AZTech Moving Forward Together

AZTech™ Phase III Program of Advanced Traveler Information Services for the Deployment of Service D:

Travel Time Estimates, Displays, and Forecasts – Final Report

Technical Report #2
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Preface

AZTech[TM] is a Model Deployment Initiative (MDI) formed by a consortium of local governmental agencies and private organizations to integrate the ITS efforts of agencies such as the Arizona Department of Transportation (ADOT), the Maricopa County Department of Transportation (MCDOT), local cities and other agencies such as fire departments and rural metro. Two phases of the project have been completed. AZTech[TM] solicited proposals for Phase III partners from private entities with innovative ideas on Advanced Traveler Information Systems (ATIS). OZ Engineering (with partners Motion Maps, LLC and TranSmart Technologies) was selected as one of the partners to deploy an Advanced Traveler Information Service module for the study, calculation, display and forecast of travel times.

This document is the second Technical Report for the Travel Time Displays and Forecasts Project. It is a technical memorandum and final report summarizing the work carried out on the overall project. Particular focus is given to the work performed during Phase 2 of the project to study alternative approaches and algorithms and to test and deploy an operating system.

The first Technical Report for Phase 1 of this project is a technical memorandum that summarizes the current state of the practice in use by other Departments of Transportation. The literature search and telephone interviews that were conducted in Phase 1 are summarized in Volume I, while Volume II, under separate cover contains the actual literature search citations and telephone interview responses.

Executive Summary

Phase I of this project was concerned with the state-of-the-art of displaying travel time estimates on Variable Message Signs as practiced by various traffic management centers from throughout the nation and nearby in Canada. Phase II was focused on the testing and development of algorithms that could be used in preparing predictive travel time estimates that could be displayed for a selected corridor in the Phoenix area. The selected test corridor was an approximate 9-mile section of Interstate 17 to the north and west of downtown Phoenix. The algorithms are primarily based on historical and current roadway detector data from ADOT's Freeway Management System for the test corridor.

A key part of the project was a structured sample of speed and travel time data that was collected using probe vehicles equipped with Global Positioning System tracking devices. The resulting calculations of observed travel times obtained from the probe vehicle data was used in developing aspects of the algorithms as well as formed a base set of conditions against which the predictive travel time estimates can be compared. The samples distinguished travel time by direction as well as by mainline lanes and High Occupancy Vehicle lanes. The samples were taken during twelve time periods: the morning and evening peak traffic periods during five consecutive weekdays and midday on the two weekend days. Those sampling periods were selected in order to capture information about when and by how much corridor travel time varies as congestion increases, plateaus, and then decreases during the peak periods. An important finding by this project is that there is a similarity between the "travel time profiles" by time-of-day of the start of the trip with that of "diurnal curves" that have long been used to characterize the daily cycles observed in the variation in the volume of traffic using a roadway.

That finding of observable patterns from the travel time data provides a basis for developing predictive travel times. Another basis is distinctions among different ways travel time is measured and represented: probe travel time, snap shot travel time, after-the-fact travel time, and predictive travel time. The project hypothesized various relationships among these different measures of travel time, which were generally confirmed from analysis of travel times from the observed data. In particular: (1) after-the-fact travel times, calculated from archived data, differ from snap shot travel time that could have been calculated "real-time", (2) after-the-fact travel time better matches the observed probe travel times, and (3) comparison of the values of after-the-fact travel time to snap shot travel time values gives larger travel times values as congestion is increasing, and smaller travel times values as congestion is decreasing.

Based upon the observed probe travel times and general knowledge of travel behavior the project has also hypothesized that there are about ten distinct time periods within which there will likely be similar travel time profiles or patterns. Free-flowing, ambient traffic conditions and travel times are anticipated to prevail for about 78% of the hours annually for weekends, evenings and nights, and weekday midday. The other periods are midweek peak periods and others such as Monday mornings and Friday afternoons, especially around holidays that exhibit more unique patterns. All time periods are subject to change according to the season, unusual weather conditions, and significant incidents of various types.

The basic structure of the algorithm was specified and several partial test versions were prepared that focused on the core feature of an After-the-Fact Travel Time calculator routine. That calculator routine was applied to the FMS archived data for the same time period of the probe travel time survey. The resulting after-the-fact travel times were in essence similar to future predictive travel times and were compared to the observed probe travel times. The comparisons showed that the calculator worked well for the southbound general purpose and HOV lanes but due to challenges of data quality from the older detectors in the south part of the northbound direction the comparisons were not as favorable. The test algorithm has been operational since Spring 2004 and the resulting snap shot and after-the-fact travel times are being logged for future analysis and to help establish the travel time pattern sets.

A prototype Web page was developed to simulate the Travel Time Displays on Variable Message Signs in the test corridor, as well as a corridor summary, a regional speed map, and CCTV displays for the test corridor. While the FMS update cycle is set at 20 seconds, for the sake of the driving public, the Variable Message Sign update was limited to a minute-cycle.

Glossary

Below is a brief description of the acronyms and technical terms used in this and the prior document.

TERM	MEANING
ADMS	Archived Data Management System
ADOT	Arizona Department of Transportation
ARTIMIS	Advanced Regional Traffic Interactive Management & Information System
ATF_TT	After-the-Fact Travel Time
ATIS	Advanced Traveler Information System
ATMS	Advanced Traffic Management System not to be confused with AZTech™ Message System.
ATSAC	Automated Traffic Surveillance and Control
AVI	Automatic Vehicle Identification
AVL	Automated Vehicle Location
AZTech™	"Arizona Technologies", the joint public and private partnership to deploy and integrate the Phoenix metropolitan area ITS and provide real-time travel information to the public.
CATF_TT	Current After-the-Fact Travel Time
CCTV	Closed Circuit Television
CMS	Changeable Message Sign
DMS	Dynamic/Displayable Message Sign
DOT	Department of Transportation
DPS	Department of Public Safety
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FMS	Freeway Management System
GDOT	Georgia Department of Transportation
GPS	Global Positioning System
GUI	Graphical User Interface
HAR	Highway Advisory Radio
HOV	High-Occupancy Vehicle
HTML	Hyper Text Markup Language
ITS	Intelligent Transportation Systems
MAG	Maricopa Association of Governments
MCDOT	Maricopa County Department of Transportation
MDI	Model Deployment Initiative
MTC	Metropolitan Transportation Commission
OCC	Operations Control Center
PANYNJ	Port Authority of New York and New Jersey
PATH	Partners for Advanced Transit and Highways
PeMS	Performance Measurement System
PTTA	Predictive Travel Time Algorithm
RADS	Regional Archived Data System
SS_TT	Snap-Shot Travel Time
TMC	Traffic Management Center
TOC	Traffic Operations Center
URL	Universal Resource Locator
UVA	University of Virginia
VATF_TT	Variable After-the-Fact Travel Time
VDOT	Virginia Department of Transportation
VMS	Variable Message Sign
VOS	Traffic flow variables of Volume, Occupancy, Speed
WSDOT	Washington State Department of Transportation

Contents

Figures

1. Summary of Phase 1 Activities & Findings

Phase 1 activities included researching and summarizing the current state of the practice in use by other Departments of Transportation with regards to the calculation and display of travel time related information on Variable Message Signs (VMS) and other media for travel corridors in their regions.

In conjunction with the Arizona Transportation Research Center, a literature review related to the topic of this project was performed. The literature search produced close to eighty citations that are listed in Appendix B (Volume II) of the Phase 1 Report. Those citations also give the "URL" web site address to reach the source of many of the citations. The research can be grouped by the context or type of organization carrying out the work, particularly whether the work was performed by or for: (a) an operating agency, (b) a university research center, or (c) as individual student research as part of a degree requirement. In some cases the cited work is a combination of two or a blend of all three of these. Depending upon which emphasis the research had the citation may be fairly practical or applications oriented, or it may be very theoretical and academically oriented. Most of the research that appears to be applicable to this project is the more application oriented work done directly for operating agencies, but usually by one of the university research centers from the state of the agency. This culling focused on three items in particular, which are discussed in more detail in the Phase 1 Report.

Potential sources of algorithms for use in estimating predictive travel times:

- Brian Smith from the University of Virginia (UVA) and his students at the Smart Travel Laboratory are working on a project for Virginia Department of Transportation (VDOT) on the estimation of travel times. In Section 4 of an unpublished Interim Report [1] he discusses that "predictive algorithms are being developed that will use templates (of travel time profiles) to obtain the expected sequences of both real-time and historical detector speeds."
- In work for Washington State DOT (WSDOT), Dan Dailey of the University of Washington has published an algorithm for estimating travel times using volume and lane occupancy data from a series of single inductance loops [2]. More recent work under development by WSDOT for the Seattle area is refining those procedures to calculate current spot speeds, adjust them using about 15 minutes of archived data, and then convert the speeds into travel times over the length of the corridor.
- Work reported by H. Al-Deek of the University of Central Florida describes work for the Florida Department of Transportation (FDOT) in Orlando that will involve the development of a traffic prediction model based on time series to predict 5-minute time horizons.
- A working paper by Rice and Van Swet of the University of California at Berkeley [4] (as referenced by Choe, Skarbadonis, and Varaiya [5]) presents a method for predicting travel times on freeways that combines historical and real-time data.
- There is other work that may have applicable algorithms that include work being done at the:
  - (a) Texas Transportation Institute using data from Houston and San Antonio [6],
  - (b) Victoria State Roads Authority using data from Melbourne [7], and
  - (c) University of Queensland using data from Brisbane [8].

Conclusions and/or findings related to the premises of this project: The work by UVA for VDOT has many parallels to the work on this project. We use the term "Snap-Shot Travel Time" (SS_TT) to characterize the "extrapolation method" identified in that research, i.e., for a given time interval, spot speed at "point" detectors are converted to current link travel time, then those times are aggregated for a route. The term of "After-the-Fact Travel Time" (ATF_TT) characterizes "retrospective" travel time used in that research, i.e., archived data can be analyzed after-the-fact, from detector speeds, to calculate past link travel times that are aggregated back over time to get route travel time. Findings in the Interim Report show three relevant conclusions that:

- Extrapolated travel time estimates severely lag the actual travel times during the onset of heavy congestion, which is a hypothesis of our work,
- Snap Shot Travel Times, as we hypothesize, will overestimate the actual travel time when congestion is waning, and when their data shows that congestion is waning, their

extrapolated estimate of travel time does somewhat over-predict the travel times relative to the actual times, and

- As we also hypothesize, the After-the-Fact or retrospective travel times should compare very well to observed travel times from probe vehicles, which their analysis does show to be the case.

Information about other methodological issues or approaches: The work by Kwon, Coifman, and Bickel at the University of California at Berkeley [9] developed several metrics to quantify changes in day-to-day changes in travel time and one such measure, the "Unusualness Measure", may be helpful to this research. The Texas Transportation Institute has dealt with different methodological concerns such as:

- Measuring the accuracy of the travel time information being displayed on the Variable Message Signs in San Antonio (Quiroga[10]),
- Aggregation methodologies using the Houston toll tag based data (Benz [11]), and
- Statistical comparisons of travel times with those from instrumented test vehicles as well as estimating corridor travel time means and variances (Eisele and Rilett [12]).

This brief synopsis should not be viewed as a complete and definitive review of the recent literature on the topic of estimating travel times. The literature does contain many worthy research activities that have been conducted and reported upon but that are not included in this specific summary.

A second main activity of Phase 1 was the identification and interviewing of staffs of selected Traffic Management Centers throughout the nation and in Canada. A structured interview questionnaire was developed with a series of questions that:

- Qualified interview candidates
- Probed into system needs, requirements and features
- Determined specific travel time estimation methods, procedures and algorithms
- Examined the public relations aspect of the program
- Queried for any background documentation and other references

Three different members of the team conducted a total of fifteen (15) telephone survey interviews. The map given in Figure 1.1 shows the names of the metropolitan areas that were covered by the interviews:

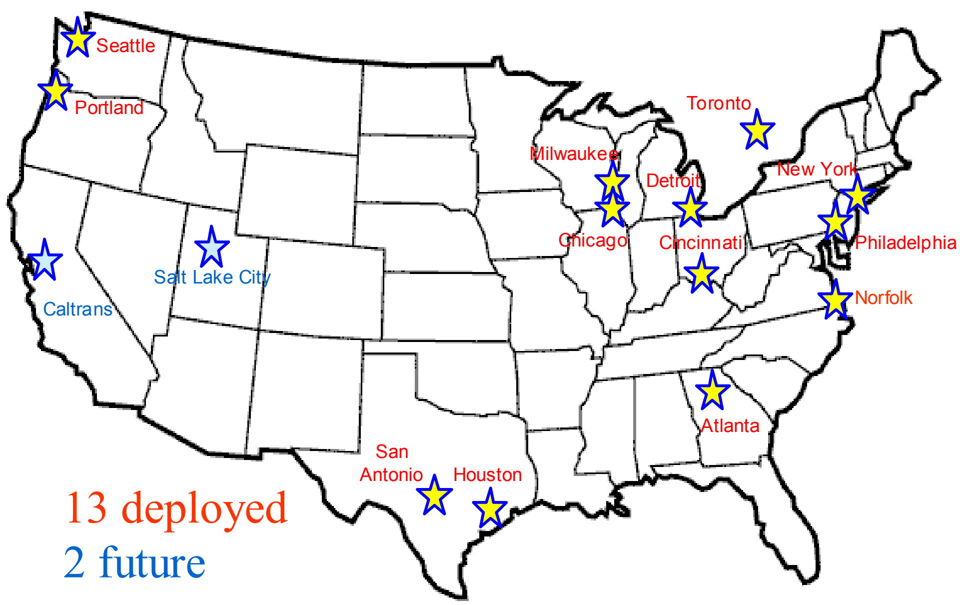


Fig. 1.1: Traffic Management Centers with Travel Time Programs

The following chart, Figure 1.2 summarizes the interview results of the thirteen (13) North American metropolitan areas that are currently performing travel time estimation/prediction. TMCs in other metropolitan areas expect to be doing so in the near-term future.

Metropolitan Area Interviewed	Agency (System name italicized)	Metropolitan Population* (in millions)	Travel Time Prediction Estimation Approach	Output Medium	After Study Conducted
Atlanta	Georgia DOT *NaviGAtor*	4.1	Snap Shot only	VMS, web	No
Chicago	Illinois DOT	9.2	Snap Shot only	VMS, web, media, HAR	TBD
Cincinnati	TRW *ARTIMIS*	2.0	Snap Shot only	VMS, web, HAR, 511	No
Detroit	Michigan DOT	5.5	Static by time-of-day	VMS only	No
Houston	Texas Transportation Institute, Texas A&M University *Transtar*	4.7	Snap Shot only using Toll tag, Automatic Vehicle Identification	VMS, web	No
Milwaukee	Wisconsin DOT	1.7	Snap Shot only	VMS, web, media	No
New York City	TransCom	21.2	Snap Shot only using Toll tag, Automatic Vehicle Identification	VMS only	TBD
Norfolk	Virginia DOT, Univ. of Virginia	1.7	Manual using CCTV images	VMS only	N/A
Philadelphia	Pennsylvania DOT	6.2	Snap Shot only	Web only	
Portland	Oregon DOT	2.3	Snap Shot only	VMS, web	No
San Antonio	Texas DOT *TransGuide*	1.6	Snap Shot only using Toll tag, Automatic Vehicle Identification	VMS, web	Yes
Seattle	Washington State DOT *Smart Trek*	4.3	Snap Shot and ±15-minute archival data smoothing	web, media	
Toronto	Ontario Ministry of Transportation *COMPASS*	2.3†	Snap Shot only	VMS only	No

* 2000 US Census Bureau † 1996 Transportation Tomorrow Survey

Fig. 1.2: Phase 1 Current Implementation Summary

Figure 1.2 shows that most of the areas are using the "Snap-Shot" approach to estimate travel times and that in only one area was archived data of prior conditions was partially being used to develop the estimated travel times. In addition, many applications used temporal and/or spatial smoothing to reduce fluctuations in the values of travel time calculated from the data sources. The most frequently cited means of dissemination were VMS and internet/web based media. Other dissemination sources included HAR, 511, and direct links to the news media.

Other results of the interviews regarding items such as public relations are presented in the Phase 1 Report.

2. Phase 2 Activities

2.1. Scope of Phase 2 Activities

There was a broad range of activities involved in Phase 2 of this project. Generally speaking the activities included some conceptual work related to measuring travel time and developing algorithms using average speeds from traffic flow detectors, travel time surveys to establish an observed data set for comparison purposes, specific development and testing of alternative algorithms, and initial comparisons to the observed conditions. Specifically the following discussions are included in this section:

- Different approaches to defining and measuring travel time
- Conceptual approach to developing and applying the algorithms
- Surveys and characteristics of observed corridor travel times
- Expectation of different travel behavior pattern time periods and seasons
- Basic components of the algorithm approach to estimate corridor travel time
- General features of the snap shot and after-the-fact travel time calculator
- Data quality and reliability concerns

2.2. Different Approaches: Defining & Measuring Travel Time

In concept, the measurement of travel time from point A to point B along a freeway should be rather straightforward on the surface if one directly measures it by driving the corridor between A and B. However, below the surface is the recognition of variations such as different drivers driving at different speeds, different vehicle types being driven at different speeds, recurring congestion at different locations along the corridor adding delay, and incidents resulting in unexpected slowdowns. A further challenge for this project was to indirectly estimate travel times using the values of average speed from a specific series of traffic flow detectors of the ADOT Freeway Management System (FMS).

This approach of an indirect measurement of travel times results in there being different ways to convert the average speeds to corridor travel times. Material was developed that provided descriptions and examples of the distinctions between several different ways of defining and measuring travel time in a corridor based upon data from speed detectors of the FMS of ADOT. Some of that material has previously been presented at various professional meetings.

Although the FMS data source is not structured this way, it is helpful for understanding to visualize the data set as being in a spreadsheet format where: (a) the rows are for each 20-second time increment with time increasing from top to bottom, and (b) the columns being the FMS detector stations in the sequence of flow from left to right. The values in the cells of such spreadsheets can be different items such as the average 20-second speed per detector station or the travel time from that station to the next.

Two basic detector station types are used in this project: (a) the mainline, which is the volume weighted average speed or travel time for those sensors of the station that monitor the mainline traffic flows, and (b) the HOV, which is the sensor for the High Occupancy Vehicle Lane for the times that the lane is in operation.

Figure 2.1 gives an example of the mainline link travel times for I-17 Southbound between 6:04 AM and 6:28 AM on Friday, October 25, 2002. Again the increasing time intervals go from top to bottom and the flow goes from upstream on the left (north) to downstream on the right (south). The colors of the cells are representative of speed ranges, with the redder the color to slower the speed.

Several different types of travel time measures are illustrated in Figure 2.1, and described next:

Hour Start decimal	362	363	364	366	367	368	371	372	373	374	375	376	377	378	128	125	124	122	158	120	152	Travel Time Type SS	VATF	Time Started decimal
6.071	17	20	25	42	20	21	60	19	22	21	19	23	22	24	12	44	20	32	11	11	10	9.50	8.435	5.916
6.077	[illegible]	20	26	43	21	20	58	20	21	20	19	23	22	25	11	43	22	31	11	12	9	9.46	8.52	5.921
6.082	18	20	25	41	21	21	56	19	22	20	20	25	23	25	11	43	22	36	11	12	10	9.32	8.25	5.927
6.088	18	20	26	40	20	21	58	19	21	20	19	24	24	25	12	44	23	38	11	11	10	9.39	8.32	5.932
6.093	18	20	24	41	21	20	55	19	22	19	19	24	23	25	12	43	21	38	11	11	10	10.23	8.16	5.938
6.099	18	19	25	40	21	21	57	20	20	20	18	24	24	24	11	46	21	40	11	12	10	9.37	8.35	5.943
6.104	18	20	25	40	20	21	59	20	22	19	19	24	23	24	11	44	22	34	12	12	10	9.49	8.46	5.949
6.110	18	20	24	41	20	21	61	20	21	19	19	24	23	24	12	44	21	43	11	13	10	9.84	8.44	5.954
6.116	18	20	24	41	21	21	61	21	22	19	19	25	23	23	12	44	20	36	11	12	10	9.05	8.52	5.960
6.121	18	21	24	42	20	21	64	21	23	19	18	23	23	24	11	44	20	37	11	12	10	9.06	8.32	5.966
6.127	18	20	24	41	20	21	61	21	23	20	19	24	22	24	12	44	20	29	11	12	10	9.01	8.44	5.971
6.132	[illegible]	21	24	43	21	20	59	21	22	19	20	24	22	24	12	46	21	31	10	12	10	8.71	8.362	5.999
6.138	19	21	26	44	21	22	60	20	23	19	19	25	23	24	11	45	21	37	11	12	10	8.64	8.34	6.004
6.143	18	22	25	40	20	21	60	20	22	21	19	26	24	23	12	42	21	34	11	12	10	8.70	8.13	6.010
6.149	19	20	25	41	21	21	56	21	22	22	19	26	22	24	11	46	22	47	11	12	9	8.69	8.20	6.016
6.154	18	21	24	40	21	20	59	21	23	21	19	29	22	25	10	44	21	33	12	12	9	8.63	8.29	6.021
6.160	18	19	25	40	21	21	60	20	21	20	21	32	22	24	11	44	21	34	11	12	11	8.71	8.26	6.027
6.166	18	20	25	41	21	21	60	20	21	20	22	34	24	24	11	43	20	36	11	12	12	8.56	8.54	6.032
6.171	18	21	25	42	21	20	61	21	22	19	23	39	22	25	12	41	21	32	12	12	11	8.45	8.16	6.038
6.177	19	21	26	41	22	21	60	20	22	20	22	41	23	24	13	41	18	43	11	13	10	8.36	8.26	6.043
6.182	19	21	25	41	21	21	59	21	22	20	26	40	21	24	11	42	19	38	12	13	9	8.25	8.38	6.049
6.188	19	20	25	42	21	21	60	20	23	22	27	46	23	24	11	46	21	34	11	13	9	8.23	8.34	6.054
6.193	18	21	24	41	21	20	61	20	23	23	31	49	22	23	12	44	24	37	11	12	10	8.36	8.57	6.060
6.199	18	21	24	42	22	21	61	20	23	23	29	46	23	24	12	42	23	37	11	11	10	8.18	8.40	6.066
6.204	19	21	25	42	21	21	60	21	23	24	29	61	23	25	11	43	25	41	11	13	10	8.27	8.38	6.067
6.210	19	22	25	41	21	21	60	20	25	26	34	53	23	25	11	43	26	31	13	11	9	8.24	8.53	6.068
6.216	19	20	26	42	20	20	61	20	25	27	37	53	21	25	11	43	23	39	11	12	9	8.34	8.69	6.069
6.221	18	21	27	42	20	21	61	21	25	28	38	87	22	25	11	44	25	39	11	12	10	8.43	8.88	6.070
6.227	19	20	27	41	20	21	62	23	27	29	40	84	22	24	10	43	25	32	11	12	9	8.27	8.548	6.071
6.232	18	22	26	43	21	21	59	26	31	31	33	93	23	25	12	41	23	34	11	12	10	8.24	8.69	6.077
6.238	19	21	26	42	22	21	67	26	30	34	30	105	23	24	11	43	24	34	11	11	10	8.34	8.84	6.082
6.243	19	22	27	42	21	21	64	30	32	37	33	121	22	25	11	42	24	29	11	11	10	8.43	8.66	6.088
6.249	19	20	25	42	21	21	64	29	32	37	37	121	21	25	12	44	23	38	10	13	10	8.29	8.69	6.093
6.254	20	23	27	43	22	21	73	29	35	39	36	121	24	24	11	44	25	32	11	11	9	8.37	8.84	6.099
6.260	20	24	27	44	21	22	81	31	37	39	37	205	24	24	13	47	23	29	11	12	10	8.30	8.76	6.104
6.266	21	24	26	44	21	21	84	36	38	40	42	228	22	25	10	44	22	40	10	12	10	8.45	9.21	6.110
6.271	21	22	27	40	22	22	92	36	41	39	42	164	22	25	11	42	27	34	11	11	10	8.36	9.01	6.116
6.277	19	22	27	46	22	22	89	37	42	42	42	130	23	24	11	44	24	32	11	12	10	8.41	9.02	6.121
6.282	19	22	28	45	23	22	98	46	41	40	47	144	21	24	10	45	24	37	11	12	10	8.27	9.79	6.122
6.288	19	21	25	45	23	23	102	56	40	45	47	142	21	23	10	42	26	29	11	12	10	8.34	9.74	6.123
6.293	19	22	27	46	23	23	96	56	36	51	48	132	21	28	11	46	22	32	11	11	10	8.53	9.99	6.123
6.299	20	22	25	44	23	23	97	66	37	45	44	124	22	25	11	45	23	34	12	11	10	8.37	10.42	6.124
6.304	19	21	28	48	22	22	104	69	38	47	34	114	23	22	11	46	23	33	11	12	9	8.64	10.39	6.125
6.310	19	21	27	47	22	23	111	42	40	56	34	152	23	24	10	42	23	37	11	12	10	8.42	10.37	6.126
6.316	19	21	30	46	23	23	114	41	41	57	61	178	24	24	11	41	25	39	12	12	10	8.27	10.551	6.127
6.321	19	21	29	47	23	25	127	39	47	51	58	142	24	25	11	42	25	34	11	13	10	8.34	11.71	6.132
6.327	19	21	34	45	23	28	124	37	54	52	65	137	24	26	12	43	25	31	9	12	10	8.53	12.27	6.138
6.332	19	21	31	44	23	30	127	37	53	56	66	105	23	24	12	43	23	35	10	11	10	8.37	11.32	6.143
6.338	19	23	33	45	24	32	132	41	64	60	56	164	23	25	12	47	24	31	11	10	10	8.64	10.61	6.145
6.343	20	23	33	46	24	32	114	46	64	67	59	132	24	27	11	45	23	35	11	11	9	8.42	10.90	6.147
6.349	20	26	31	44	28	31	130	52	62	74	65	105	24	24	11	44	24	33	11	12	9	8.51	11.10	6.149
6.354	22	26	30	49	29	28	154	50	62	63	56	79	24	24	11	44	24	30	11	11	10	8.61	10.99	6.150
6.360	22	26	30	54	31	27	120	59	56	60	52	63	24	25	11	44	23	34	11	11	9	8.69	11.06	6.152
6.366	22	27	28	52	34	32	154	67	66	61	55	54	24	24	11	45	25	39	11	12	9	8.84	10.79	6.153
6.371	22	26	31	57	33	29	123	59	69	45	52	54	24	24	11	44	26	34	11	12	10	8.75	11.84	6.154
6.377	22	28	32	67	32	30	146	61	61	55	46	53	23	25	11	46	24	30	10	12	10	8.95	12.33	6.155
6.382	23	27	31	67	32	31	152	60	52	49	41	50	23	25	12	45	23	34	11	11	10	9.11	11.82	6.157
6.388	22	29	33	75	31	31	150	73	45	45	43	47	24	25	14	43	25	29	11	11	10	9.11	11.76	6.157
6.393	24	29	35	79	29	35	144	75	43	52	40	51	25	25	12	44	23	31	11	11	10	9.47	11.43	6.159
6.399	24	27	33	100	31	37	169	68	40	49	39	51	25	24	12	46	23	38	11	11	9	8.51	12.27	6.160
6.404	23	25	38	82	32	39	204	58	41	43	36	57	23	24	12	46	26	41	11	11	10	8.61	11.68	6.166
6.410	22	26	38	78	34	36	200	63	40	37	38	59	22	23	12	45	28	31	11	12	9	8.69	11.66	6.171
6.416	22	29	44	74	35	36	161	59	39	39	37	61	24	24	11	44	23	36	11	12	10	8.84	11.38	6.177
6.421	24	30	47	73	38	32	186	48	34	39	36	76	24	25	11	48	25	32	11	11	10	8.75	12.40	6.182
6.427	24	34	43	71	34	31	164	42	37	34	40	87	22	25	13	44	24	34	11	12	10	8.95	11.79	6.188
6.432	26	35	45	86	35	37	183	42	35	35	43	76	25	25	12	45	25	34	11	11	10	9.11	12.16	6.193
6.438	27	34	44	96	34	38	177	39	32	36	47	59	24	25	11	47	25	35	11	11	10	9.11	12.09	6.199
6.443	27	38	40	119	38	39	157	43	33	36	46	79	24	25	11	47	25	33	11	11	10	9.47	11.85	6.204
6.449	28	42	40	98	36	37	126	52	34	36	55	71	24	24	12	47	24	30	11	13	9	9.34	12.04	6.210
6.454	30	41	37	98	39	39	123	49	33	39	52	60	24	26	11	46	24	37	11	12	9	9.41	11.92	6.216
6.460	30	36	36	100	43	34	121	39	35	42	58	56	24	27	13	45	26	36	11	12	10	10.12	11.58	6.221
6.466	28	33	33	87	45	39	116	44	39	41	49	56	24	26	13	42	26	34	11	12	10	10.02	11.994	6.227
6.471	28	31	37	90	57	41	114	40	36	49	52	57	23	27	12	47	25	34	11	12	11	10.18	12.093	6.232
6.477	27	29	42	99	50	35	113	43	37	51	49	66	23	25	13	47	25	35	11	12	10	10.56	12.436	6.238

Snapshot Travel Time

Variable After the Fact Travel Time

Predictive Travel Time Algorithm

Fig. 2.1: Example of Mainline Link Travel Times for I-17 Southbound

Probe Travel Time: These are field measurements that track the time duration amount that one or more probe vehicles take to travel a defined route. When floating-car procedures are followed, probe travel time values represent the actual average route travel time. In Figure 2.1 five complete probe travel time runs and two partial runs are indicated. The first five of the light green boxes in the left hand column of 20-second start time increments show the start times of the five complete probe travel time runs and the last five pink boxes in the second column from the right are in the rows that are the end times for those probe travel time runs. Thus we know that the travel time trajectories through this distance-time diagram started at those observed start times and ended at those observed end times.

