Empirical Assessment on Factors Affecting Travel Time of Bus Rapid Transit

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Abstract—Since the beginning of the century, many cities around the world adopt the bus rapid transit (BRT) system to fulfill their need of mass transportation system. The system features with platform-level boarding, bus lanes in the central verge of the road, off-vehicle fare collection, and physically protected busway. So far, these criteria are considered to be the most important aspects with respect to the BRT performance. In this research, we intend to study to what extent the BRT performance may be affected by the interference of the mixed traffic during the BRT operation. We adopt an empirical approach by observing the phenomenon unfolding in the eleven TransJakarta BRT corridors. The TransJakarta BRT operates in the city of Jakarta, the capital of the Republic of Indonesia. We record the travel time data from station to station for the case where the TransJakarta bus can travel smoothly and the case where the traveling bus is interfered with the mixed traffic. For the cases, we evaluate the travel time variation. As the results, we found that the Corridor 1 of TransJakarta BRT has the best performance in term of the travel time variation. For the two directions, the corridor has the mean travel time of 34 min, the standard deviation of 3 min, and the travel time variation of 8%. On this corridor, the mixed-traffic interference is relatively negligible. On the Corridor 7, the two-direction travel times have the mean of 45 min, the standard deviation of 8 min, and the travel time variation of 16%. On the Corridor 9, the two-direction travel times have the mean of 1 hr and 25 min, the standard deviation of 11 min, and the travel time variation of 14%. On the last two corridors, the busways are heavily interfered by the mixed traffic; thus, the end-to-end travel times are significantly uncertain although only very few road segments are interfered. The research leads us to a conclusion that the interference, although only occurs on a road segment, may compromise the end-to-end travel time considerably.

Keyword-Bus Rapid Transit (BRT); Travel Time; Travel Time Reliability; Buffer Time Index; Busway

I. INTRODUCTION

Ability for a bus of the bus rapid transit (BRT) system to smoothly travel along its dedicated lane is very important. The dedicated lane is usually a single lane; thus, a delay on the bus can quickly propagate to the following buses and makes the entire system unreliable.

The travel time reliability or consistency of the transportation system is important for traffic engineers and essential for the end-users of the system. It is a measure of the level of consistency in transportation service for a mode, trip, route, or corridor during a time period. Travelers concern with unpredictable travel time according to several surveys [1].

The travel time reliability depends strongly on traffic congestion, which has many sources such as bottlenecks (40%), traffic incidents (25%), bad weather (15%), work zones (10%), poor signal timing (5%), and special events (5%) [2]. And, various measures were proposed to measure congestion. Those measures were delay (29%), level of service (20%), travel time (14%), volume/capacity (14%), and speed (13%) [3].

There are a growing interest among researchers to establish a metric to quantify the travel time variability. Generally, the travel time is described using statistical distributions. Many researchers believe that the travel time is distributed following the normal distribution. Some researchers use the log-normal distribution [4--6]. Susilawati et al. [7] propose the Burr distribution. Noland and Polak [8] review the travel time variability from theoretical and empirical aspects specifically in relation with traveler behavior where Polak [9] proposes the mean-variance approach. Susilawati et al. [10] study the travel time reliability using two reliability parameters: the travel time variation and the buffer time index. The travel time---a measure of level of congestion---is strongly related to the buffer time index---a measure of the transportation reliability [11].

In addition, Robert Noland [12] develop a simulation methodology to analyze policies for reducing congestion and study the effects of providing commuters with the travel time information. Saberi and Bertini [13] have further utilized the travel time reliability concept, and employ the methodology to determine the hot-spots, sources of traffic congestion, across time and spatial dimensions of a freeway. Mahdi [14] also assesses the freeway travel time reliability using the same approach. Finally, Lyman and Bertini [15] utilize the method to improve transportation management in real time.

A reliable travel time has many advantages including saving time and fuel, reducing vehicle emission, reducing transportation cost and benefits the economy, and improving safety. Modern society demand rather high travel time reliability. Yamanote line, a subway system running in a loop in the city of Tokyo, is an excellent example of the transportation system that has very high travel time reliability. This single line with a length of 34.5 km is able to serve 3.2 million passengers per day in 2008 (see Table I for the case of the BRT-based system). Because the travel time variation of train-based vehicle is so low, many consider the time to be a constant [16].

