Development of an ITS Data Archive Application for Improving Freeway Travel Time Estimation

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***Abstract*— The dissemination of travel time information has become crucial with the advent of ATIS. This paper summarizes the results of a comparative analysis between two travel time algorithms applied to archived loop detector data. Travel time estimates derived from the algorithms are compared to ground truth probe vehicle data. Our results indicate that Coifman's algorithm is more accurate for estimating travel times than a standard segment midpoint algorithm. However, the accuracy of the travel time estimates was dependent on the location and spacing of detectors and the location and formation of queues with respect to the detector positioning.**

I. Introduction

Advanced Traveler Information Systems (ATIS) have been employed by transportation agencies and the private sector to inform people about current (and future) travel conditions and travel time estimates. If the information is accurate, timely, and available, travelers can make informed decisions about their trips. Consequentially the accuracy of travel time estimates has become a high priority. Travel time estimates can be provided to the public through dynamic message signs, 511, the Internet, highway advisory radio, and other sources [1].

Travel time estimates can be generated using different techniques and sources including fixed sensors such as inductive loop detectors; automatic vehicle identification (AVI) through the use of license plate matching, video detection, toll tag reading, and cell phone matching; and automatic vehicle location (AVL) through the use of GPS equipped probe vehicles. One of the most common methods is to use data from inductive loop detectors to generate travel time estimates.

A number of different algorithms have been developed for estimating travel time from single loop detectors. In this study, a standard midpoint algorithm and one developed by Coifman have been used to estimate travel time for selected freeway links in the Portland, Oregon freeway network. We compare the estimated travel times to the ground truth probe vehicle data for the same links.

The remainder of this paper is divided into four sections. The next section will outline the data sources and the location of the site. Next the methodology used in the study will be described, followed by a description of the analysis. Finally we present our findings and some recommendations.

II. Site Location And Data

Nine links were chosen from the Portland, Oregon freeway network to test the performance of the standard midpoint algorithm and the one developed by Coifman. A map showing the location of the links is shown in Fig 1. These links were chosen on the basis of availability of

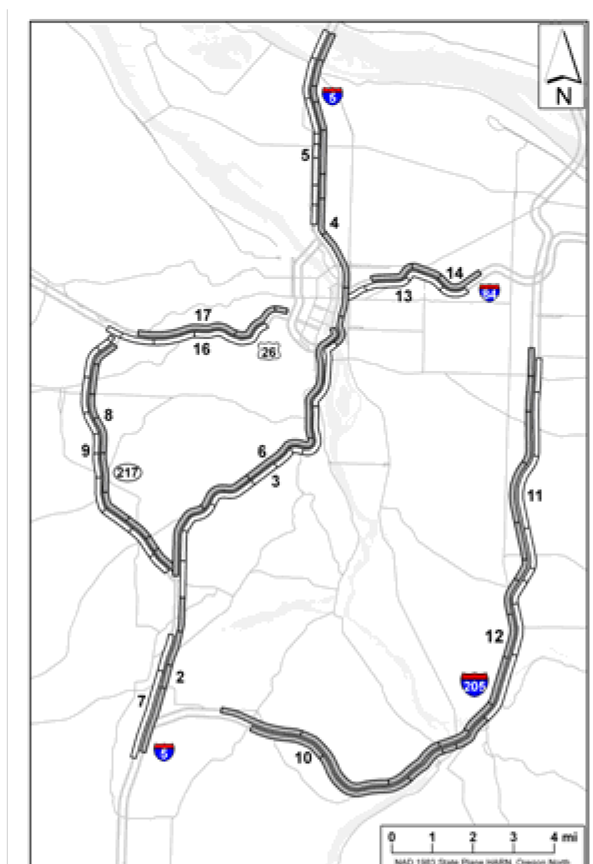

Fig. 1. Freeway map showing all links

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ground truth probe vehicle data and high traffic flows and congestion during peak periods. Travel time estimates were computed for links 3, 4, 5, 6, 8, 9, 10, 12 and 13.

