A STUDY ON TEMPORAL AND SPATIAL VARIABILITY OF TRAVEL TIME

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ABSTRACT

Travel time estimation and forecasting is very important in helping Intelligent Transportation Systems (ITS) provide drivers with useful and accurate route guidance. Travel time is by nature stochastic, however study on the variability and reliability of travel time is very limited. One restriction comes from data collection techniques. It is evident that gathering travel times with moving vehicles produces point-to-point measures, which are more representative of highway performance than the point estimates of speed from fixed detectors, particularly for capturing stochastic times through intersections. To secure sufficient data to describe highway performance in an accurate and timely manner without interrupting the traffic flow, a relatively large number of participating vehicles would be required which is unimaginable without wide-use of GPS-based Personal Navigation Assistants (PNAs) until very recently. Another restriction roots from data analysis. When making route choice decision, one is particularly interested in the route travel time rather than the individual link travel time. Since the route travel time depends on the link travel times, the error in the route travel time estimate will be the accumulation of the errors in each link travel times. However, a statistical difficulty that arises from analyzing travel time data is the lack of independence between each link travel time. With the adequate data collected by GPS based PNAs, this paper addressed the issue of temporal and spatial variations and correlations in travel times. The results from the case study at Princeton, New Jersey, indicated strong evidence of significant correlation between link travel times and between link travel time and arrival time. And that temporal conditional link and route travel time distributions could not be well fitted by Normal or Lognormal distributions. The results also implied that different linear combinations of Normal distributions may be a better representation of path travel time.

KEY WORDS

Travel Time, Spatial Variability, Temporal Variability, GPS, PNA

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1. INTRODUCTION

Route guidance is always an interest in the area of Advanced Traveler Information Systems (ATIS). A wide range of factors influences individual's route choice. Besides factors such as perceived travel times, delays, monetary cost, comfort and safety, the variability of the travel time is also very important. When making route choice decision, one is particularly interested in the route travel time rather than the individual link travel time. Since the route travel time depends on the link travel times, the error in the route travel time estimate will be the accumulation of the errors in each link travel times. However, a statistical difficulty that arises from analyzing travel time data is the lack of independence between each link travel time. Study of long-term (day-to-day) travel time variations usually concluded that would follow a normal or log-normal distribution under the conditions as (1) travel times on all separate route sections are independent and (2) trip times per unit distance on all sections are identically distributed. Study on temporal and spatial correlations of travel times is rare, and the results and conditions concluded from long-term study need to be justified by the actuality.

In order to provide drivers with accurate and useful information on congested routes, anticipated travel times and alternate routes, it is necessary to ensure that two important components of ITS system are functioning successfully: travel time data collection and analysis.

The travel time data collection part is most commonly done with the use of loop detectors and/or video cameras on the roadway sections of interest. While many travel time data collection techniques, such as license plate matching, point detection devices, radio navigation, AVI, cellular phone, etc., exist, one that is relatively accurate with low operating costs is the probe vehicle with GPS-based Personal Navigation Assistant (PNA). In a GPS-based route guidance system, the GPS receiver usually provides one to ten-second updates of latitude, longitude and time as long as the antenna can "see" four of the GPS satellites, which guarantees providing accurate, continuous and automated data with low operating costs. Gathering travel times with moving vehicles produces point-to-point measures, which are more representative of highway performance than the point estimates of speed from fixed detectors, particularly for capturing stochastic times through intersections. To secure sufficient data to describe highway performance in an accurate and timely manner without interrupting the traffic flow, a relatively large number of participating vehicles would be required which is unimaginable without wide-use of PNAs until very recently.

With adequate data collected by PNAs, this paper summarizes the extraction of important traffic features such as link travel time distributions and path travel time distributions from probe vehicle data for the experimental site. Statistical process is executed to build the link/path travel time distributions and to study the spatial correlation between link travel times and temporal correlation between link travel time and link arrival time. Our goal is to utilize those probe vehicle data to produce time-dependent link travel time distributions for each link as in Figure 1, as well as path travel time distributions with consideration of correlation among them.