TABLE I
Comparison of Some Large Bus Rapid Transit Systems [17]

System length (in km)	TransJakarta	TransMilenio	GuangZhou
Daily ridership (in Million)	172	84	22.5
Number of lines	0.36	1.6	1
Number of stations	12	9	1
Price of ticket (in USD)	181	114	26
Began operation	0.40	0.85	0.31
Location	Jan 2004	Dec 2000	Feb 2010
Population	9580000	9600000	12700800

TransJakarta, the BRT operating in the capital of Indonesia, Jakarta, is expected to lessen frequency and size of traffic congestions enduring by the city. The system was reported to promote a shift from private vehicles by 14% during peak hours, and to reduce pollutants: CO_2 20000 ton/year, NO_x 155 ton/year, and particulate matters 23 ton/year [18]. The average speed of TransJakarta buses is significantly higher than those of non-transit vehicles because the TransJakarta buses travel on a physically protected busway. Even in a moderately congested traffic, the BRT bus may travel at least 20% faster than the speed of the non-transit traffic [19, 20].

However, after seven years in operation, the public acceptance of the system is relatively low as clearly indicated by the daily ridership data (see Table I). At this time, TransJakarta is able to attract only about 360,000 passengers per day. At the same time, two smaller BRT systems, TransMilenio and Guangzhou BRT, attract significantly more passengers of 1.6 million and 1 million passengers, respectively.

Many factors can potentially contribute to the low ridership including marketing and branding, reliability of the service, and the accessibility of the system among others. Yunita [21] identified four aspects including the long bus waiting time, which can be associated with the bus travel time.

In this investigation, we empirically measure the travel time of a BRT system and determine factors affecting the travel time. More specifically, we measure the travel time and its variability in terms of the travel time variation and travel time index (TTI). This approach is relevant with the need of the present traveler that the current measure of congestion should include the notion of the actual travel time [3].

II. RESEARCH METHOD AND STUDY SITES

To investigate the factors affecting the travel time of the BRT system, we analyze the empirical data collected from the operation of TransJakarta BRT. The BRT is operating in the capital of Republic of Indonesia, Jakarta. The system currently has 12 corridors where the last corridor is officially opened on February 14, 2013. Figure 1 shows those corridors and Table II shows the data regarding the length and the number of stations.

TABLE II
The Twelve Corridors of TransJakarta

Corridor	Route	Length (km)	Number of Stations	Distance between Stations (m)
1	Blok M-Kota	12.9	20	650
2	Pulo Gadung-Harmoni	14.0	23	700-800
3	Kalideres-Harmoni	19.0	13	700-800
4	Pulo Gadung-Dukuh Atas	11.9	17	400-1600
5	Ancol-Kp. Melayu	13.5	17	400-2250
6	Ragunan-Duku Atas	13.3	18	400-1000
7	Kp. Rambutan-Kp. Melayu	12.8	13	500-1500
8	Lebak Bulus-Harmoni	26.0	21	500-1500
9	Pinang Ranti-Pluit	28.8	24	500-1500
10	Tanjung Priok-Cililitan	19.4	18	500-1000
11	Pulo Gebang-Kp. Melayu	11.8	14	300-1000
12	Pluit-Tanjung Priok	23.8	24	

