TRAVEL TIME RELIABILITY ASSESSMENT OF PUBLIC TRANSPORT: A CASE STUDY OF THE JOHANNESBURG BUS RAPID TRANSIT (BRT) CORRIDORS

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ABSTRACT

Travel time reliability is one of the key measures of transport network performance. It also provides an indication of the level of predictability of travel time from origin to destination for any mode of transport. This paper presents an investigation of the travel time reliability of the Bus Rapid Transit system in Johannesburg - the Rea Vaya Bus service. The study method involves field collection of travel time information through onboard surveys along the BRT corridors. Travel time reliability is measured using a set of indicators proposed by the Federal Highway Administration (FHWA) of the US Department of Transportation. Among the objectives of the study is to gain some insight into the critical operational and road network factors that impact travel time for both peak and off-peak periods. Some of the factors considered include commuter boarding and alighting delays, stop frequency and delays at intersections. From the study, one of the notable factors found to currently affect travel time reliability for the BRT system was additional delays from traffic signal disruption due to the ongoing load-shedding scheme implemented by the national power agency, ESKOM.

1. INTRODUCTION

The reliability of any mode of transportation has a bearing on travel behaviour as it directly influences mode choice among trip makers. Travel time reliability has been considered one of the performance measures of a transport system (Lyman & Bertini, 2008). For public transportation, the anticipated travel time to complete a journey from origin to destination and the probable variation in travel time is important to both the operator and user of the system (Taylor, 2013). For trip-makers, punctuality is a function of on-time performance, and especially the travel time reliability of the system in relation to the overall transport network (Sen et al., 2019). In urban environments, travellers are often used to road network congestion and usually expect and plan for some delays. However, tolerance levels of travellers for unexpected delays can vary according to trip purpose and traveller personal attributes. For example, the tolerance level for delays in work commute trips may be lower for most travellers compared to leisure or shopping trips. Travel time reliability measures the extent of these delays that impact on-time arrival. From the transit operator's perspective, unreliability can have a significant impact on revenue if trip makers' decision to patronise the system is dependent on observed or perceived reliability level.

Since the 1970s, researchers have been investigating travel time reliability and multiple definitions have been proposed over the last four decades. The Federal Highway Administration (FHWA) provided a widely accepted definition as the consistency or

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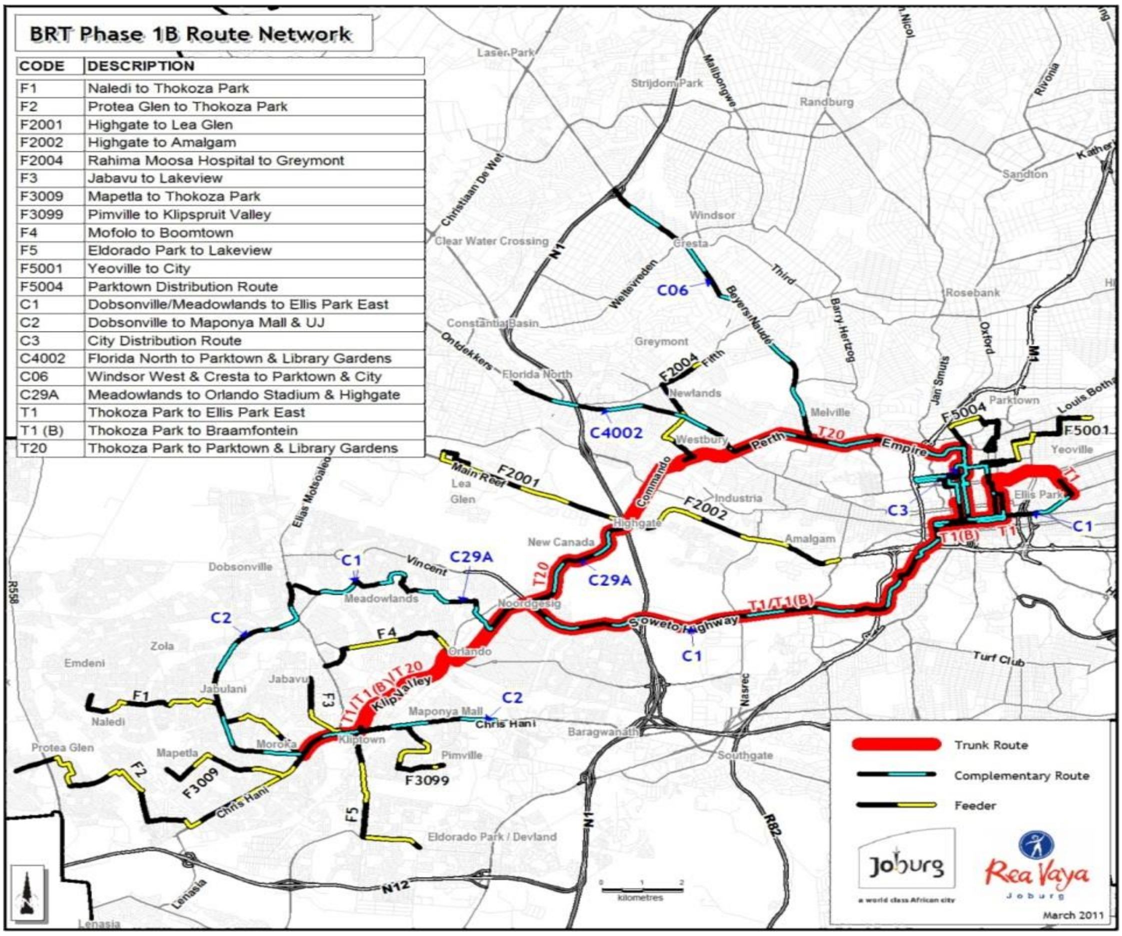
dependability in travel times measured from day to day and or across different times of the day (Texas Transportation Institute & Cambridge Systems, 2006). The objectives of this study are: 1) to apply existing reliability measures in assessing the travel time reliability of the Bus Rapid Transit (BRT) system of Johannesburg; 2) to gain some insight into the critical factors that affect delays and bus travel time along the corridors; and 3) make recommendations on strategies to improve travel time reliability and operational performance of the BRT corridors investigated.

