BUS TRAVEL TIME PREDICTION USING BUS PROBE DATA*

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1. Introduction

This research aims to explore the bus travel time variability on arterial roads with respect to time of the day, day of the week and land use patterns by using bus probe data collected on a bus route in Yokohama, Japan. Bus travel time is considered to have three components, namely cruise time, delay at intersections and dwell time at bus stops. The variability of each component is separately examined. Subsequently these results are used to develop a travel time model for an arterial road to explain the effect of different variables on bus travel times.

The travel time of a bus on an arterial route varies considerably throughout the day and during the days of the week. Travel time variability (or the uncertainty) is an added cost to a traveler[1)]. Nakamura et al[2)] found that the standard deviation of the difference between the displayed and the actual bus arrival time at bus stops is up to 2.5 minutes. This variation would reduce the reliability of the system as the variability is considered to be a measure of reliability. To predict the bus travel time accurately it is needed to consider the variability associated with it. However, literature review reveals that variability of bus travel time on an arterial road has not been extensively studied. The available research is mostly limited to freeway travel time variability[3), 4)]. Liu et al [5)] have found that the variability of arterial travel time increases with increase in traffic demand and reaches its peak when the intersection is saturated and decreases after that point. However, the effects of other factors such as land use patterns and road geometry are not considered in this study.

This paper is organized as follows: Section 2 discusses the data used and data processing methodology. The hypothetical bus trajectory model is explained in Section 3. The data analysis and results are presented in Section 4. Finally, section 5 gives some conclusions as well as future directions.

2. Data And Methodology For Data Processing

1) Route data

The bus probe data collected on a bus route from Shin-Yokohama station to Kami-Sueyoshi intersection having a length of 5.8km are used in this study. The inbound direction is from intersection to station. This bus route runs through different land use zones, broadly categorized as residential, commercial and industrial. There are 24 signalized intersections and number of lanes varies from 2 to 4. There are about 15 bus stops in each direction.

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2) Probe data

Bus probe data from real world bus operations provide a valuable input to the analysis of variability of bus travel time. From August 2003 to July 2004 twenty buses equipped with GPS devices were deployed on the said route to collect the position data of the buses. Data were available for 2178 bus-days within this period. The buses have run from 6:00 to 23:00 in each direction. Bus probe data contains location, instantaneous speed, cumulative odometer reading and on/off status of left turn/right turn signals recorded every second.

3) Data Processing

A map matching technique was applied to match the raw location data to the route map and extract the data which represents the bus movement along the specified route, as almost all the buses have been deployed on service on other routes. The trajectory of each probe bus during one-day trip is a continuous path. This was broken up into inbound and outbound trajectories depending on the distance from the origin. The inbound and outbound bus trajectories obtained in this step contain outliers due to GPS measurement errors and missed measurements, as well as reasons specific to buses. For instance, some buses have stopped at the bus depot located about 1 km from the Shin Yokohama station for services and changing of drivers. Those outliers were identified using simple rules and were removed from the data base. Finally, 5114 inbound trajectories and 4643 outbound trajectories were identified for travel time analysis.

3. Hypothetical Bus Trajectory Method

A typical time space diagram for a bus running on an urban arterial route can be considered as shown in Figure 1 (Black line).

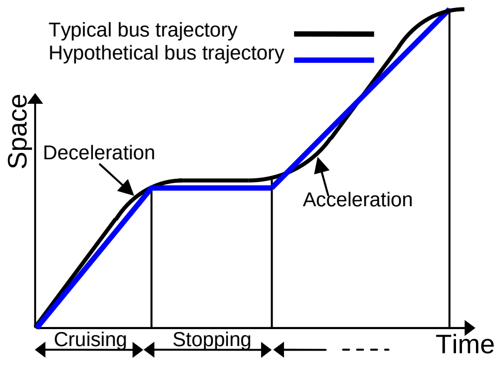


Figure 1: Actual and hypothetical bus trajectory

Travel time of the bus can be divided into two components: running time and stopping time. Running time can further be sub-divided into cruise time and acceleration /deceleration time. Cruise time is the time at which the bus is cruising at its desired speed.

In an actual bus trajectory, a deceleration phase occurs when a bus is preparing to stop and reduce speed from cruise speed to a halt while an acceleration phase occurs when a bus is preparing to cruise and increase its speed from zero to cruise speed. In our study we assume an ideal bus trajectory which consists of only cruise time and stopping time (blue line in Figure 1). The total travel time of the probe bus trajectories was separated into cruise time and stopping time, assuming that if the instantaneous speed is less than 4 km/h continuously for a minimum of 10 seconds then the bus is considered to have stopped, otherwise it is considered as moving. This assumption reduces the cruise speed from its actual speed to reflect the effect of the acceleration/deceleration time experienced by the bus.