Snapshot Travel Time (SS_TT): For a given time interval (row) in Figure 2.1, average speeds at or between a set of detectors are converted to current link travel times and those link travel times are aggregated to estimate a route travel time. The speeds can be spot speeds at the "point" detectors, or link speeds derived from a toll tag equipped probe vehicles that are observed passing a series of detectors. Either way, the sum of link travel times in the horizontal rows is defined as the "Snapshot Travel Time". The example SS_TTs are shown by the five blue arrows. These two operational measures of travel time are the ones most commonly used by traffic management centers as the travel time values they display on their variable message signs.

After-the-Fact Travel Time (ATF_TT): Since we know the time increment during which each of these five probe runs finished their trips, and that each passed a detector station once and only once we can also work backwards using this historic, archived data and estimate the time increment during which each probe passed each detector. The black boxes indicate those time increments for the series of detectors and generally show the space-time trajectory that each probe had. When the sum of the link travel times in those boxes are aggregated, the resulting value is an estimate of the after-the-fact travel time, which we are defining in particular as the "Variable After-the-Fact" Travel Time (VATF). The term "variable" is used because a trip starting at any time increment may encounter a uniquely different trajectory depending upon the future speeds and link travel times that happened. Since this is all being done with historic, archived data and looking backwards in time we term it "After-the-Fact". The set of five red lines represent the five VATF travel time trajectories of the five completed probe runs during this time period. The values in the pink boxes in the VATF column are the estimated travel times for those five probe runs, which can be compared to the probe travel times observed in the field.

Predictive Travel Time: This is a mathematical projection using a set of decision rules that estimates the near-term future time to travel a route. This project is seeking to define a Predictive Travel Time Algorithm (PTTA) looking forward in time, which is represented by the dashed green trajectory in the example. It is anticipated that at each time increment a new PTTA trajectory may be uniquely different from the one before and the one after, but have many similarities.

2.3. Conceptual Approach to Developing and Applying the Algorithms

Conceptual work was carried out to have an algorithm that calculates sets of VATF travel times, but that is forward looking in time rather than one that scans back over past time periods. This approach would use: (a) a small sample of archived FMS data, and (b) the same decision rules that would be used for developing the PTTA. Those calculations were used in attempting to "calibrate" the logical and mathematical steps of the PTTA. This calibration is an iterative process in which a series of algorithms is defined and refined until one appears to suitably compare to the hand calculated VATF travel times for that sample period. The result of that calibration was an initial PTTA that was later tested and "validated" against the sample of probe travel times over the full set of sampling periods during the week of the probe travel time samples.

This conceptual approach has the PTTA and the VATF being like the opposite sides of a coin. When the PTTA is applied to actual archived data the result is a "prediction" of past historic VATF travel times for the range of time increments analyzed. When the PTTA is applied to estimates of "future" link speeds and link travel times, the result will be a predictive travel time estimate of likely future travel times for the route or corridor. The challenge then becomes having appropriate means to reliably estimate such "future link speeds and link travel times". Our solution is to develop from the archived data, sets of average link speeds and link travel times for each detector and time increment that are representative of distinctly different travel behavior patterns that result in different travel times for different typical time periods during the year.

We are using the term "travel behavior pattern time periods" to refer to these analysis time periods for predictive travel times. We are using the term "anticipated travel time patterns" to refer to these data sets of average link speeds and link travel times for each detector and time increment. Each travel behavior pattern time period has its own unique set of anticipated travel time patterns.

The conceptual approach to calculating predictive travel times on an on-going basis in the future is to use: (1) the appropriate set of anticipated travel time patterns as an information source against which the PTTA is applied, along with (2) future "current after-the-fact" (CAFT) calculations of travel time. The Predictive Travel Times are being designed to be dependent upon a blend of the observed historic link speeds, link travel times, and corridor travel times, as well as the CAFT. CAFT is not intended as an oxymoron – rather for a given current time increment, we want to be able to look at the most recent detector data, go back in very recent time, and estimate the time it took to travel the route. Research by P. Varaiya [13] has suggested that knowledge of very recent traffic conditions, compared to average conditions, tends to be a good indicator of short-term conditions in the "future" when compared to the average expected conditions. To rephrase that in more common terms, when conditions are already bad they tend to continue to be bad in the short-term and when they are already good, they tend to continue to be good in the short-term.

2.4. Surveys and Characteristics of Observed Corridor Travel Times

Probe Travel Time Surveys in the Study Corridor: A significant effort was carried out as an early step in Phase 2 of the project to collect a fairly extensive set of travel time surveys in the part of the I-17 corridor being studied. These surveys were conducted using probe vehicles equipped with Global Positioning System (GPS) tracking devices. Each travel time survey, or "run", resulted in a second-by-second trajectory of the latitude and longitude of the travel of the probe vehicles. The drivers were instructed to first of all drive safely and then to try driving at the average speed of the vehicles around their location as they drove along the route.

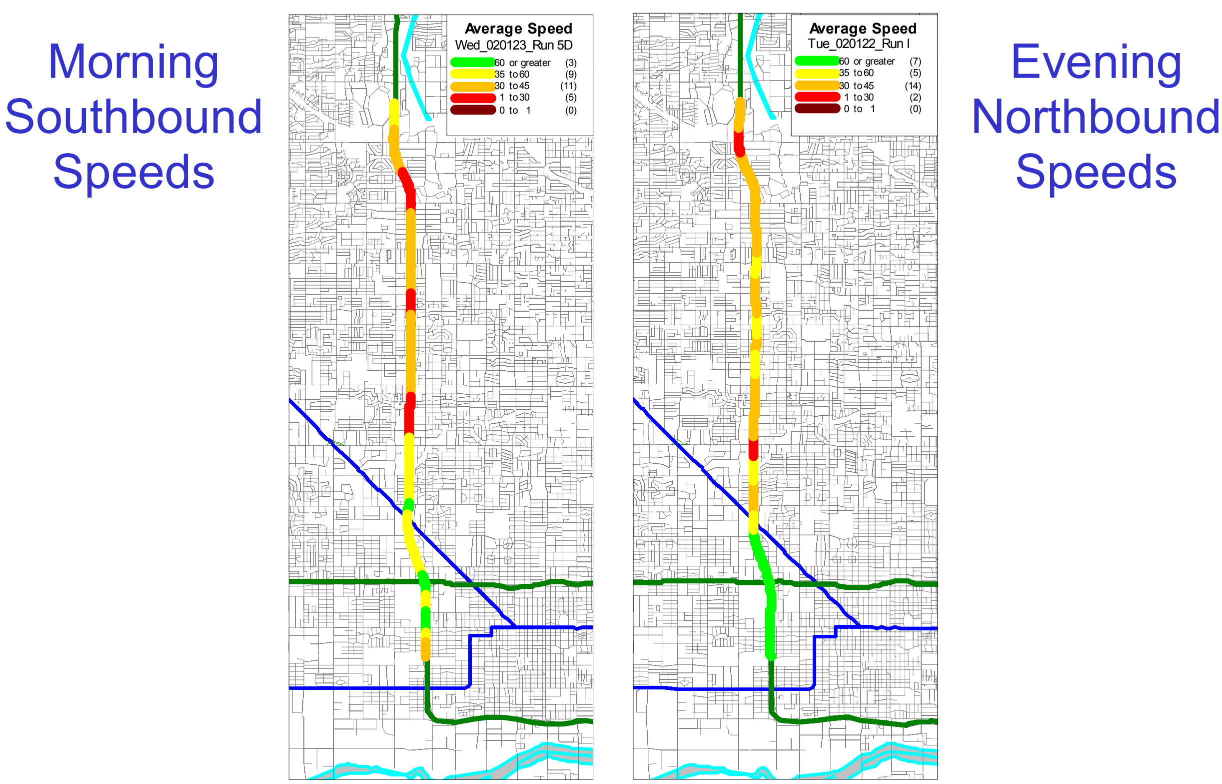


Fig. 2.2: Avg. Speed Between Detectors based on GPS Data

The data set for each run was processed to calculate the observed travel time between common start and end locations as well as the spot speed for each second of each survey run. There are more than twenty-five FMS traffic flow detector stations in each direction of the study corridor. The relative locations of the stations along the corridor were determined and used to automatically identify as part of the data processing the nearest second that each probe vehicle passed each detector station. That also allowed the automated calculation of the average space mean speeds between the detector stations. Figure: 2.2 displays examples of the average speed between detectors as calculated from two different GPS travel time runs. Such displays are comparable to the level of detail shown in the FMS Speed Maps.

The survey design called for the GPS travel time data to be collected at specific time intervals during a one-week time period of seven consecutive days in late October 2002. Of most interest was observing travel times before, during, and after the build-up of daily congestion in the morning and evening peak periods as well as that for the daily lessening of congestion in the late morning, typically about nine AM and in the evening typically after six PM. Thus it was determined that the sampling on the weekdays would be between about 5:00 and 9:00 AM and about 3:00 and 7:00 PM. Samples were also collected on a Saturday and a Sunday during what was thought to be the busiest times of those days, between 10 AM and 2 PM on Saturday and 2 and 6 PM on Sunday. Thus travel time surveys were conducted during ten time periods that consisted of about 48 hours in total.

The desired sampling frequency was to have an observation about once every five minutes in the peak flow direction on the weekdays and about once every ten minutes on the weekends. With an anticipated peak circuit time of about thirty minutes for a probe vehicle to go back and forth along the corridor, six probes were needed to result in a sample about once every five minutes. In addition, sampling of the High Occupancy Vehicle (HOV) lanes was also carried out, but with an expected circuit time of about twenty minutes and a desired sampling frequency of ten minutes only two probes were required. However, arrangements needed to be made to have a passenger ride in the vehicle in order for the probe to qualify using the HOV lane, which doubled the staffing requirements for the HOV travel time surveys. It should be noted that the temporal spacing between the successive probes tended to be more random than uniform at once every five minutes. While on average that tended to be the temporal spacing, there were times that two or three probes were being driven very close to one another.

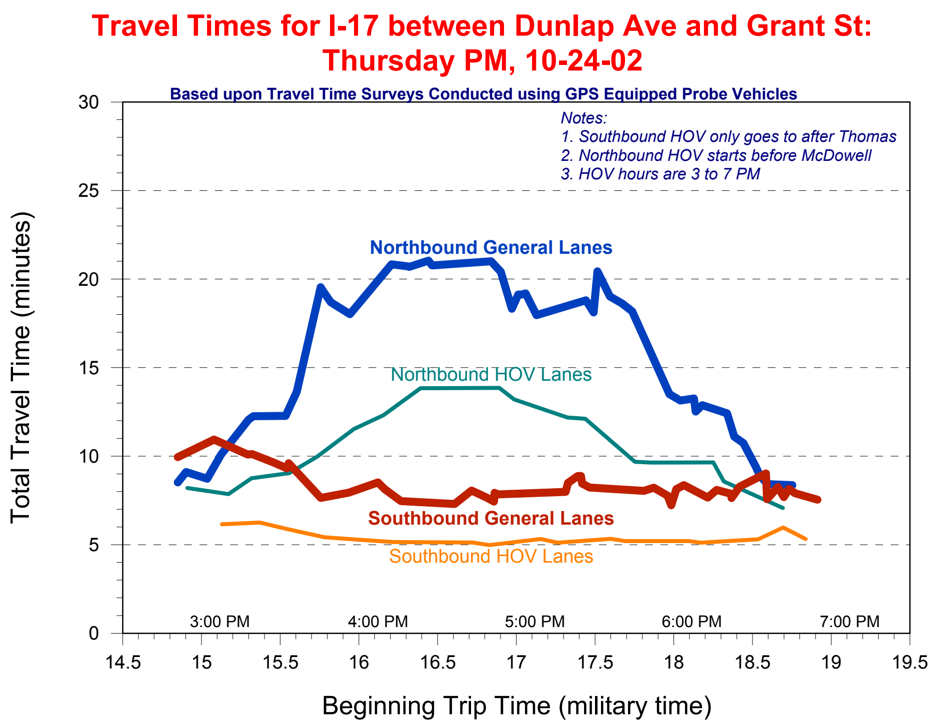


Fig. 2.3: Example of a Travel Time Profile for the Study Corridor

Observed Probe Travel Times: Figure 2.3 presents an example of what we are terming as a “travel time profile” for the I-17 study corridor. This figure gives the results of the first of the ten observation periods of between about 15:00 (3:00 PM) and about 19:00 (7:00 PM) for Thursday October 24, 2002. The x-axis gives the start time for the travel time runs, expressed in military decimal time by hour. The y-axis gives the cumulative corridor travel time in minutes. Four travel time profiles are shown, one for each combination of direction and lane type. During that sampling period there were about 45 travel time runs in the general-purpose lanes and seventeen runs in the HOV lanes. There is a point shown for each of the runs where the value for each point is the start time of the run and the cumulative time of the run.

The lines are constructed by “connecting the points” for the same combination of direction and lane type. The travel time profile line representing the northbound general-purpose lanes is the slowest (the largest values on the y-axis) of the four profiles shown with runs starting at about 3:45 PM to about 5:45 PM taking in the range of between eighteen to 21 minutes. Before those times the travel times increase from about eight minutes to about fifteen minutes as the traffic gets slower, while after the slowest period, the observed travel times wane from about fifteen minutes to about eight minutes, which is about the free flow travel time for the study section of the corridor. The shorter northbound HOV lane has a different profile starting from a free flow time of about seven minutes and increasing to a about an eleven minute travel time between 4 and 5 PM and then gradually declining back to the free flow travel time.

The four other afternoon-evening peak periods that were observed showed similar but somewhat different temporal profiles. Likewise for the AM peak periods, similar but reverse-direction profiles were also found. In essence these travel time profile curves are comparable to the “diurnal curves” associated with the daily fluctuations in traffic volumes that have been consistently observed over many years on all roadways as part of traffic counting programs. While speed-monitoring programs have focused on the fluctuations on average speed at a given location, programs to monitor and summarize corridor travel times by time-of-day, day-of-the-week, and season of the year have not been traditionally carried out. **Thus, the similarities between these travel time profiles with the traffic volume diurnal curves is an important finding by this project and forms one of the basis for anticipating developing predictive corridor travel times**. However, one key difference between the travel time profiles and the traffic volume diurnal curves is that during periods of light traffic flow the travel times are those associated with the ambient free flow speed, while at those times the volumes can get very low to a few vehicles per minute, especially during the late-night to early-morning hours.

Figures 2.4 A and B present an interesting observed difference in the travel time profile for the AM peak period for the observed Friday and Monday, which confirms a conventional wisdom about travel behavior prior to and after a weekend. In many major metropolitan areas on major radial freeways a generalization has often been made that commuters come in early on Fridays so they can leave earlier that afternoon. Conversely, they tend to come in later on Monday mornings due to many being away for the weekend or other reasons. These two figures generally confirm that conventional wisdom and put a specific quantification of the relative propensity for such cumulative travel behavior in the study corridor. The figures show that the observed Friday travel times peaked earlier in the morning at about 6:45 AM and by 8:00 AM conditions were almost free flowing. On Monday on the other hand, travel times were almost free flowing until about 6:30 to 7:00 AM and then slowed and peaked by about 7:45 AM. A comparison of the afternoon travel time profiles by day of the week show that while there are similar peak amplitudes of total travel time, the profile for Friday tends to peak earlier in the afternoon and the travel times return to more free flowing conditions about a half-hour to forty-five minutes earlier than on the other weekdays.

These profiles can also be used to clearly distinguish abnormal travel time patterns due to a significant incident by showing the slowing of traffic in unexpected directions and/or at unexpected times of the day. Figure 2.5 A and B presents two examples of that type of situation that were observed during the seven-day survey period. One traffic crash related incident took place on Tuesday morning of October 29, 2002 in the northbound lanes while the other was a weather related incident that occurred on midday on Saturday October 26, 2002. For the former there was a significant increase in travel time in the three non-peak traffic flow directions during the peak period for the fourth, while for the later both directions were affected, but one somewhat more than the other. For this project, a key consideration is that such effects of incidents on traffic flows and cumulative travel times can be measured and documented.

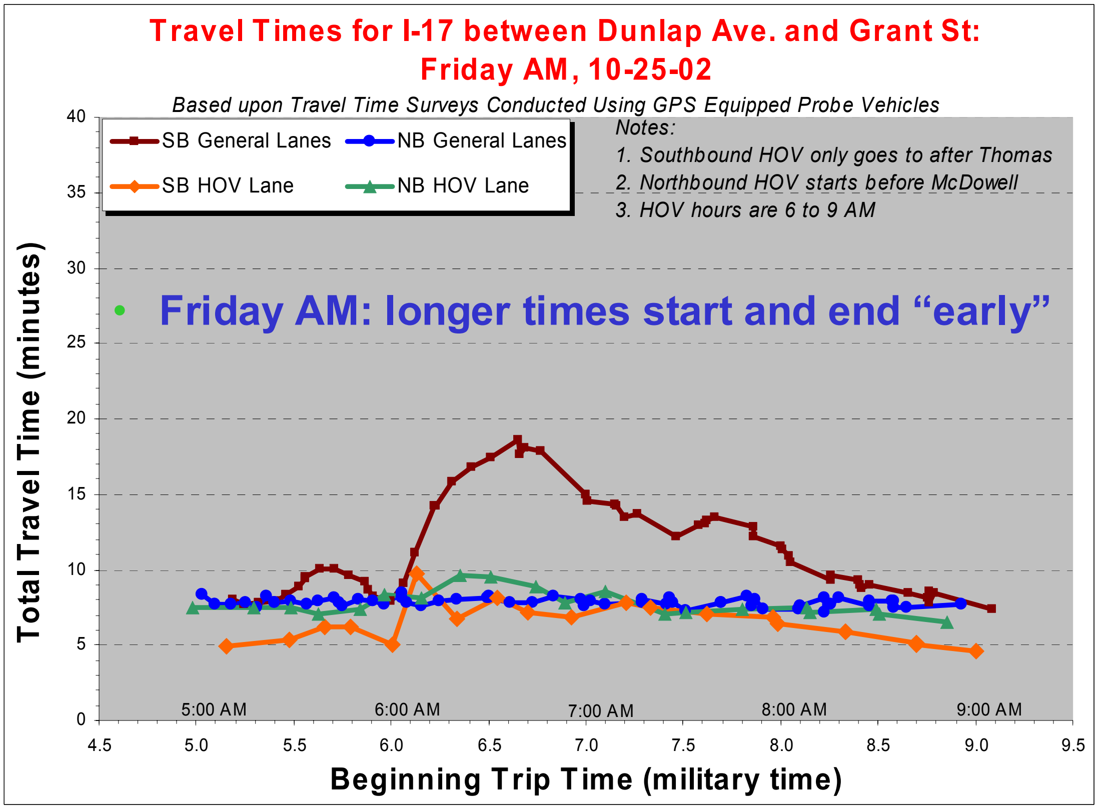


Fig. 2.4A: Travel Time Profile for Friday Morning October 25, 2002

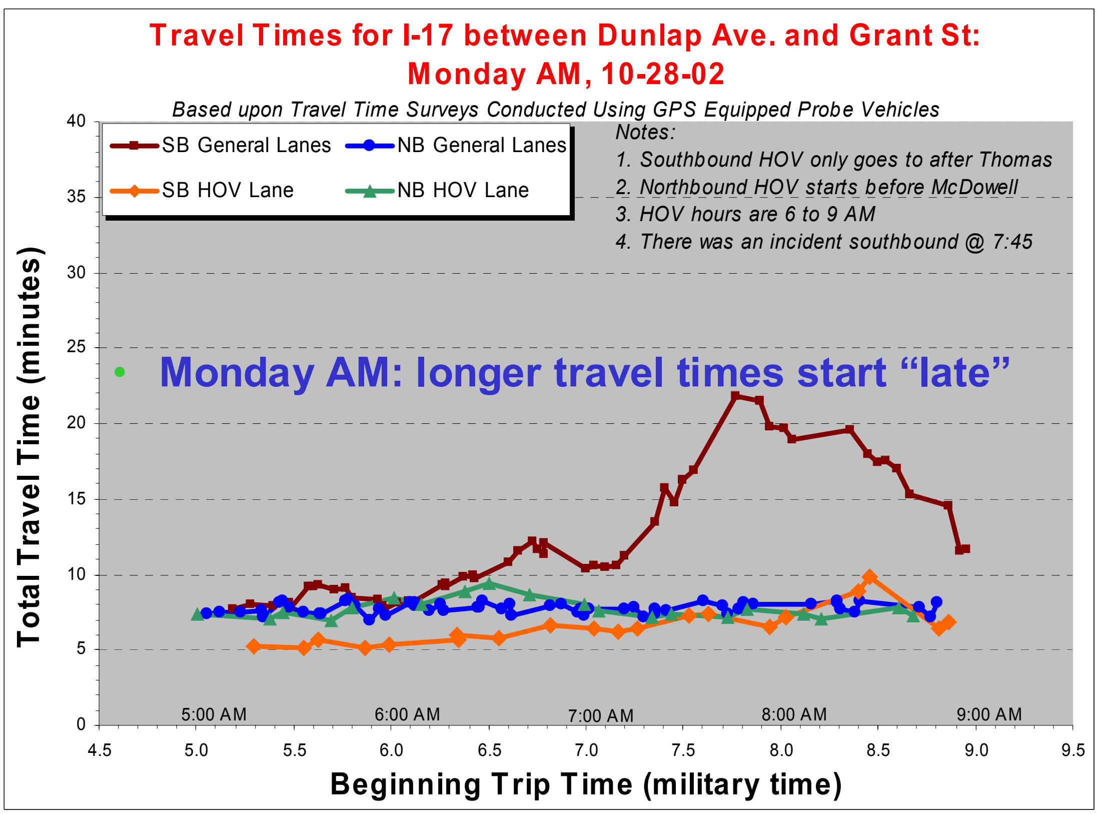


Fig. 2.4B: Travel Time Profile for Monday October 28, 2002

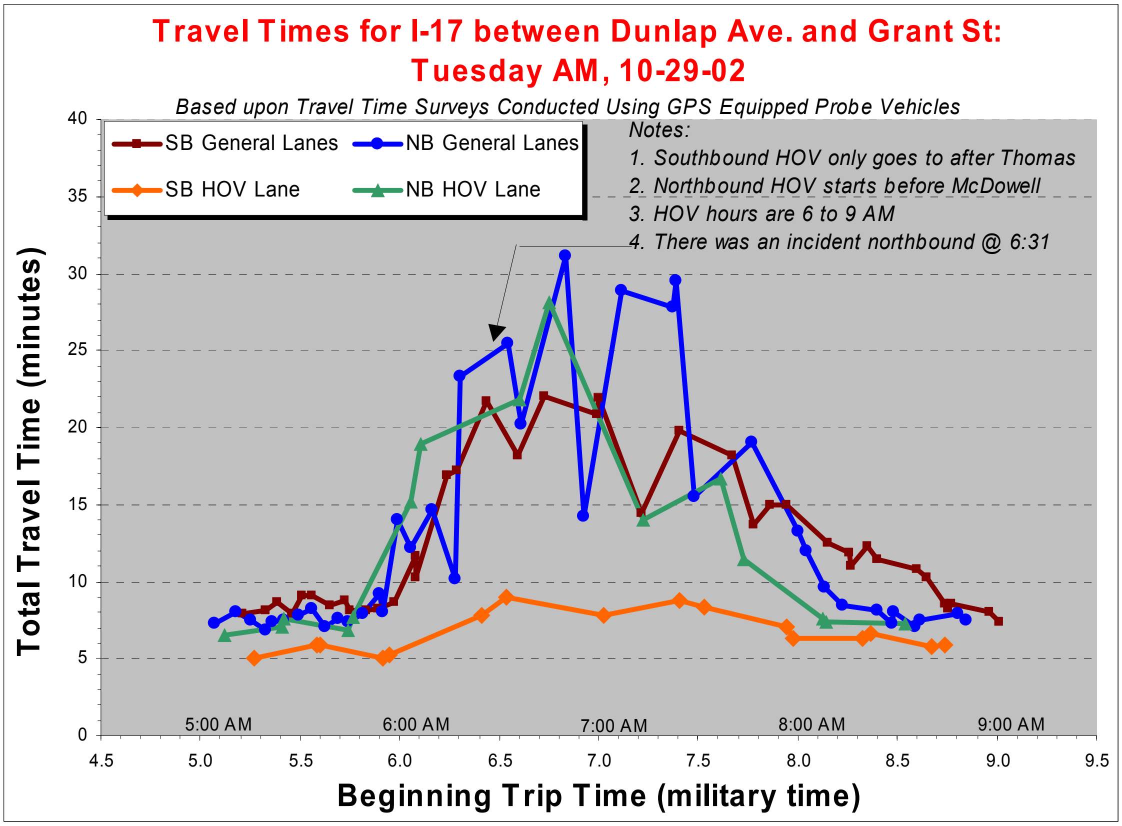


Fig. 2.5A: Travel Time Profile for Tuesday Morning October 29, 2002

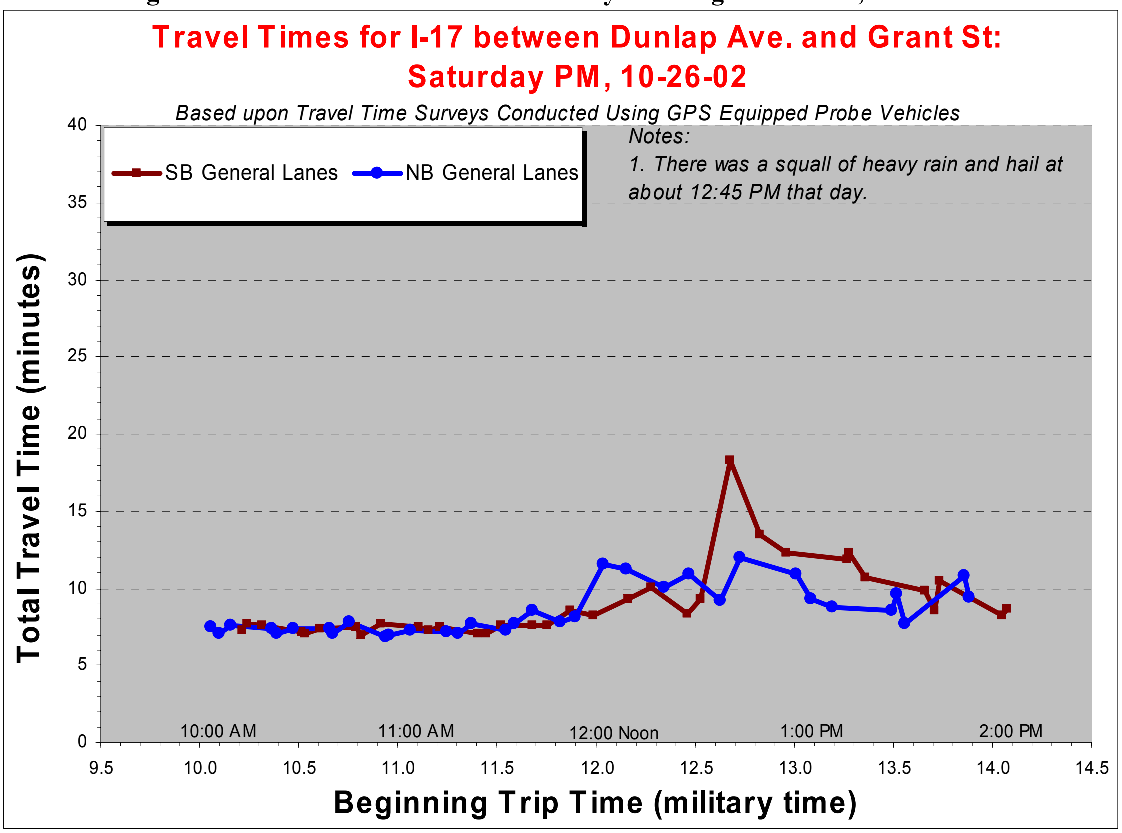


Fig. 2.5B: Travel Time Profile for Part of Saturday October 26, 2002

Appendix A of this report presents the set of travel time profiles for the ones already discussed as well those for the remainder of the survey time periods. In addition, summary charts that compare different days-of-the-week for different roadway types are also given there.