1.1 Bus Rapid Transit System in Johannesburg

Prior to enacting the proposal of the BRT in South Africa, public transportation was mainly controlled by administrators from the private sector, which often led to unreliable public transportation (Khumalo & Ogra, 2018). After the implementation of the first BRT network in Curitiba during the 1970s (Prayogi, 2015), the replication of the BRT concept gained traction which led to the development of the BRT system in Johannesburg, also known as the 'Rea Vaya' (Adewumi & Allopi, 2013). Construction commenced in 2009 with Phase 1A becoming operational in 2009, followed by Phase 1B in 2013 and Phase 1C in 2018 (National Parliament South Africa, 2017). The arterial route runs from Johannesburg CBD to Alexandra and Sandton, connecting numerous feeder routes in Soweto and its environs (Risimati & Gumbo, 2018). According to the National Parliament report of 2017 on the performance of the Rea Vaya system, the Rea Vaya buses serve up to 53,000 commuters daily (National Parliament South Africa, 2017). Figure 1 below shows the Rea Vaya bus route network.



Source: National Parliament South Africa, 2017

Figure 1: Rea Vaya bus route

2. TRAVEL TIME RELIABILITY MEASURES

The Federal Highway Administration (FHWA) proposed several indicators of travel time reliability which include the travel time index (TTI), buffer time index (BI), planning time index (PTI) and the 90th or 95th percentile travel time index (Texas Transportation Institute & Cambridge Systems, 2006; Lyman & Bertini, 2008). The subsections below briefly discuss each of these measures.

2.1 Travel Time Index

The travel time index (TTI) is calculated by dividing the average travel time by the free-flow travel time. This index represents an average measure of congestion (Texas Transportation Institute & Cambridge Systems, 2006) and takes into consideration the additional time that one would have to account for when undertaking a journey during peak periods versus when one would take the same trip when there is no traffic. If the travel duration is longer than usual, a value close to or above 1 implies that there are frequent congestion conditions. Provided that TTI is linked to an urban population, a linear relationship exists between population growth and congestion levels. This also suggests that there is a lack of dependence on vehicle ownership and commuters are heavily reliant on public transportation (Rodrigue, 2020).

2.2 95th Percentile Travel Time Index

The 95th Percentile Travel Time (T_{95}) is defined differently according to various sources. It predicts the severity of delays on a day-to-day basis on particular routes subjected to heavy traffic (Texas Transportation Institute & Cambridge Systems, 2006). For this study, the adopted definition used for travel time reliability index is that the 95th percentile travel time is less than or equal to 95% of the sample travel times. This denotes that a greater T_{95} implies that the bus's travel time varies significantly. This suggests that the particular mode of transport under investigation is not reliable (Sen et al., 2019).

2.3 Buffer Time Index

Buffer time index (BTI) is computed based on the amount of buffer time (or cushion time) that passengers would need to add to their usual journey times that would ensure on-time arrival. The additional time is added to account for unforeseen delays (Texas Transportation Institute & Cambridge Systems, 2006). Buffer time is the difference between the average travel time and the 95th percentile of the overall travel time distribution. This is the additional time required to make up for unanticipated delays. A passenger's means of transportation is less reliable if the buffer index is high (Sen et al., 2019). Buffer time is given as follows:

$$BT = T_{95} - \mu_T \tag{1}$$

Thus, the Buffer time index is given as:

$$BTI = \frac{T_{95} - \mu_T}{\mu_T} \times 100\% \tag{2}$$

where BTI is the Buffer time index (%); T_{95} is the 95th percentile travel time; μ_T is average travel time.