Three data sources were used in this study. As part of the Portland area's Advanced Traveler Managed Systems (ATMS), the Oregon Department of Transportation (ODOT) Region 1 Traffic Management Operations Center (TMOC) maintains a fiber optic communication system linking 485 inductive loop detectors. These detectors report count, occupancy and speed every 20 seconds. These data are fed into the Portland Oregon Regional Transportation Archive Listing (PORTAL), a database that was developed at Portland State University based on the Archived Data User Service (ADUS) framework for archiving intelligent transportation systems data. PORTAL provides an extensive and valuable data set that can be used for improved performance assessment and modeling (portal.its.pdx.edu) [2]. A customized travel time area was set up in PORTAL to generate travel time estimates from archived loop detector data.

Travel time estimates generated from PORTAL's archived loop data were compared with two sets of ground truth data. Probe vehicle data (87 runs) were collected during April–May 2005 for selected links of the Portland freeway network by researchers at Portland State University [3]. Travel time data for all the freeway links were collected using global positioning systems (GPS) devices. Custom software (ITS-GPS) developed specifically for use with Palm handheld computers and the GPS devices was used to record the position of each probe vehicle every 3 seconds. These data streams could also be used to calculate speed and distance traveled [4].

In addition to the probe vehicle data, transit probe data was provided by TriMet for bus routes 95 and 96. Three days of the northbound runs for route 96 were analyzed in this study. The route traced I-5 N between OR-217 and I-405 interchange can be represented by link 3, shown in Fig 1. The TriMet buses are equipped with an AVL system that also archives detailed stop-level activities [5].

For a three week experiment in November 2002, TriMet's buses were programmed to record arrival times for "pseudo stops" located at fixed, designated points on the freeway, since buses do not stop on the freeway. The data from TriMet for these virtual detectors for northbound route 96 [147 runs] contained an arrival time and a leave time for each "pseudo stop" along with the distance traveled from the start to the end of the trip.

III. Methodology

Travel time estimates from the archived loop detector data were generated using a standard midpoint algorithm and one developed by Coifman. The algorithm proposed by Coifman uses traffic flow theory to estimate travel times for a link [5]. Coifman proposed that the velocity of a vehicle can be represented by:

$$v(x,t) = f(x + u.t) \tag{1}$$

where x is the distance, t is time and u can be either u_f the free flow signal velocity or u_c the congested signal velocity. The vehicle trajectories in a time space diagram can be represented by the differential equation:

$$\frac{dx}{dt} = v(x,t) \tag{2}$$

The vehicle's travel time across a link is the time taken by the corresponding trajectory to travel across the link. Travel time for a link can be estimated using vehicle velocity (v_j), headway (h_j) and congested signal speed using the relationship:

$$\tau_j = \frac{h_j}{1 + \frac{v_j}{u_c}} \tag{3}$$

$$x_j = v_j \tau_j \tag{4}$$

By measuring headway (h_j) and velocity (v_j) from the loop data, and using equations (3) and (4), t_j and x_j can be calculated. The successive x_js are added to obtain the link distance. However, the total distance obtained can exceed the link distance. Therefore, to accurately estimate the link distance, a weight p is calculated as shown in equation 5:

$$p = \frac{\left(x_{k+N_k+1} + \sum_{j=k}^{k+N_k} x_j \right) - d}{x_{k+N_k+1}} \tag{5}$$

Finally travel time is estimated as:

$$T_k = p.\tau_{k+N_k+1} + \sum_{j=k}^{k+N_k} \tau_j \tag{6}$$

These equations were coded into PORTAL for use with archived loop detector data and Coifman travel time estimates were produced every 20 seconds for selected links. The Coifman travel time estimates can be produced using speed readings from either the upstream or the downstream detector station. For this research, the readings from the upstream station were used.

The standard midpoint algorithm used in this analysis is based on ODOT's travel time algorithm which is used to generate travel time estimates for display via dynamic message signs. The key feature of this algorithm is the use of influence areas around each detector station as shown in Fig 2. It is assumed that the detector station is at the midpoint of each influence area. Travel time for each

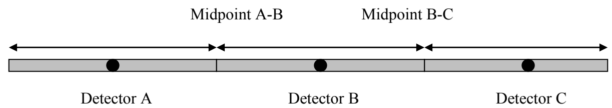

Fig. 2. Midpoint influence areas

segment is calculated as the ratio of segment length to measured speed. Travel time is estimated for each segment at each 20-sec interval and aggregated over the entire link.