The exact locations of bus stops and intersections along the route were identified from the site maps and field visits. The stop locations obtained from GPS data were matched with bus stop and intersection locations and the stopping time was further divided into delay at intersections and dwelling at bus-stops.

In this study the route travel time of the bus is expressed as follows:

$$TT = T_{cruise} + T_{delay} + T_{dwell}$$

where TT is total travel time, T_{cruise} is the cruising time along the route and T_{delay} and T_{dwell} are the delay at intersections and dwell at bus-stops along the route, respectively.

4. Data Analysis

The variability of travel time and its components: cruise time, delay and dwell time; with the time of the day and day of the week are analyzed to determine the contribution of each component to the total travel time variability. The inbound and outbound directions are considered separately for the analysis.

1) Bus travel time variability

To analyze the variability of bus travel time, the statistics of total travel time, cruise time, delay at intersections and bus-stop dwell time were computed using 5114 inbound trajectories and 4643 outbound trajectories (Table 1). It is seen that more than 60% of the bus travel time is composed of cruise time, while on average, the intersection delay and dwelling time are 25% and 13%, respectively. These proportions are almost the same for both directions. Analysis reveals that total travel time has a coefficient of variation about 12-15% in both directions. A further breakdown of the travel time components reveals that the variation in cruise time is not more than 10% while intersection delay has a variation of around 35% and bus-stop dwelling time has the highest variation of 45%. It is seen that the coefficients of variability of travel time and its components are higher for the inbound direction than for the outbound direction.

2) Variability by time of day

Information on bus travel time fluctuations at different times of the day is useful for a traveler to decide a departure time for reaching the destination on time.

In this study travel times were aggregated to 15-minute intervals and the mean was used as the representative travel time for that interval. The standard deviation was also calculated for each interval. The following equations were used to calculate the mean and the standard deviation of travel time in each interval, *t*.

$$\mu_t = \frac{\sum_{i=1}^{N_t} t_i}{N_t}$$

$$\sigma_t = \sqrt{\frac{1}{(N_t - 1)} \sum_{i=1}^{N_t} \left[(\mu_t - t_i)^2 \right]}$$

where,
μ_t = mean travel time during time interval t
t_i= travel time during time interval t where $i=1,2,.....,N_t$
N_t=total number of bus trajectories in time interval t
σ_t=standard deviation of travel time in time interval t

Figure 2 shows the variation of bus travel time and its two components, cruise time and stopping time, with the time of day. It is clearly seen that the travel time profile exactly follows the stopping time pattern. This is same for both directions. For the above route throughout the day the variability of travel time is higher in the inbound direction (Figure 3). Except during the morning peak (7:00-10:00) and evening peak (17:00-18:00), the cruise times are almost constant and equal in both directions. This implies that the fluctuations of bus travel time along the route with time of day are mainly due to stopping. The two components of the stopping time, i.e. delay at intersections and dwell at bus stops show high fluctuation with time of day (Figure 4). The dwell time clearly shows a peak during morning and evening peak periods while delay at bus stops is continuously increasing during the day time and gradually decreases after 18:00 (Figure 5).

3) Variability by day of week

Bus travel time varies with the day of the week also. The days of the week were grouped into three categories: weekday, Saturday and Sunday/holiday. In the inbound direction there are 3612, 636 and 866 bus trajectories for weekday, Saturday and Sunday/Holidays and for outbound direction these figures are 3231,598 and 814 respectively.

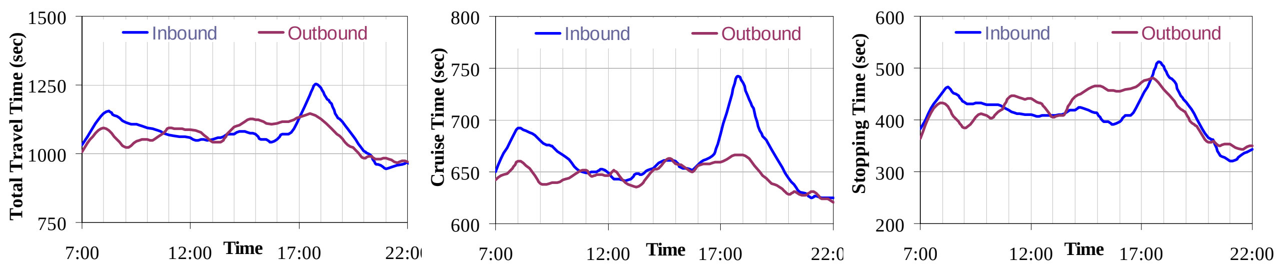
The analysis reveals that for the inbound direction the total travel time, cruise time and delay at intersections are highest for Saturday and lowest for Sunday/holiday (Table 2). However, the dwell time at bus stops is highest for weekdays. The results show that the number of stops at bus stops per trajectory is almost same for all the days. Therefore, as we might expect, there are more boarding and alighting passengers at bus stops on week days compared to Saturdays and Sundays/holidays. On average Saturday travel times are 6% higher than Sunday/holiday travel times. This trend is slightly different for the outbound direction where weekday travel times are the highest and Sunday/holiday travel times are the lowest. On average there is a 9% difference between weekday travel times and Sunday/holiday travel times. The distribution of the travel time by the time of day for the three categories of days of the week is shown in Figure 5.