2.4 Planning Time Index

The Planning Time Index (PTI) is obtained by dividing the 95th percentile travel time by the free-flow travel time. Less reliable modes of transportation are those with higher planning time indices. This occurs when the percentile values are less. The Planning Time Index is defined as a factor added to free flow time to ensure that the on-time arrival is met 95% of the time (Pu, 2011). When the PTI value is high, it denotes that there is unreliability amounting to the existence of variance in travel time. The equation below summarises this definition.

$$PTI = \frac{T_{95}}{T_f} \tag{3}$$

where T_{95} is the 95th percentile travel time, and T_f is the free flow travel time. The free flow travel time refers to a scenario in which a vehicle is not constrained by the speed of other vehicles in its lane or the lane adjacent to it (Dowling, 1997). This definition is adopted for analysis of free flow conditions for urban interrupted facilities.

2.5 Travel Time Reliability (Statistical Index)

This measure stems from the traditional statistical measure of reliability, which is a function of mean and standard deviation. Travel time reliability is obtained by dividing the mean travel time from observations by the standard deviation (Sen et al., 2019). This definition captures the variation of travel that occurs within the same day a journey undertaken throughout a route or a segment of a route. According to this definition, a higher value denotes more reliability (Liu & Sinha, 2007). The formula can be written as follows:

$$TTR = \frac{\mu_T}{\sigma_T} \tag{4}$$

where TTR is Travel time reliability, μ_T is the mean travel time and σ_T is the Standard deviation.

3. METHODOLOGY

3.1 Study Design and Data Collection

The overall research design process is described in Figure 2.

The study design described in Figure 2 below aligns with the 5-step methodical approach proposed by the FHWA (Texas Transportation Institute & Cambridge Systems, 2006).

The study was conducted in the city of Johannesburg over 14 days between June and July 2022. Two Rea Vaya Bus corridors are considered in the study. The first corridor is 15.93 km which starts from Johannesburg theatre station to Orlando Station shown in Figure 3 below. The second corridor is 13.83 km and runs from Johannesburg theatre station to Beyers Naude & Edward West bus stop which is shown in Figure 4.

