimes accurate and reliable and sometimes not accurate and reliable) appear to indicate that the motoring public is sensitive and does perceive a certain inaccuracy contained in the predicted travel times.

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.

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 such predicted travel times would need to be conducted. It should also be noted that in spite of the observed somewhat limited predicted travel time accuracy, as well as the motorists' inaccuracy perceptions, according to the survey questionnaire responses to Question #7 almost 97% of the motoring public think that such a system is either outright helpful or maybe helpful.

Based on the survey results from Question #6 it would seem useful and beneficial to evaluate and possibly improve the readability or legibility of the displayed information (improve the readability under glare and under night time conditions) by the changeable message signs through the use of better and state of the art changeable message signs.

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 and appears to be perceived by the motoring public as a helpful and useful.

7 REFERENCES

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

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

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

[6] Minitab, Inc., Minitab release 13.1, 2000.