The travel time data are derived from the time data, which record the time when the TransJakarta buses departure and arrive at the stations. On a few corridors, TransJakarta BRT has already installed a monitoring system; but, the system is inaccessible to the author at the time.
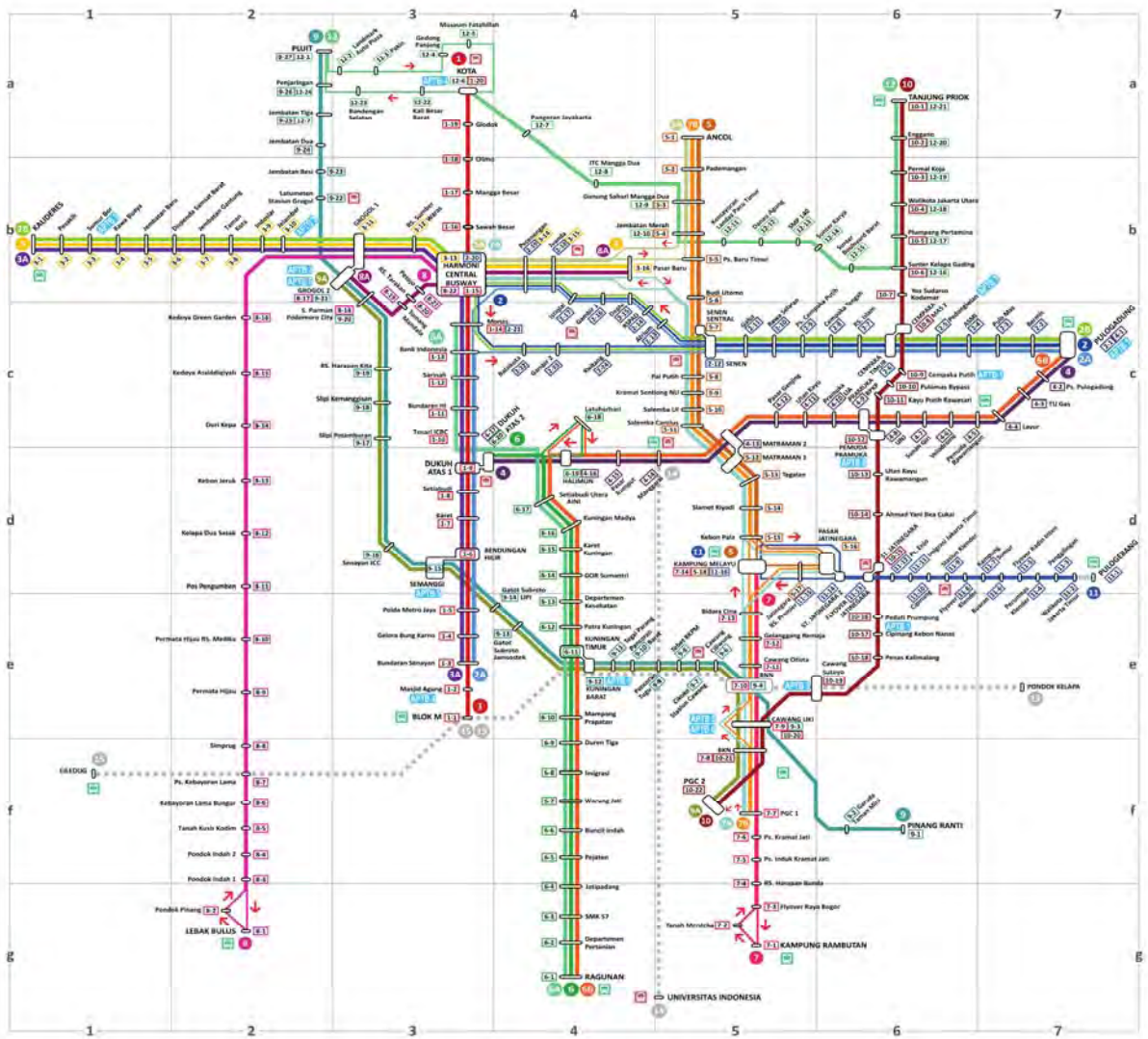

Fig. 1. The corridor of TransJakarta BRT. Source: http://www.transjakarta.co.id

Thus, the time data are recorded manually. Only the first eleven corridor are monitored, one corridor per week, during 3 months of observation. The recording is limited to the rush hours of 07:00--10:00 morning local time. The time data are collected during week days only.