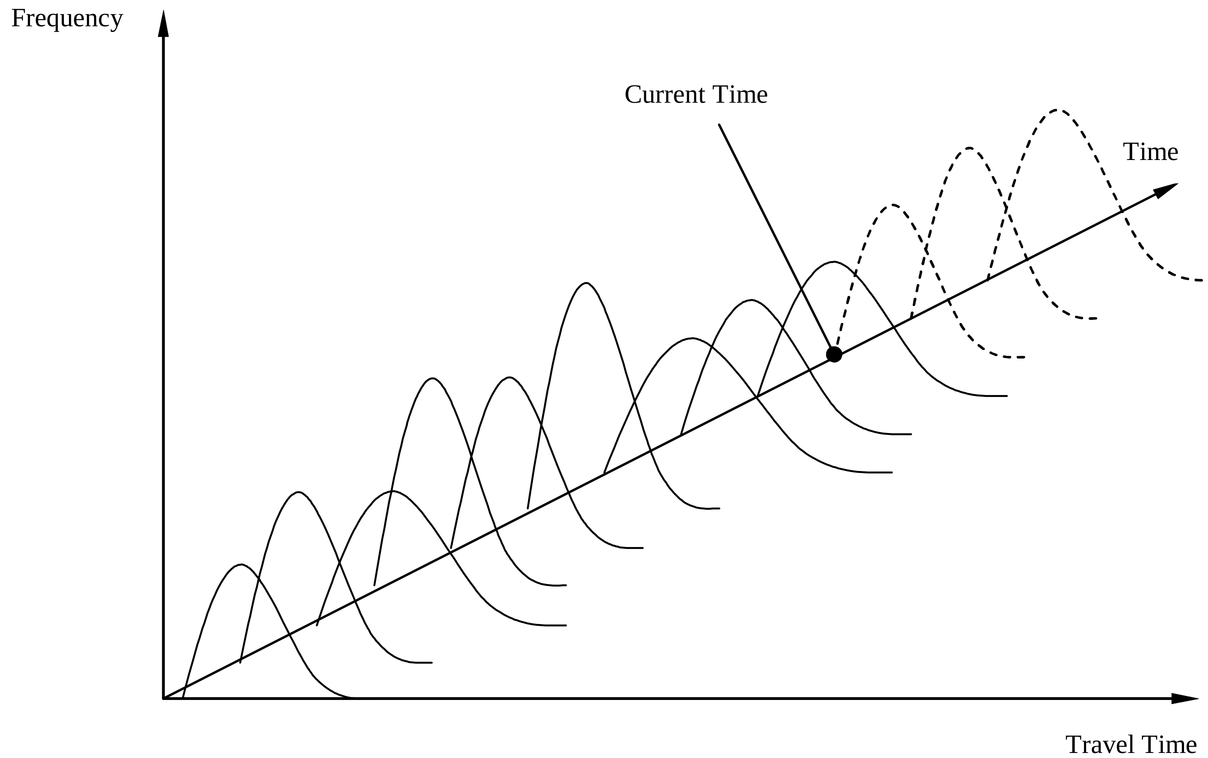

Figure 1. Dynamic Attributes of Link Travel Time

Experimental site, method of network building and data processing procedure are described in section 2. In Section 3 the temporal distributions of link travel times conditional on link arrival time are statistically justified. Then the spatial correlation in travel times is statistically examined in Section 4. Section 5 discusses the findings and concluding remarks.

2. THE STUDY AREA AND DATA PROCESSING

We consider only private car mode in this study. The data consist of more than 20,000 travel time records collected by CoPilot® - a commerically sucessful PNA. These trips were made on Route 27, locally called Nassau St., in downtown Princeton, New Jersey. Locations and routes are shown in Figure 2. The route we chose to study consists of 16 links with signal-controlled or no-controlled intersections. The locations of cars and times were recorded every 1 to 3 seconds. The reasons to choose a major collector street over major highways are two: one is the data availability and the other one comes from the consideration that the traffic congestion and signalized intersections are the key factors for the travel time variations, that is why travel times on freeways are usually more stable than travel time on local streets.