Comparison of Calculated Travel Times to the Observed Probe Travel Times: Subsection 2.2 above discussed conceptual distinctions among four different ways travel time is measured and represented: probe travel time, snap shot travel time (SS_TT), after-the-fact travel time (ATF_TT), and predictive travel time. The project hypothesized various relationships among these different measures of travel time, particularly those between SS_TT and ATF_TT. This project tested those hypotheses by first calculating those two measures and then comparing them to the observed probe travel times. The validity of those hypotheses has implications as to the need to develop algorithms to estimate predictive travel times.

Figures: 2.6 to 2.9 present a series of comparisons of calculated travel times to the observed travel times for an example time period of the Friday morning traffic conditions. Other days and time periods were also studied and compared but are not reported on here. A series of spreadsheets were prepared that used the archived data from the ADOT FMS detectors in the corridor to calculate SS_TT and ATF_TT. Figure 2.1 given above showed a portion of one of those spreadsheets. Those two time series of calculated travel times could then be compared to each other and to the observed probe travel times. Figure 2.6 and 2.7 respectively show those comparisons of the SS_TT to the observed probe travel times and the ATF_TT to the observed probe travel times for the Friday AM peak period example.

- **First Hypothesis**: It was first hypothesized that the two calculated measures of travel time would produce different results for the same trip start times. Comparing the relative locations of the two calculated travel times to the observed probe travel times show that the two calculated times do indeed differ from one another. This example and the other comparisons for the other time periods generally confirm this first hypothesis.

- **Second Hypothesis**: The second hypothesis was that the ATF_TT would more closely match observed the probe travel times. By studying Figures 2.6 and 2.7 it can be seen that the overlap of the ATF_TT in Figure 2.7 compares better to the observed probe travel times than the SS_TT overlap given in Figure 2.6 compares to the same observed probe travel times. That is most evident for the time period of about 5:30 to 7:00 AM where the two curves in Figure 2.7 align more closely than the two curves in Figure 2.6. This example and the other comparisons for the other time periods generally confirm this second hypothesis.

- **Third Hypothesis**: A third hypothesis was that there would be some systematic differences In how the two calculated travel times differed from on another with: (a) SS_TT underestimating the travel time as congestion is building or increasing in the corridor, and (b) SS_TT overestimating the travel times as congestion is waning or decreasing in the corridor. Figure: 2.8 has two features with the first overlapping the two calculated travel times with the observed probe travel times in the top part of the Figure. There it is easier to see that the SS_TT tends to lag in the value of the calculated travel time for start times when there is a steady increase in the observed probe travel times, such as between about 5:30 and 5:45 AM and then again from about 6:15 to 6:45 AM. From about 6:45 to about 7:15 AM the SS_TT, when the observed probe travel times are decreasing, the values of the SS_TT tend to be relatively larger in value than those of the observed probe travel times for the same start time.

- The second feature of Figure 2.8 is given in the bottom part that is a relative comparison of the ATF_TT to the SS_TT that subtracts the latter from the former. Thus a positive value of the difference is above the zero line and shown in red, while a negative difference is below the line and shown in green. The positive, red time slices and clusters tend to correspond to time periods during which the observed probe travel times are increasing. The negative, green time slices and clusters tend to correspond to time periods during which the observed probe travel times are decreasing. This example from both parts of Figure 2.8 and the other similar comparisons for the other time periods generally confirm this third hypothesis.

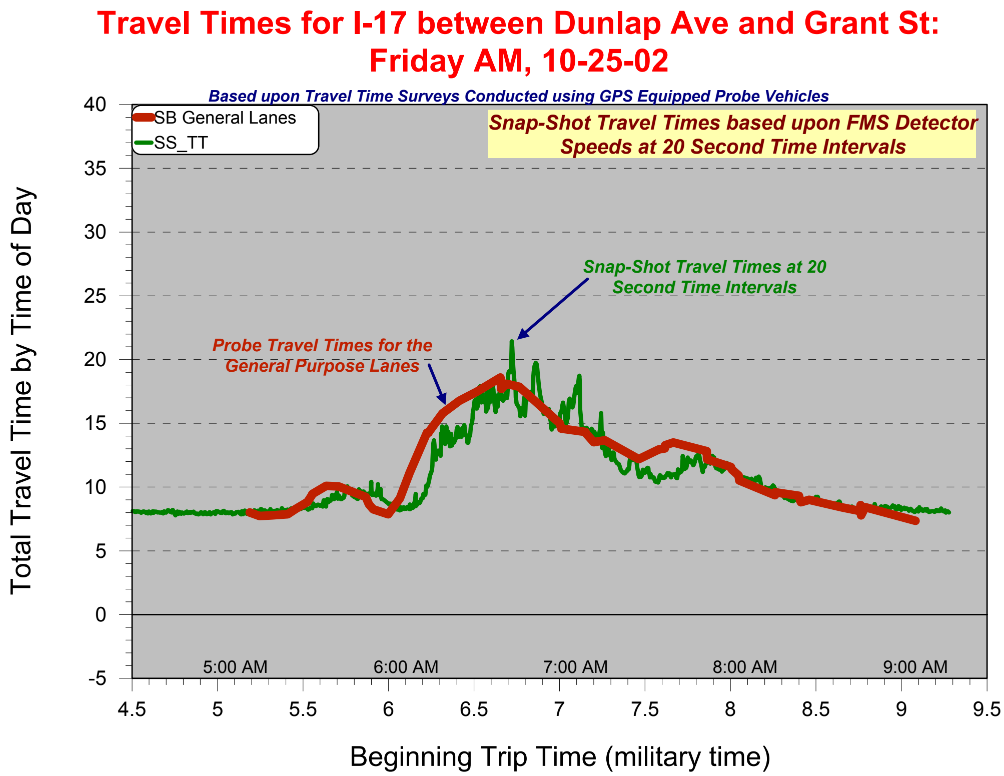


Fig. 2.6: Example of Snap Shot Travel Compared to Observed Probe Travel Time

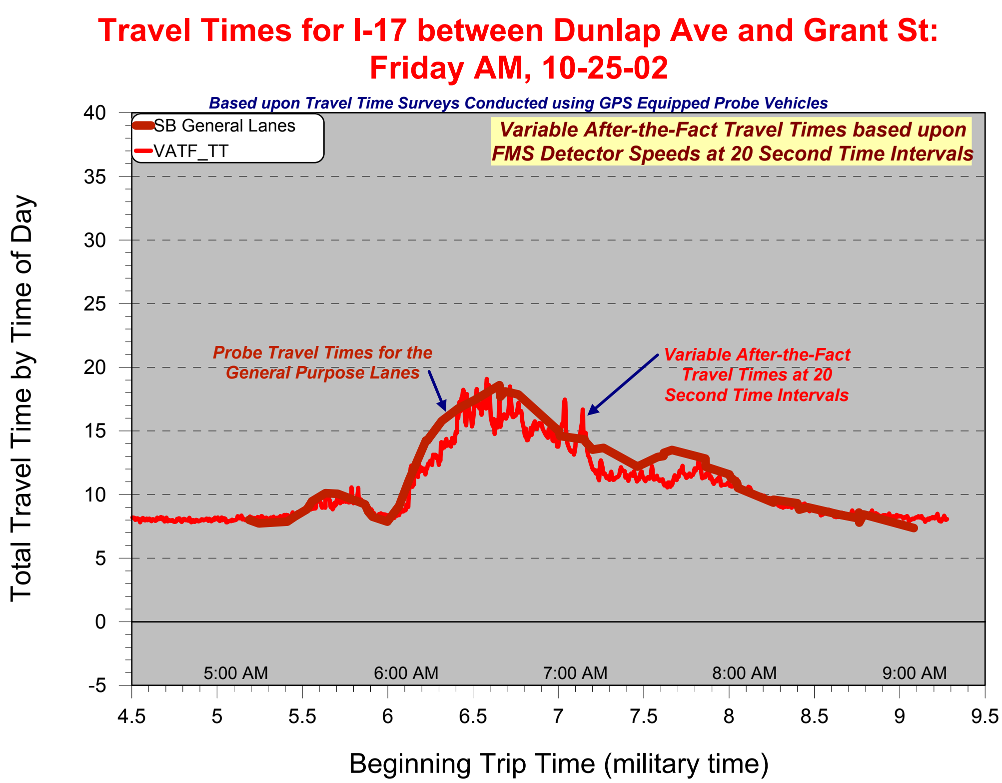


Fig. 2.7: Example of After-the-Fact Travel Time Compared to Observed Probe Travel Time

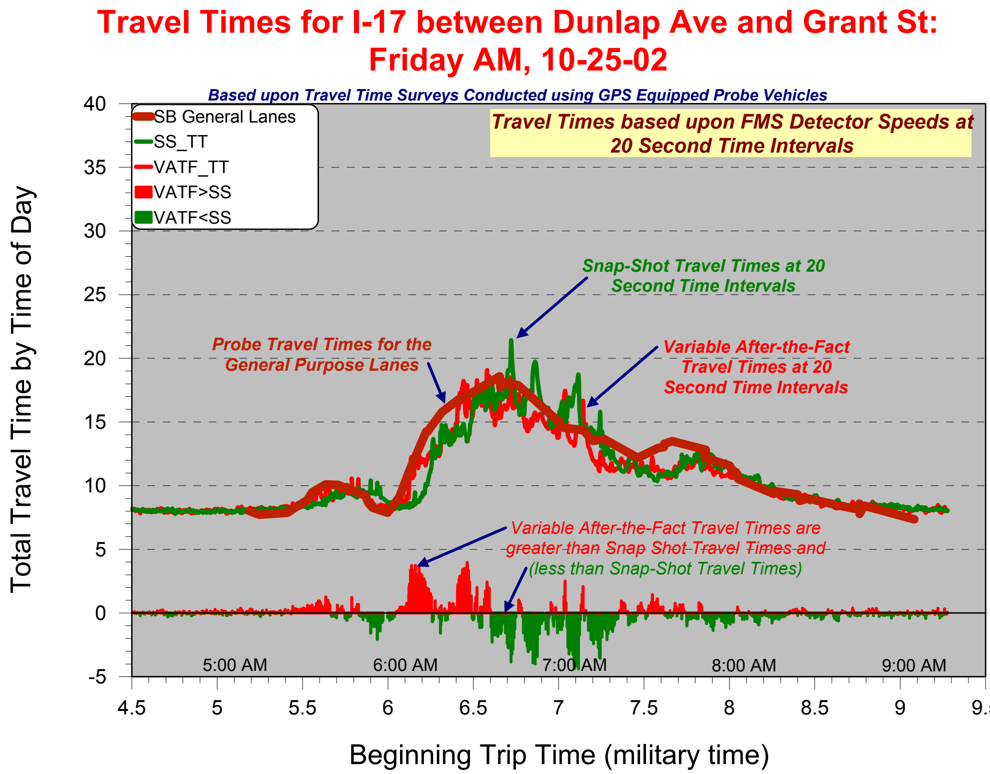


Fig. 2.8: Example of Comparison of Snap Shot Travel Time to After the Fact Travel Time

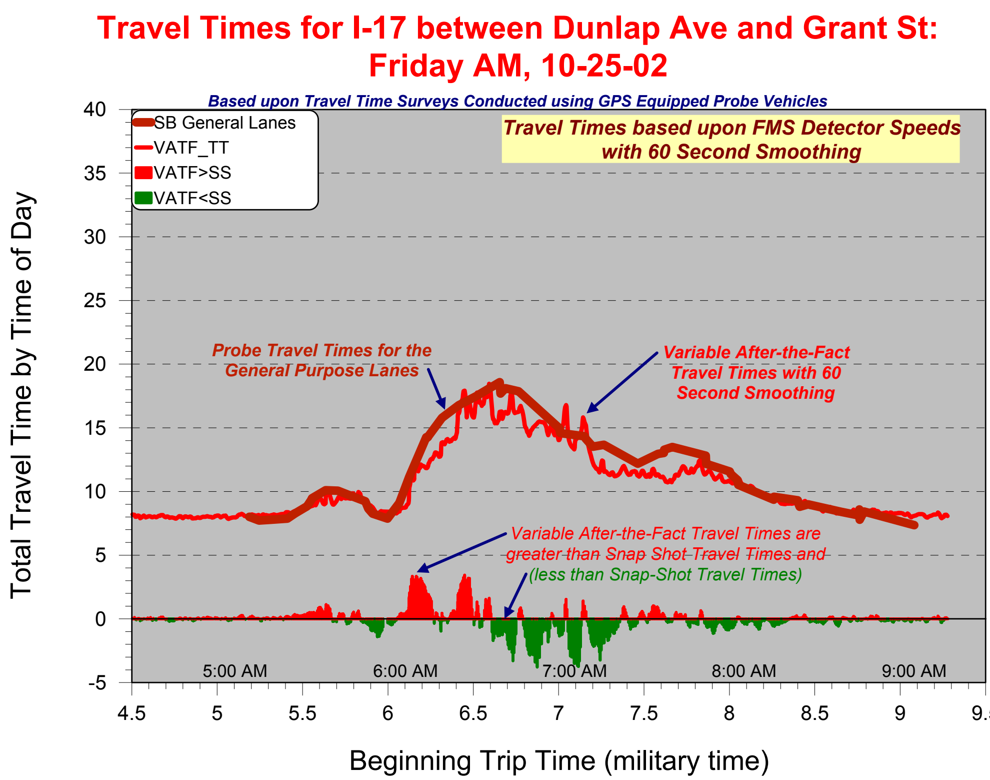


Fig. 2.9: Snap Shot Travel Time Versus After the Fact Travel Time with Smoothing

The confirming of these three hypotheses has important significance to the objectives of this project. As noted above in the discussion of the results from the state-of-the-practice survey, the SS_TT approach is the typical travel time calculation procedure used to estimate travel times displayed on the VMS of other traffic management centers. For the example shown in Figure 2.8, if AZTech™ was to just use the SS_TT then for the time period when travel times are increasing, the SS_TT would be underestimating the short-term travel times that by examining the historical data was found to be experienced. Conversely, when travel times were beginning to decease, the SS_TT would overestimate the travel times to be experienced by travelers. Examination of the amplitude of the red and green clusters in Figure 2.8 relative to the values of the observed probe travel times at that trip start time, it can be seen that the peak underestimation would have been about 35 percent (about 9 minutes versus about 14 minutes), while the peak overestimation would also have been about 35 percent (about 20 minutes versus about 15 minutes).

Another aspect of the calculation of the ATF_TT that was explored by the project was the effect of including a temporal smoothing of the resulting values so as to: (a) dampen fluctuations in travel time that are due to localized pockets of congestion, and (b) lessening the likelihood of having too frequent swings in values being displayed on the VMS. In Figure 2.9 the ATF_TT that were given in Figure: 2.8 were adjusted so that the smoothed value at a particular time increment was from a series calculated: (a) using the regular procedures for the current and the two previous time increments and then averaging the three values, (b) moving forward one time increment and repeating the individual and another average calculation, and (c) then continuing to go forward one increment in time each increment in time. The resulting estimate of smoothed ATF_TT shows less variability over time when contrasted to the ATF_TT given in Figure: 2.8. In the lower part of Figure 2.9, the differences between the ATF_TT and the SS_TT also display less variability per unit of time. The use of a temporal smoothing procedure such as this would seem to be a helpful feature of the predictive travel time algorithm.

The next sub-section focuses on identifying different "travel behavior pattern time periods" that were derived in part from the day-of-the-week variations in corridor travel times that were found in the analysis of the observed probe travel times.

2.5. Expectation of Different Travel Behavior Pattern Time Periods and Seasons

An important premise of this project is that seasonal, weekly, and diurnal patterns that are well known for traffic volumes similarly apply to segment speed and corridor travel times. That coupled with the information gained from the observations of variations in corridor travel time that were just discussed led us to hypothesize that there are about ten distinct time periods within which there will likely be similar travel time profiles or patterns. The next question was how often during the course of a year would those different patterns likely be experienced. Thus an analysis was performed that classified each of the 8,760 annual-hours according to that hour likely being one of these ten different typical travel behavior pattern time periods. As just indicated, the selection of the particular ten time periods is a judgment call based in part upon experience in transportation planning and operations and the particular observations of route travel time profiles found from the summary of the probe travel time runs. Figure 2.10 summarizes the percent distribution of the hours according to these ten different time periods.

The results of the analysis given in Figure 2.10 show that category A of "ambient", or generally free-flowing traffic conditions, can be expected for about 61% of the hours annually. However, when incident congestion gets accounted for, that percentage would likely decline somewhat. The next largest block of hours is category B for the midday, non-peak hours, which are expected to occur about 17% of the total hours. Again however, when incident congestion gets accounted for, that percentage would likely decline somewhat. Thus for about 75 to 80% of the time annually, traffic is expected to be generally free flowing and route travel times should show little if any variation. However, analysis may find that the travel times for Category B may not be quite as free flowing and fast as the travel times associated with Category A.

#	Time Period Description	Day of Week	Time From	Time To	Number of Hours	Percent of the Year	Percent of Peak Traffic
A	Ambient	Weekends Weekdays	All Day 7:00 PM	 5:00 AM	5,388	60.9%	
B	Midday Non-Peak	Weekdays	9:00 AM	3:00 PM	1,499	17.1%	
C	Midweek PM Peak	M,T,W,Th	3:00 PM	7:00 PM	789	9.0%	41.0%
D	Midweek AM Peak	T, W, Th	5:00 AM	9:00 AM	580	6.6%	30.2%
E	Friday AM Peak	Friday	5:00 AM	9:00 AM	212	2.4%	11.0%
F	Friday PM Peak	Friday	3:00 PM	7:00 PM	141	1.6%	7.3%
G	Monday AM Peak	Monday	6:00 AM	9:00 AM	132	1.5%	6.9%
H	3-Day Holiday PM Departure Peak	Friday	2:00 PM	8:00 PM	24	0.3%	1.2%
I	Holiday AM Return Peak	Day After	6:00 AM	9:00 AM	27	0.3%	1.4%
J	Long Holiday PM Departure Peak	Day Before	2:00 PM	8:00 PM	18	0.2%	0.9%
				Totals	8,760	100.0%	100.0%
				Numbers used as the base for the percentages		N=8,760	N=1,923

Fig. 2.10: Percent Distribution of Annual Hours by Proposed Travel Behavior Time Periods

It is for the remaining 20 to 25 percent of the time, or on the order of 1,900 plus hours per year, that having a predictive travel time algorithm in operation would be more important. Generally speaking for any given season there are expected to be eight remaining typical time periods within those approximate 1,900 hours that we anticipate different travel behavior patterns affecting the route travel time. The right-hand column of Figure 2.10 shows the percentage that each of these remaining eight-time-pattern time periods is of the 1,900 or so hours of peak traffic hours. Category C of the midweek PM peak period and Category D of midweek AM peak period accounted for about 41 and 30 percent, respectively, of the approximate 1,900 peak traffic hours. The three categories of E, F, and G, associated with non-holiday Friday AM and PM peaks and Monday AM peaks, account for about a combined percentage of about 25% of the peak traffic hours. The last three categories of H, I, and J, that are associated with holiday traffic conditions, account for about 3 to 4% of the 1,900 or so peak traffic hours.

It is further expected that the first seven categories given in Figure 2.10 (Types A to G) are likely to show seasonal variations. For example, for Category F of Friday PM Peak, the average link speeds, link travel times, and route travel times will likely differ when a summer-time average is calculated and contrasted to the averages for winter-time traffic when all of the vacationing, retired, or intermediate-term residents – the “snowbirds” – are in the region. With regards to seasonality, Figure 2.11 shows that we are assuming that there are three basic travel time pattern “seasons” consisting of five time periods each year, with the seasons being termed winter, spring/fall, and summer.

Travel Time Pattern Seasons	Beginning Date		End Date		Relative Travel Times
	Month	Date	Month	Date	
~~A.~~Winter (Early and Late)	January	1	April	15	Slower
	October	19	December	31	
Spring/Fall	April	16	June	30	Normal
	September	1	October	18	
Summer	July	1	August	31	Faster

Fig. 2.11: Seasons for Analysis of Travel Behavior Pattern Time Periods (for 2002)

Figure 2.11 also gives an indication of the expected relative travel times for season-to-season for the same category of travel time behavior time period of the week. It is expected that analysis will find that: (1) the spring/fall season has normal or average travel times, (2) the winter season has slower travel times on average than the spring/fall season, and (3) the summer season has faster average travel times than the spring/fall season. Making these distinctions among different travel behavior time periods and travel time pattern seasons is to help facilitate the calculation of predictive travel times on an on-going basis in the future. The appropriate set of anticipated travel time patterns for the then current point in time becomes a key information source against which a predictive travel time algorithm can be applied.

It is important to note that the recent work performed by the Texas Transportation Institute for the Federal Highway Administration, *Monitoring Urban Roadways in 2001: Examining Reliability and Mobility with Archived Data* [14], that analyzes and compares data from the traffic management centers of twenty-six areas, including the ADOT FMS, found that the Phoenix area seasonal differences are more pronounced than in any other area. Further, congestion is higher in the fall and winter (November to March) when the weather attracts tourists from colder areas and in the summer congestion and unreliability are relatively low. Their analysis keeps the data for each month together and does not combine data across months.

2.6. Prerequisites & Desired Features: Algorithm Approach to Estimate Predictive Corridor Travel Time

The work done on this project identified several prerequisites and several desired features for the development of a predictive travel time algorithm. From our perspective the algorithm is more than just the mathematical expressions used in an effort to estimate travel time from average speeds from a set of detectors – rather the predictive travel time algorithm is the whole process of integration of current traffic conditions and historic patterns with an understanding of how current conditions are varying from the historic patterns. The following list identifies the prerequisites and the desired features:

- Prerequisites:
  - Reliable on-going stream of data from detectors
  - Long and short-term Archived Data Management System
  - Calculator for Snap Shot and After-the-Fact travel times
  - Seasonal sets of anticipated travel time patterns
- Anticipated travel time for next time increment
- Current After-the-Fact travel times
- Trend of recent corridor travel time conditions
- If incident occurs, judgment as to the severity-duration
- Calculation of predictive travel time
- Quality control checks and transmittal to the ATIS system media;
- Periodic validations and recalibrations

Figure 2.12 presents a schematic diagram of how these basic components of the predictive travel time algorithm are seen as working together to help produce predictive travel times for a corridor. The following discussion covers these prerequisites and each of the desired features of the algorithm and helps to explain the interrelationship among them as illustrated in Figure 2.12.

Prerequisites: The first of the prerequisites is to have a reliable on-going stream of data from the traffic flow detectors in the corridor being studied. Figure 2.12 shows that at the bottom of the diagram and depicts it as an on going "stream" of data from the detectors into which the algorithm process needs to be continually dipping and extracting pertinent data and information. The current time is depicted as the vertical gray bar going from the bottom to the top of the figure. Historic or archived time is to the left and future or predictive time is to the right of the gray bar.

The second of the prerequisites is to have a long-term Archived Data Management System (ADMS) and a short-term operational archive, which are schematically shown in the upper left and upper middle parts of the figure. The long-term ADMS is seen as working independently from the purpose of this project, but its existence is supportive of the purpose and can be used periodically to assess seasonal sets of anticipated travel time patterns, which is one of the other prerequisites. The ADOT FMS has a basic ADMS function as part of the system operations and a Regional Archived Data System (RADS) is in final stages of development by the Maricopa County DOT as an AZTech™ project.

The third of the prerequisites is having what we are terming as a Variable After-the-Fact (VATF) Travel Time Calculator. Such a calculator is necessary to properly "mine" the ADMS regarding different travel time patterns as well as being central to the functioning of the overall algorithm. More discussion about that is given in the next sub-section.

The previous sub-section talked about the importance of having seasonal sets of anticipated travel time patterns, which is the fourth of the prerequisites. To have an understanding of how current conditions are varying from the historic patterns, it is first necessary to know what historic patterns can be anticipated in this season, this day-of-the-week, and this time-of-day.

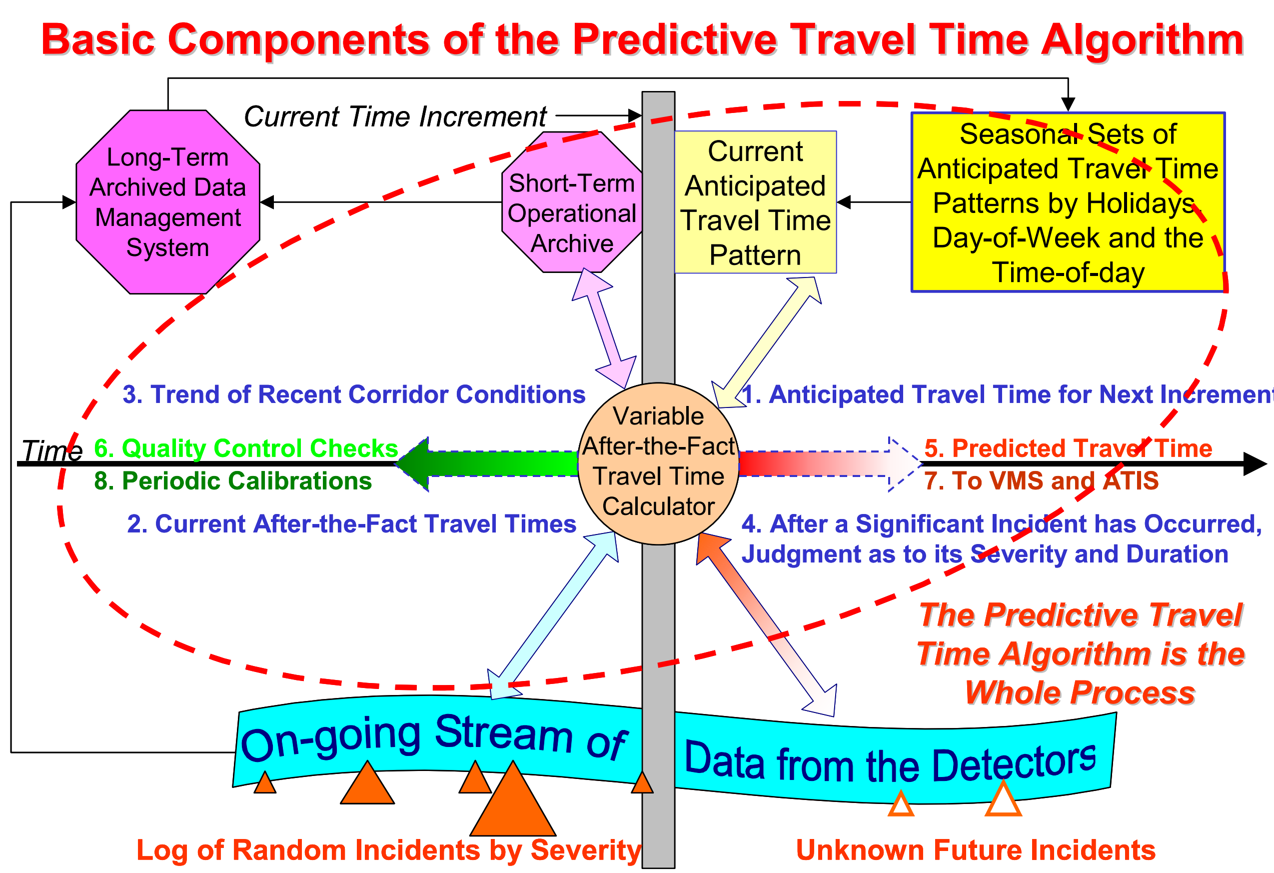


Fig. 2.12: Basic Components of the Predictive Travel Time Algorithm

The other basic components in Figure 2.12 show eight process steps that taken together carry out the algorithm, which are as follows:

1. **Anticipated travel time for the next time increment**: This step would use, select, and look-up for the current anticipated travel time pattern what could be the corridor travel times for each direction

and lane type for the next time increment. That could also include the travel times to a set of pre-determined VMS in the corridor.

2. **Current After-the-Fact travel times**: This step would use the ATF_TT calculator to search back through the most recent on-going stream of data from the appropriate detectors to calculate the current ATF_TT values, which would then be compared to the anticipated value from step 1. An option would be to allow for a time lag to build up and log the series of ATF_TT values such that at any current time, the ATF_TT of 10, 15, 20, or so minutes ago is known.

3. **Trend of recent corridor travel time conditions**: This step would query the short-term operational archive to check on the trend of recent corridor travel time conditions to see the degree to which the most recent sets of the ATF_TT have been tracking the values of the anticipated travel time, where this too would allow for the time lag between the current time and the last known trip-start time to travel the corridor.

4. **If incident occurs, judgment of severity-duration**: This step is more of an anticipated future step once sufficient experience with the use of the algorithm has taken place. In essence if in the previous step the trend of recent conditions indicates that an on-going significant incident is occurring checks would first be made as to the judgments made by operations staff as to its severity and expected duration. A look-up would be made of a library of similar incident conditions and the multiplier effect that they had on corridor travel times by direction and lane type.