Furthermore, we derive some measures of the travel time variability following Lomax et al. [1]'s proposal. The first measure of the travel time reliability is the travel time variation, which is defined by:

$$\text{Percent Variation} = \frac{\text{Standard Deviation}}{\text{Average Travel Time}} \times 100\% \ . \tag{1}$$

In addition, the second measure is the travel time buffer, which is defined by:

$$\text{Buffer Time Index} = \frac{\text{Buffer Time}}{\text{Average Travel Time}} \times 100\% \ , \tag{2}$$

where the buffer time is defined by:

$$\text{Buffer Time} = \text{95th percent travel time for a trip} - \text{Average Travel Time} \ . \tag{3}$$

The buffer index expresses the amount of extra ''buffer'' time needed to be on time for 95% percent of trips. Finally, the last reliability measure, the planning index, is the additional travel time of 95% trips in order to arrive on time which is obtained from the 95th percentile of the actual travel time:

$$\text{Planning index} = \text{95th Percent Travel Time for a Trip} . \qquad (4)$$

III. DATA ANALYSIS AND FINDINGS

A. Variability of the End-to-End Travel Time

The travel time variability of the subway mass transportation system is usually very low and is often regarded to be negligible. But for the case of the BRT system, the variability is rather high because the BRT lane or the busway usually builds in the central verge of the road where interference with the mixed traffic often occurs and delays the traveling bus. In the developing countries such as Indonesia where the traffic regulation is not strictly enforced, we often observe the mixed traffic utilizes the busway. Despite of this fact, in the good BRT design, the busway should be protected from the mixed traffic; the BRT bus should receive signal priority in the intersection, and the turn crossing the busway should be eliminated.
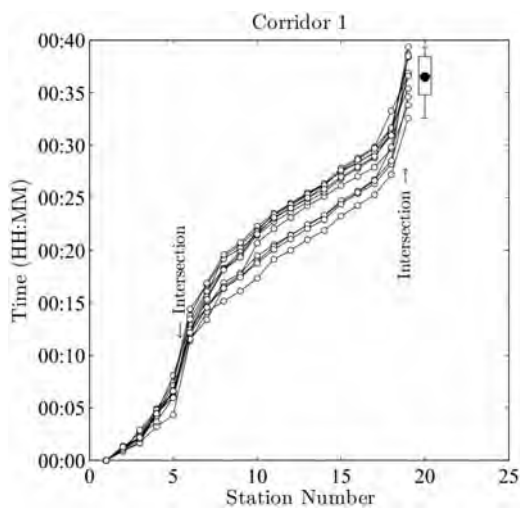
We study to what extent the BRT performance is compromised when the mixed traffic interferes the BRT bus in the unprotected or weakly protected busway. We also study the effect of the uncoordinated traffic signal.

In Fig. 2, we show how the traffic signal, the mixed traffic, and the unprotected busway affects the BRT travel time on various corridors. Although the figure only shows the data on Corridors 1--4, 8, and 9, but we collect the travel time data for Corridor 1--11 for the both traveling directions. The travel time data in the figure represent the station-to-station traveling time and are compensated to zero for the departure time from the first station, which is numbered as Station 1. The bus waiting time on each station is not accounted. On the right side of each figure, a box plot is also displayed to summarize the distribution of the end-to-end travel time. A black dot on the box plot denotes the mean travel time.
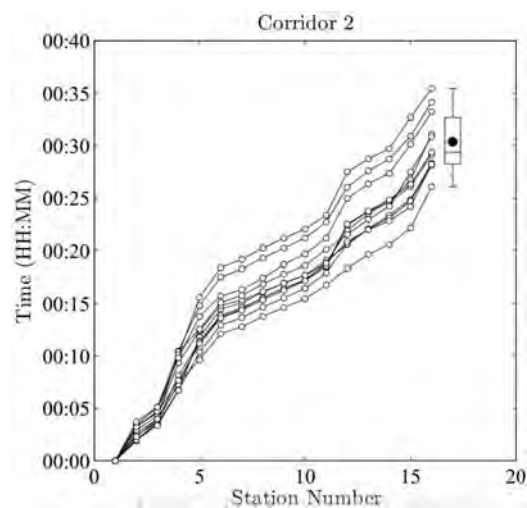
Firstly, we closely observe the travel time data displayed in Fig. 2(f). These data are for the buses on Corridor 9 bounds for Pluit station. The figure shows that the end-to-end travel time data greatly vary with the mode around 56 minutes and the range around 43 minutes, which means the end-to-end travel time variation is about 75%. We can also clearly see that the long travel time occur mostly on Segment 1 and Segment 7. On Segment 1, the travel time data, numerically shown in Table III, are in the range of 20 min to 30 min, which is about 50% of the mode travel time. We note that the 56-minute travel time is that required to travel the 24 road-segments on the corridor. Thus, a segment that costs 20--30 min travel time is very significant and a big issue.

