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Travel time reliability – a comparative assessment of formal and informal public transport in Johannesburg, South Africa

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Abstract

Travel time reliability is a transport system performance measure that captures the level of consistency or variability in travel time from origin to destination by any mode of transport. This paper presents an investigation of travel time reliability for the formal Bus Rapid Transit (BRT) and the informal paratransit (minibus taxi) services running on a common corridor in Johannesburg, South Africa. Paratransit and the BRT are two major modes of public transport in major cities in South Africa like Johannesburg. This study employs field collection of travel time data through on-board surveys along bus corridors with parallel BRT and paratransit service. Among the objectives of the investigation is to quantify the travel time reliability of these two modes using a set of reliability indicators proposed by the Federal Highway Administration (FHWA) US Department of Transportation. The study also aims to gain some insight into the critical factors that impact delays and overall travel time for the modes and to propose some measures that could improve reliability. The implication of the measured travel time reliability indicators for overall journey time planning for trip makers and bus operators is also discussed.

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Keywords: Travel time reliability; Public transport; Paratransit; Bus Rapid Transit; Johannesburg

1. Introduction

Public transportation plays a key role in the economic development of cities and regions. Johannesburg, a major economic hub in South Africa, experiences high levels of vehicular congestion in most of its urban road network, especially during peak travel periods. As recognized in the literature on urban mobility, a modal shift from car to public transportation has some potential to address vehicular congestion in cities. Therefore, an effective public transportation system is crucial if planning objectives of achieving a modal shift from automobile to public transport are to be realized. One of the measures of effectiveness is the reliability of the system. The reliability of any mode of transportation has a direct influence on mode choice among travellers (Lyman and Bertini, 2008). For public transportation, reliability can be associated with the various operational aspects of the system that contribute towards overall service quality. Alkubati, Khalifa and Al-barakani (2023) provide a comprehensive discussion of various public transport reliability components and variables.

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Travel time reliability is one of the measures of transport system performance that describes the level of consistency in travel time from origin to destination from day to day and/or across different times of day (Texas Transportation Institute and Cambridge Systems, 2006). In public transport operations, numerous factors contribute to delays and overall travel time. Understanding the anticipated travel time to complete a journey by public transport and the expected variation in travel time can be useful to various stakeholders such as the planning authority, service provider and the end-user or trip-maker (Taylor, 2013). Although trip makers usually anticipate delays due to congestion and other unforeseen conditions, there is an expectation of some consistency in travel time. Measures of travel time reliability have been considered to be a better representation of user experience than the simple average travel time (Texas Transportation Institute and Cambridge Systems, 2006). For the formal public transport system with operations schedules, travel time reliability can inform both users and operators of the level of deviation between expected travel time according to public transport schedules and the actual travel time for different periods of the day. Furthermore, understanding the factors that drive the variation in travel time is equally vital for planners and operators of the system.

The objectives of this study are: 1) to carry out empirical observation of travel time for the BRT (referred to as the bus) and paratransit (minibus) systems running on a common corridor in Johannesburg; 2) to apply existing reliability measures in a comparative assessment of travel time reliability between both modes, specifically looking at the variability that exists between peak and off-peak travel periods and; 3) gain some insight into the critical delay components that affect overall travel times along the corridors.

2. Literature review

2.1. Travel time reliability- Definition and measures

Travel time reliability has been defined in many studies in multiple but similar ways. Sen *et al.* (2019) described reliability in the context of transportation systems as the level of variability between the user's expectation and their experience. It has also been described as the probability of completing a trip within a specified time interval (Susilawati, Taylor and Somenahalli, 2010). A broader characterization of travel time reliability describes it as the level of consistency of transportation services for a given trip, mode, route, or corridor for a given period (Susilawati, Taylor and Somenahalli, 2010). Furthermore, travel time reliability has been viewed from three different perspectives: day-to-day variability, variability over the day, and vehicle-to-vehicle variability (Büchel and Corman, 2020). The day-to-day variability refers to variability between similar trips, within the same period, or on different days. The variability over the day refers to variability between vehicles making similar trips at different times in the day. The vehicle-to-vehicle variability refers to a comparison of travel times of two subsequent vehicles (Büchel and Corman, 2020).