5. **Calculation of predictive travel time**: In this step the results of the previous four steps would be compared and combined in some fashion to select the most appropriate likely corridor predictive travel time by direction and lane group. There may also be sub-corridor estimates made to correspond to the times to reach or travel from various intermediate points that may be associated with different VMS. Options for that combining are discussed in the next sub-section.

6. **Quality control checks**: In this step, a quality control reasonableness check would automatically be made relative to the most recent observed and predictive travel times so as to avoid substantial swings and shifts in the values. This may involve a temporal smoothing or other similar such routine.

7. **Transmittal to the ATIS media:** After the proceeding steps have been completed, this step would then involve the transmittal of the appropriate predictive travel times to the selected Advanced Traveler Information Systems and to the short-term operational archive.

8. **Periodic validations and recalibrations**: This step would involve the periodic comparison of the results for validation and recalibration purposes with the calculated set of ATF_TT as well as those of field observations that may be performed from time-to-time.

In summary, it is important to note that there is a particular analysis need and requirement that should be attended to in order to have an effective implementation of the predictive travel time algorithm. This need and requirement is that the predictive travel time algorithm should process through a full cycle <u>within</u> the current time increment being used by the ADOT FMS, which is twenty seconds. It should be noted however, that there may be some latitude for the predictive times that would be posted on the VMS as it may be better from a customer perspective to have the potential of somewhat less frequent changes in the travel time values. Having a new estimate no more than once every minute might be more desirable than having a new value once every twenty seconds.

2.7. General Features of the Snap Shot and Variable After-the-Fact Travel Time Calculator

The ATF_TT calculator is central to the effective functioning of the full predictive travel time algorithm. In addition, the calculator can be used to quickly calculate the current values of the Snap-Shot Travel Times. This sub-section reviews the general features that have been used to develop this calculator as well as some of the key ways in which it has been working and is being used in testing out the operation of the overall algorithm.

The ATF_TT calculator has been designed to process the FMS detector data from ADOT, particularly that of the average speed data. That data first needs to be sorted through to cull out those detectors associated with the corridor being tested that are then arrayed and grouped by detector station, lane, and lane-type where stations are arranged by direction. The values for the auxiliary lanes are not used while those for the High Occupancy Vehicle lanes are kept separate for those times during which those lanes are being operated for that purpose. In the corridor there is a traffic flow detector for each mainline lane so an aggregation and averaging process needs to be performed to get the detector station average speed. The distance to the next downstream detector is used as a multiplier against the average speed to get an estimate of the directional link travel time from one station to the next.

Before those link travel times are aggregated to estimate corridor travel times, a quality control check is made for that time increment. If a particular detector station is missing a value or has an unreasonably fast or slow value then one of a number of imputation steps might be used to supply a substitute value. One step would be to use the average of the upstream and downstream value and/or that from the previous time increment if those values are themselves valid. Another step would be to retrieve an appropriate value from a look-up table that is representative of the current time period but based upon historic values. A third step would be to stop imputing estimated link travel times if there are too many missing values at one or more detector stations and/or for what would be considered as a protracted period of time. Those imputed values for the current time increment would be saved along with the direct values and would be smoothed temporally with the values from the two previous time increments when the smoothing routines are being used.

The calculator is designed to concurrently produce two types of corridor travel time estimates – SS_TT and ATF_TT. The SS_TT estimate for the current time increment is simply obtained by adding the individual detector station to detector station link travel time values in the direction of flow for the corridor. Those values are continually logged by the system according to the beginning value of the time increments. The calculator also works to step forward in the downstream direction of flow estimating what distance would be traveled for that time increment where a new series is tracked for the start time of each time increment and the current estimate of link speed is used to determine the distance travel along each link. Thus there can be many such series being tracked during each time increment and the distances being "moved" in the direction of flow reflect the current congestion conditions and detector speeds throughout the whole corridor.

Eventually each of the start time increments being tracked "reach" the end of the corridor – in which case the then accumulated link travel time values for that series becomes the ATF_TT and is associated with the trip start time for that series. The relative value differences and/or ratio of the ATF_TT for that start time increment compared to the SS_TT value is then calculated and logged as well. The overall set of these relative difference logs and ratios when rolled up by day, week, and month can be transformed to become, supplement, or modify the seasonal sets of anticipated travel time patterns for on-going use in application of the ATF_TT calculator and overall PTTA.

This calculator has been running since spring of 2004 and the resulting estimates of SS_TT and ATF_TT have been and are continuing to be logged. Minimal review and analysis has been performed to date on that accumulating set of information.

2.8. Data Quality and Reliability Concerns based on the Algorithm Calibration

Subsection 2.4 above on Surveys and Characteristics of Observed Corridor Travel Times became an excellent source of data for use in developing a calibration of alternative predictive travel time algorithms. The archived FMS traffic flow data for the detectors in the study corridor for the subject week were retrieved and summarized into data files that were organized to facilitate comparison to predictive travel times calculated from a series of alternative algorithms and ATF_TT calculators. The calibration technique that was followed tested a specific algorithm approach and then compared the resulting estimate of predictions of the historic travel time to the actual, observed travel times. Similarities and differences were noted and further testing of alternatives was to proceed until a reasonable comparison was obtained.

Initially a special version of the week's worth of FMS archived data was prepared in a spreadsheet format that was used in a manual analysis and testing of the distinctions between the different ways of defining travel time. Figure 2.1, given above, is a partial example of the style of analysis that was performed using the spreadsheet version of the set of archived detector data. To set up those spreadsheets for each of the days of the week observation period a variety of data quality control editing and imputation procedures was manually applied. Various metadata codes and reference were used to keep track of which data quality procedure was used at which detectors and at which particular time increments. Generally speaking the editing and imputation procedures included the following types, although other various special cases were encountered:

- A particular detector at a particular time would have an abnormally high value of average speed — in which case the speeds from the surrounding detectors and time increments were used to impute a likely appropriate value
- A particular detector at a particular time would have a very low but reasonable value of average speed while all the average speed for all of the surrounding detectors and time increment were free-flowing and the time of day was such that congestion was not expected, — in which case the speeds from the surrounding detectors and time increments were used to impute a likely appropriate value
- One or a few adjacent detectors and/or time periods would have no reported average speed value — in which case the speeds from the surrounding detectors and time increments were used to impute a likely appropriate value
- For one or more detectors there would be a relatively long time period during which there were no reported values of average speed, where the period could be a few minutes or more to hours — in which case, if there were valid appearing values from the adjacent detectors, those values were averaged and applied to the missing time periods
- For one or more detectors there would be a whole day or more during which there were no reported values of average speed — in which case, the detector was ignored and the distance to the next detector was lengthened and the link travel time between detectors was estimated based on the longer distance applied against the average speed at the next valid detector

Part of the development of the specific functionality of the ATF_TT calculator was in essence to be able to automatically recognize the need for such data quality routines and to incorporate appropriate editing and imputation approaches. The algorithm and the ATF_TT calculator were then applied to the "raw" archived data file in its more native format. It is those results that are then compared to the observed travel time data obtained from the probe travel time runs. A series of comparison tests and displays were then run as part of these comparisons. Figure 2.13 is an example of one of the comparison displays. Appendix B presents a more complete set of similar such comparisons for different travel directions, lane types, and observation days.

In Figure 2.13 two basic data sets are shown, the first being in two parts of: (a) the series of points from the observed travel times by time-of-day of the start of the trip at the north end of the corridor, and (b) lines formed by those values plus or minus five and twenty percent. Thus the area between the two lines represents the observed value of travel time within an error of estimate of five to twenty percent. The second data set of the trial values of the predicted travel time from Algorithm version 3 is the estimated values of travel time for every twenty seconds over that time period. The intent is to have the second line of the predicted values "fall within" the range of the error of estimate from the observed travel times.

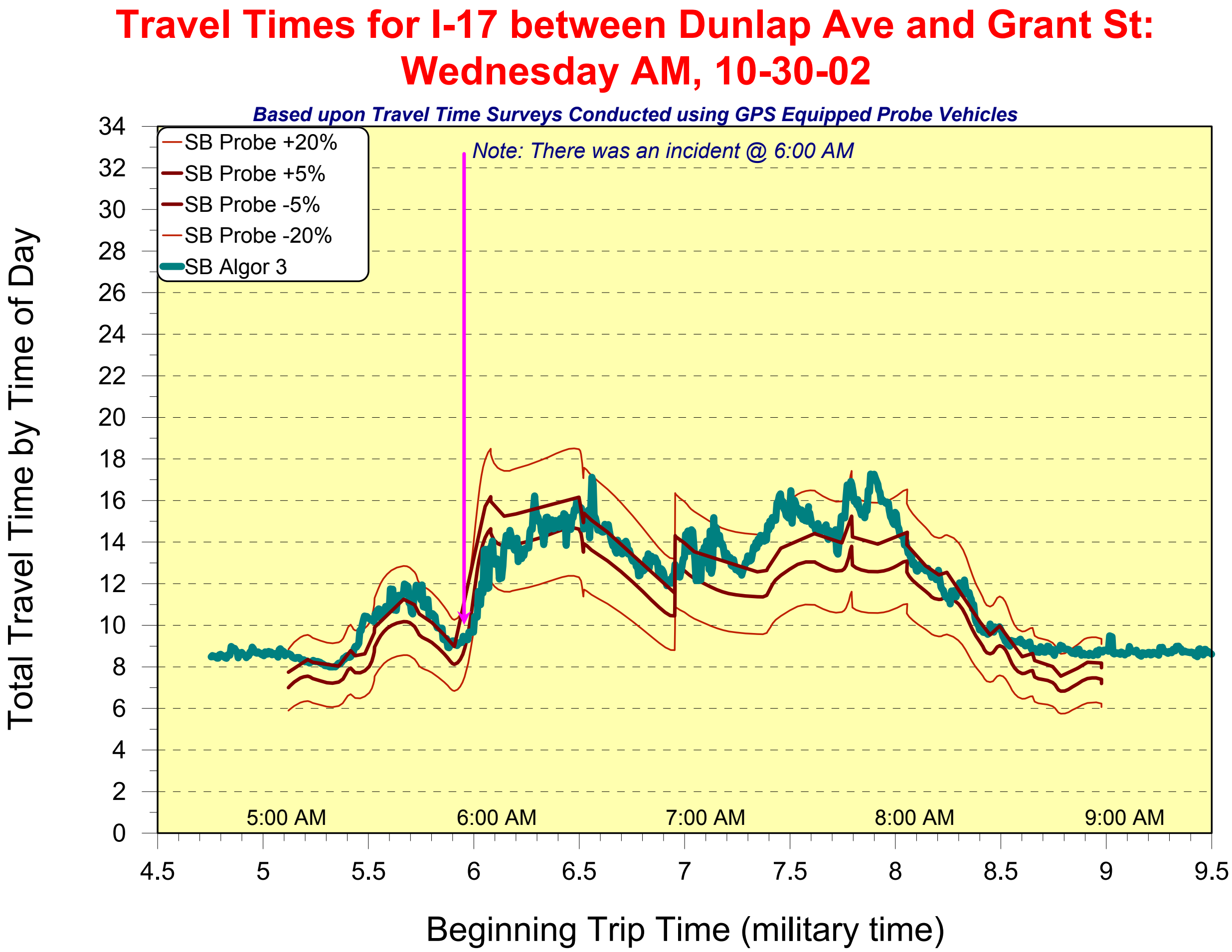


Fig. 2.13: Comparison of the Results of the Predictive Travel Time Algorithm with Comparable Observed Travel Times for the Southbound General-Purpose Lanes Results

The generalized comparison shown in Figure 2.13 is that of a "pretty good" match between the trial predictive travel time and the range of observed values for that sample day, direction, and lane type, as follows:

- Between 5:30 and 6:00 AM the predicted values track well by rising and falling in close proportion to the observed values
- Starting at about 6:00 AM the predicted values rises sharply and then start leveling off until about 6:30 AM when it starts declining again until about 7:00 AM — which again tracks in close proportion to the observed values
- At about 7:00 AM there is a small spike in the predicted travel time which then oscillates but gradually increases until 8:00 AM when the values start a steady decline to free-flowing times at about 8:30 AM — which again generally follows in proportion to the observed values, but not as close as the comparison for the first two hours — more on the order of a twenty percent range of match than a five percent range — which is still good when contrasted to the Snap-Shot Travel Times.

Appendix B presents the similar comparisons for the four other weekday morning conditions as well as those for the Saturday and Sunday observation periods. Of those days, the matches for the Thursday morning and Sunday afternoon are also "pretty good" matches. The comparisons for Monday, Tuesday, Friday, and Saturday were reasonably good for parts of the observation time periods, but were substantially off for other parts of the observed time periods. For three of those days, Monday, Tuesday, and Saturday there were incidents in the corridor that probably caused greater variability in the observed travel times. For those three days the algorithm resulted in considerably greater values of travel time, for example on Monday values of 26 to 30 minutes as contrasted to a range of sixteen to 20 minutes for the hour or so after the incident. The other two incident days were also similarly under predicted. **All things considered, for the southbound general-purpose lanes the algorithm worked fairly well except for the time periods associated with incident conditions.**

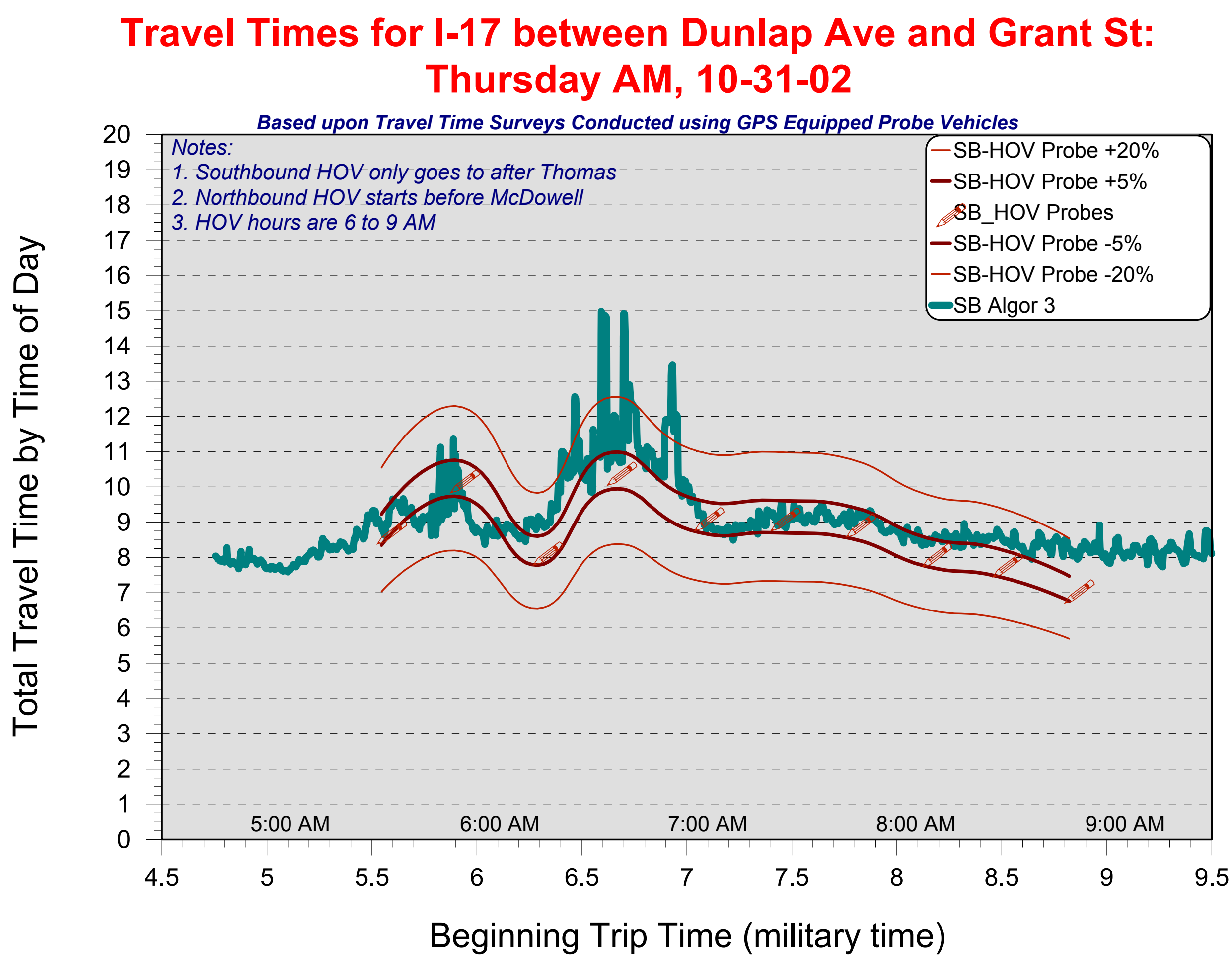


Fig. 2.14: Comparison of the Results of the Predictive Travel Time Algorithm with Comparable Observed Travel Times for Southbound HOV Lanes

Figure 2.14 shows a similarly constructed display for the southbound HOV lane for Thursday AM while those for the all of the weekdays are also given in Appendix B. This example was chosen because it illustrates one of the difficulties with this approach to making the comparisons. While for the general-purpose lanes example previously shown there were observed travel times about once every five minutes, in Figure 2.14 there should have been observed travel times of only about once every ten minutes on the average and but on that day they were even less frequent. While the ten observed travel time comparison points that morning each match very closely to the results calculated by the test algorithm for the same start times, the graph of the very frequent predicted travel times shows considerable variation at times when we did not have comparison observations. Thus, in this instance we really do not have a complete enough basis of comparison of the algorithm results to the observed travel times. Similar situations were generally found for the other remaining weekdays given in Appendix B with the exception of two observed time periods, one on Monday at about 8:30 AM and the other on Friday at about 6:15 AM when there were some slower spikes in observed travel times that were slower than the values of the predicted travel times.

Not shown are comparisons for the northbound general-purpose lanes, which did not fair as well as the comparison for the southbound lanes primarily due to issues of data quality associated with particular detectors at the southern end of the northbound corridor. That section of the study corridor often has very congested traffic conditions and very slow speeds that logically contribute to a large part of the observed slower travel times during the afternoon peak traffic period. However, due to the unreliable reporting of average traffic speeds from the older style detectors in that part of the study corridor, the algorithm did not have sufficient data to accurately estimate travel times for the whole corridor — there was not enough known data to do proper imputation and the distances to the next properly functioning detectors became too long to properly convert average speeds there to travel time over the longer distance.

2.9. Current Limitations on Further Development of Predictive Travel Time Algorithm

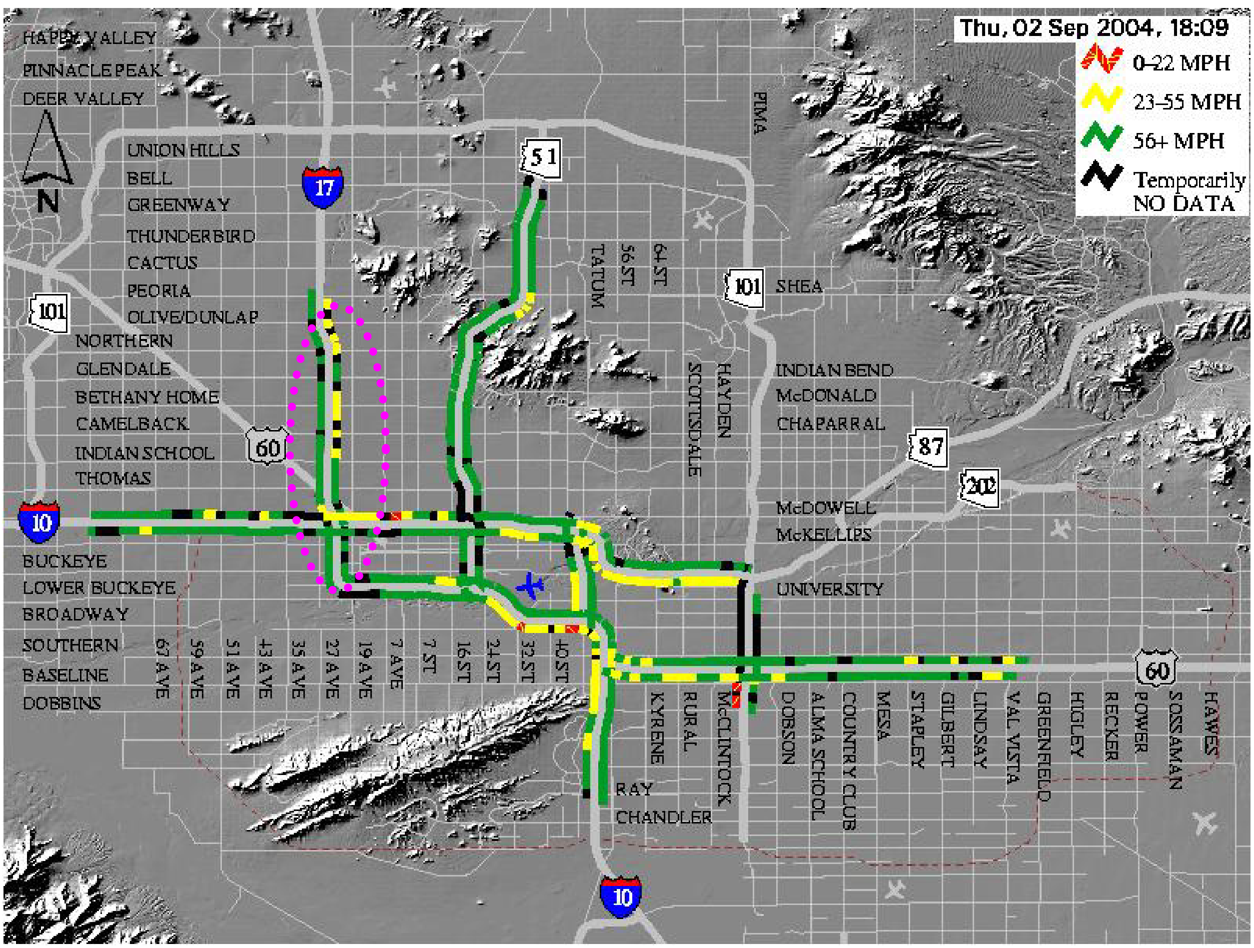
Given this situation, these aspects of the further development and application of the predictive travel time algorithm was put on hold pending the results of efforts to identify and improve the reliability of detector data, which is covered in part of the discussion in the next section.

3. Results of Display & Testing of Operational System & Related Systems

While the work was being carried out to test and develop an appropriate algorithm for the predictive travel times in the study corridor, other project related activities were also being done to develop appropriate displays of the resulting information. In addition, other AZTech™ related activities were also underway or started that have a bearing on this project. Those other activities are discussed first in this section and then the other directly related activities are covered.

3.1. ADOT Improved Speed Maps for the 511 Program

Another AZTech™ Advanced Traveler Information Systems (ATIS) related activity that has also been underway is the "511 Program". The main thrust of that program is to provide ATIS traveler information via telephone systems by having users call the newly established 3-digit dialing of 511. However, a website has also been established as part of that program of AZ511.com to provide other ATIS aspects, such as maps of travel speed and access to video images from Close Circuit Television Cameras.



Source: AZ511.com

Fig. 3.1: Improved Speed Map from the AZ511 Program

Figure 3.1 is an example of a type of display prepared for the AZ511 program to show the variation in average travel speeds derived from the FMS detectors of ADOT. The style of this display is an improved and updated version of the "speed maps" formats that have previously been used by ADOT and the AZTech™ program. The specified study corridor of this project of I-17 between approximately Dunlap Avenue and Buckeye Road is indicated by the dashed magenta oval. With an average spacing between most detectors of about one third of a mile the display typically shows three short segment bars per mile indicating the average speed by direction for that time increment for each of those segments. Thus in the study corridor for the northbound information there are clearly three values shown in Figure 3.1 for between Indian School Road and Camelback Road.

From a broad system wide perspective this improved speed map is a very effective display for communicating to travelers at a glance the then current travel conditions being experienced throughout the parts of freeway system being monitored. However, please note that the display also appropriately gives an indication of a black bar for those individual segment detectors that for some reason are then currently not reporting useable data to the display system. There is enough valid information being reported from most of the detectors that most users of the display can gloss over or anticipate the general conditions in their future direction of travel — and satisfy the prime purpose of the speed map as an ATIS feature.

However, from the perspective and purposes of this project those gaps in reporting of valid observations is proving to be problematic because this project depends upon having an accumulation of values of travel time between successive detectors in the direction of flow. The algorithm that can automatically estimate, interpolate, or fill in valid values for the missing ones thus needs to have decision rules that: (1) appropriately accounts for such gaps in observed data wherever, whenever, and for as long as they occur, and (2) selects reasonable likely values to use in the absence of observed data. One solution to minimize the impact of this situation is to improve the reporting reliability of the system of detectors, as discussed next.

3.2. ADOT Program to Improve Detector Reporting Reliability

Another AZTech™ Advanced Traveler Information Systems (ATIS) related activity that was recently initiated by ADOT is a program to improve the reliability of reporting of valid observations from the detectors throughout the system and not just in the study corridor of this project. While the work related to this project may have contributed to the decision to initiate that other activity, other overall AZTech™ activities and needs were contributing factors as well as several different activities depend upon having timely and accurate data coming from the detectors throughout the entire system.

The first and most important aspect of this reporting reliability program has been the growing recognition that it is important to have a high degree of reliable reporting of data from the detectors. There can be many reasons for a lack of reliable reporting such as: (1) failures in the field of the sensors and/or the field processing equipment, (2) failure or interruption of various components of the communications links that bring the data from the field devices to either intermediate processing equipment or directly to the Traffic Management Center, and (3) problems at the receiving end of the communication that limit the reception of the transmitted signals from the field devices.

There seems to be some relationships with the age of the detector station and the type of sensors and other equipment that is associated with them and their data reporting reliability, with the older stations tending to be less reliable. As noted in the discussion of subsection 2.8 above, the southern part of the study corridor has older style detectors stations while the more northern part, basically north of Thomas Road, has a newer style detector and was installed more recently.

Each of those different types of failure can stem from either hardware, software, communication lines, power supplies, or be the result of some roadway maintenance practices, activities, or accident that affects one or more detector stations or individual sensors associated with it. Sometimes there can be multiple issues at the same time that are affecting the reliability. Further the lack of reliability can be just for one detector station for one time increment or it could affect a group of detectors, or one or more detectors for multiple and sometimes very prolonged periods of time.

A second key premise of this new program is that some detectors are more critical than others from an overall ATIS and traffic operations perspective. As such, their reporting of data should achieve a higher degree of reliability. That may mean when priorities need to be set either due to restricted time or funding, or both, that these more critical detectors should receive priority for inspection of the cause of the unreliable reporting and maintenance crews should work on them before others with a lesser degree of importance to the overall system. ADOT staff and their consultants assisting them in that activity have gone though a process to identify and categorize different detector stations according to their importance to the systems and to AZTech™. The new practices associated with this program have only recently begun to be put in place. The new procedure is that as soon as a problem is found is to notify the contractor, who is tasked with maintaining the critical detectors, to go out, find out the problems, and fix them.

3.3. Prototype System for Web-Based Travel Time Information

In the interim one of the activities of this project has been to work on a prototype system for dissemination of the predictive travel times. The main expectation has been that the values of the predictive travel time algorithm would be automatically posted on the several VMS in the study corridor for en-route traveler information as soon as sufficient testing was done. In the interim, it would also be a service to travelers to provide similar information as part of the ATIS web page for the 511 Program as pre-trip traveler information. Figure 3.2 presents a prototype of such a web page that has been developed by this project.