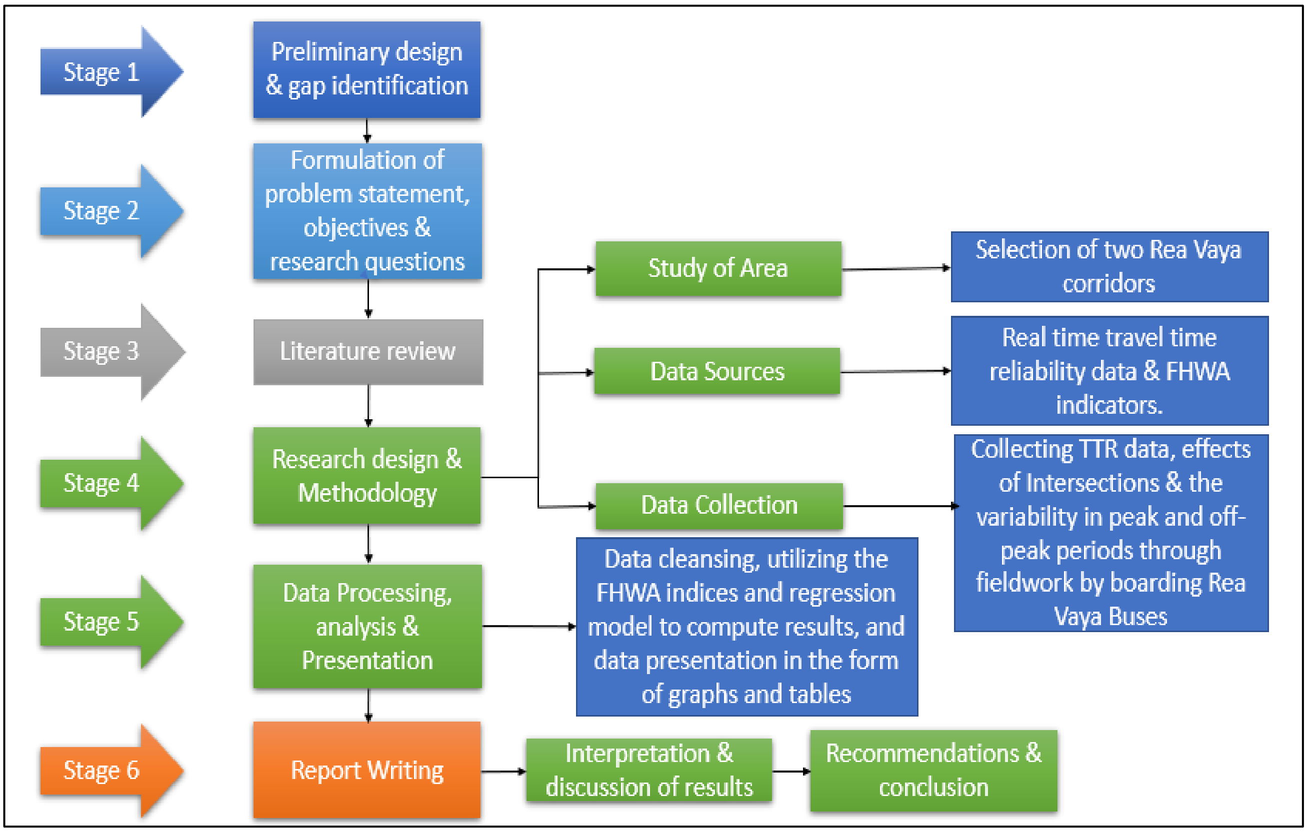
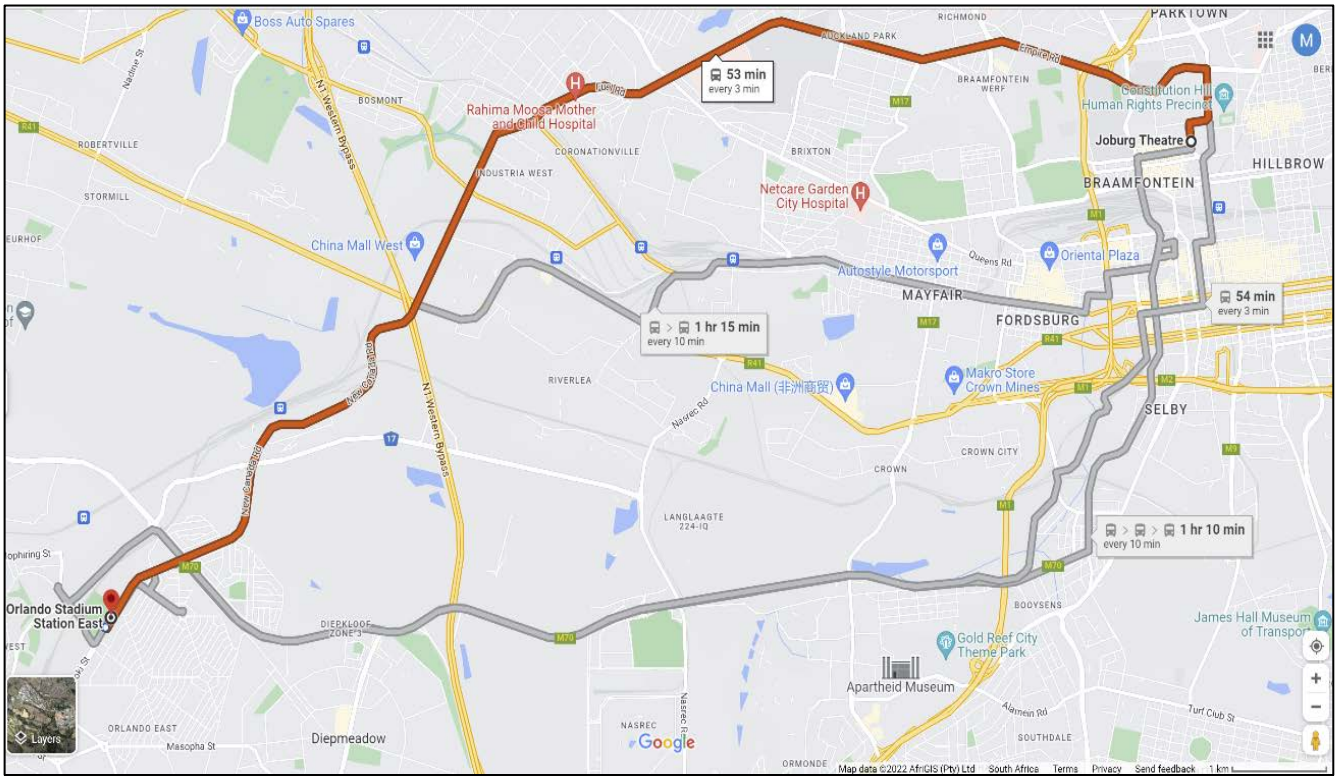
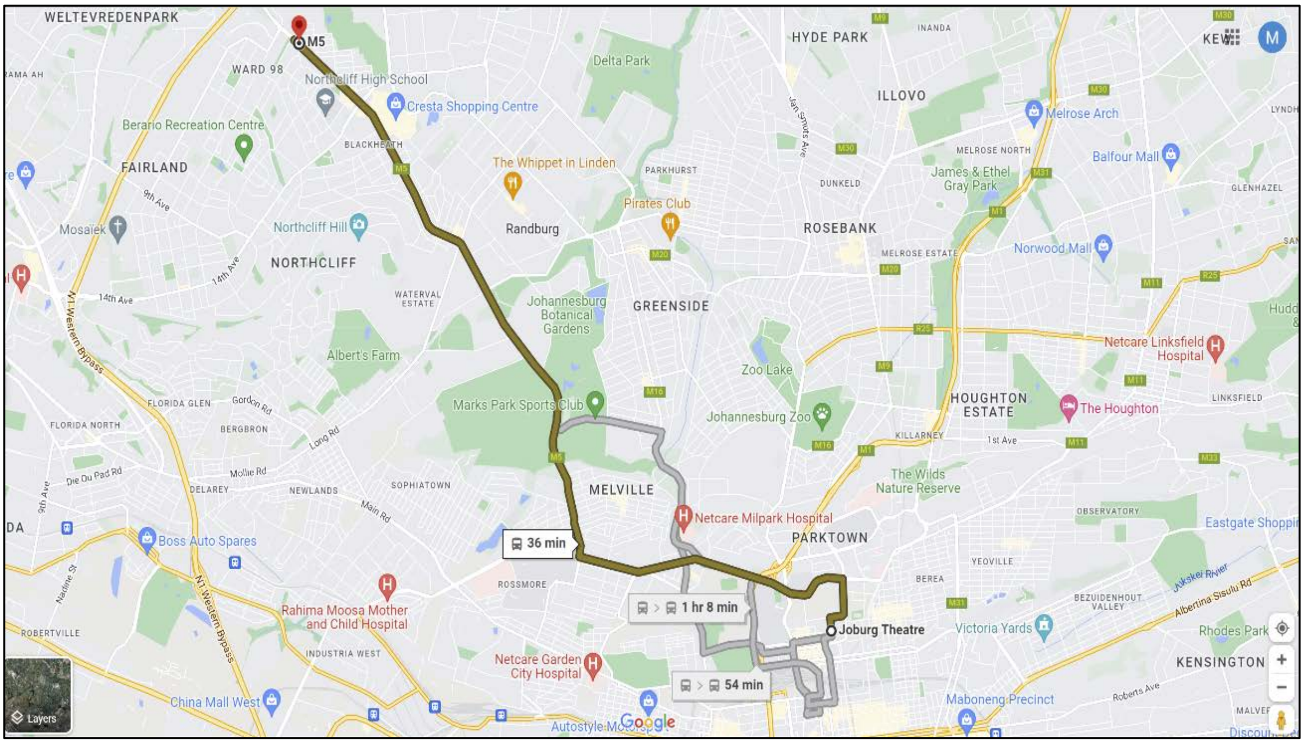