Several factors affect the travel time reliability of public transport. These factors can be classified as short-term or long-term factors. A typical example of a short-term factor is road incidents such as accidents, while that of a long-term factor will include things like road rehabilitation. Factors can also be classified as endogenous or exogenous factors. Endogenous factors describe internal factors such as route specification, scheduling duties and operator behaviour, whereas exogenous factors describe external factors such as traffic signals, traffic jams and traffic incidents (Moosav*i et al*, 2020). There have been various travel time reliability measures developed over the years which have been employed in the literature to assess the performance of public transport. Most of the measures rely on the day-to-day distribution of travel times on specified routes (van Lint, van Zuylen and Tu, 2008). The measures are categorized in Lomax *et al.*, (2003) and van Lint, van Zuylen and Tu (2008) as statistical range measures, tardy-trip measures, buffer time measures and probabilistic measures. The statistical range methods consider the travel time windows in the form of the expected travel time plus or minus a factor multiplied by the standard deviation. The buffer time indices are a representation of the extra percentage of travel time due to the variability of travel time on a trip that a commuter should take into account to arrive on time. The tardy-trip measures express the travel time unreliability using the number of trips that result in late arrivals. This measure makes use of indices such as the misery index "which takes the difference between the average travel time of the 20% worst trips with the overall travel time average" (van Lint, van Zuylen and Tu, 2008). Lastly, probability-based measures express travel time reliability in terms of probability distributions.

The Federal Highway Administration (FHWA) prescribed measures of travel time reliability consisting of the buffer time, buffer time index, planning time, planning time index and the 95th percentile travel time index (Texas Transportation Institute and Cambridge Systems, 2006). These measures have been applied in various studies to quantify the travel time reliability of transport systems. A study by Susilawati, Taylor and Somenahalli (2010) made use of the planning time index, the travel time index, and the buffer index for ten corridors in the Adelaide metropolitan area in Australia. The buffer time is the difference between the 95th percentile travel time and the average travel time in a given set of observations. The 95th percentile is used to show the travel time which is less than or equal to 95% of the travel times recorded in the sample. The buffer time index expresses the relationship between the buffer time and the average travel time as a percentage. The planning time index is the additional travel time of the 95th percentile trips to arrive on time (Susilawati, Taylor and Somenahalli, 2010). Another study by Chepuri *et al.* (2018) on the travel time reliability of bus routes in India utilized GPS-trajectory data of bus trips and estimated reliability indices such as the planning time index and the buffer time index. Statistical distribution such as the generalized extreme value (GEV) distribution was also employed in explaining the variability in travel time. A similar study by Se*n et al*. (2019) for the case of Kolkata made use of five standard measures prescribed by the Federal Highway Administration (FHWA) as well as a statistical reliability index. The study defined the statistical reliability index as the ratio of the mean travel time to the standard deviation. The higher this value is, the more reliable the transport system was considered. Other studies such as Chepuri *et al.* (2018) have also employed similar measures.

This study adopts the FHWA measures as well as the statistical reliability index in quantifying the travel time reliability of the BRT and paratransit systems in Johannesburg. The approach employed involves field collection of travel time data through on-board surveys, which allows for consideration and quantification of different delay components of the overall travel time.

2.2. Public Transport System in Johannesburg South Africa

A study of Johannesburg's BRT system (also known as the Rea Vaya Bus) investigated the distribution of the city's public transport trips and observed that the informal paratransit (minibus taxis) carry 50% of the total public transport trips. The other 50% comprises 32% from the Metrorail, 6% from the formal subsidized commuter bus services, 5% from formal urban public bus services (the Metrobus), 4% from the Gautrain and 3% from the Rea Vaya (Scorcia and Munoz-Raskin, 2019). The study compared the operational indicators of the Rea Vaya with its Latin American siblings. It was concluded that the performance of the Rea Vaya Bus (like its Latin American siblings) was affected by the presence of parallel informal services which were a more competitive alternative as well as the awareness of potential users regarding how to use and navigate the system. However, the most significant factor affecting the performance was the demand patterns – these patterns are a result of the unusual form of Johannesburg which is characterized by long distances between townships and economic opportunities (which are found in the city centres) and uneven population distribution with a wide variation of densities along the BRT corridors (Scorcia and Munoz-Raskin, 2019). An analysis of the quality of public transport in Johannesburg was conducted in 2020 with the use of the Servqual model (Luke and Heyns, 2020). It was performed by comparing the commuter's perception of the current service levels with their expectations. The study concluded that the minibus taxi reliability scores were relatively high. This is believed to be due to minibus taxi users not perceiving differences in the reliability of the services as compared to the Metrobus and Rea Vaya (Luke and Heyns, 2020). This could be because they work under similar conditions as minibus taxi drivers often use the bus priority lanes whose use has proven to possibly reduce travel time by up to 50% during peak hours (Johannes du Preez and Venter, 2022). Another reason for the high-reliability score of minibus taxis could also be due to minibus taxi users not having as high an expectation of reliability for the minibus taxis as they do for the Rea Vaya buses, as they are new and therefore expected to be in considerably better shape (Luke and Heyns, 2020). The results of this study could be considered subjective as they are based on the user's expectation and perception of reliability. A measurement parameter of public transport that could be more precise is the travel time reliability.