In order to compare travel times over the same distances, the starting and ending mileposts for each link were noted from the probe vehicle data and the estimated travel times were computed over the same distance. The start time of each probe vehicle run was matched to the nearest prior 20 second reading in PORTAL. The travel time estimated at the nearest prior 20 second interval was

TABLE 1
LINK AND PROBE SUMMARY STATISTICS

Link	Distance (mi)	Average Detector Spacing (mi)	Number of Probe Runs
3	7.52	1.07	6
4	5.40	1.08	5
5	4.00	0.57	4
6	5.89	1.96	9
8	5.95	0.74	7
9	6.32	0.70	4
10	5.90	1.48	4
12	16.39	1.26	4
13	3.70	1.06	11

taken as the travel time for the link. Also, the average travel time estimates for 1 minute and 3 minutes prior to the start time were also used in the analysis to determine whether prior short term data can improve travel time estimates.

IV. ANALYSIS

The summary of probe vehicle runs, including the link number, the length of each link in miles and the average detector spacing, and the number of probe vehicle runs for each analyzed link is shown in Table 1.

Mean travel times (and standard deviations) for the probe vehicle and the mean estimates obtained from the Coifman and Midpoint algorithms are shown in Table 2.

The percent error is calculated as the ratio of the average difference between the travel times of the probe vehicle and the algorithm estimated travel times to the average time of the probe vehicle expressed as a percentage and are represented as:

$$Percent\ error = \left(\overline{X}_d \big/ \overline{P} \right) \qquad (7)$$

where: $\overline{P} =$ average probe travel time for the link.

Comparing the travel time estimates with respect to percent error, the travel times estimated by the Coifman algorithm exhibit less error than the midpoint estimates for links 3, 4, 5, 8 and 10. The errors are similar for links 9, 12 and 13 and only link 6 exhibited a smaller error for the midpoint estimate.

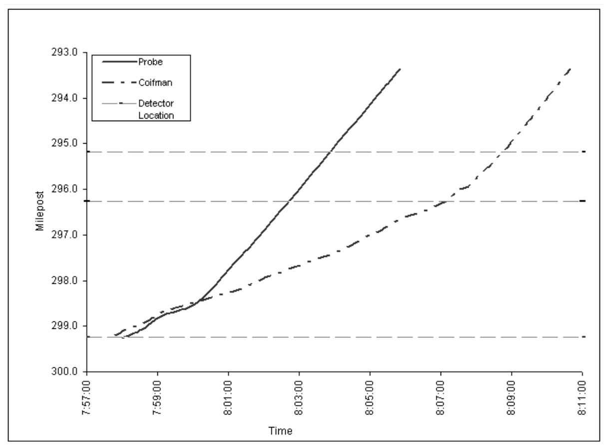

Fig. 3. Probe and Coifman Trajectories

TABLE 2
20 SECOND TRAVEL TIME STATISTICS

Link	Probe		Coifman			Midpoint		
	Mean (sec)	Standard Deviation	Mean (sec)	Standard Deviation	% Error	Mean (sec)	Standard Deviation	% Error
3	8.33	0.31	8.45	0.43	1.42%	9.08	0.49	8.96%
4	14.08	5.91	13.18	5.37	-6.42%	17.75	9.89	26.09%
5	5.95	2.41	6.52	3.01	9.58%	6.78	2.88	13.95%
6	6.99	0.51	8.25	2.18	17.92%	7.93	2.12	13.34%
8	18.82	10.53	15.96	8.66	-11.81%	14.82	7.70	-16.54%
9	7.11	0.60	6.47	0.33	-4.01%	6.58	0.11	-3.36%
10	12.73	0.99	14.72	0.36	6.98%	15.10	5.01	8.28%
12	17.29	0.54	17.87	0.17	1.50%	17.30	0.22	0.03%
13	5.23	2.40	5.38	2.35	2.29%	5.35	2.14	1.84%