TABLE III
The travel time, in min:sec, on Segments 1 and 7 of Corridor 9 bounds for Pluit Station

Segment 1						
27:16	20:47	23:02	29:57	25:12	25:36	27:58
24:25	22:11	20:26	22:31	24:00	26:02	22:11
Segment 7						
04:10	01:36	05:34	25:51	19:11	17:15	05:29
03:17	03:32	03:15	02:25	04:53	05:18	04:09

(a) Bound for Blok M Station   (b) Bound for Pulo Gadung Station

(c) Bound for Kalideres Station

(d) Bound for Dukuh Atas Station

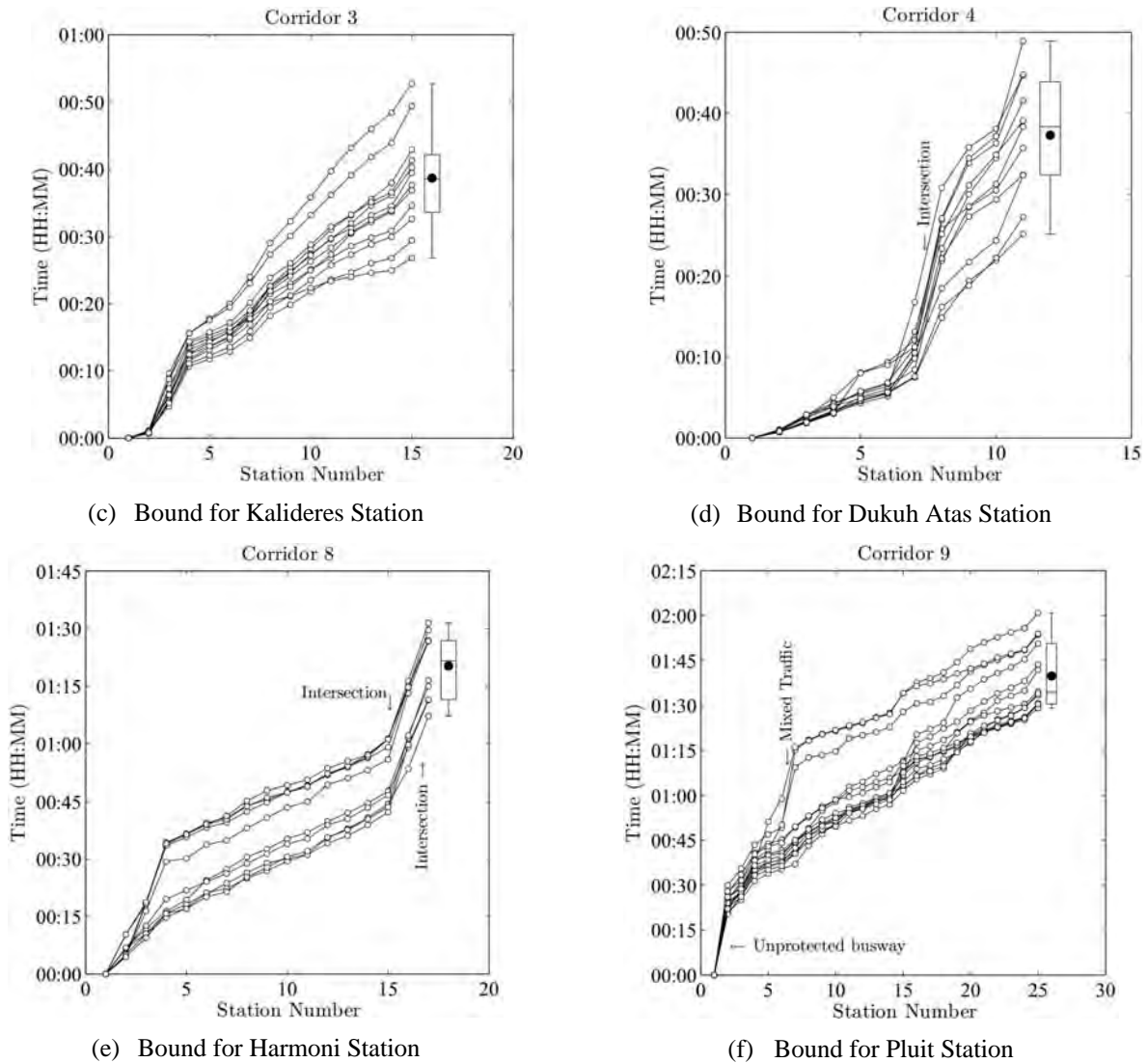(e) Bound for Harmoni Station

(f) Bound for Pluit Station

Fig. 2. The end-to-end travel time variability

The long travel time on Segment 1 of Corridor 9 is because the busway is not available on the segment; hence, the BRT bus should travel within the mixed traffic. Meanwhile, on Segment 7, see Table III, the busway does exist, but the mixed traffic often interferes the BRT bus. At its best, the BRT bus only requires about 3 min to travel Segment 7; but, when interference occurs, the traveling time increases to about 26 min, or about eight times longer. The data also indicate that when the delay occurs on an earlier segment, it is extremely difficult for the bus to recoup the travel time from the latter segments. Thus, the delay propagates to the entire travel time.

In addition, the intersection is rather often to be the cause of the bus delay. For many cases, the BRT bus does not receive any signal priority on the intersection and the traffic conflict between the BRT bus and the mixed traffic often occurs. Table IV shows the amount of delay on Corridor 1 due to the intersection. The magnitude of the delay is not as severe as those occurred on the unprotected segment.

TABLE IV
The travel time, in min:sec, on Segments 6 and 19 of Corridor 1 bounds for Blok M station