3. Methodology

3.1. Case study description

Johannesburg is the largest city in South Africa with an estimated 4.8 million residents and 1.84 million households according to the latest 2022 census report by Statistics South Africa. The population of the city is spread over a surface area of 1645 square kilometers. The Bus Rapid Transit system also known as the 'Rea Vaya' operates along the major transport corridors in the city. This study considers one of the existing corridors, the 'C4' corridor, which runs from Windsor West (a mixed residential and commercial suburb) to Braamfontein in the central business district. The selected route runs from Park Station (in Braamfontein) to Cresta Mall through Beyers Naude main road, with a total distance of about 13.3km. This route was selected as it covers a variety of residential and commercial areas and gives a good indication of the traffic situation in Johannesburg. A small portion of the route runs on dedicated BRT lanes which are mostly also utilized by the minibus taxis.

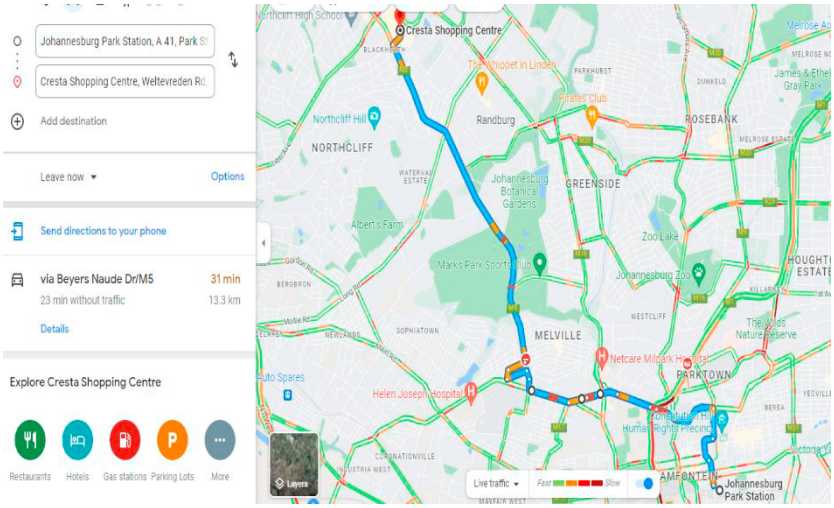


Figure 1: BRT Route considered in the study (map data © Google)

The minibus route investigated also follows a similar route as the BRT, with only a slight difference in distance as both modes do not have their final destination at the same stop point. Another aspect of the minibus operation that affects route distance is random route altering by drivers mostly to avoid traffic congestion. The difference in route distance does not affect the comparative assessment of travel time reliability of both modes as the focus is on variability in travel time rather than actual travel time. However, the discrepancies allow for the study of route choice and its effect on travel time reliability.

3.2. Data collection

Travel time data was collected via on-board surveys from origin to destination along the selected corridor for morning peak and off-peak periods. For the morning peak period, data was collected between 06:00 am and 08:00 am, while the off-peak data collection period was 10:00 am -12:00 noon. Data was collected by a team of two researchers with the aid of a handheld GPS tracker and stopwatch. Between origin and destination points, the following information was collected: departure time from the origin, arrival and departure time at each stop along the route, number of stops made, arrival and departure times at intersections, and delays due to any road incidents such as roadworks or accidents. Data is recorded separately for both the onward and return legs of the trips by BRT and by Minibus taxi.

3.3. Computing travel time reliability

As mentioned in Section 2, the statistical reliability index and two of the FHWA measures (buffer time index and planning time index) were considered for travel time reliability measurement in this study. The statistical reliability index is computed as the ratio of the mean travel time to the standard deviation, given by

$$\mathrm{RI} = \frac{\mu_t}{\sigma_t} \tag{1}$$

Where RI is the statistical reliability index; μ_t is the mean travel time in minutes; σ_t is the standard deviation of the mean in minutes. The higher the value of RI, the more reliable the mode is, from a travel time perspective.

The mean travel time is computed as

$$\mu_t = \frac{\sum_{i=1}^{n} x_i}{n} \tag{2}$$

Where μ_t is the mean travel time for n number of trips from origin to destination, and x_i is the travel time of the i^{th} trip.