Table 1: Mean, standard deviation and coefficient of variation of bus travel times

	Inbound			Outbound		
	μ(sec)	σ(sec)	CV(%)	μ(sec)	σ(sec)	CV(%)
Travel Time	1076	160	14.8	1070	133	12.5
Cruise Time	663	70	10.5	648	51	7.9
Dwell Time	141	70	49.3	127	55	43.5
Delay Time	272	95	34.8	295	98	33.2

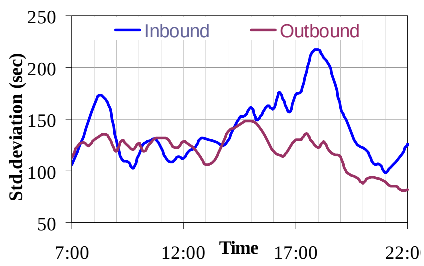
Table 2: Mean, standard deviation and coefficient of variation of bus travel times for different days

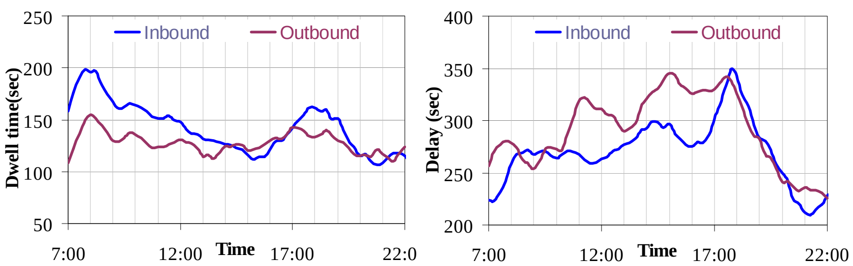
	Inbound direction									Outbound direction								
	Weekday			Saturday			Sunday			Weekday			Saturday			Sunday		
	μ	σ	CV	μ	σ	CV	μ	σ	CV	μ	σ	CV	μ	σ	CV	μ	σ	CV
Travel Time(sec)	1082	156	14.5	1097	175	15.9	1034	153	14.8	1088	133	12.2	1065	135	12.7	999	106	10.6
Cruise Time(sec)	666	69	10.4	668	77	11.5	645	64	10.0	653	51	7.8	643	55	8..5	630	45	7.2
Dwell Time(sec)	144	69	48.0	134	69	51.5	132	69	52.6	132	53	40.5	121	60	49.3	109	56	51.1
Delay (sec)	272	92	34.0	294	104	35.3	257	95	36.9	303	99	32.8	301	96	31.7	260	87	33.3



(a) Total travel time (b) Cruise time (c) Stopping time

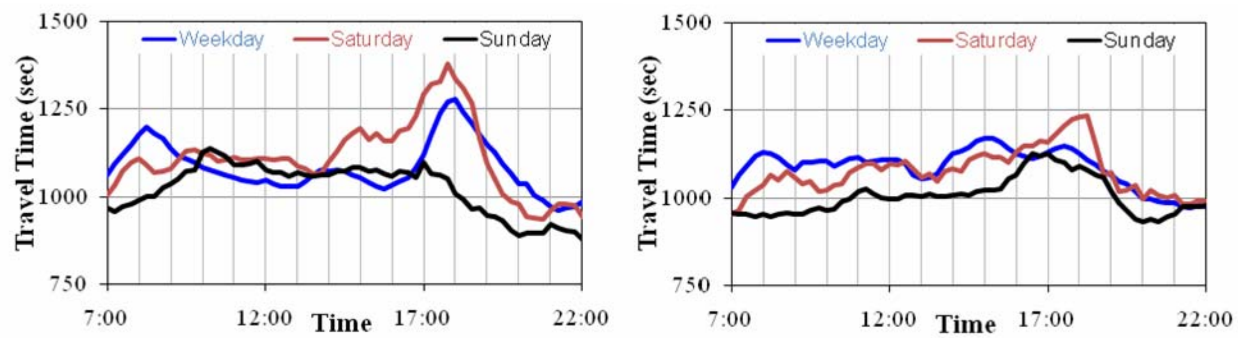
Figure 2: Variation of mean bus travel time by time of day





(a) Dwelling time at bus-stops (b) Delay at intersections

Figure 3: Std. deviation of TT **Figure 4: Variation of components of stopping time by time of day**



(a) Inbound (b) Outbound

Figure 5: Travel time variation by days of week

4) Link travel time variability

Beyond time of day and day of week variability, the effects of the factors such as link length, roadside land use patterns, number of cross roads intersecting the link, number of lanes and number of bus stops on the link travel time were also analyzed.