Segment 6						
06:33	05:36	07:06	05:32	04:50	06:59	
06:40	05:32	07:28	05:48	05:34		
Segment 19						
06:23	10:10	05:21	04:11	03:49	07:04	
03:24	07:03	08:25	06:49	05:04		

In Table V, we summarize the end-to-end travel time and its variation. The data show a few interesting phenomena. The end-to-end travel may increase by twice due to the unprotected busway. On Corridor 7, for an

example, the travel time is likely about 40 min, and so does its variation. On Corridors 2, 3, 6, and 7, there are a big difference of the travel time between the two directions on each corridor.

TABLE V
The statistics of the TransJakarta bus travel times. The mode represent the data with the highest probability.

Corridor	Origin-Destination	Mean	Deviation	Mode	Range
1	Blok M--Kota	0:32:26	0:03:01	0:28:56	0:08:57
1	Kota--Blok M	0:36:30	0:02:11	0:32:34	0:06:48
2	Harmoni--Pulo Gadung	0:30:22	0:02:54	0:26:04	0:09:22
2	Pulo Gadung--Harmoni	0:45:47	0:08:51	0:37:10	0:26:05
3	Kalideres--Pasar Baru	0:54:05	0:03:06	0:51:12	0:08:11
3	Pasar Baru--Kalideres	0:38:41	0:07:33	0:26:48	0:25:59
4	Dukuh Atas--Velodrome	0:20:24	0:02:29	0:17:42	0:07:57
4	Velodrome--Dukuh Atas	0:37:17	0:07:32	0:25:05	0:23:49
5	Ancol--Melayu	0:34:13	0:02:11	0:30:13	0:07:27
5	Melayu--Ancol	0:40:02	0:03:30	0:34:47	0:10:39
6	Dukuh Atas--Ragunan	0:31:00	0:03:25	0:26:25	0:10:04
6	Ragunan--Dukuh Atas	0:51:43	0:10:41	0:34:25	0:34:06
7	Melayu--Rambutan	0:36:52	0:02:27	0:31:57	0:09:48
7	Rambutan--Melayu	0:52:36	0:13:15	0:39:42	0:41:39
8	Harmoni--Lebak Bulus	0:57:15	0:08:00	0:45:29	0:23:18
8	Lebak Bulus--Harmoni	1:20:17	0:08:53	1:07:12	0:24:17
9	Pinang Ranti--Pluit	1:39:50	0:10:52	1:29:05	0:31:50
9	Pluit--Pinang Ranti	1:09:31	0:11:32	0:55:48	0:42:35