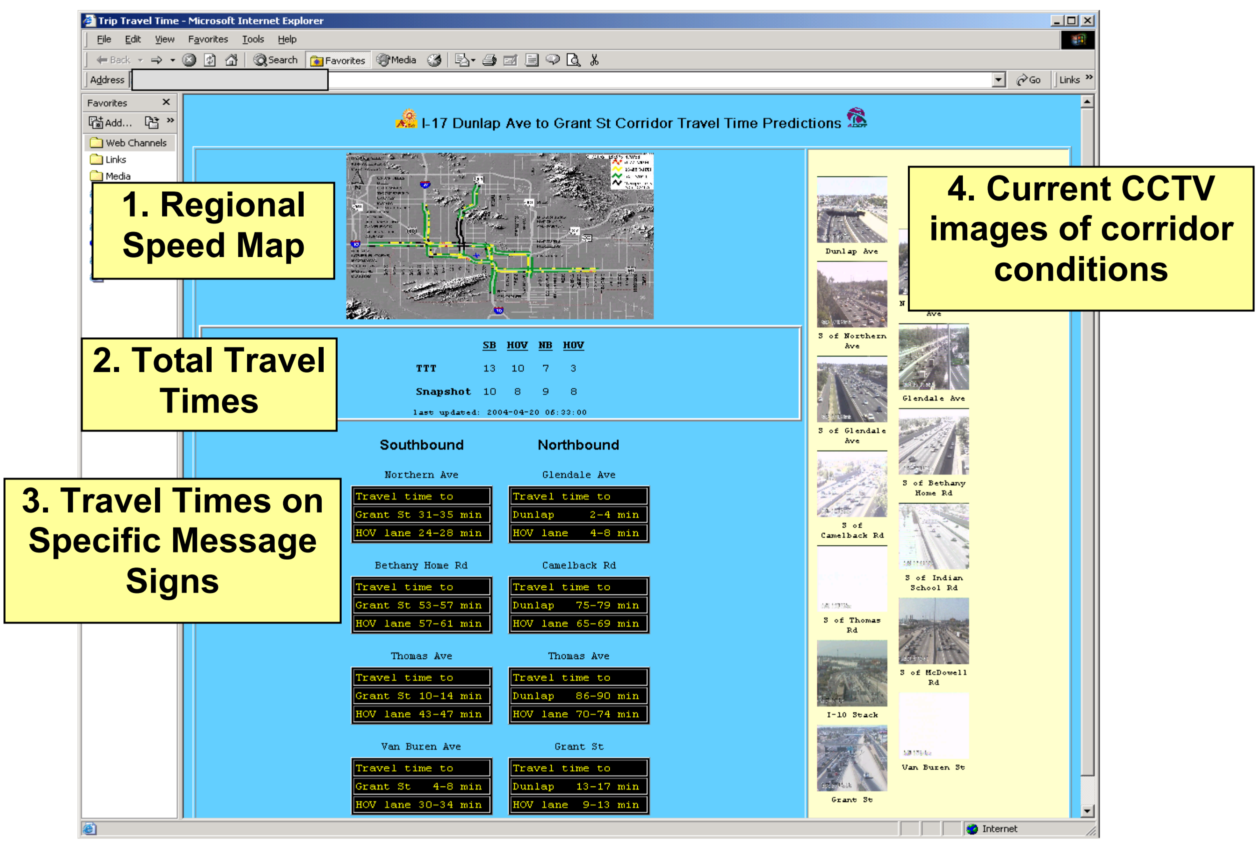


Fig. 3.2: Prototype Web Page for Travel Time Information

Figure 3.2 has four basic component parts, as indicated by the overlay text placed on the prototype web page. While more work needs to be done to improve the layout, formatting, readability, understandability, and usability of the prototype, these four basic components seem to go together. These four components are as follows:

1. Regional Speed Map: This would be the current speed map from the 511 Program as discussed above in subsection 3.1. One thing that could be done to scale up from this initial study corridor would be to ask the user to click on one of several corridors where travel time information is being provided. That could be done in an incremental fashion as more corridors or destination activity centers have specific predictive travel times developed for them.

2. Total Travel Times: For the corridor selected by the user, which in this prototype is shown as the study corridor, a table of currently predicted and snap-shot total travel time for the corridor by direction and lane type would be presented. The value of travel time could be given to the nearest minute. It is possible that a subsidiary table or link could be developed that would give the expected future travel time values for a limited number of future time periods, such as the next fifteen, 30, 45, and 60 minutes. More uncertainty would be attributed to any such later time periods. Such a feature could help travelers in their pre-trip planning better decide at what time they would like to start their trip. Of course they would also be advised to check the en-route VMS as they are actually making their trip.

3. Travel Times on Specific Message Signs: This part of the web page would show the current actual values being posted on the specific VMS in the corridor, by direction. In this figure the values shown is dummy content pending further development of the algorithm. It is anticipated that a range of values of travel time might be shown to reflect that different drivers tend to drive at with different styles and at different speeds. The more distant the destination, the likely the broader the range of values would be shown. It would be the intent to always show the current predictive estimated range even for the anticipated 75 to 80 percent of the time when traffic in the corridor would be at ambient free flow speeds. Such information would help tourists and other out-of-town travelers as well as local travelers who do not normally travel that corridor at that time of day or travel it only very infrequently.

4. Current Closed Circuit TeleVison (CCTV) Images of Corridor Conditions: This last component part of the web page would have mini-views from the current corridor CCTV images that would be arrayed by direction and in the direction of flow. If a user wanted to focus on more detail for their own curiosity, they could click on the appropriate images to see an enlarged version of it.

3.4. Foregoing of VMS Displays for the Near-term

The situation of not having sufficiently reliable detector data, particularly for the northbound direction of the study corridor, has caused the project to temporarily halt further development of the predictive travel time algorithm for display on the VMS. It could technically be feasible to give sufficiently accurate and reliable predictive travel time estimates for the southbound direction. However, it is not thought to be a good thing to do from a customer-relations perspective to have a system working in a corridor helping travelers during the southbound AM congested time period, but then not to have it available for the same travelers for their return trip during the PM congested time period.

Currently, the algorithm is being run and results archived to gather more examples of the similarities and differences in the values of travel time as calculated by the snap-shot approach and the predictive travel time algorithm. There may be some benefit to actually placing those results on the web page for the southbound direction, as it would still be a service to the traveling public. The approach of continuing to apply the algorithm and carry out the calculations may also lead to a better understanding and agreement as to when conditions of sufficient detector reliability have been obtained so as to continue with the original intent of this Predictive Travel Time Project.

4. Project Conclusions & Potential Further Steps

4.1. Project Accomplishments

Phase 1 activities concentrated on researching and summarizing the current state of the practice in use by other Departments of Transportation with regards to the calculation and display of travel time related information on VMS and other media for travel corridors in their regions. We identified about fifteen other states and urban areas in which travel time systems have been or are being thought about for implementation. We designed and conducted a cost-efficient, structured-interview telephone survey that enable the development a thorough and comprehensive discussion of the practices being used in each of the survey areas. Our work included the preparation of (1) a summary write-up and documentation of the responses from each interview as well as (2) a Phase 1 report that characterized the overall findings and represented a very good state-of-the-practice documentation as of that time of the summer of 2002. It is interesting to note that the summary material was subsequently distributed by FHWA at a specialty workshop on travel time that was held in conjunction with the ITS America Annual Meeting in April 2003, thus providing a national benefit. In addition summary presentation style material was prepared and a review meeting was held with the project sponsor in Fall 2002.

Phase 2 activities have resulted in more of a research project than the implementation action test and demonstration that had been anticipated. The activities began with developing clarifying material that highlighted the results of taking different approaches to defining and measuring corridor travel time based on the use of short-term average speeds from the ADOT FMS traffic flow detectors. A second main accomplishment was the collection and analysis of a fairly extensive set of observed corridor travel times using a group of probe-vehicles equipped with GPS devices in the selected test corridor of I-17 between Dunlap Avenue and Buckeye/Grant Street. The information on corridor travel time characteristics represented a rather unique set of information for testing and comparing the results of alternative conceptual approaches to developing and applying algorithms to estimate predictive corridor travel times. Conceptualization was done as to expected differences in travel behavior patterns throughout the year, seasons, and weeks that should result in systematic variations in corridor travel times. Further work on "mining" the Archived Data Management System associated with the FMS detector data to better discern differences for different Travel Time Behavior Time Periods still needs to be accomplished.

The basic components of a predictive travel time to meet the project needs and requirements were identified and several alternative algorithm configurations were tested against the observed corridor travel time data and information characteristics. Work was performed to prepare a prototype web-based display system for such travel time information. The algorithm worked fairly well for the southbound direction in the test corridor for both the general purpose lanes and the HOV lane. The algorithm was less reliable during those time periods when moderate to significant incidents affected traffic flow conditions in the corridor. For the northbound general-purpose lanes, the travel time estimates for them did not fair as well as the comparison for the southbound lanes primarily due to issues of data quality associated with particular detectors at the southern end of the northbound corridor. Work has been initiated by ADOT to have a program that should result in improved detector reporting reliability for the average speed and other data from key traffic flow detectors throughout the entire system.

4.2. Summary of the Delivered System

The delivered algorithm is more than just the mathematical expressions used to estimate travel time from average speeds from a set of detectors. Rather, the predictive travel time algorithm is the whole process of integration of: (a) current traffic conditions, and (b) historic travel time patterns, with (c) an understanding of how current conditions are varying from the historic patterns. The delivered system depends on having several prerequisites:

- First and foremost, the system depends on having a reliable on-going stream of accurate data from the traffic flow detectors in the corridor, which in this case comes from the ADOT FMS.

- Secondly the system depends on the availability of both a long-term Archived Data Management System (ADMS) and a short-term operational archive. The long-term ADMS works independently from the direct purpose of this project but is indirectly supportive, for example being used periodically to assess seasonal sets of anticipated travel time patterns. The ADOT FMS has a basic ADMS function as part of the system operations and a Regional Archived Data System (RADS) is in final stages of development by Maricopa County DOT.

- Thirdly the delivered system has developed a set of routines termed as the After-the-Fact Travel Time Calculator. That calculator is necessary to properly "mine" the ADMS regarding different travel time patterns as well as being central to the functioning of the overall algorithm. That set of routines has been tested and works with the ADOT systems producing an on-going stream of Snap-Shot an After-the-Fact Travel Times as part of the prototype web display.

- Finally, full implementation of the system depends on having seasonal sets of anticipated travel time patterns. That is needed because in order to have an understanding of how current conditions are varying from the historic patterns, it is first necessary to know what historic patterns can be anticipated for the: (1) current season, (2) holiday status, (3) day-of-the-week, and (4) time-of-day. The results from the prototype web display are being accumulated and archived and will in part begin to be used to constitute the necessary and sufficient set of anticipated travel time behavior patterns.

Other features or steps of the system include the following:

- Anticipated travel time for next time increment
- Current After-the-Fact travel times
- Trend of recent corridor travel time conditions
- If an incident is occurring, judgment by field personnel as to the severity-duration
- Calculation of the predictive travel time estimate
- Quality control checks and transmittal to the ATIS system media;
- Periodic validations and recalibrations

4.3. Expectation of Expansion: Other Corridors, Extension of Algorithm, & Recent Federal Guidance

The approach and techniques carried out for this project, while initially focused on the study corridor, were generic with the assumption and expectation that they would be geographically expanded to cover other corridors and eventually the entire region when there is sufficient data coverage from the FMS detectors. There is also an expectation of the expansion and refinement of the algorithm over time, particularly with regard to the way the impact of incident on corridor travel time can be accounted for in the predictive travel time process. As such the design of systems and prototype were done in a modular fashion given these expectations so that the developed system could be incrementally expanded at appropriate times.

It is the recommendation of the project team, however, that such incremental expansions should be accompanied with collection of primary and secondary travel time data to use in the process of corridor-specific calibration and validation of the application of the generic algorithm. That should especially be the case in the first few incremental expansions as it would be more important for them to be more assured that the approach is working well and it has not encountered some unforeseen situation that could diminish the effectiveness of the approach. Over time less primary data collection would seem necessary and more reliance could be given to secondary travel time data collected by other agencies for other purposes.

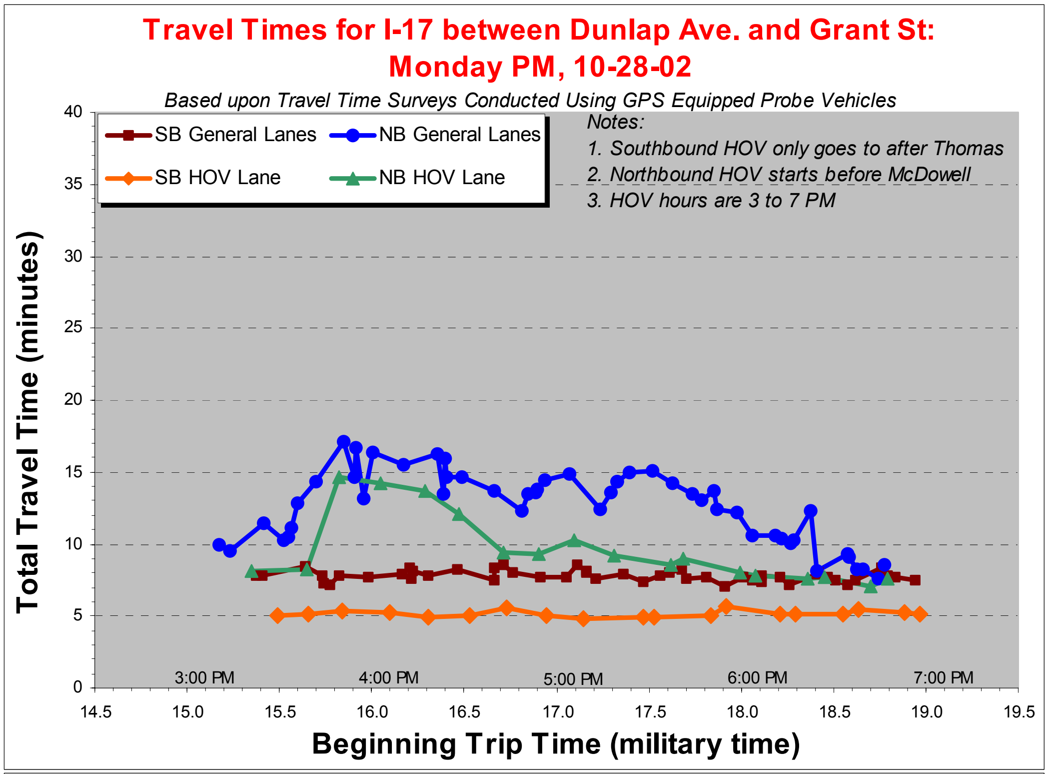
Discussion has been initiated at ADOT over the development of travel time estimates for travel to the Sky Harbor International Airport. Given the distances and corridor directions involved it would seem plausible that having predictive travel times would prove to be more accurate than the use of the Snap-Shot Travel

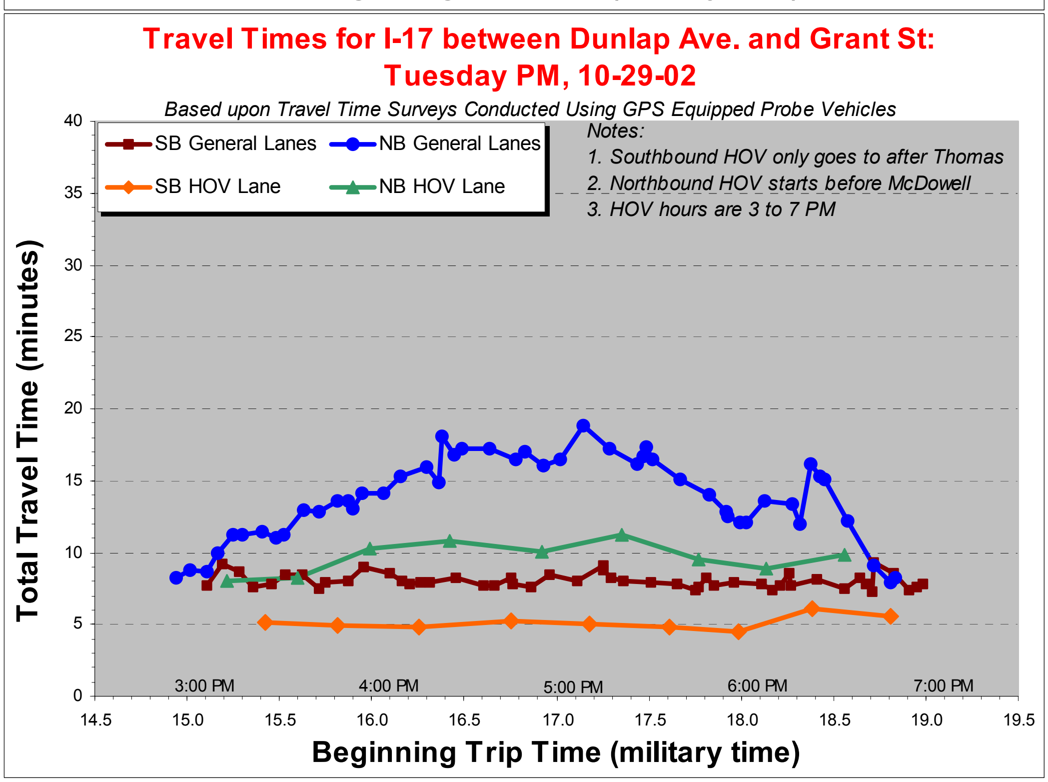
Time approach. It would be desirable to collect some new travel time data to and from the airport to use as a validation data set. In addition, there is a resource of recently observed regional travel time data collected by the Maricopa Association of Governments (MAG) that could provide a calibration data set to help in such an effort. Such a project could be a logical extension of this Predictive Travel Time Project and could provide a good transition to the incremental extension to other corridors. The timing might also be such that the ADOT Program for improving detector reporting reliability may have sufficiently advanced that the situation encountered by this project would have been self-corrected.

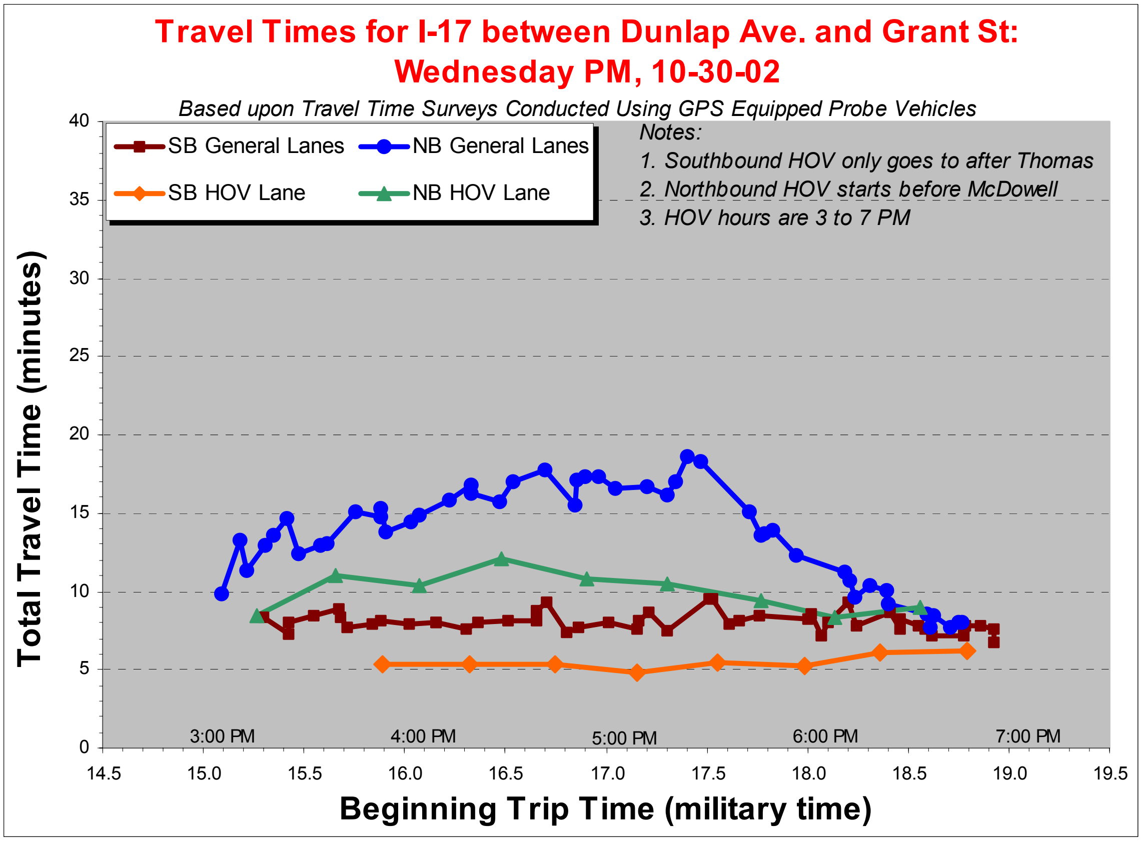
The Federal Highway Administration (FHWA) has recently released an Information and Action Memorandum on the topic of Dynamic Message Sign Recommended Practice and Guidance (dated July 16, 2004) directed to FHWA Division Administrators and field personnel. The memorandum notes that "…Better DMS messages, based on travel times, can be displayed with the information currently available…Further, no new DMS should be installed in a major metropolitan area or along a heavily traveled route unless the operating agency and the jurisdiction have the capability to display travel time messages." A number of recommendations from a more detailed guidance report are provided. Among them are the following, "…It is important to note that effective travel time messages do not require the data to be 100% accurate. Research has indicated that data with error rates of 20% produce useful traveler information. When presenting a range of travel times on DMS the acceptable error rate may even be higher."…Other recommendations pertinent to the objectives of this project are also given in that memorandum. Further analysis of the memorandum and the full guidance report should be carried out in considering expansion of the predictive travel time approach to other corridors.

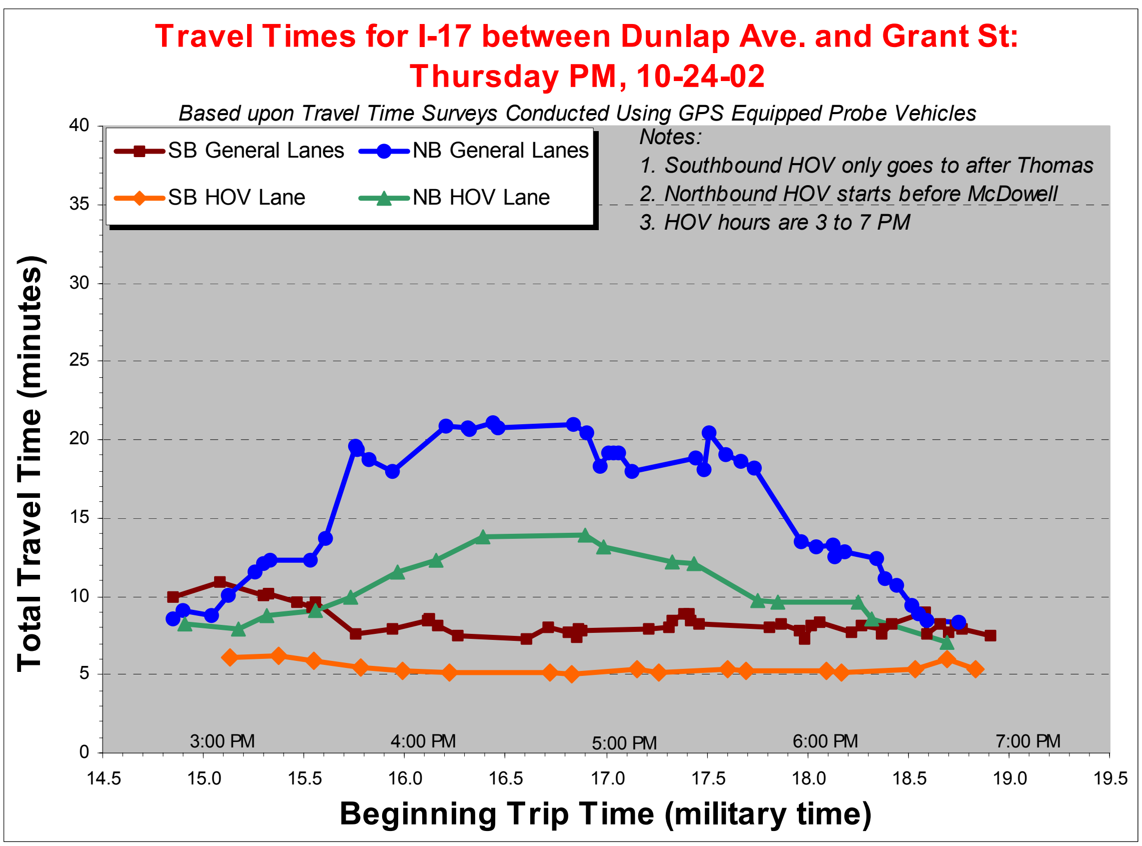
Appendices

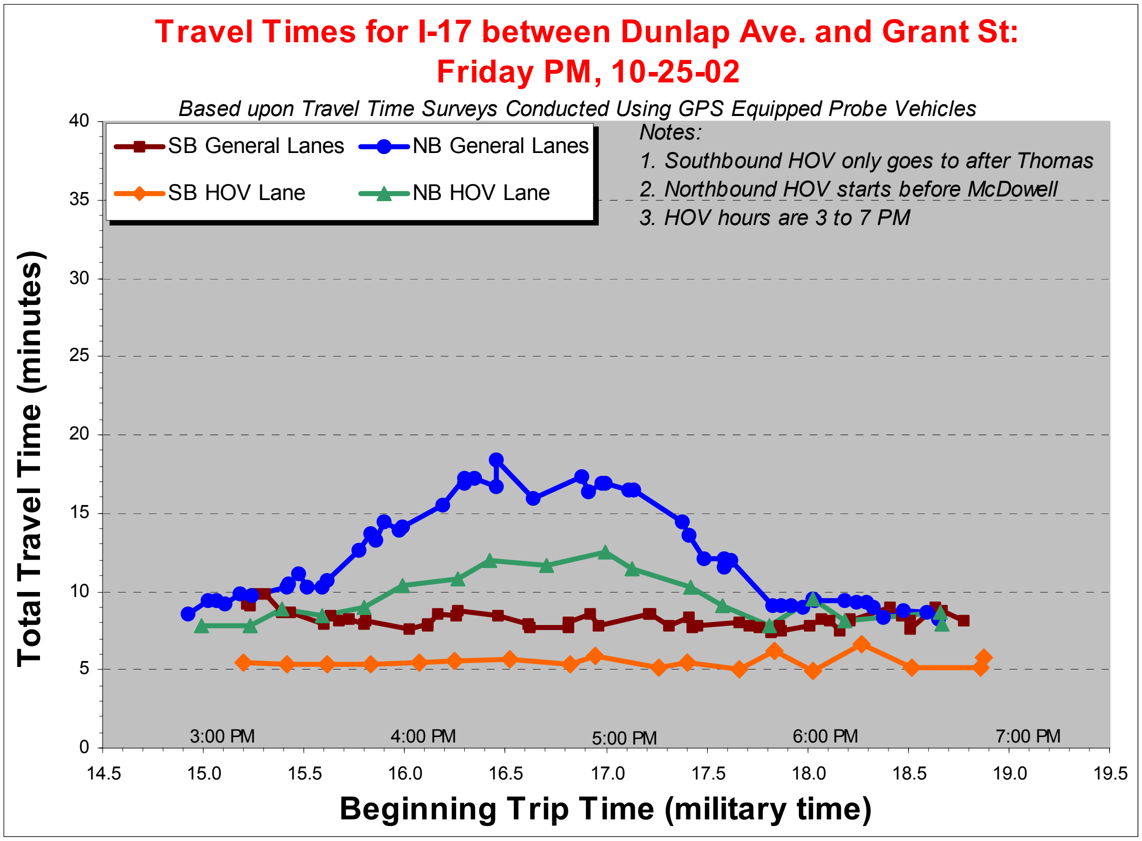
A. Summary Displays of Observed Corridor Travel Times