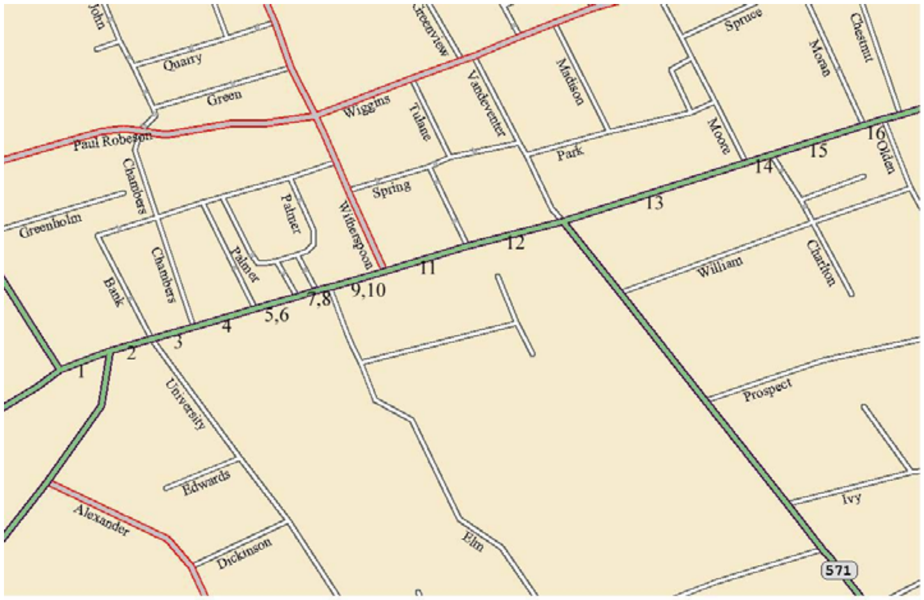

Figure 2. Downtown Princeton, NJ

It is very important to note that we utilize a unique method to represent network in this study. Traditional links between intersections result in unnecessary complexity because of stochastic signal control delay. In this study links are defined as the pairs between “monument" and "monument” instead of traditional links. “Monuments” are on half way between intersections where the probability of the uniform flows is maximized, that is, there is usually no delay at monuments. We propose this “monument-to-monument” network building method not only to avoid the complexity because the link travel time in our study includes the random time spent at the intersection, but also to easily manipulate the data collected from GPS-equipped probe vehicles. We only need to find the probe data points that bracket the monument M_i, then interpolate time and assign T_i to M_i. From the set of [M_i, T_i], we can derive the set of [$M_i, M_j, \Delta T$]. ΔT is the travel time between monuments M_i and M_j, which is one sample of stochastic link travel times in our study. The GPS-based probe vehicle records are collected and shown in Figure 3.

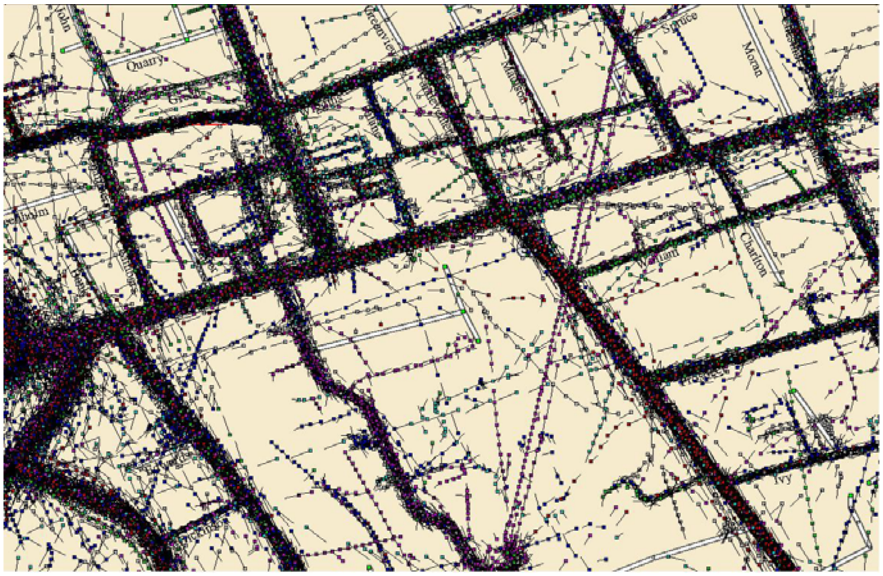

Figure 3. GPS Points collected in the Center of Princeton, NJ

The GPS-based data we used has been collected since May 1, 2000 when President Clinton ordered to turn off SA (Selective Availability) on satellites signals. Now, civilian GPS users around the world will no longer experience the up to 100 meter (approximate 300 feet) random errors that SA added to keep GPS a more powerful tool for the military. Today, GPS units are accurate to within 20 meters (approximately 60 feet); although in good conditions, units should display an error of less than 10 meters. The processing of raw data includes map-matching data points to most reasonable links, identifying noise data, and removing problematic data such as the speed of a vehicle is more than 90mph or less than 4mph for half an hour.