TABLE 3
1 AND 3 MINUTE TRAVEL TIME STATISTICS

Link	Probe		Coifman-1 minute			Coifman – 3 minutes			Midpoint – 1 minute			Midpoint – 3 minutes		
	Mean (min)	Stdev (min)	Mean (min)	Stdev (min)	Error (%)	Mean (min)	Stdev (min)	Error (%)	Mean (min)	Stdev (min)	Error (%)	Mean (min)	Stdev (min)	Error (%)
3	8.33	0.31	8.43	0.41	1.22	8.40	0.36	0.77	8.96	0.53	7.47	9.02	0.79	8.20
4	14.08	5.91	13.25	5.53	-5.91	13.44	5.58	-4.56	16.48	8.84	17.06	17.99	8.88	27.77
5	5.95	2.41	6.52	2.89	9.63	6.64	2.85	11.62	7.17	2.88	20.46	6.91	2.59	16.16
6	6.99	0.51	8.86	2.25	18.03	8.31	2.34	18.80	8.29	2.25	18.58	8.30	2.13	18.65
8	18.82	10.53	15.96	8.63	-11.84	16.00	8.64	-11.66	14.43	7.29	-18.16	14.34	7.13	-18.53
9	7.11	0.60	6.45	0.30	-4.12	6.44	0.24	-4.22	6.71	0.18	-2.54	6.65	0.15	-2.90
10	12.73	0.99	14.65	0.40	6.74	14.90	0.43	7.59	14.60	3.13	6.54	14.31	1.94	5.55
12	17.29	0.54	17.83	0.07	1.40	17.84	0.06	1.42	17.57	0.43	0.74	17.59	0.26	0.77
13	5.23	2.40	5.35	2.32	1.88	5.38	2.37	2.35	5.11	1.97	-2.01	5.21	2.02	-1.19

In order to explore the reason behind the large error estimated by the Coifman algorithm for link 6, time space trajectories for the probe vehicle and the Coifman algorithm were constructed for one run. A sample trajectory for the probe vehicle and the Coifman algorithm for one of the link 6 runs is shown in Fig 3. The solid line represents the probe vehicle trajectory and the dashed line is the Coifman trajectory. The detector locations are plotted as dashed horizontal lines. From the plot it is apparent that the probe and the Coifman trajectories track one another fairly closely in the beginning. However, the probe vehicle accelerates between mileposts 299.0 and 298.0 and the Coifman algorithm fails to pick up the increase in speed until the next detector station at milepost 296.26 is reached. The large distance between the detector stations (~3 miles) is a contributing factor for the large error of the Coifman estimate in this case. Since the midpoint algorithm makes use of influence areas, this effect will be less pronounced thereby resulting in lower error as compared to the Coifman estimate. A potential solution for improving the accuracy of the Coifman algorithm is to apply it using midpoint influence areas. This would especially benefit cases where a large spacing exists between detectors and there is a change in the traffic conditions between the detectors.

The algorithms were set up to produce travel time estimates every 20 seconds based on the loop detector data. The travel time estimates were extracted for each 20 second period for 1 minute and 3 minutes prior to the start of travel. The average was computed and compared to the probe vehicle travel time. The estimates are shown in Table 3.

Table 3 indicates that averaging the recent travel time estimates over both 1 minute and 3 minutes has helped to improve the travel time estimates. Except for link 6, the average percent error for the Coifman travel time estimates is on the order of 10%. However the Midpoint travel time estimates for four links show errors on the order of 20%. The average percent errors for Coifman and Midpoint algorithms for 1 minute prior to the start of travel are shown graphically in Fig. 4.

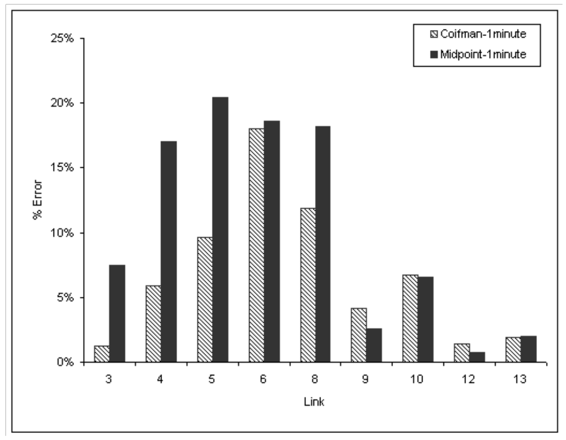

Fig 4. Coifman and midpoint average errors (1min)

In addition to the comparison of algorithm estimated travel times to the probe vehicle, the Coifman and Midpoint travel times were also compared to the bus travel times. The archived loop detector data from November 2002 was used estimate travel times using both the algorithms.