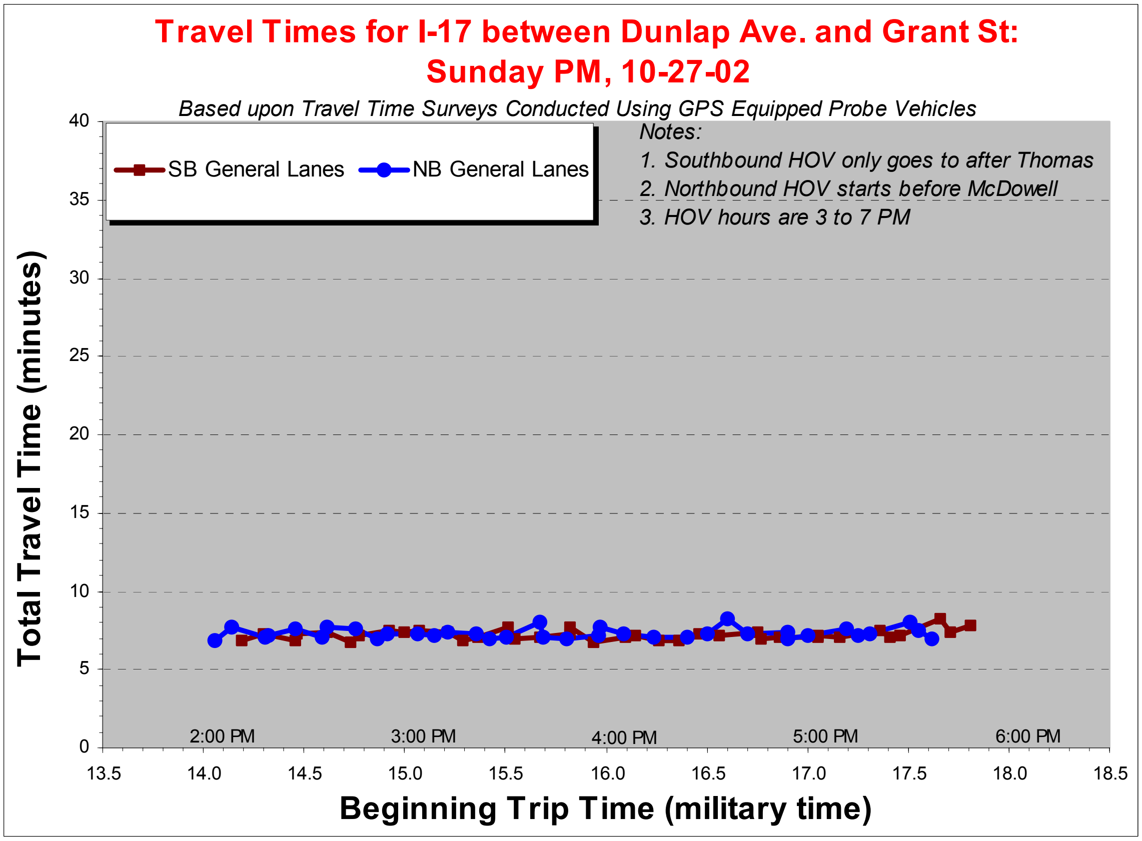




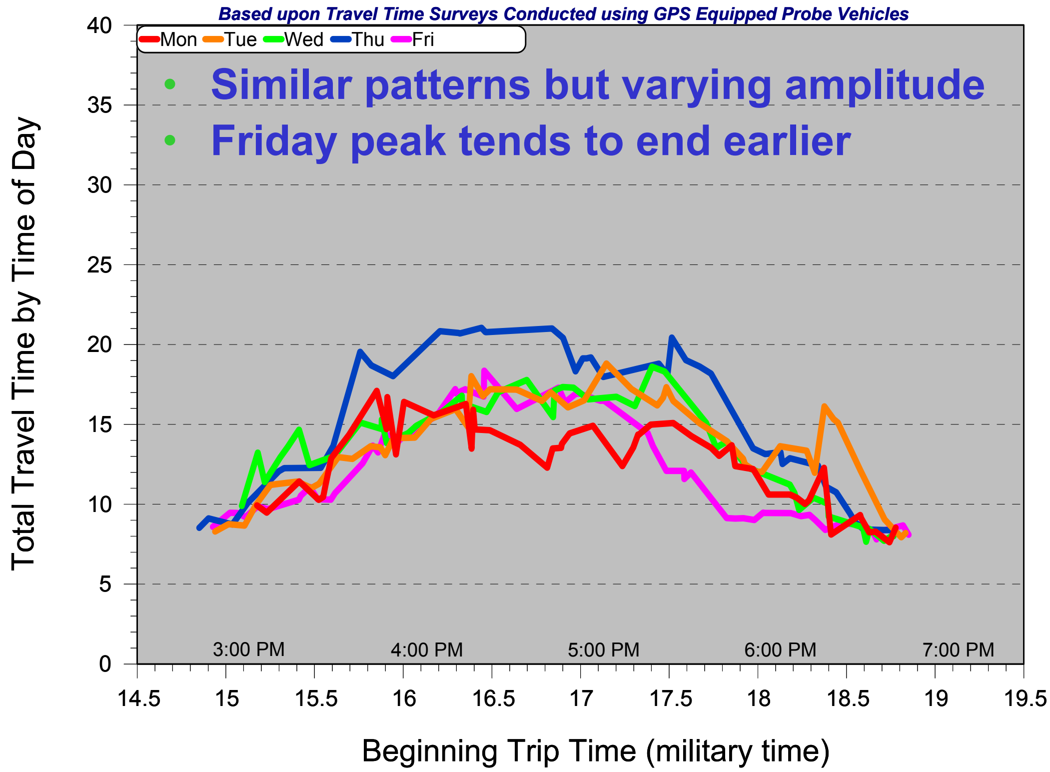

Travel Times for I-17 between Dunlap Ave. and Grant St:
Wednesday PM, 10-30-02
Based upon Travel Time Surveys Conducted Using GPS Equipped Probe Vehicles
SB General Lanes
NB General Lanes
SB HOV Lane
NB HOV Lane
Notes:
1. Southbound HOV only goes to after Thomas
2. Northbound HOV starts before McDowell
3. HOV hours are 3 to 7 PM
Total Travel Time (minutes)
0
5
10
15
20
25
30
35
40
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
14.5
15.0
15.5
16.0
16.5
17.0
17.5
18.0
18.5
19.0
19.5
Beginning Trip Time (military time)


Travel Times for I-17 between Dunlap Ave. and Grant St:
Thursday PM, 10-24-02
Based upon Travel Time Surveys Conducted Using GPS Equipped Probe Vehicles
SB General Lanes
NB General Lanes
SB HOV Lane
NB HOV Lane
Notes:
1. Southbound HOV only goes to after Thomas
2. Northbound HOV starts before McDowell
3. HOV hours are 3 to 7 PM
Total Travel Time (minutes)
0
5
10
15
20
25
30
35
40
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
14.5
15.0
15.5
16.0
16.5
17.0
17.5
18.0
18.5
19.0
19.5
Beginning Trip Time (military time)

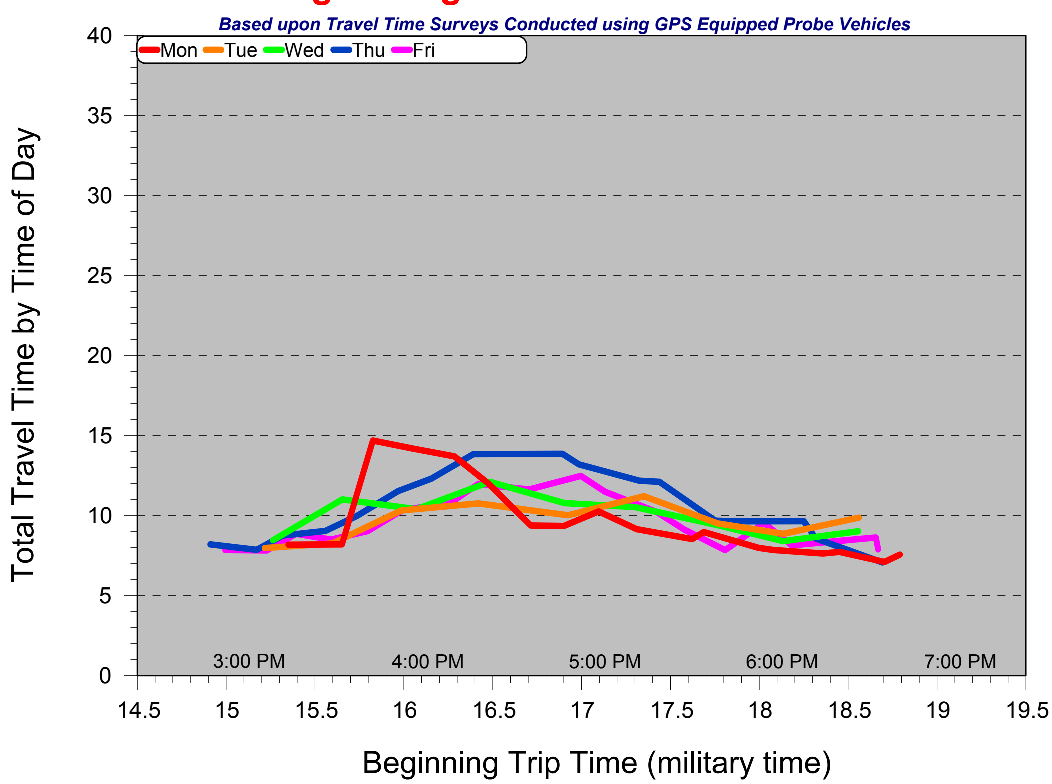

Travel Times for I-17 between Dunlap Ave. and Grant St:
Friday PM, 10-25-02
Based upon Travel Time Surveys Conducted Using GPS Equipped Probe Vehicles
SB General Lanes
NB General Lanes
SB HOV Lane
NB HOV Lane
Notes:
1. Southbound HOV only goes to after Thomas
2. Northbound HOV starts before McDowell
3. HOV hours are 3 to 7 PM
Total Travel Time (minutes)
0
5
10
15
20
25
30
35
40
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
14.5
15.0
15.5
16.0
16.5
17.0
17.5
18.0
18.5
19.0
19.5
Beginning Trip Time (military time)

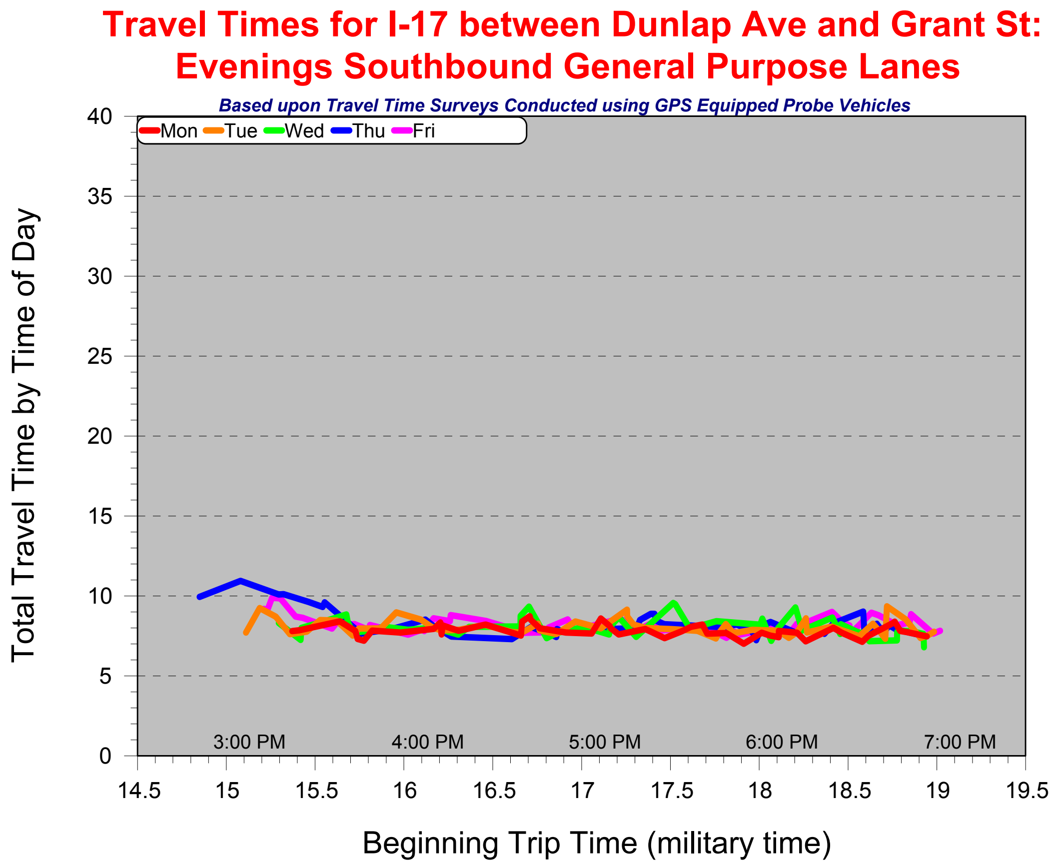

Travel Times for I-17 between Dunlap Ave. and Grant St:
Sunday PM, 10-27-02
Based upon Travel Time Surveys Conducted Using GPS Equipped Probe Vehicles
SB General Lanes
NB General Lanes
Notes:
1. Southbound HOV only goes to after Thomas
2. Northbound HOV starts before McDowell
3. HOV hours are 3 to 7 PM
Total Travel Time (minutes)
0
5
10
15
20
25
30
35
40
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
13.5
14.0
14.5
15.0
15.5
16.0
16.5
17.0
17.5
18.0
18.5
Beginning Trip Time (military time)

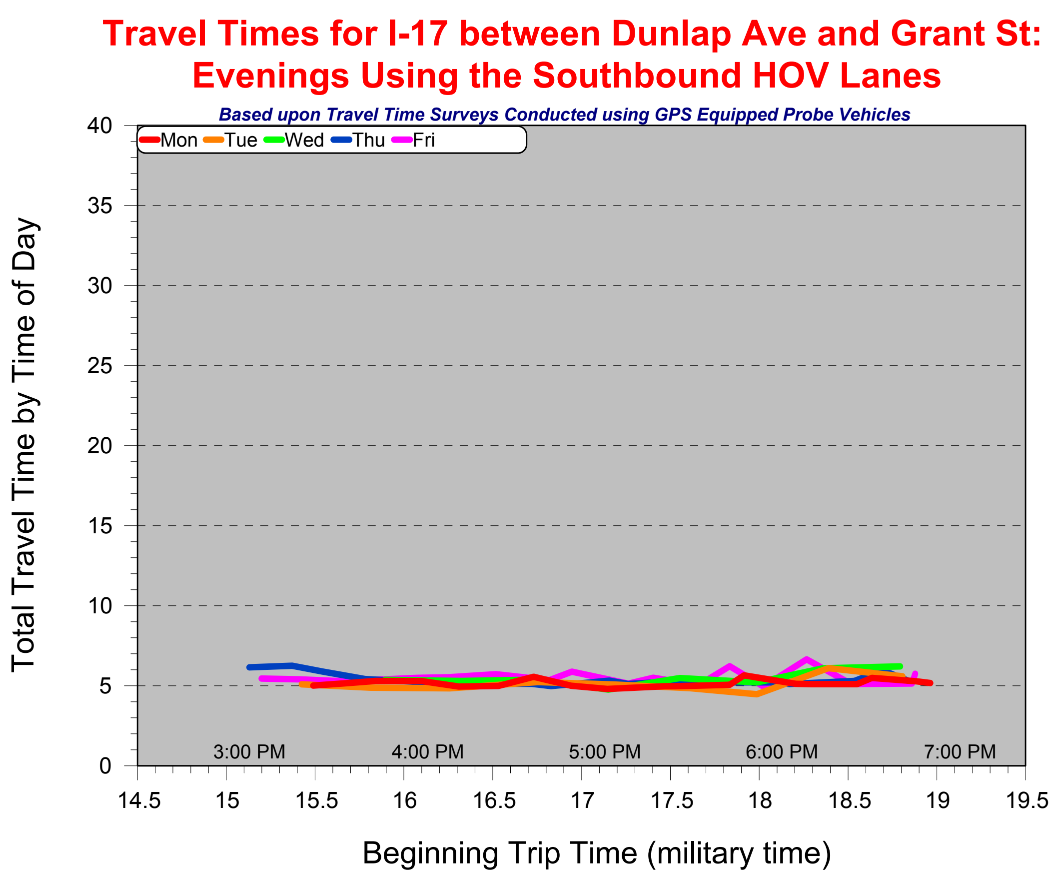
Travel Times for I-17 between Dunlap Ave and Grant St: Evenings Northbound General Purpose Lanes

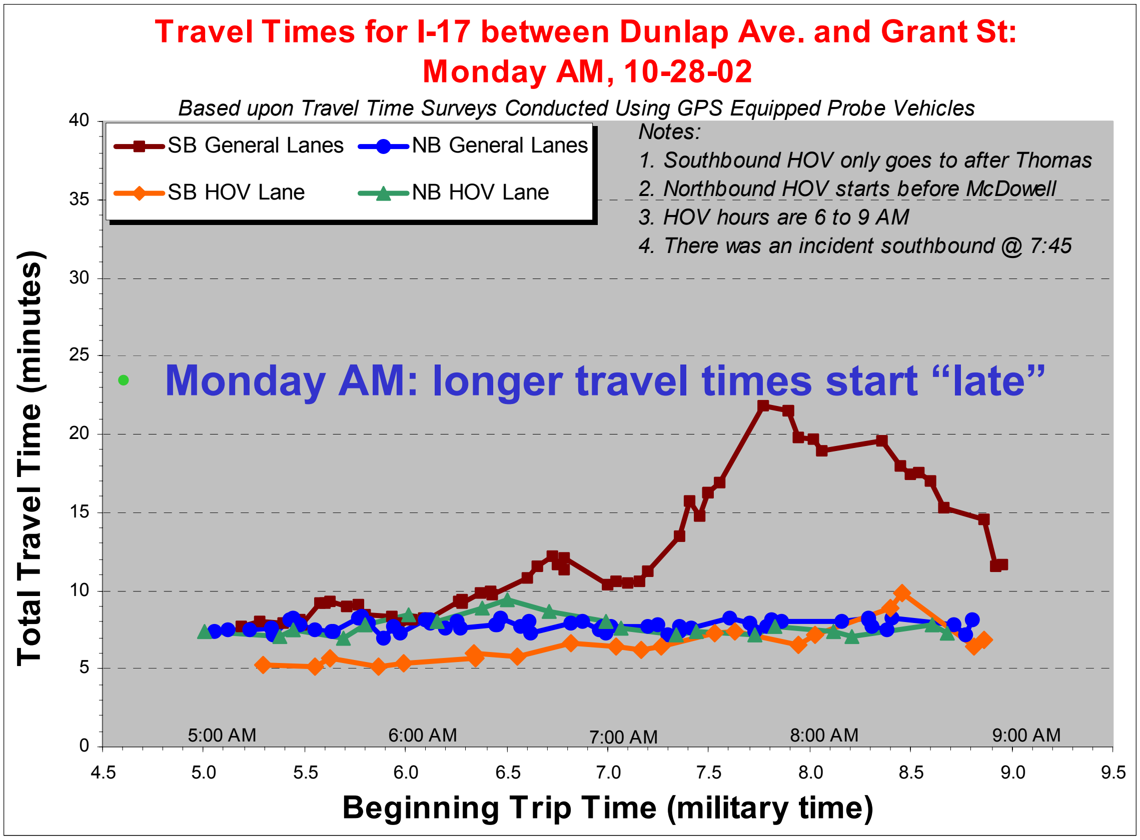


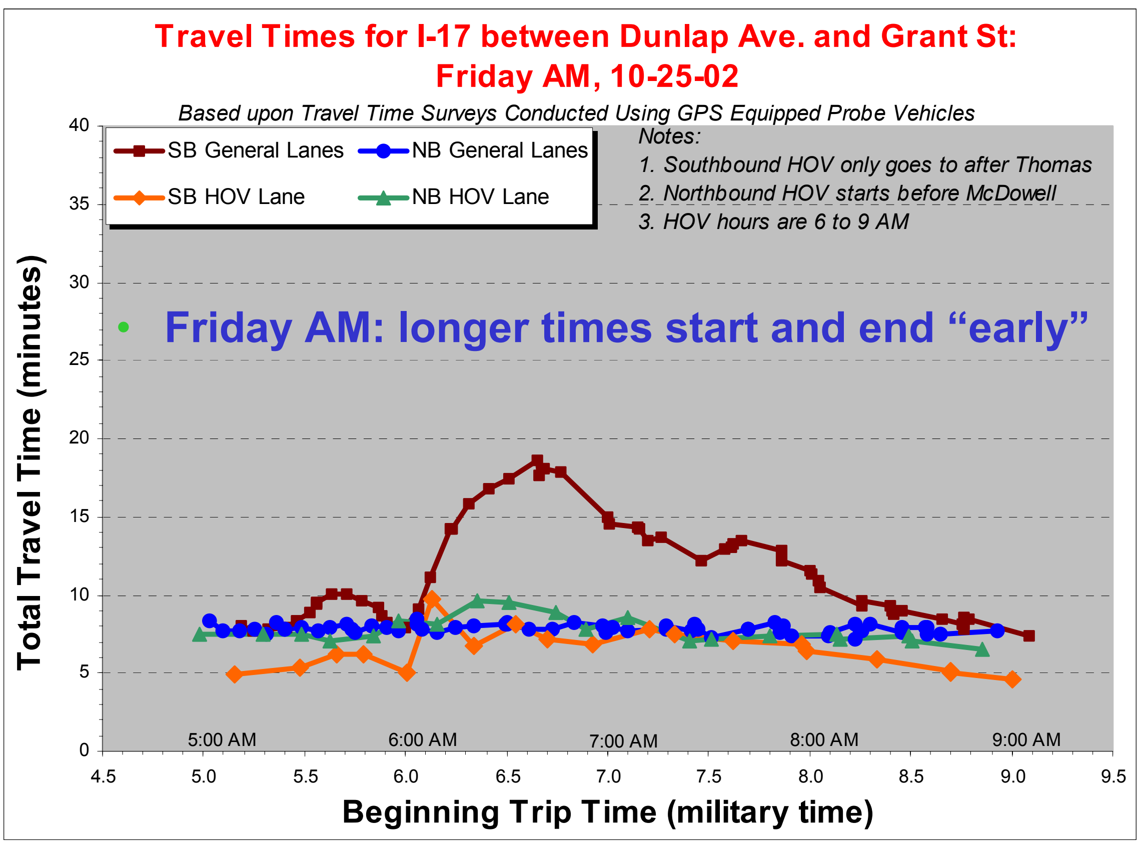
Travel Times for I-17 between Dunlap Ave and Grant St: Evenings Using the Northbound HOV Lanes

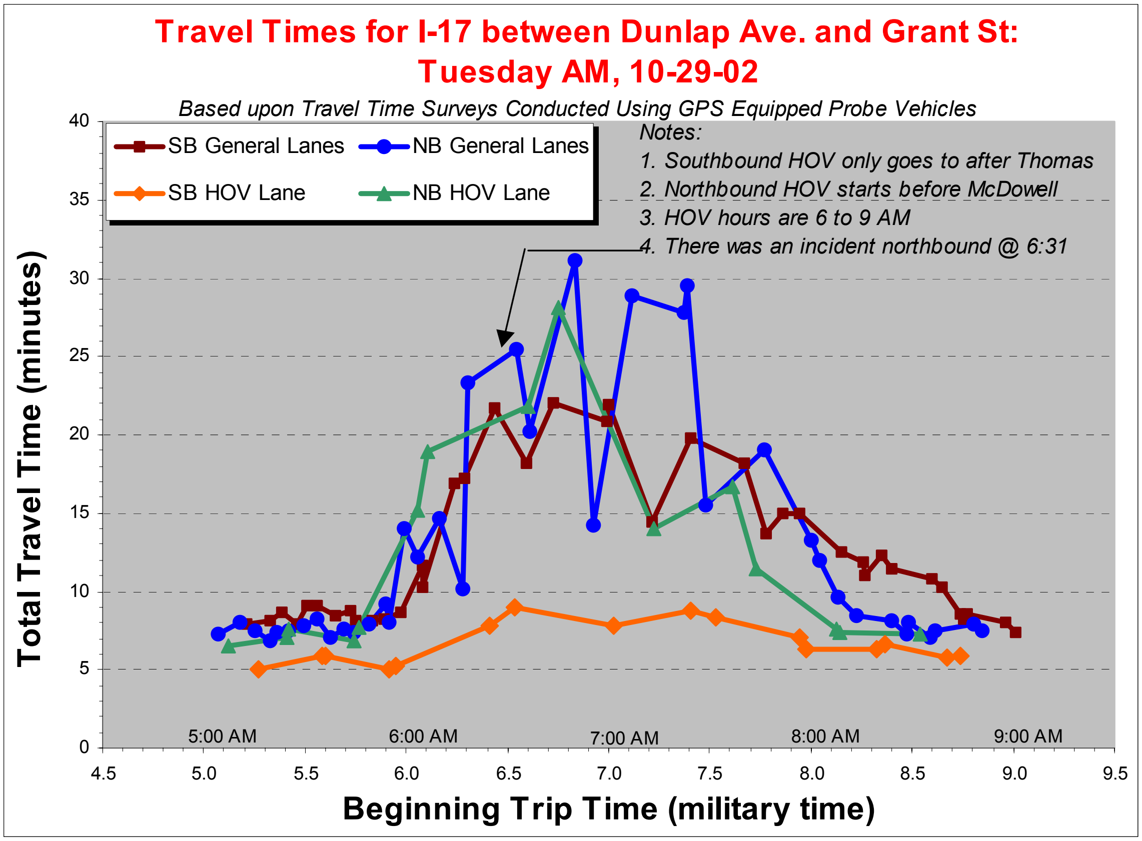


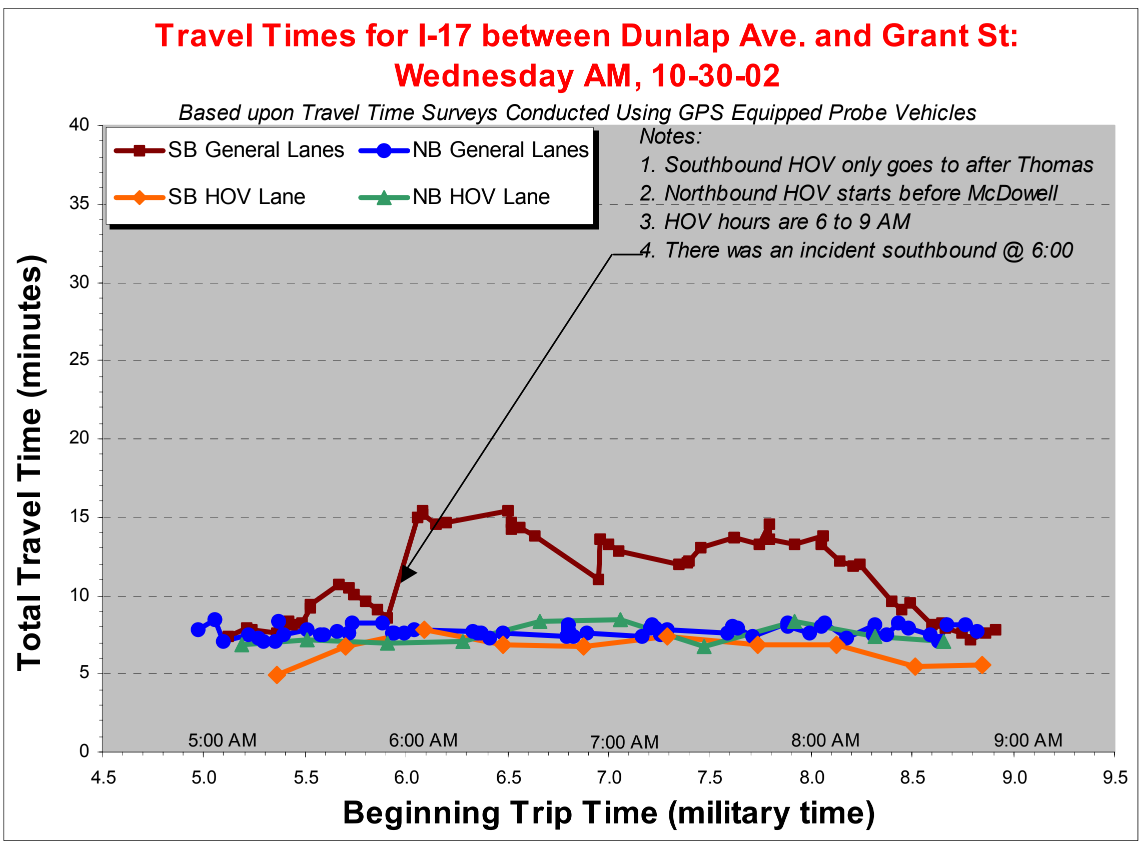

Travel Times for I-17 between Dunlap Ave and Grant St:
Evenings Southbound General Purpose Lanes
Based upon Travel Time Surveys Conducted using GPS Equipped Probe Vehicles
Mon Tue Wed Thu Fri
Total Travel Time by Time of Day
0
5
10
15
20
25
30
35
40
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
14.5
15
15.5
16
16.5
17
17.5
18
18.5
19
19.5
Beginning Trip Time (military time)

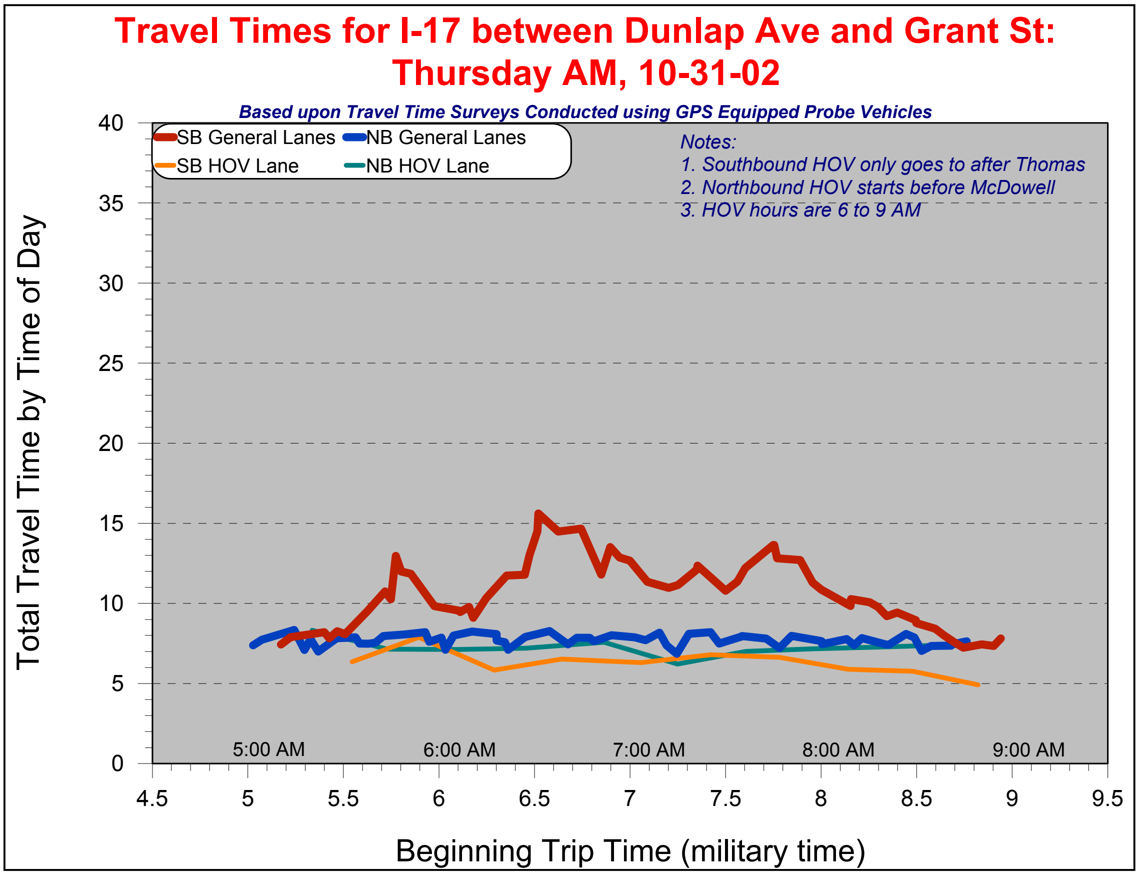

Travel Times for I-17 between Dunlap Ave and Grant St:
Evenings Using the Southbound HOV Lanes
Based upon Travel Time Surveys Conducted using GPS Equipped Probe Vehicles
Mon Tue Wed Thu Fri
Total Travel Time by Time of Day
0
5
10
15
20
25
30
35
40
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
14.5
15
15.5
16
16.5
17
17.5
18
18.5
19
19.5
Beginning Trip Time (military time)