B. Travel Time on All Road Segments of All Corridors

The entire travel time data are arranged in a cumulative distribution and a frequency distribution in Fig. 3. In the same figure, the requirements set by TransJakarta authority and by Institute of Transportation and Development Policy (ITDP) are shown as vertical-broken lines. Basically, the standards are defined as the frequency of the bus arriving in a station; thus, these requirements are relevant to be compared with the travel time between the stations because when the bus can efficiently travel on a road segment then it will arrive accordingly. ITDP requirement regarding the bus frequency is less than 3 min during rush hours [22]. In addition, we also plot the travel time required by a train traveling at an assumed operation velocity of 30 km/h and the segment length of 1 km. Thus, it is interesting to compare the performance of the BRT system to that potentially offered by a subway system. It is generally accepted that the performance of the BRT system is lower than that of the subway system but the BRT system requires a lower development cost. This comparison is intended to provide an insight of the performance of the two systems.

The data in Fig. 3 leads us to the following conclusions. The cumulative distribution indicates that about 85% of the travel time between two adjacent stations are within the duration set by TransJakarta authority. However, the travel time on many road segments is longer than the standard, and on a few road segments, the travel time can be longer than 30 min. Since almost all road segments are only having single bus-way lane, the travel time of a bus will affect the following buses. Thus, it may reduce the bus arrival frequency on stations significantly. Furthermore, only about 65% of the travel time are below the standard set by ITDP, and the performance is significantly lower than that of the subway system. The data in the right panel of Fig. 3 suggest that the distribution of the travel time seems to follow the exponential distribution function with the average travel time of 2 min and 59 sec. However, the Kolmogorov-Smirnov goodness-of-fit hypothesis test rejects the hypothesis at a significance level of 0.05.
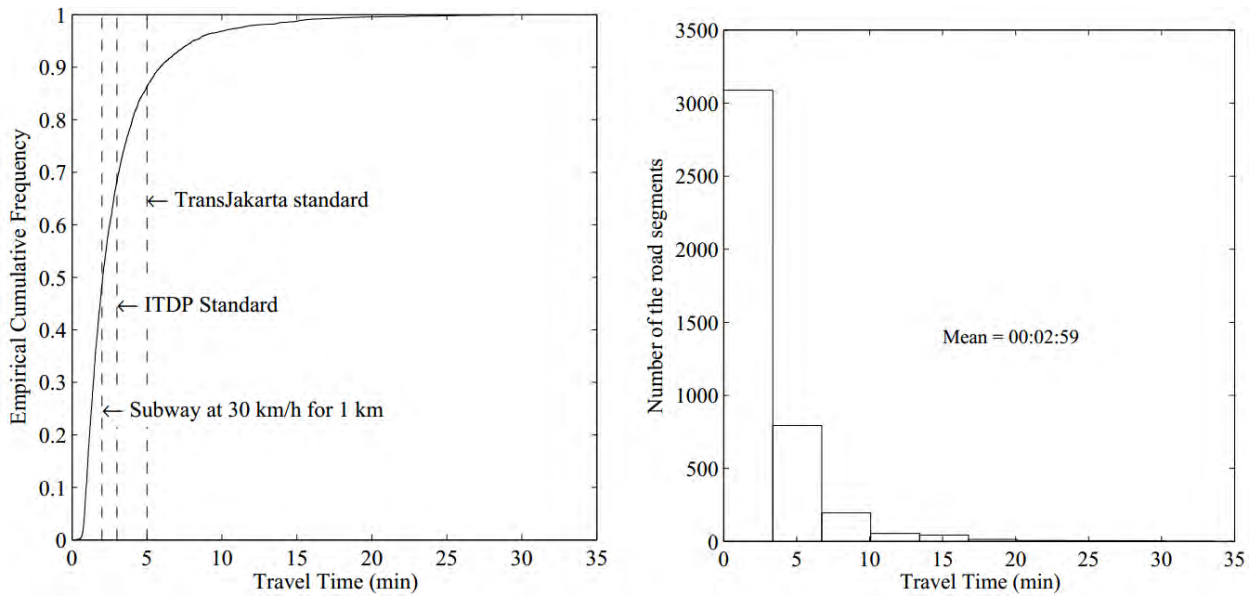
Fig. 3. Empirical cumulative and distribution frequency of the travel time.