3. THE CONDITIONAL DISTRIBUTIONS OF TRAVEL TIMES

After processing the data from CoPilot® according to our network building method and processing steps described above, we get the observed means and standard deviations of the link travel times with normal and lognormal tests for a 24-hour period for the east bound route and links shown in Table 1.

Table 1 Statistics of Travel Times for Eastbound Route

Link No. (# of observations || traffic control mode)	Mean Time (seconds)	Standard Deviation (seconds)	Coefficient of Variation	Kolmogorov-Smirnov Test for Normality and Lognormality P-value
1-2 (252 || no control)	44.88	139.88	3.12	0
2-3 (145 || signal)	17.46	38.41	2.2	0
3-4 (214 || no control)	9.34	13.16	1.41	0
4-5 (141 || no control)	7.36	3.63	0.49	0
5-6 (77 || no control)	4.75	3.84	0.81	0
6-7 (65 || no control)	6.95	21.89	3.15	0
7-8 (50 || no control)	3.88	2.54	0.66	0

8-9 (23 || no control)	3.17	0.89	0.28	0
9-10 (93 || no control)	10.4	9.31	0.9	0
10-11 (135 || signal)	19.87	45.87	2.31	0
11-12 (196 || no control)	19.72	44.42	2.25	0
12-13 (125 || signal)	46.88	71.54	1.53	0
13-14 (107 || no control)	31.68	91.1	2.88	0
14-15 (138 || no control)	8.84	4.98	0.56	0
15-16 (124 || no control)	31.8	107.51	3.38	0
Path Travel Time (35)	**624.43**	**637.26**	**1.02**	**0.0002**

The great variability of these link and route travel times is shown by the coefficient of variation. Normal and lognormal hypotheses were rejected for all of the links and route, which can be observed in Figure 4 and 5.

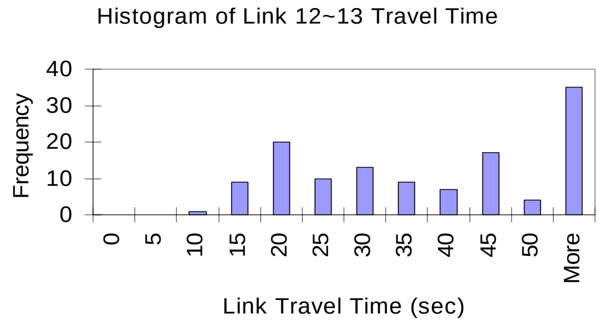

Figure 4. An Example of Observed Link Travel Time Distributions

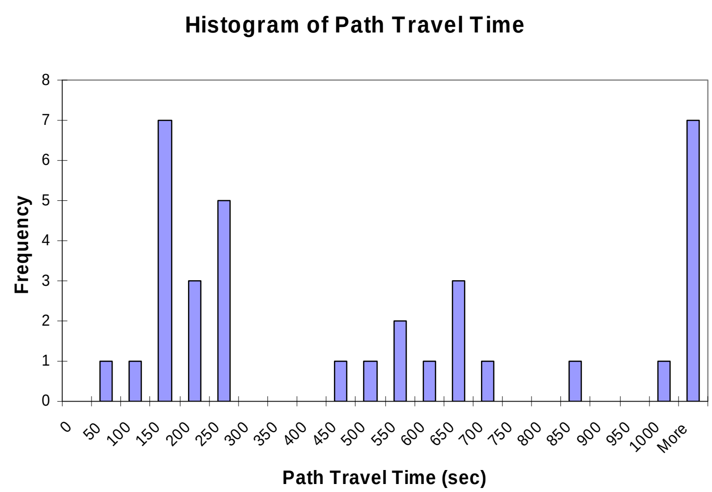

Figure 5. Observed Path Travel Time Distribution

It is also observed that link and route travel time distributions are conditional on the arrival time, that is, the analyzed link and route travel time data exhibits different patterns depending on the arrival time, such morning peak, midday, evening peak and overnight, as shown in Figure 6 and 7.