Table 4 displays the bus summary statistics. The Coifman algorithm is more accurate in estimating travel times that closer to the bus travel times as indicated by the reduced margin of error. The average errors for the Coifman algorithm estimated travel times were around 10% whereas the Midpoint errors were higher. As with the probe vehicle, the average of the prior 1 minute and 3 minute Coifman and Midpoint travel times were tested against the bus travel times.

TABLE 4
BUS TRAVEL TIME STATISTICS (IN MINUTES)

Day	Bus		Coifman			Midpoint		
	Mean	Stdev	Mean	Stdev	% Error	Mean	Stdev	% Error
Nov 12	16.15	4.93	16.39	3.99	1.48%	20.59	8.10	27.45%
Nov 13	16.55	6.67	17.90	5.79	11.17%	17.91	6.28	12.31%
Nov 14	11.51	3.19	12.13	2.45	5.96%	12.92	3.79	12.75%

TABLE 5
TRAVEL TIME STATISTICS

Day	Bus		Coifman-1 minute			Coifman – 3 minutes			Midpoint – 1 minute			Midpoint – 3 minutes		
	Mean	Stdev	Mean	Stdev	%Error	Mean	Stdev	%Error	Mean	Stdev	%Error	Mean	Stdev	% Error
Nov 12	16.15	4.93	16.37	4.05	1.33%	16.30	4.09	0.91%	19.22	6.39	18.99%	17.67	4.97	9.39%
Nov 13	16.55	6.67	17.81	5.81	10.51%	17.63	5.88	8.86%	18.27	6.74	12.92%	19.03	7.27	14.59%
Nov 14	11.51	3.19	12.06	2.42	5.45%	11.96	2.38	4.43%	12.85	3.74	11.34%	13.19	3.35	13.73%

The results are shown in Table 5. Averaging the travel times over 1 minute and 3 minutes before the start of travel helped in reducing the errors for the travel times estimated by the Coifman algorithm. However the results for the Midpoint estimates were mixed. This is due to the large variance in travel times estimated by the Midpoint algorithm for the prior 1 minute and 3 minute intervals. Often the 20 second travel time estimate may be an outlier and therefore erroneous. If provided to the public through dynamic messages signs, travel time information needs to be reliable. Therefore, averaging the travel time estimates over 1 or 3 minutes helps to smooth the data and filter the outliers.

The average errors for the 1 minute Coifman and Midpoint travel times for 3 days in November 2002 (TriMet data) are plotted in Fig 5. The plot shows that the Coifman algorithm estimated travel time errors are much lower than the Midpoint algorithm errors.

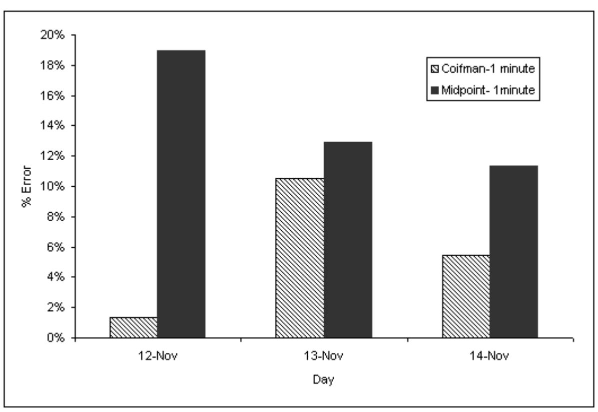

Fig 5. Coifman and midpoint average errors (1min)

The Midpoint travel time estimate for November 12 showed an error of 30% for the 20 second estimate and the error was reduced to 20% and 10% when the 1 minute and 3 minute averages were computed. In order to understand the reason for the large error magnitude, time space trajectories (Fig 6) were constructed for one run on November 12.