C. Travel Time Variation and Buffer Time Index

Using Eqs. 1 and 2, we calculate the travel time variation and the buffer time index. The results are presented in Fig. 4. Regarding the travel time variation, the data are skewly distributed for most of the corridors. Many corridors have outliers, and those are related to the largest delay on each corridor. For an example, on Corridor 2, the largest travel time variation is about 120%, and it is associated with the buffer time index of 350%. This example means that if passengers require about 1 hr travel time in average, then they should preserve about 3 hr and 30 min to avoid late arrival more than a day in a month. In general, the travel time variation is high; 75% trips have travel time variation below 40%.
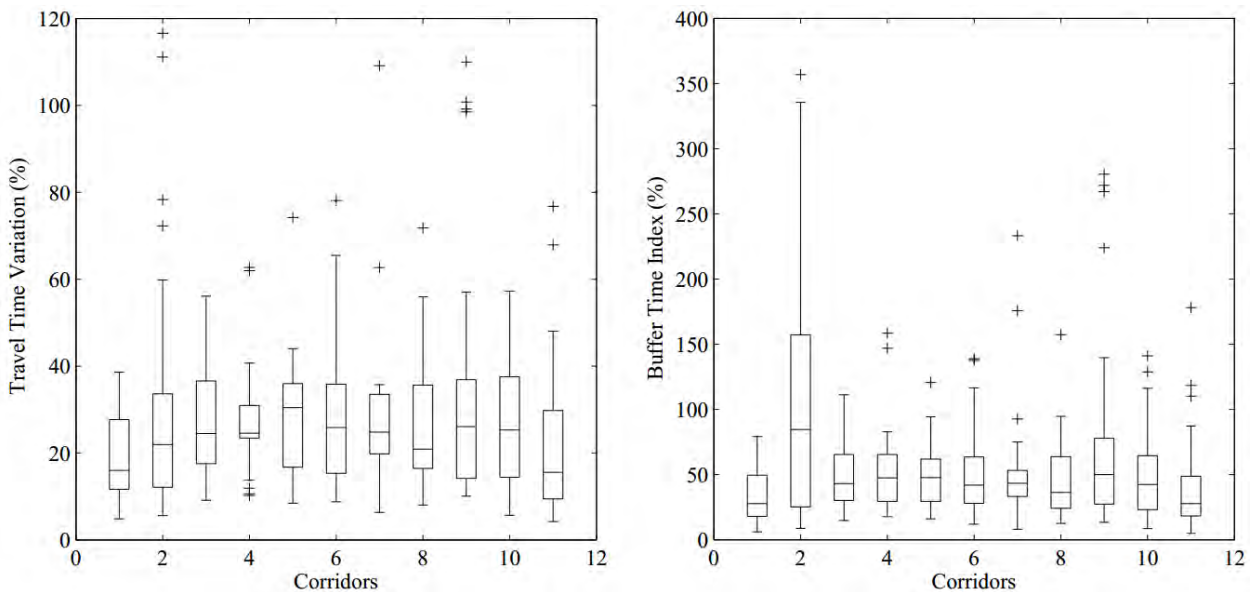

Fig. 4. Distribution of the travel time variation and buffer time index across all corridors

IV. CONCLUSIONS

Weinstock et al. [22] have clearly described the design criteria or the BRT standard of a good BRT system. The standard considers three aspects to be the most important and each aspect is awarded with the highest point of seven. Those aspects are: the BRT lane should be in the central verge of the road, the off-vehicle fare collection, and the physically-separated busway lane. In addition, the standard awards four point for the aspect of intersection treatments.

On the intersection, it is very difficult to protect the busway from interference of the mixed traffic. Although the busway on the intersection is color-marked, the mixed traffic often ignores the mark, also ignoring the traffic regulation, and clogs the busway.

This research has brought the data of the travel time of a BRT system into our perspective and has quantified implications of the mixed traffic interference to the end-to-end travel time. The research leads us to a conclusion that the interference, although only occurs on a road segment, can compromise the end-to-end travel time considerably.

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