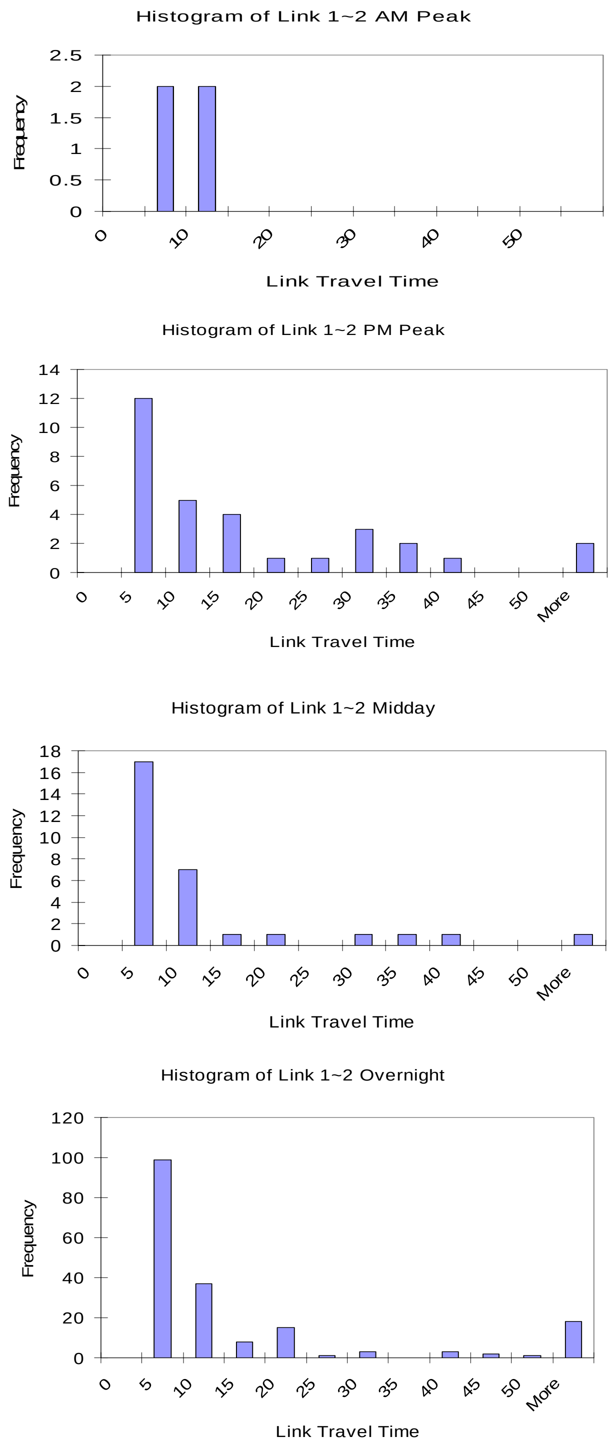

Figure 6. Examples of Histogram of Conditional Link Travel Time (AM peak 6:00~9:00, PM peak 15:00~18:00, Midday 9:00~15:00 and overnight 18:00~6:00)

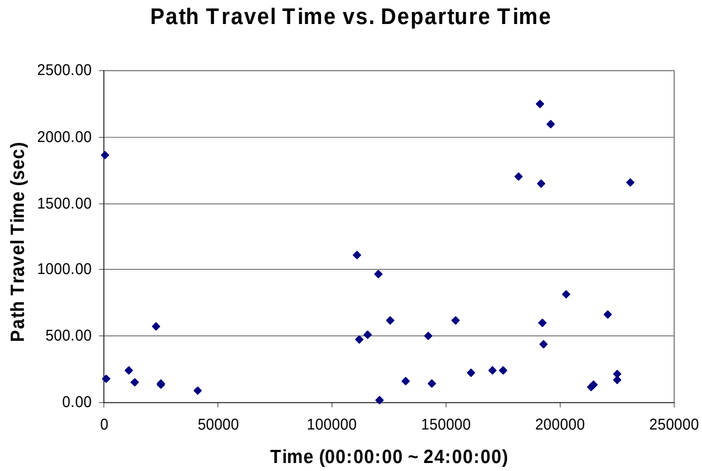

Figure 7. Observed Conditional Path Travel Time

For example for link 1~2, p-value derived from two-sample Kolmogorov-Smirnov test for AM peak and PM peak is 0.6877 which means these two distribution are statistically significantly different. P-value for AM peak and midday is 0.2401, for AM peak and overnight is 0.9989, for PM peak and midday is 0.7015, for PM peak and overnight is 0.9401, and for midday and overnight is 0.9117. All of these supported our observations that link travel times are strongly time-dependent.