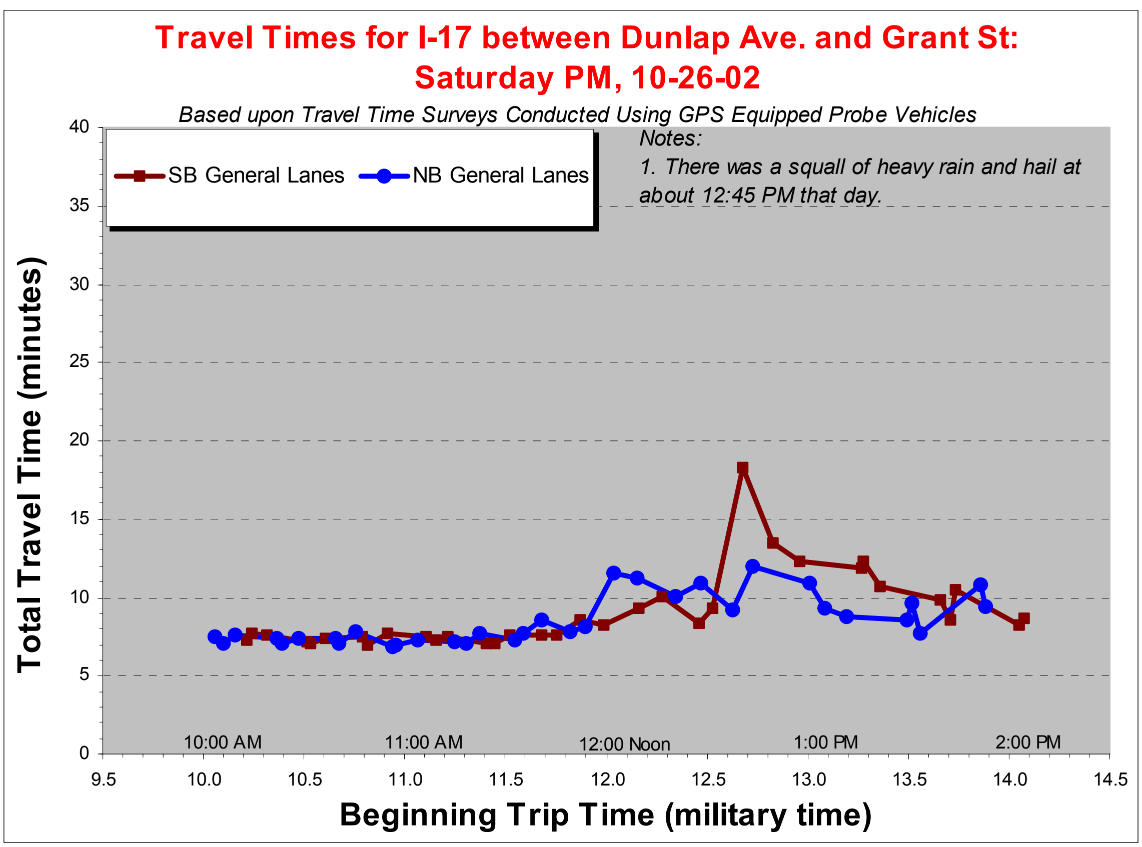

Travel Times for I-17 between Dunlap Ave. and Grant St:
Monday AM, 10-28-02
Based upon Travel Time Surveys Conducted Using GPS Equipped Probe Vehicles
SB General Lanes
NB General Lanes
SB HOV Lane
NB HOV Lane
Notes:
1. Southbound HOV only goes to after Thomas
2. Northbound HOV starts before McDowell
3. HOV hours are 6 to 9 AM
4. There was an incident southbound @ 7:45
Monday AM: longer travel times start "late"
Total Travel Time (minutes)
Beginning Trip Time (military time)
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM


Travel Times for I-17 between Dunlap Ave. and Grant St:
Friday AM, 10-25-02
Based upon Travel Time Surveys Conducted Using GPS Equipped Probe Vehicles
SB General Lanes
NB General Lanes
SB HOV Lane
NB HOV Lane
Notes:
1. Southbound HOV only goes to after Thomas
2. Northbound HOV starts before McDowell
3. HOV hours are 6 to 9 AM
Friday AM: longer times start and end "early"
Total Travel Time (minutes)
Beginning Trip Time (military time)
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM

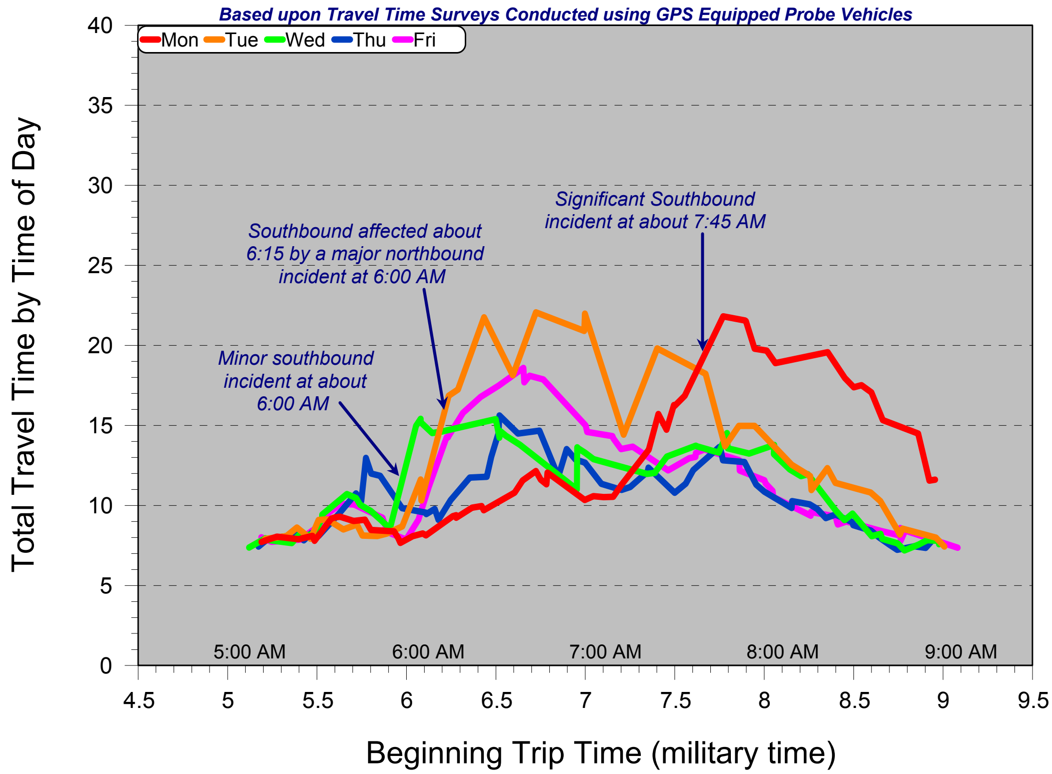

Travel Times for I-17 between Dunlap Ave. and Grant St:
Tuesday AM, 10-29-02
Based upon Travel Time Surveys Conducted Using GPS Equipped Probe Vehicles
SB General Lanes
NB General Lanes
SB HOV Lane
NB HOV Lane
Notes:
1. Southbound HOV only goes to after Thomas
2. Northbound HOV starts before McDowell
3. HOV hours are 6 to 9 AM
4. There was an incident northbound @ 6:31
Total Travel Time (minutes)
0
5
10
15
20
25
30
35
40
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
Beginning Trip Time (military time)


Travel Times for I-17 between Dunlap Ave. and Grant St:
Wednesday AM, 10-30-02
Based upon Travel Time Surveys Conducted Using GPS Equipped Probe Vehicles
SB General Lanes
NB General Lanes
SB HOV Lane
NB HOV Lane
Notes:
1. Southbound HOV only goes to after Thomas
2. Northbound HOV starts before McDowell
3. HOV hours are 6 to 9 AM
4. There was an incident southbound @ 6:00
Total Travel Time (minutes)
0
5
10
15
20
25
30
35
40
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
Beginning Trip Time (military time)

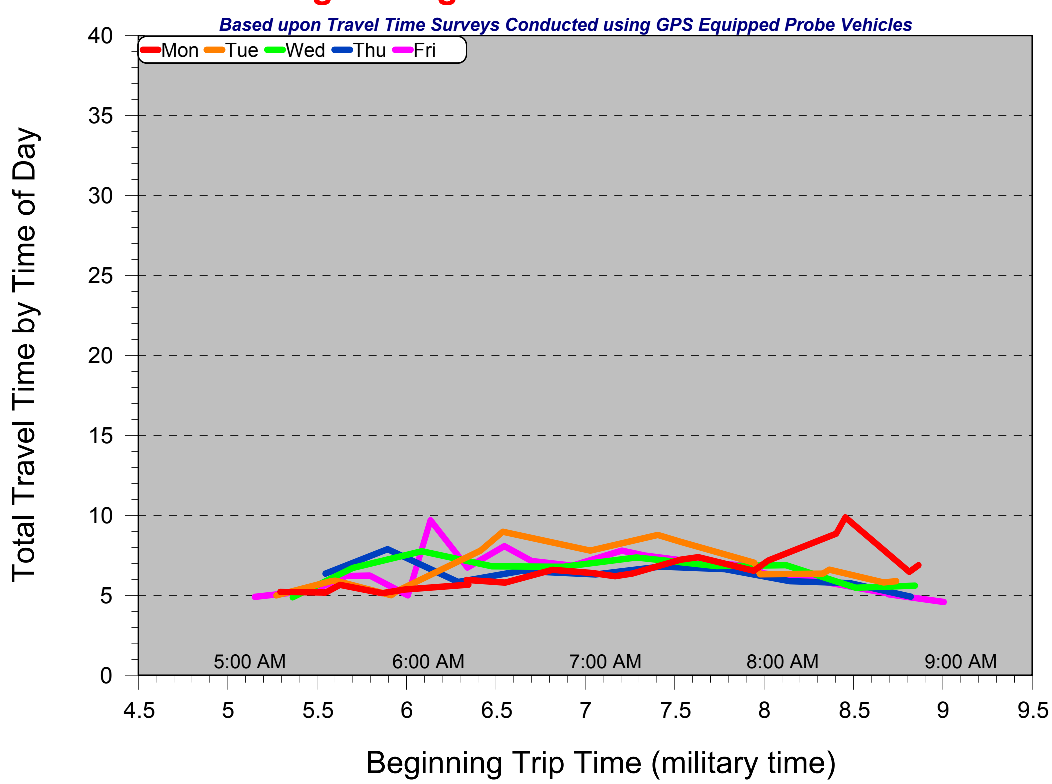

Travel Times for I-17 between Dunlap Ave and Grant St:
Thursday AM, 10-31-02
Based upon Travel Time Surveys Conducted using GPS Equipped Probe Vehicles
SB General Lanes
NB General Lanes
SB HOV Lane
NB HOV Lane
Notes:
1. Southbound HOV only goes to after Thomas
2. Northbound HOV starts before McDowell
3. HOV hours are 6 to 9 AM
Total Travel Time by Time of Day
0
5
10
15
20
25
30
35
40
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
Beginning Trip Time (military time)

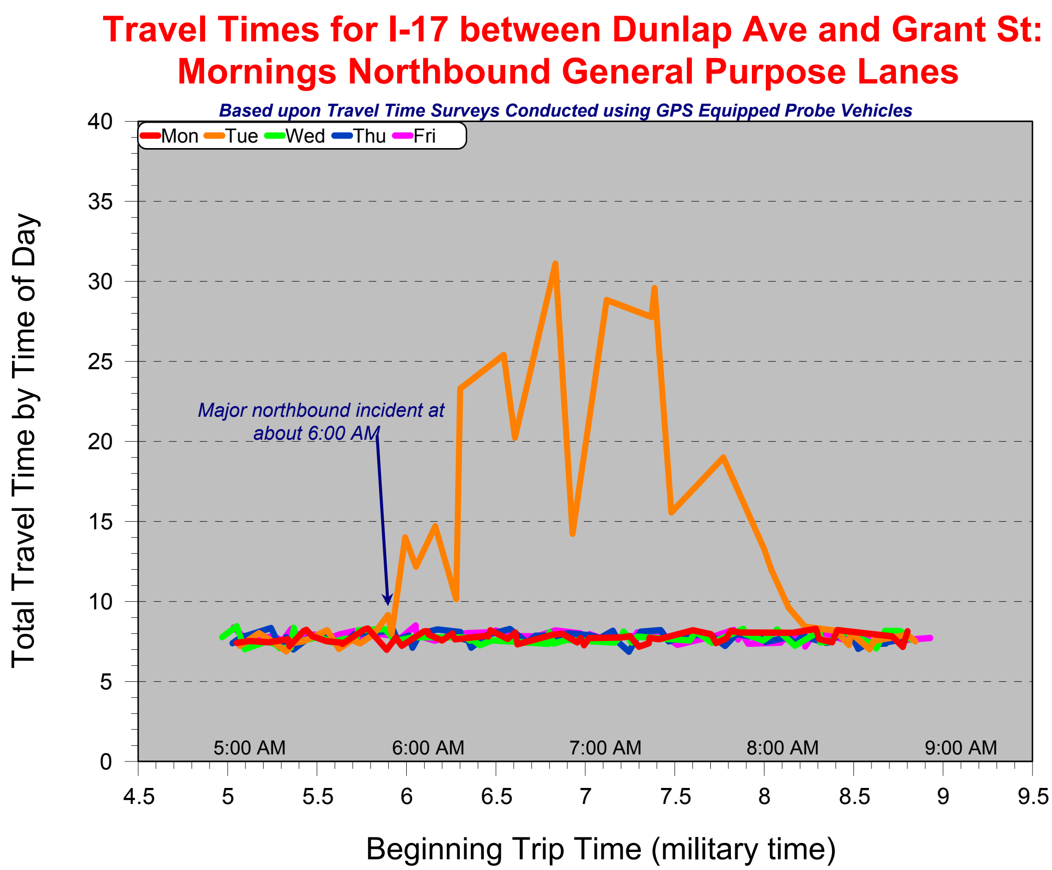

Travel Times for I-17 between Dunlap Ave. and Grant St:
Saturday PM, 10-26-02
Based upon Travel Time Surveys Conducted Using GPS Equipped Probe Vehicles
SB General Lanes
NB General Lanes
Notes:
1. There was a squall of heavy rain and hail at about 12:45 PM that day.
Total Travel Time (minutes)
0
5
10
15
20
25
30
35
40
10:00 AM
11:00 AM
12:00 Noon
1:00 PM
2:00 PM
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
Beginning Trip Time (military time)

Travel Times for I-17 between Dunlap Ave and Grant St: Mornings Southbound General Purpose Lanes

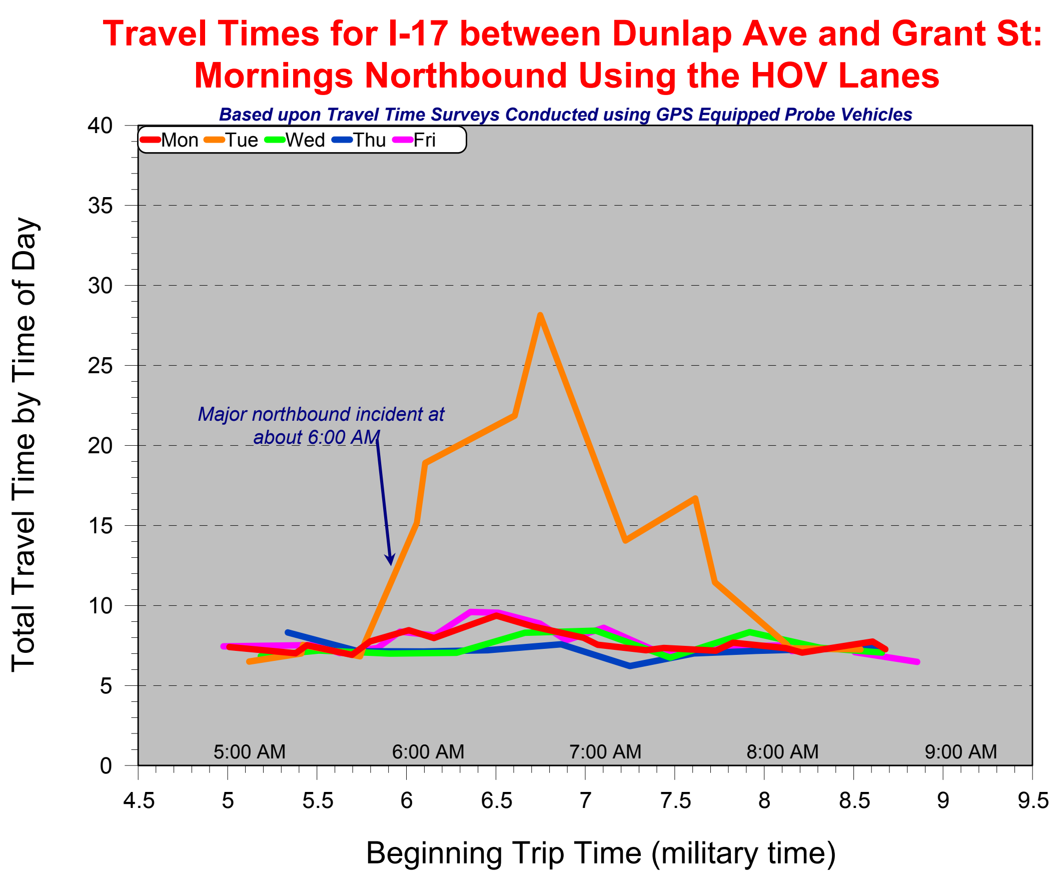


Travel Times for I-17 between Dunlap Ave and Grant St: Mornings using the Southbound HOV Lanes





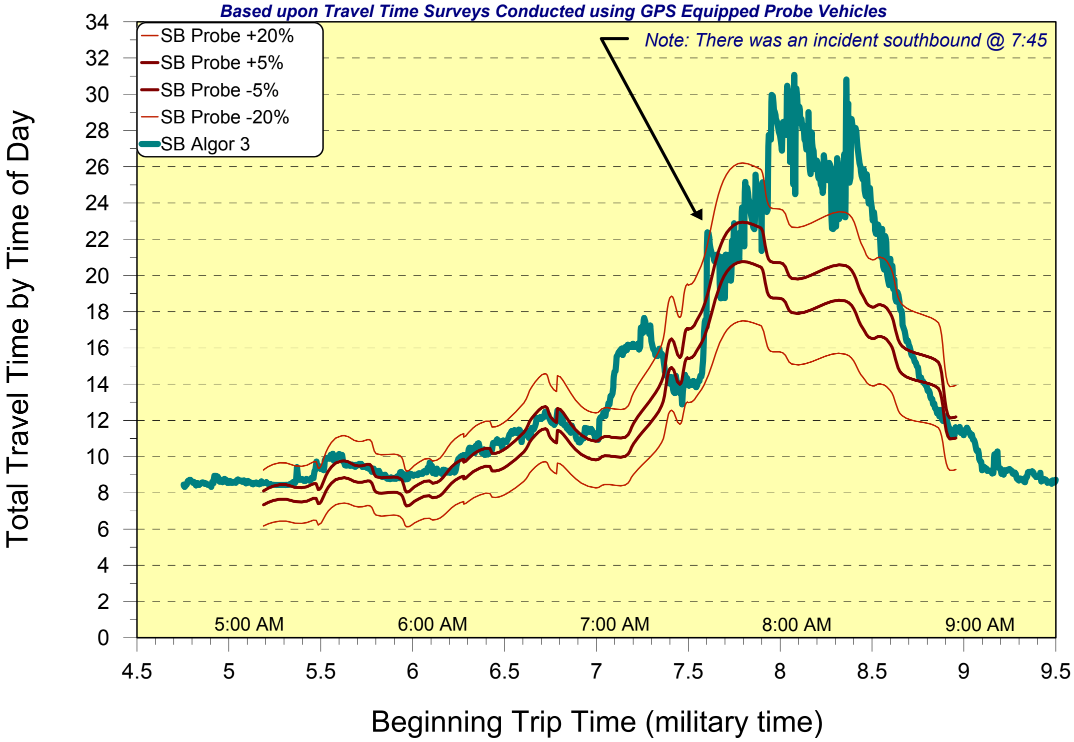
Travel Times for I-17 between Dunlap Ave and Grant St:
Mornings Northbound General Purpose Lanes
Based upon Travel Time Surveys Conducted using GPS Equipped Probe Vehicles
Mon
Tue
Wed
Thu
Fri
Major northbound incident at about 6:00 AM
Total Travel Time by Time of Day
Beginning Trip Time (military time)
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM



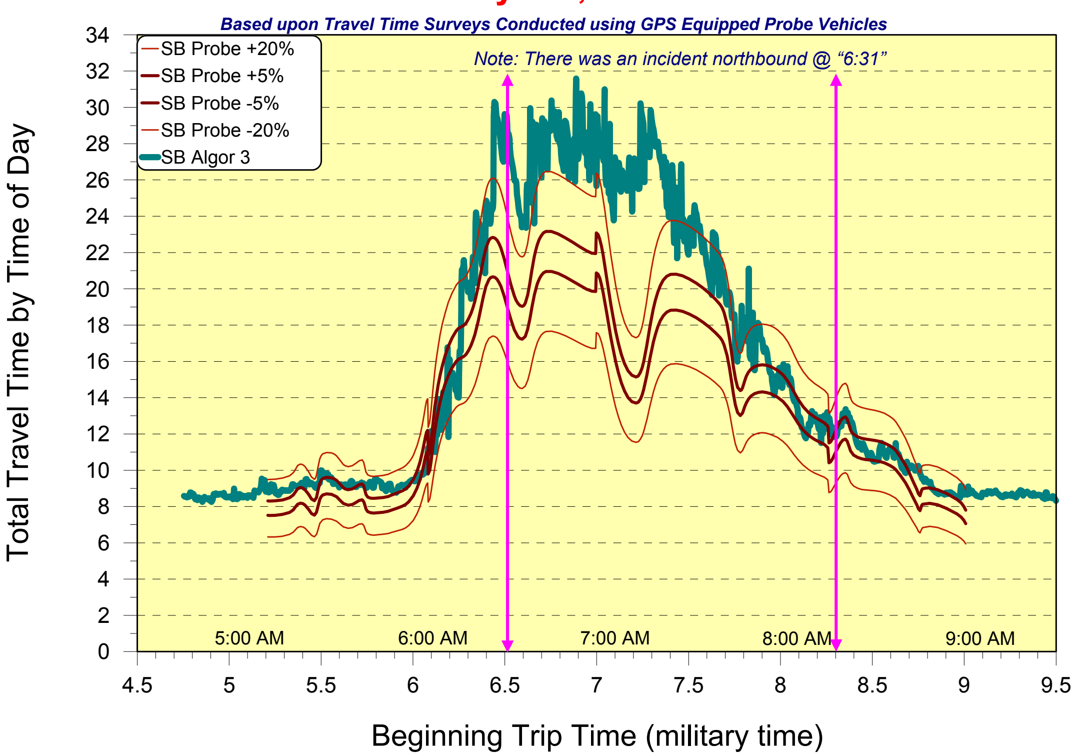
Travel Times for I-17 between Dunlap Ave and Grant St:
Mornings Northbound Using the HOV Lanes
Based upon Travel Time Surveys Conducted using GPS Equipped Probe Vehicles
Mon
Tue
Wed
Thu
Fri
Major northbound incident at about 6:00 AM
Total Travel Time by Time of Day
Beginning Trip Time (military time)
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM

B. General Comparison of Algorithm Travel Times to Observed Travel Times

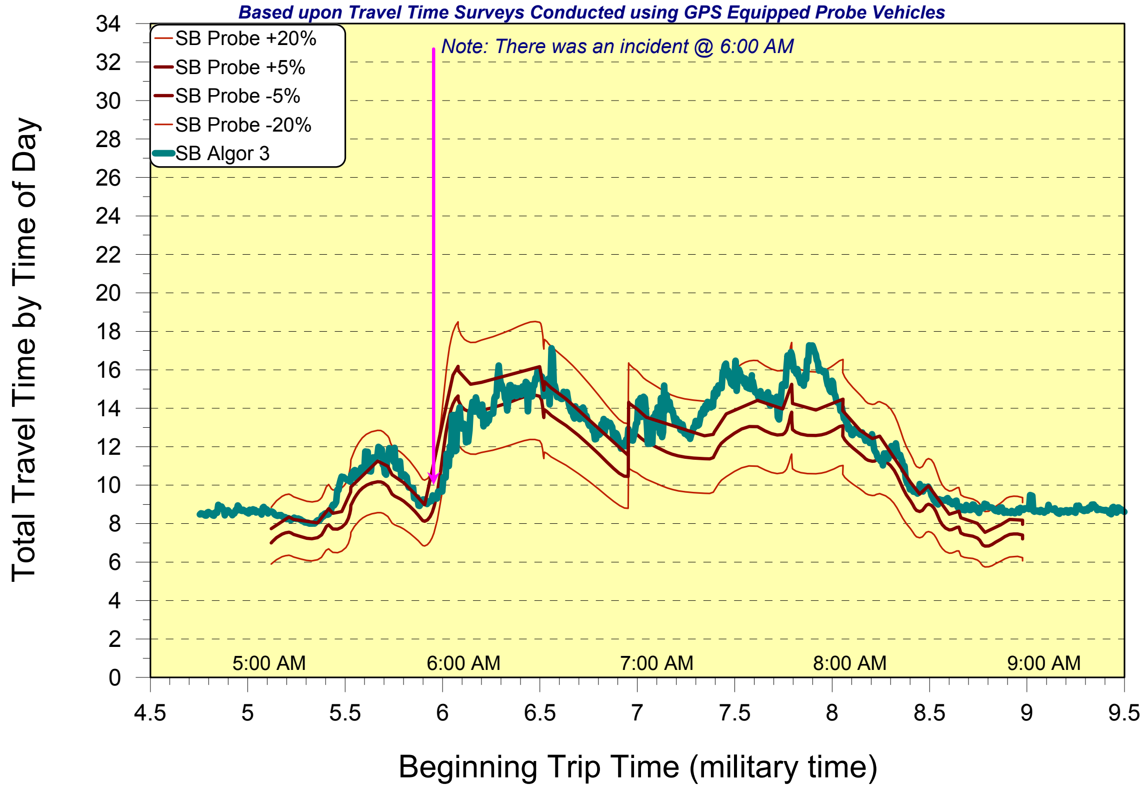
Travel Times for I-17 between Dunlap Ave and Grant St: Monday AM, 10-28-02