Figure 2: Study design



Source: Google Maps

Figure 3: Joburg Theatre to Orlando Stadium route



Source: Google Maps

Figure 4: Joburg Theatre to Windsor West route

Travel time data was collected via onboard surveys from origin to destination along the two selected corridors for morning peak and off-peak periods. For the morning peak period, data was collected between 06:00 – 08:00 am, while the off-peak data collection period was between 10:00 am – 12:00 noon. Data was collected by a team of two researchers for two weeks (1 corridor per week). The instruments and tools for the survey include the use of Google Maps in which bespoke routes were created to track the location of the bus as it journeyed through various intersections, stations, and bus stops. Tracking applications such as My Tracks and RunKeeper were also used to track the bus location. In conjunction with the abovementioned instruments, a stopwatch was used to capture the arrival and departure times as well as the passenger boarding or aligning times at every stop. The time spent at every road intersection (intersection delays) was also recorded. Other road observations such as the pavement condition of the road segment between stops or intersections were also recorded. Unforeseen stops or delays due to mechanical breakdowns, accidents, roadworks, etc. at road segments as well as the nature of the infrastructure (such as the number of lanes) between stops or intersections were also recorded. The length of the road segment between stations was also recorded during field observation. All this information was captured using a customized data collection sheet designed for the study. The collected data was then entered into Microsoft Excel and processed. Using the previously discussed travel time reliability indices, travel time reliability was measured for each corridor. It was imperative to also determine free flow speed along the corridors. Free flow speed was established by considering the corridor as an interrupted flow facility (Moses & Mtoi, 2013) and using models proposed in the Highway Capacity Manual (HCM 2010). Analyses of data were performed and conclusions were drawn regarding the various travel time components, reliability and the critical factors that affect travel times during peak and off-peak periods.