Path Travel Times show the same property – time-dependent. During PM peak, path travel times are obviously much longer than midday and overnight. The lack for moring peak data is due to the data collectors living style. Since the data that under analysis is sent willingly be Copilot users, most of them are students, transportation officers and business executives. The analysis is limited to this sample of population, which may differ from other types of drivers.

4. SPATIAL CORRELATIONS IN TRAVEL TIME

4.1 Spatial Correlations in Link Travel Times

The correlation between link travel times is dependent on drivers' behavior and traffic condition. We found evidence of significant correlation between link travel times from analysis of the correlation coefficients between travel times on adjacent links, as shown in Table 2. The correlation is not consistent, sometimes positive while sometimes negative, which might be the true reflection of the stop-and-go driving experience in the center of Princeton.

Table 2 Covariance of Link Travel Times

Link A	Link B	Covariance Matrix	
1-2	2-3	112.64	0.14
		0.14	37.5
2-3	3-4	183175.79	-33.71
		-33.71	86.97
3-4	4-5	195.0	128.36
		128.36	70100.14

4-5	5-6	115632.73 15.86 15.86 14.71
5-6	6-7	17.63 -1.12 -1.12 587.02
6-7	7-8	1152.68 -3.59 -3.59 2.31
7-8	8-9	15.18 2673.0 2673.0 6861551.0
8-9	9-10	5431948.78 15246.11 15246.11 144.56
9-10	10-11	67.21 -65.55 -65.55 333105.58
10-11	11-12	13541441.0 11027694.0 11027694.0 11135800.0
11-12	12-13	864.43 -2215.46 -2215.46 19417387.26
12-13	13-14	864.43 -2215.46 -2215.46 19417387.26
13-14	14-15	8952.36 -399.03 -399.03 145322.63
14-15	15-16	179843.9 176875.7 176875.7 313857.4

4.2 Constructing Path Travel Time Distribution from Link Travel Time Distributions

Travelers are more interested to know path travel time information instead of individual link travel time informations. This brings about a problem, how to construct path travel time from link travel times with their dependency on time and spatical correlation? As we have known, travel time is stochastic, following certain distributions which cannot be well fitted by either Normal or Lognormal distributions based on our GPS-based study. Most researchers and practitioners now are looking at the expected path travel time which is the addition of expected link travel times belonging to the path assuming independence among links. There are at least two flaws in this way. One is the assumption of independence among links has been proved to be incorrect. The other flaw is the expected travel time. However drivers' perferences are obviously different, some may prefer a route with stable travel time, some may like to take risk to try route with higher variability, some may perfer arrival before certain time with high probability, etc. So only one travel time index, expectation, is not adequate. The true distribution showing every aspect of route travel time is a must.

In this study, we found out the link travel times cannot be well fitted by either Normal or Lognormal distributions or any other well defined distributions, so it's very hard to develope a general rule to "add" them to get route travel time. However route travel time histogram shown in Figure 5 gave us a good hint that it migt be well fitted by linear combination of several normal distributions and after testing we found the best combination: Normal (204.4, 58.8^2) with probablity of 0.49, Normal (640, 113.2^2) with probablity of 0.28 and Normal (1046.9, 8.8^2) with probablity of 0.23.

CONCLUSIONS

Travel time estimation and forecasting is very important in helping Intelligent Transportation Systems provide drivers with useful and accurate route guidance. With the adequate data collected by Personal Navigation Assistant, this paper addressed the issue of temporal and spatial variations and correlations in travel times. The results from the case study in Princeton, New Jersey, indicated strong evidence of time-dependent link travel time and significant correlation between link travel times. And that temporal conditional link and route travel time distributions could not be well fitted by Normal or Lognormal distributions. The best approximation is done by different linear combinations of Normal distributions.

The analysis presented in the paper also poses the need for future research on a more rigorous approach to obtain path travel time by "adding" link travel times.

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