Since the lengths of links differ along the bus route, for purpose of comparison, the cruise speed along the link was considered instead of the cruise time which was considered in route level. The cruise speed along a link is almost constant throughout the day but it varies from link to link considerably based on the land use pattern in the nearby area. For example, Figure 6 shows the cruise speed for three links in different land use zones. The cruise speed is almost same for the commercial and industrial zones but is considerably lower in the residential zones indicating that buses travel at lower speeds in residential areas.

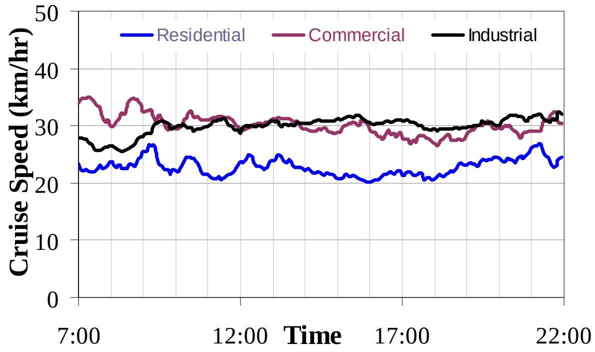


Figure 6: Cruise speed in different land use zones

5) Link travel time prediction model

The link travel time data were fitted to a non-linear regression model utilizing the results obtained in the above analysis. The variables which are statistically significant at 90% confidence interval were chosen for the model. The multicollinearity amongst independent variables was also tested and it was found that the model is statistically robust.

Since the travel time along inbound direction and outbound direction shows different behavior, the two directions were considered separately. According to the model, the length of the link has the maximum correlation to the travel time of a link. The variable which has the minimum correlation to the link travel time differs for the model in the two directions. For the inbound direction it is the number of lanes and for the out bound direction it is land use patterns. The link travel time along this route can be explained by the following model, which has a goodness-of-fit given by an R^2 value of 0.66 and 0.73 in the inbound and outbound directions, respectively.

For the inbound direction:

$$TT_{link} = 0.16\sqrt{l} + 0.0009X^4 + 4.03\beta + 15.58\frac{1}{N^{1/3}} + 8.09H^{0.2} - 7.36$$

For the outbound direction:

$$TT_{link} = 0.17\sqrt{l} + 0.004X^4 + 1.69\beta + 12.62\frac{1}{N^{1/3}} + 6.76H^{0.2} + 2.25$$

where TT_{link} is link travel time in seconds , l is link length in metres, X is number of cross roads joining the link, β is a parameter which depends on the land use pattern: β=1 if commercial area and β=0 otherwise, N is the number of lanes in the link and H is the number of bus stops.

This model can be utilized to predict how the link travel time will vary by making some changes to the above variables. For example, if the road is widened and a lane is added, how it affects the link travel time can be estimated from this model. This would be useful information for bus transit companies as a prior knowledge about the bus travel time can be obtained before any changes are implemented.

5. Conclusions and future work

This paper explored the variability of bus travel time and its components at the route and link level. Variability of route travel time by time of the day and day of the week was explored. Beyond that, the variability caused by road side land use pattern was explored at the link level. Finally a regression model was developed to quantify the effects of the link length, number of cross roads, number of bus stops, land use patterns and number of lanes, on the link travel time. Due to the lack of data, the effect of traffic flow was not included in the model, although incorporation of the flow rate can further improve the model.

In this study it is seen that the number of bus stops on a link is a significant factor for the bus travel time. It will be useful to study the variability of link travel time and the route travel time with the passenger demand at bus stops. At the same time it is needed to verify this model for some other route also if bus probe data is available.

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References

1) Noland, R.B. and Polak, J.W.: Travel time variability: A review of theoretical and empirical issues, 80th Annual Meeting of the Transportation Research Board, Washington, D.C., 2001

2) Nakamura, F., Babasaki, Y. and Konda, Y.: Analysis on the effects of real time service information provision, 5th World Congress on Intelligent Transportation Systems, Korea,1998

3) Oh, J. and Chung, Y.: Calculation of travel time variability from loop detector data, 85th Annual Meeting of the Transportation Research Board, Washington, D.C., 2006

4) Li, R., Rose, G. and Sarvi, M.: Modelling and estimation of travel time variability, 86th Annual Meeting of the Transportation Research Board, Washington D.C., 2007

5) Liu, H., Lint, H. and Zuylen, H.: An investigation of urban arterial travel time variability, Proceedings of 16th Mini-Euro conference and 10th meeting of the EWGT,2005