Similarly, the standard deviation is given by

$$\sigma_t = \left[\frac{\sum_{i=1}^{n}(x_i - \mu_t)^2}{n-1}\right]^{1/2} \tag{3}$$

The Buffer time index is given as the ratio of the buffer time to the mean travel time expressed as a percentage. The buffer time is the difference between the 95th percentile travel time and the mean travel time from the observation. Buffer time as discussed in Section 2, represents the additional time that should allow for delays that are not anticipated.

$$BI = \frac{t_{95} - \mu_t}{\mu_t} \times 100\% \tag{4}$$

Where BI is the buffer index and t_{95} is the 95th percentile travel time. A low buffer index is indicative of high travel time reliability and vice versa.

The Planning time index is the total time needed to plan for an on-time arrival 95% of the time and is computed as the ratio of the 95th percentile travel time (the planning time) to the free-flow travel time (Lyman and Bertini, 2008).

$$PI = \frac{t_{95}}{t_f} \tag{5}$$

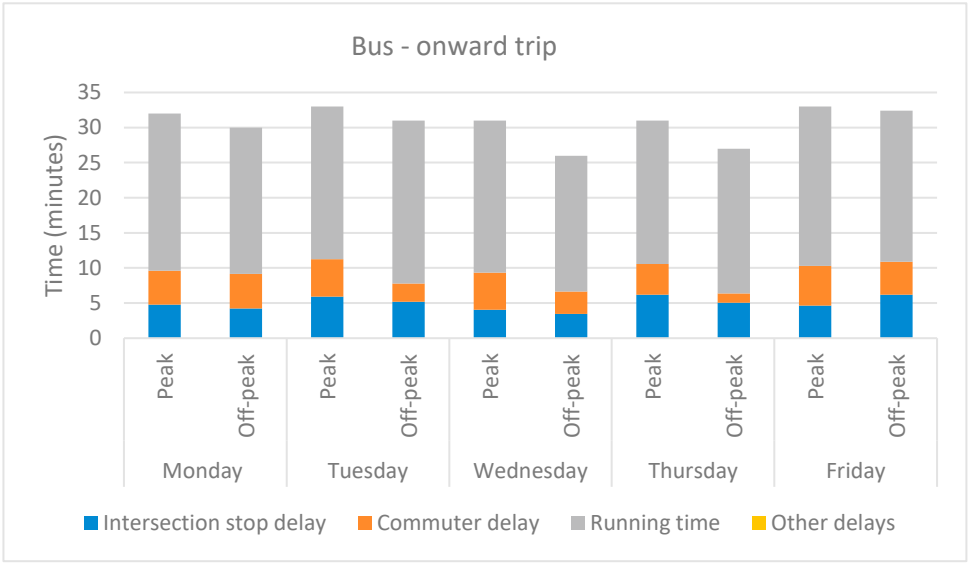
Where PI is the planning time index, and t_f is the free-flow travel time. The free-flow travel time represents the time it would take to make a trip under uninterrupted flow conditions in light traffic. This is complex to determine for public transport in urban roads. For ease of computation, a simplified estimate is utilised and is computed as the ratio of the route distance to the speed limit of the road.

The planning time or the 95th percentile travel time t_{95}, is the sum of the buffer time and the mean travel time.