The Midpoint trajectory tracks the bus trajectory fairly closely until the midpoint between the last pair of detectors is reached. From that point on, there is almost a 3 mile segment where there are no additional detectors. Since the Midpoint algorithm estimates travel time as the ratio of distance to speed, the slope of the trajectory will

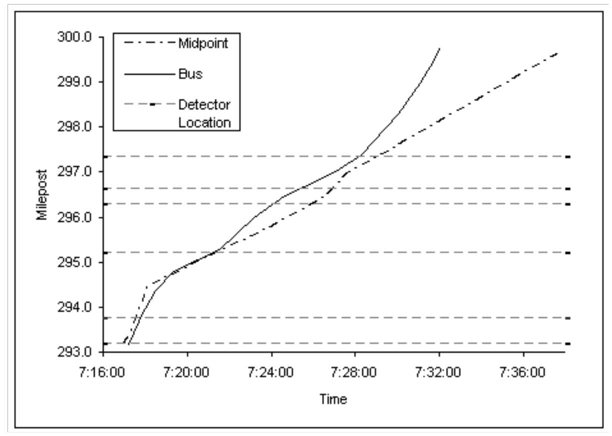

Fig 6. Bus and midpoint trajectories

not change even if the traffic conditions change. The bus accelerates after passing the last detector. The Midpoint algorithm takes a single speed reading to calculate travel time and therefore does not take the acceleration into account for the 20 second estimate.

As the Coifman algorithm uses many speed readings to build a vehicle trajectory, in its current form, it is more suitable for offline travel time analysis. On the other hand, the Midpoint algorithm can generate travel time for a link instantly as the ratio of distance to speed making it suitable for real time applications. The Midpoint algorithm can be used for offline analysis with a slight modification. Instead of taking the speeds at each detector at a particular time to calculate travel time, the speed at the first detector can be used to calculate travel time for the first segment. The travel time obtained for the first segment can be added to the start time to obtain a new start time for segment 2. The speed measurement corresponding to the new start time is taken and the travel time for segment 2 is calculated. The travel times for the remaining segments that constitute a link are calculated in the same manner.

This method was tested on links 3, 4, 5 and 6 and a graph showing the errors for the traditional and the modified Midpoint is shown in Fig. 7. The advantage of this method over the traditional Midpoint method is the ability to take into account changes in traffic conditions. Fig 7 shows the error calculated based on 20 second travel time estimates.

Except for link 5, the modified Midpoint algorithm reduced errors for all other links. Since the errors were calculated using a 20 second estimate, averaging the estimates over the prior 1 minute and 3 minutes and

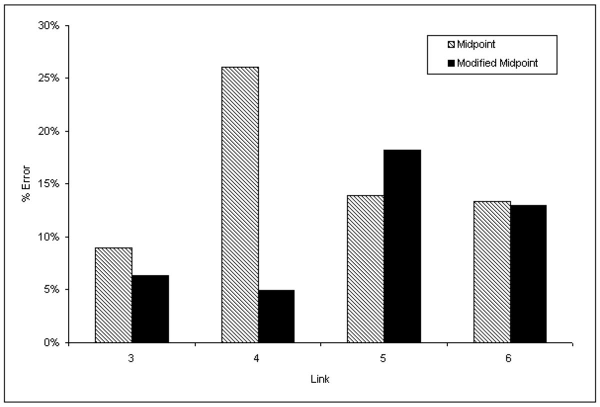

Fig 7. Midpoint and modified midpoint errors

computing the average error may help improve the modified Midpoint estimate for link 5.

V. Conclusions

The results presented in this paper indicate that the Coifman algorithm is more accurate than the Midpoint algorithm in the prediction of travel times. However the accuracy depends on the spacing between detectors, and the location and formation of queue with respect to the detector. For links with large spacing between detectors, using the Coifman algorithm over the midpoint influence areas might help in reducing the error. These results can be used to help ODOT plan for installation of new detectors in optimal locations. This study was limited by the small number of probe runs. Further testing is necessary and the ability of the algorithm to predict travel times during congestion and the occurrence of incidents needs to studied.

In its current form, the Coifman algorithm is more suited for historical analysis than real time application. For real time applications, averaging the estimates obtained from the midpoint algorithm will help reduce the error. Research to further develop these ideas is ongoing.

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