4. RESULTS & DISCUSSION

4.1 Travel Time Distribution for Peak and Off-Peak Periods

The stacked bar chart below shows the distribution of the travel time components as recorded from the onboard survey of the two corridors. Captured in each stacked bar is the total time at intersections, total vehicle running time and the total boarding & alighting time. The running time indicates the time the buses are in motion between each stop. The summation of the times taken to traverse each segment (distance between stops) gives the total running time.

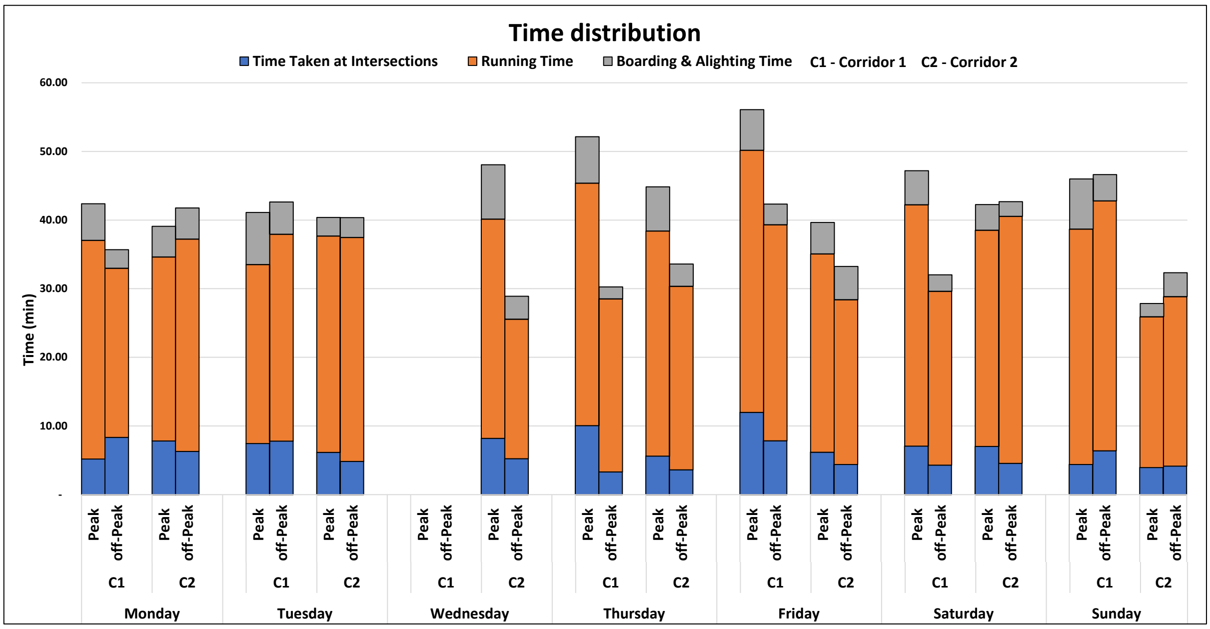


Figure 5: Distribution of travel time for morning peak and off-peak periods

In the peak periods for Corridor 1, the total time taken for boarding and alighting of passengers at stations is about 6 minutes on average which is about 13% of the total travel time. Total delay at intersections is found to be slightly higher at about 8 minutes or 17% of the total travel time. The average running time is found to be about 33 minutes. Compared to off-peak periods, the total time taken for passengers to board and alight at stations during off-peak periods on Corridor 1 is 3 minutes on average or 8% of the total travel time while intersections delay time is about 6 minutes or roughly 16% of the overall travel time. Running time for morning off-peak is slightly less at 29 minutes compared to the 33 minutes observed during the peak period. These are very reasonable considering that traffic levels were expectedly higher during the peak period. It must be emphasised that data was not collected for Corridor 1 on Wednesday due to bus workers' industrial action that led to disruption and non-availability of service for that day. However, data collected in the days following the disruptions are quite consistent with those collected before the disruption as reflected in Figure 5.

For Corridor 2, the time taken for boarding and alighting passengers at stations during peak hours is about 5 minutes or 13% of the total travel time. Intersections delay is about 6 minutes or 15% of the total travel time. Running time for this Corridor is also about 29 minutes. During the off-peak periods for corridor 2, it is evident that the time taken for boarding and alighting passengers at stations is about 3 minutes or 8% of the total travel time. Approximately 14% of the total travel time or 5 minutes is spent at intersections during off-peak periods while the running time is about 28 minutes for this corridor. It must be emphasised that these figures are the averages of the daily records presented in Figure 5.

4.2 FHWA Travel Time Reliability Indicators

Using the data collected, the travel time reliability of the two Rea Vaya corridors was measured using the FWHA indicators previously discussed in Section 2. These include the 95th percentile travel time, travel time index, buffer time index, and planning time index. Table 1 below presents the indicator values.