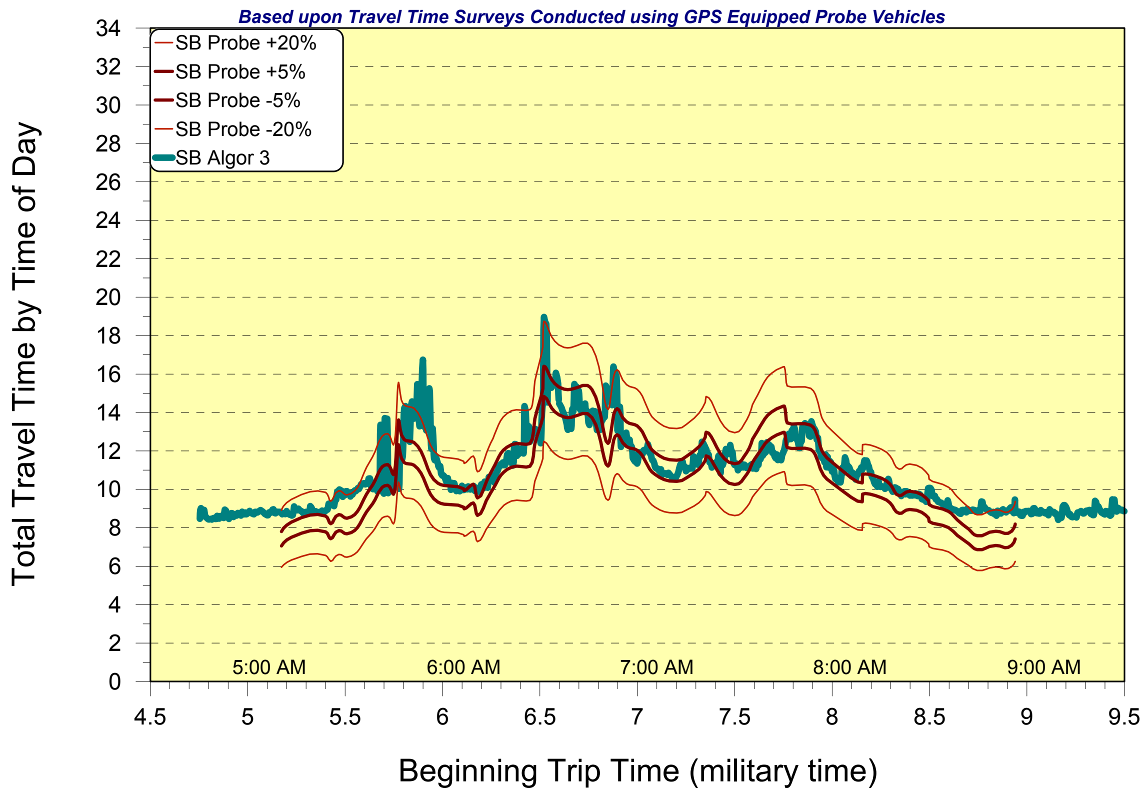
Travel Times for I-17 between Dunlap Ave and Grant St: Tuesday AM, 10-29-02



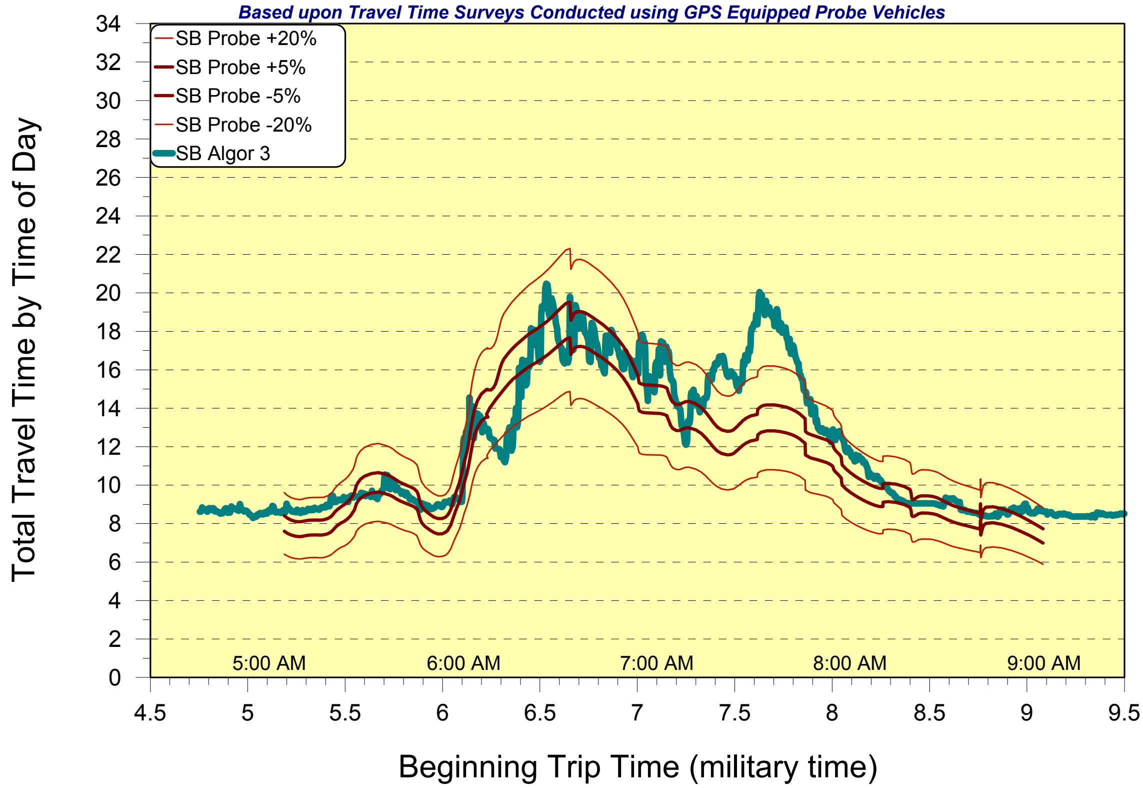
Travel Times for I-17 between Dunlap Ave and Grant St: Wednesday AM, 10-30-02



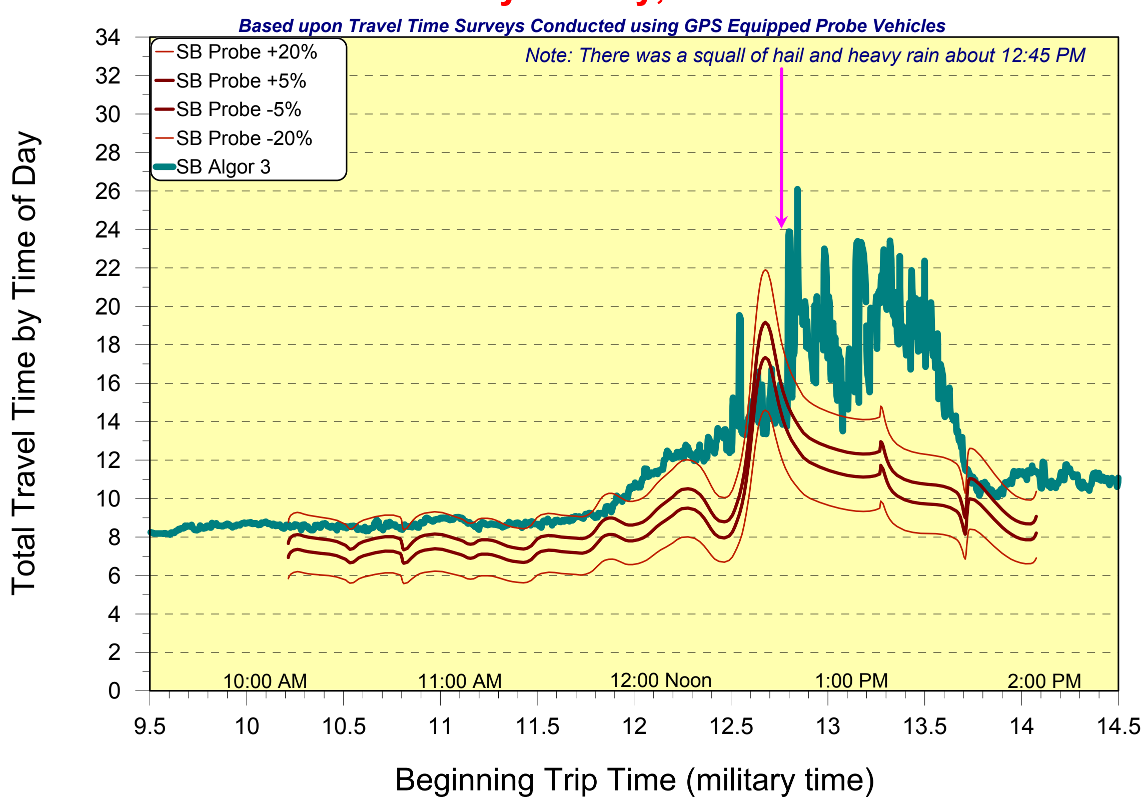
Travel Times for I-17 between Dunlap Ave and Grant St: Thursday AM, 10-31-02



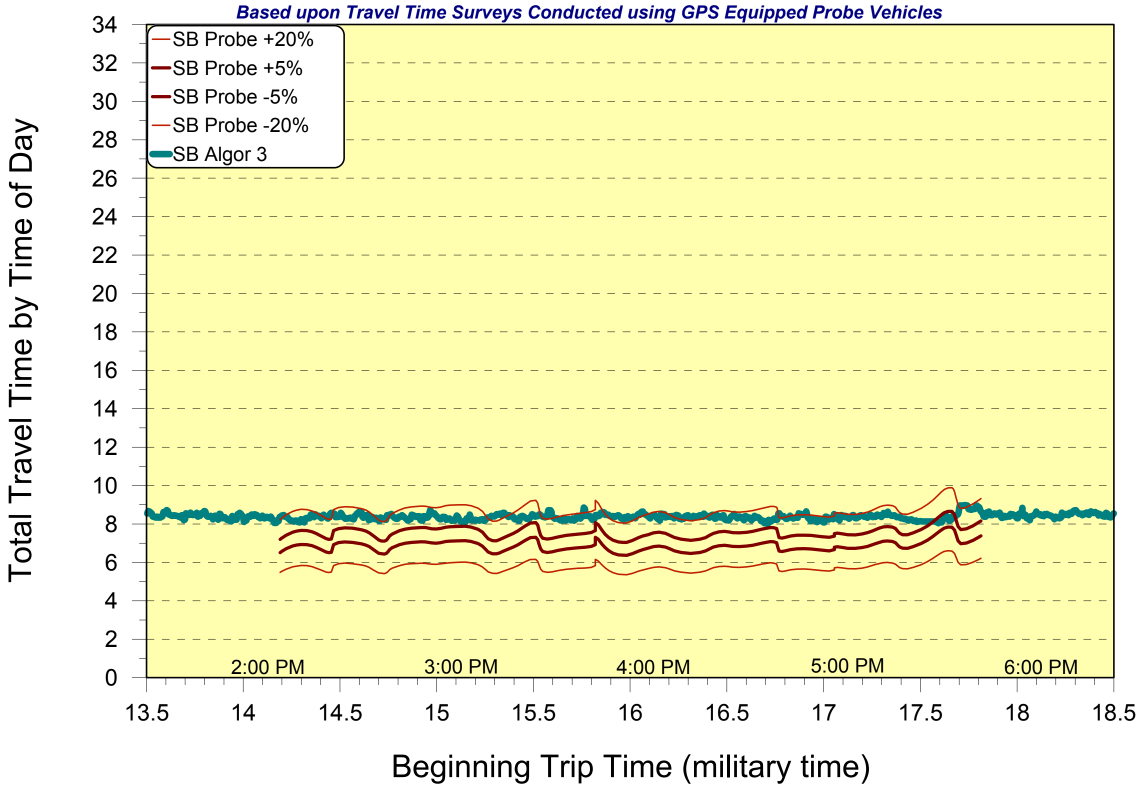
Travel Times for I-17 between Dunlap Ave and Grant St: Friday AM, 10-25-02



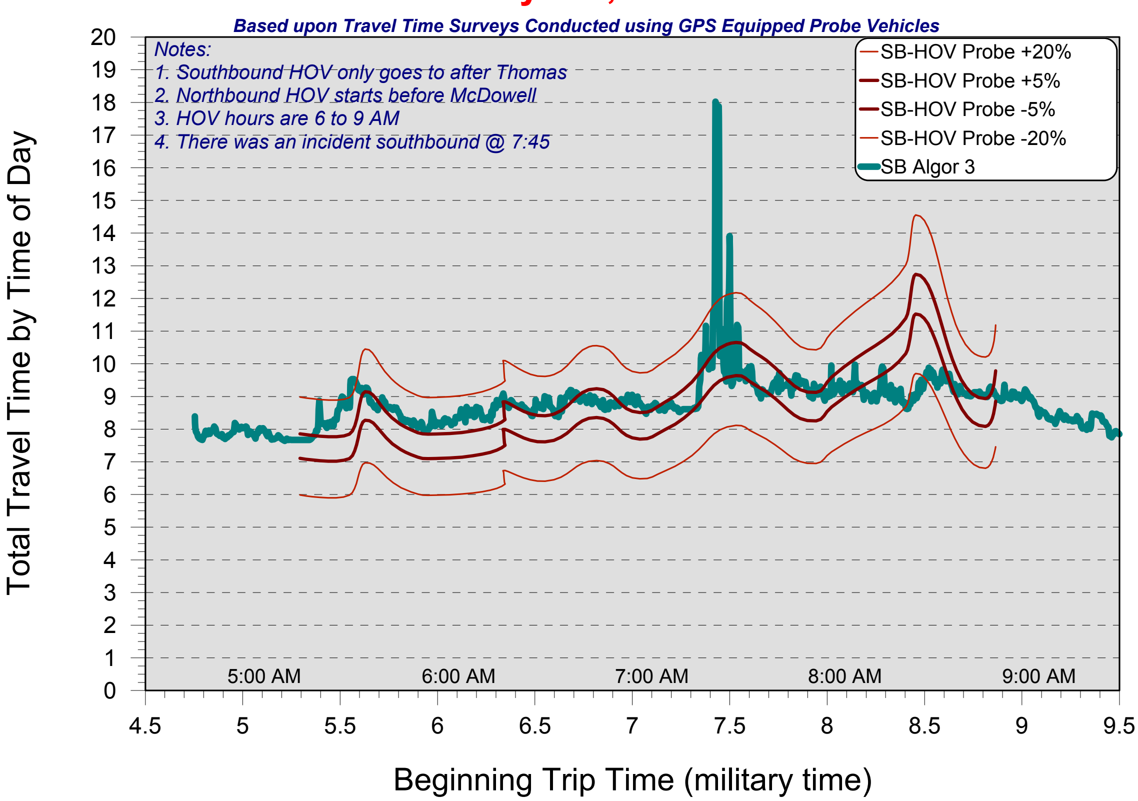
Travel Times for I-17 between Dunlap Ave and Grant St: Saturday Midday, 10-26-02



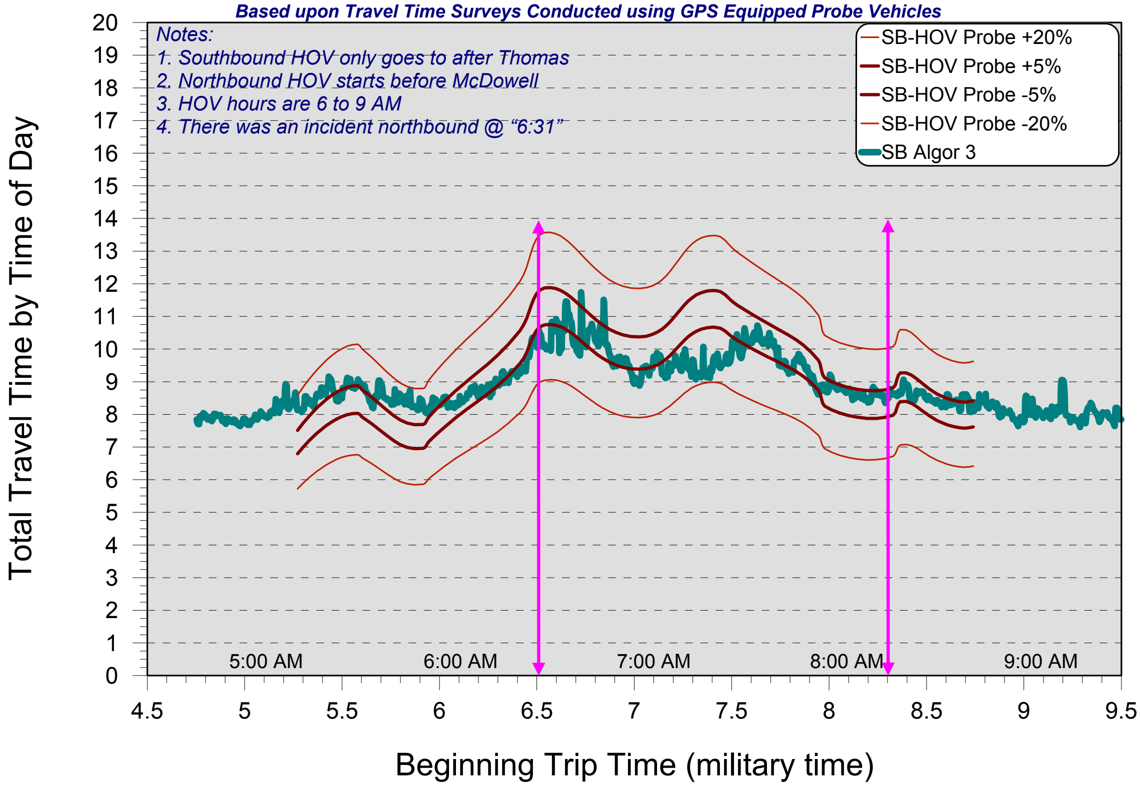
Travel Times for I-17 between Dunlap Ave and Grant St: Sunday PM, 10-27-02



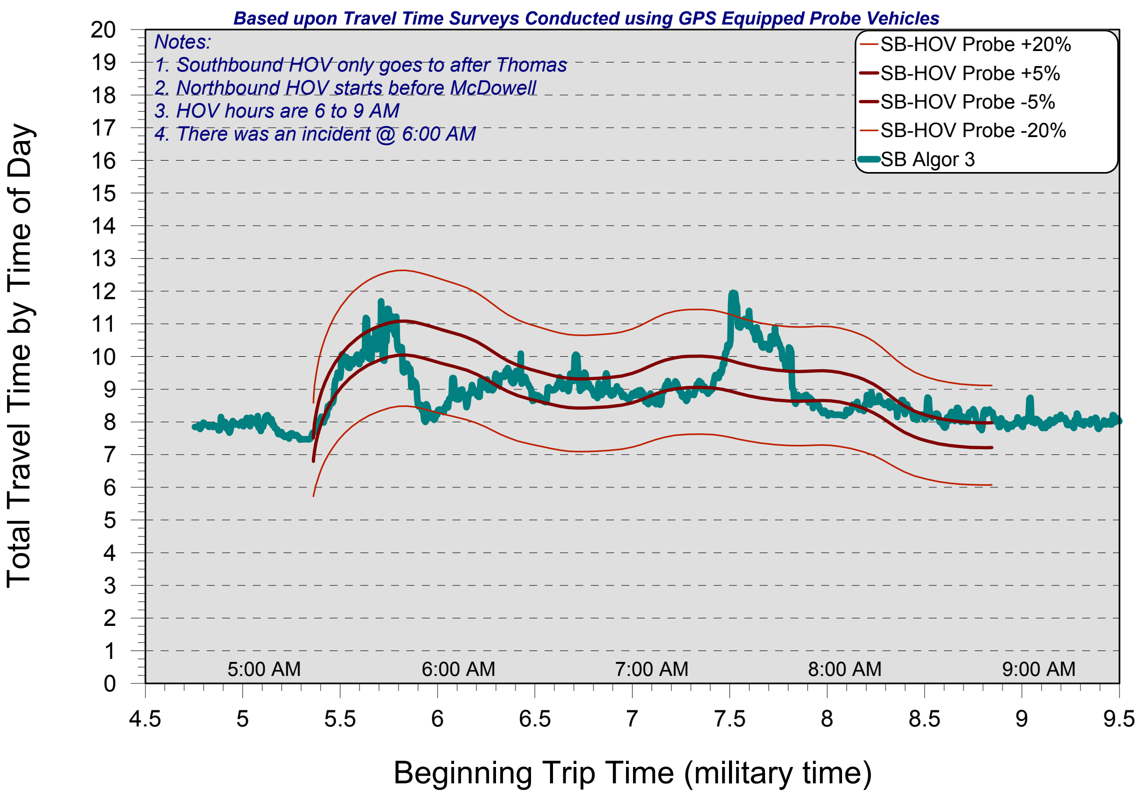
Travel Times for I-17 between Dunlap Ave and Grant St: Monday AM, 10-28-02



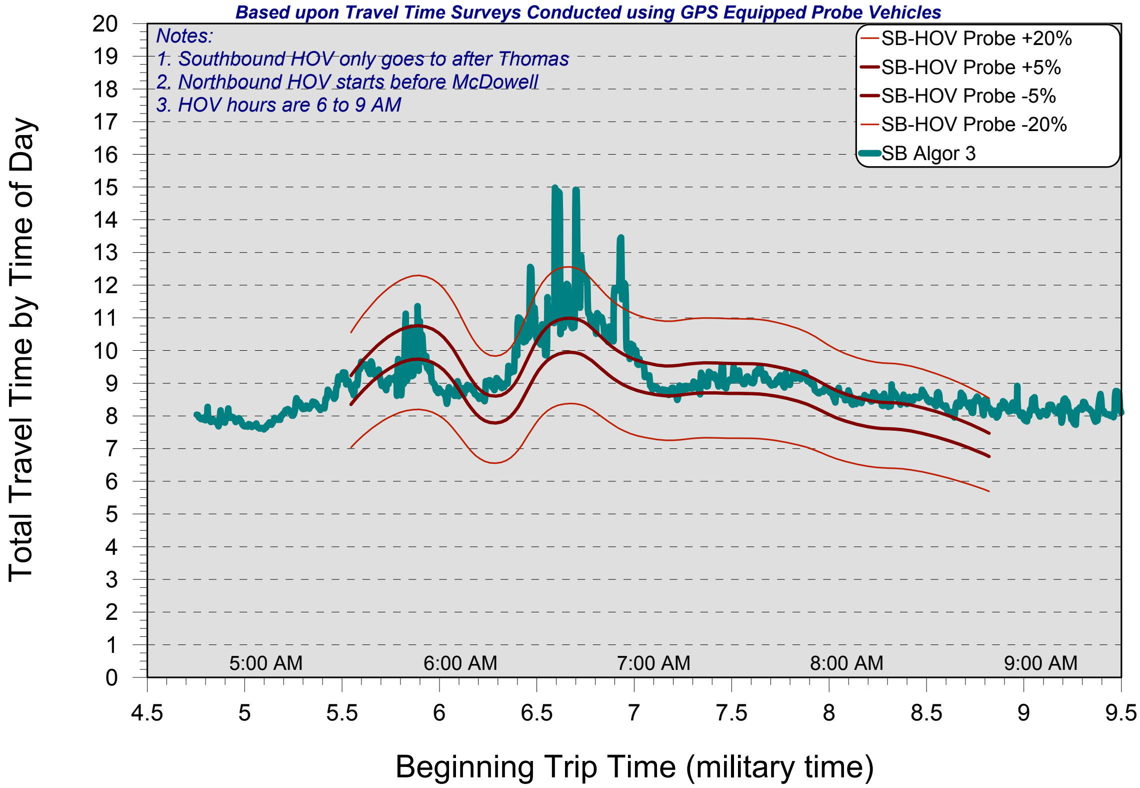
Travel Times for I-17 between Dunlap Ave and Grant St: Tuesday AM, 10-29-02



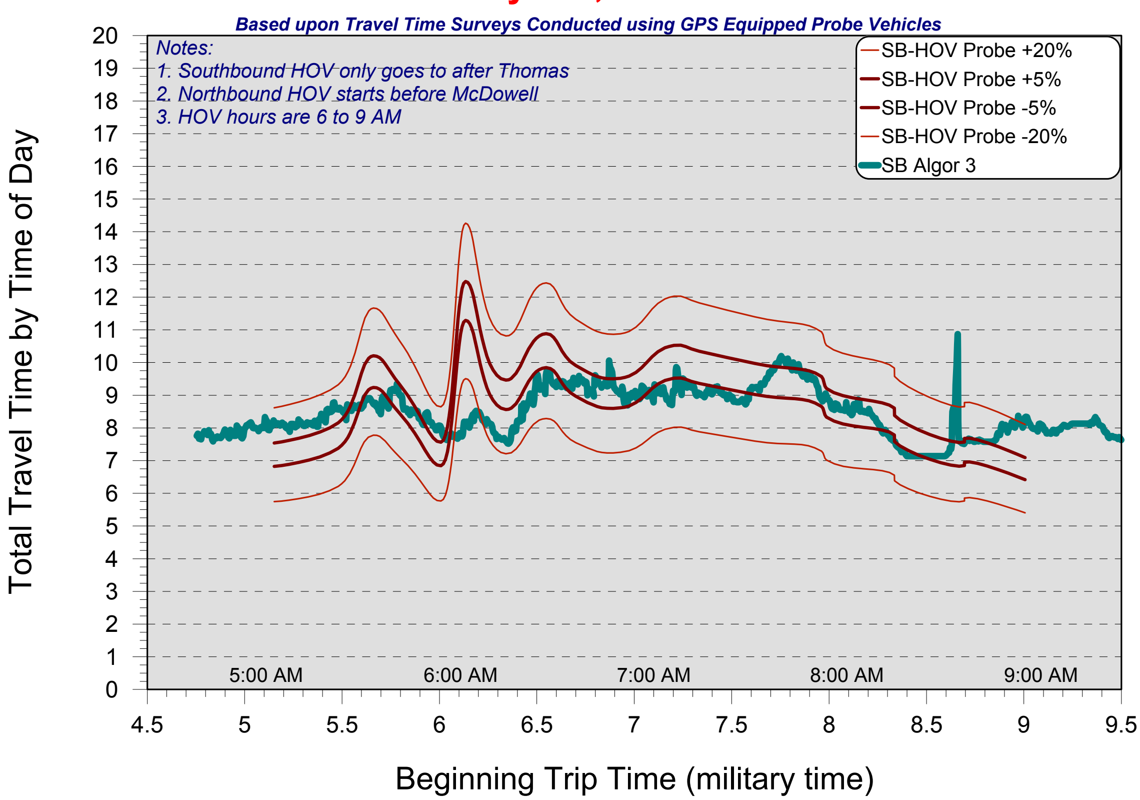
Travel Times for I-17 between Dunlap Ave and Grant St: Wednesday AM, 10-30-02



Travel Times for I-17 between Dunlap Ave and Grant St: Thursday AM, 10-31-02



Travel Times for I-17 between Dunlap Ave and Grant St: Friday AM, 10-25-02



References

[1] Smith, B., B.P. Park, R. Holt, M. Agee, and M. Green, "Travel Time Estimation Using Point Detectors," Interim Report, (unpublished), University of Virginia, April 15, 2002.

[2] Dailey, D. "Travel Time Estimates Using a Series of Single Loop Volume and Occupancy Measurements," paper 970378, presented at the 76th Transportation Research Board Annual Meeting, Washington DC, January 1997.

[3] Al-Deek, H. and S. Ishak, "Evaluation of ANN-Based Freeway Incident Detection Systems," Aug 1999.

[4] Rice, J., and E. Van Swet, "A Simple and Effective Method for Predicting Travel Times on Freeways, " PATH Working Paper, Institute of Transportation Studies, University of California, Berkeley, June 2001.

[5] Choe, T., A. Skarbadonis, and P. Varaiya, "Freeway Performance Measurement System (PeMS): an Operational Analysis Tool," paper presented at the 81st Transportation Research Board Annual Meeting, Washington DC, January 2002, compendium of papers, TRB-02-3679.

[6] Quiroga, C., "Assessment of Dynamic Message Sign Travel Time Information Accuracy," paper presented at the North American Travel Monitoring Conference and Exposition - NATMEC 2000 August 27-31, 2000

[7] Rose, G. and D. Paterson, "Travel Time Prediction on Motorways", Victoria State Roads Authority

[8] Dia, H., "An Object-Oriented Neural Network Approach To Short-Term Traffic Forecasting," paper presented at 11th Mini Euro Conference on Artificial Intelligence in Transportation Systems and Sciences, Helsinki, Aug 1999, Forthcoming in a Special Issue of the European Journal of Operations Research, December 2000.

[9] Kwon, J., B. Coifman, and P. Bickel, "Day-to-Day Travel Time Trends and Travel Time Prediction from Loop Detector Data" University of California, Berkley.

[10] Quiroga, C., "Assessment of Dynamic Message Sign Travel Time Information Accuracy," paper presented at the North American Travel Monitoring Conference and Exposition - NATMEC 2000 August 27-31, 2000

[11] Benz, R.J., "Travel Time Methodologies: Better Simulating the User Experience," presentation to North American Travel Monitoring Exhibition and Conference NATMEC 2000, Madison WI, Aug, 2000.

[12] Eisele, W. and L.R. Rilett, "A Statistical Comparison of Travel Time Estimates Obtained from Intelligent Transportation Systems and Instrumented Test Vehicles", presentation to the Transportation Research Board, January, 2002, compendium of papers, TRB-02-2124.

[13] Varaiya, P., et. al., "Constructing Transportation System Intelligence Using PeMS", Seminar presentation given at the University of Maryland, April 2003

[14] Texas Transportation Institute, "Monitoring Urban Roadways in 2001: Examining Reliability and Mobility with Archived Data," for the Federal Highway Administration, Oct. 2003