Table 1: FHWA Travel Time Reliability Indices for Morning peak and off-peak periods

FHWA Reliability Indicators	Corridor 1		Corridor 2	
	Peak	Off-Peak	Peak	Off-Peak
95th percentile travel time (minutes)	37.46	36.34	33.79	34.96
Travel time index	1.11	1.02	1.05	0.96
Buffer time index (%)	11.95	18.09	11.20	25.39
Planning time index (%)	1.24	1.20	1.17	1.21

From the table, the 95th percentile travel time during the peak period for Corridor 1 is slightly higher than that for off-peak. The travel time index for both corridors 1 and 2 during peak and off-peak hours is greater than 1. This indicates that there is a repeated occurrence of congestion conditions. The morning off-peak planning time index values for corridors 1 and 2 were computed to be 1.20 and 1.21 respectively, whereas the morning peak values for both corridors were found to be 1.24 and 1.17. The planning time indices are less than 1.3 for both Rea Vaya corridors. The planning time indices represent that factor that should be applied to free flow travel time to ensure that on-time arrival is met 95% of the time (Pu, 2011). The higher the value of the PTI, the less reliable the system is from a travel time perspective. Some studies have proposed a PTI value of 1.3 as a benchmark for reliability such that values higher than this are considered to be unreliable systems. Therefore it is concluded that the Rea Vaya Buses are reliable regarding travel time.

According to the buffer index values, commuters would need to add extra buffer time (6.3 minutes for corridor 1 and 7.1 minutes for corridor 2) to the average travel time for the morning off-peak period to be punctual and reach their destination on time. This may be because the two corridors run every 15 minutes and 20 minutes respectively during the morning off-peak period, and every 10 minutes and 8 minutes respectively, during the morning peak period, causing reliability to decrease as the buffer index increases. Due to fewer buses operating during off-peak periods and more buses operating during peak periods, both corridors 1 and 2 had longer bus arrival delays during the off-peak period and shorter bus arrival delays during peak periods.

4.3 Travel Time Reliability (Statistical Indicator)

Using equation 4, the travel time reliability value was calculated based on the observed average travel time from the survey.

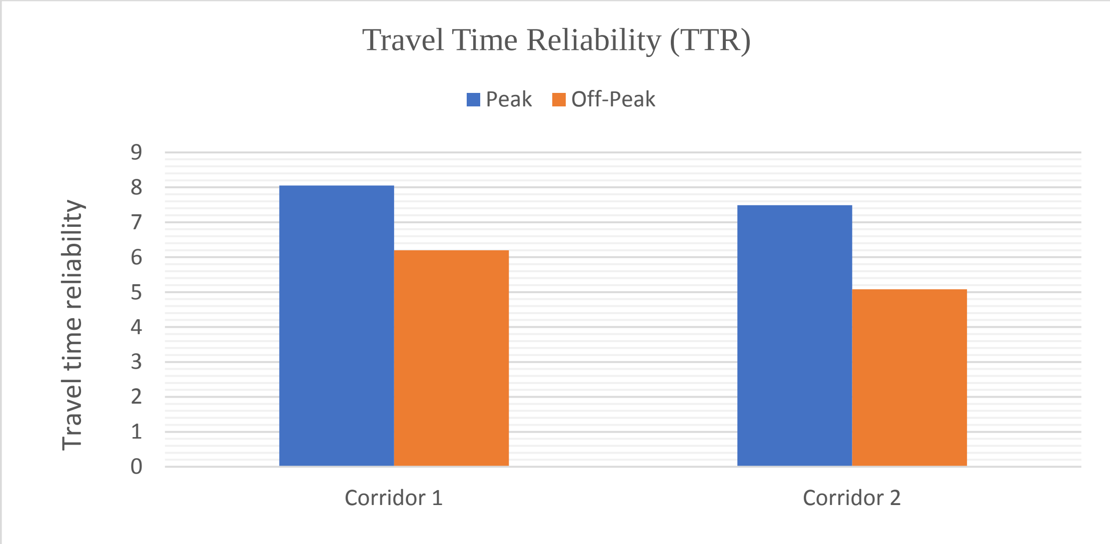


Figure 6: Travel time reliability of Corridors 1 and 2 for morning peak and off-peak periods

The Travel time reliability values for Corridor 1 and Corridor 2 for the morning peak period are 8.05 and 7.49 respectively, which is higher than the morning off-peak period which was determined to be 6.20 for Corridor 1 and 5.08 for Corridor 2. Considering that TTR values decrease when the variance increases and vice versa, higher TTR values imply a higher level of reliability. From the collected data, the morning off-peak period was observed to have higher variance (or deviation) resulting in a low level of reliability when compared to peak period data.

4.4 Survey Findings on Other Factors That Affect Bus Travel Times

The independent variables for this study were found during data collection and some form part of the characteristics of the Rea Vaya Bus Transit System. Features such as transit signal priorities were found to minimize intersection delay except on the arterial route of Corridor 2 which led to a low travel time reliability. The number of stations was seen to have an effect on travel time rather than the number of bus stops that a corridor would have. This is also because there were more Rea Vaya passengers at the stations waiting to board the bus than there were at the bus stops. Pre-boarding fare collection was effective in minimizing the time spent waiting to pay the bus driver which reduced travel time. Another critical observation was the impact of load shedding on travel times along the corridors. It was observed that delays at intersections were longer during signal system downtimes. Obstructions caused by the encroachment of other motor vehicles on Rea Vaya bus lanes also resulted in delays.

The occurrence of a protest affected the data collected, as no Rea Vaya buses operated during the morning peak and morning off-peak periods. Construction work was also a factor that slightly affected the travel time as drivers had to find a way to manoeuvre through traffic in such situations. Road grade is another factor that affected travel time, as speed reduction was often observed when the Rea Vaya bus went uphills. Such speed reduction at uphills will mainly introduce variability in the travel time if it varies with the occupancy level of the bus. However, the actual extent to which speed is affected by grade and bus occupancy is beyond the scope of this study, and therefore not captured in the survey. Concerning the variability in peak and off-peak periods, more time is spent at road intersections on Corridor 1 during peak hours compared to off-peak hours. This could be attributed to more traffic during peak hours than off-peak hours. Additionally, the boarding and alighting time were far higher during peak hours compared to off-peak hours. While the overall travel times were higher for peak periods compared to off-peak, there was lower variance during the peak hours resulting in higher travel time reliability.

5. CONCLUSION

This study investigated the travel time reliability of two corridors of the Rea Vaya BRT service using field data collected through an onboard survey. Although numerous indicators have been developed by researchers over the past few decades, this study specifically employed four of the FHWA indicators as well as the traditional statistical reliability measure to quantify travel time reliability. In addition to measuring reliability, the study also investigated the factors that contribute to travel time and the reliability of the system. The survey revealed that travel times are impacted by both operational features and infrastructure. Infrastructure features such as transit signal priorities were found to minimize intersection delays for bus operations. The exception is however on Corridor 2 which incidentally, was found to have a lower reliability level compared to Corridor 1. In situations where the traffic signal systems were not operational due to the load-shedding, travel times were seen to be affected as a result of the long delays at the intersections. Obstructions caused by the encroachment of other motor vehicles on dedicated Rea Vaya bus lanes also resulted in delays. The number of major stations was seen to have more effect on travel time rather than the number of bus stops (other than stations) that a corridor would have. One explanation for this is that there are more Rea Vaya passengers at the stations waiting to board the bus than there were at the bus stops. Pre-boarding fare collection was also observed to be effective in minimizing delays as the total time spent waiting to pay the bus driver is significantly reduced or eliminated.

The Rea Vaya schedule was compared to the data collected. There is a travel time difference of 17.5 minutes and 22.15 minutes for the morning peak and morning off-peak periods respectively for corridor 1. Corridor 2 was found to have a 6.7 minutes travel time difference during the morning peak period and an 8.1 minutes travel time difference during the off-peak period. One explanation for the difference between scheduled and actual travel time is that scheduled travel time assumes the scenario where there is boarding and alighting at every stop. However, actual travel time will depend on the number of actual stops made by a bus on any given trip. Thus, the number of stops has a significant effect on travel time.

Corridor 1 and Corridor 2 have travel time reliability values for the morning peak period as 8.05 and 7.49, respectively. These values are greater than those for the morning off-peak period, which were calculated to be 6.20 for Corridor 1 and 5.08 for Corridor 2. The Rea Vaya buses were not particularly reliable during the morning off-peak period as the morning peak period showed minimal fluctuation in travel time while the morning off-peak period showed significant variation in travel time. Considering that peak-period travel is more significant as more commuters are served during this period, it can then be concluded that the Rea Vaya bus service is reliable from a travel time perspective. The schedules were also found to overestimate travel time compared to the average travel time obtained when conducting onboard surveys. Again, this gives some buffer time for trip makers to accommodate unexpected delays. Some factors that were found to impact travel time such as dedicated bus lane infringement by other vehicles could be addressed through proper monitoring and control of the infrastructure.

Although only two corridors were investigated in this study with a relatively short data collection period of two weeks due to the limited time and resources available for the project, the approach implemented could be further replicated to investigate more BRT corridors and other public transport modes such as the metro rail, regular bus and the minibus taxi.

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