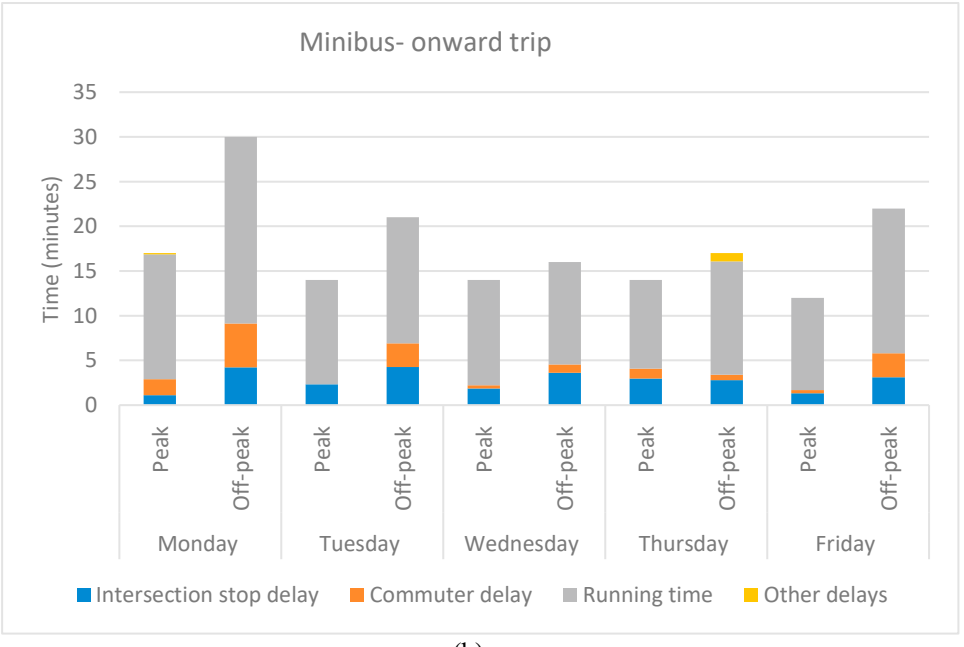
4. Results and Discussion

4.1. Distribution of travel time components

Travel time was observed for a period of one week in 2022 for bus and minibus systems. The travel time components from the onboard observation include the running time between road segments, the delays at intersections, commuter delays (due to boarding and/or alighting) and other delays due to road incidents. Presented in Figure 2 is the distribution for travel time for the onward trip leg for bus and minibus.



(a)



(b)

Figure 2: Observed travel time components for (a) bus and (b) minibus

From visual observation of Figure 2, it is seen that there is more consistency in the overall travel times recorded daily for the bus system compared to minibus. The analysis of reliability of travel times is further discussed in the next subsection.

4.2. Travel time reliability

Based on the travel time data collected for peak and off-peak periods over one week (weekdays only), the indicators presented in Table 1 were computed. An onward trip is considered to be the trip from Park Station in the CBD to Cresta public transport terminal, while the return trip is the reverse from Cresta to Park Station.

Table 1: Travel time reliability indicators

Mode	BRT (Route distance =13.3km)				Minibus (Route distance = 11.6km)			
Period	Peak		Off-Peak		Peak		Off-peak	
Trip leg	*onward*	*return*	*onward*	*return*	*onward*	*return*	*onward*	*return*
Mobility indicators								
Mean travel time (min)	32	26.8	36.6	27.6	14.2	20.6	19.0	19.8
Standard deviation (min)	1.0	3.11	16.30*	1.8	1.78	2.96	2.55	1.92
Mean travel speed (km/h)	24.93	29.7	21.8	28.9	49.01	33.78	36.63	35.15
Statistical Reliability								
Reliability index (-)	32.0	8.60	2.24	15.2	7.94	6.94	7.45	10.29
FHWA Reliability indicators								
Buffer time (min)	1.0	2.95	22.90	2.0	2.20	3.60	2.80	2.60
Buffer index (%)	3.12	11.0	62.57	7.24	15.5	17.48	14.74	13.13
Planning time (min)	33.0	29.75	59.5	29.6	16.40	24.20	21.80	22.40
Planning time index	1.65	1.50	2.98	1.48	0.96	1.42	1.28	1.31

* Unusual delays due to road incident

The mean travel time is the average of the observed travel times and takes into account all the stops (and other delays) from trip origin to destination. Five observations were made for each trip leg and travel period for each mode. For buses, the mean travel time for off-peak periods is found to be slightly higher than that for peak periods. A direct comparison of travel time cannot be made between bus and minibus due to the slight difference in route distances for the two modes as indicated in Table 1. In this case, the mean travel speed is considered the better comparative indicator of mobility as it is a function of the route distance and the mean travel time. From the values presented in Table 1, the travel speed of the minibus is higher than that of the bus for each respective trip leg for peak and off-peak periods. This is within reasonable expectations considering the nature of the minibus taxi operations where the drivers usually try to avoid delays along the route using various manoeuvres and aggressive driving behaviours. Disobedience of traffic stop signals at signalised intersections is also another common practice of minibus taxi drivers to reduce delays.

The statistical reliability index (see equation 1) is computed by dividing the mean travel time by the standard deviation for each set of observations. Therefore, the higher the standard deviation, the less the reliability value and vice versa. From Table 1, it is seen that reliability is generally higher for buses compared to minibuses. The exception is the off-peak onward trip for the bus, which is seen to have a significantly lower reliability value of about 2.2. The low reliability can be attributed to the unusual delay occurring due to a vehicle breakdown that was observed for one of the five observed trips for that particular trip leg, where travel time was significantly higher than the average. Due to the relatively few (five) data points for each set of observations, an unusually higher value of travel time for one of the observations will have a significant effect on the overall reliability outcome. The reliability values for both modes according to travel periods are further shown in Figure 3.

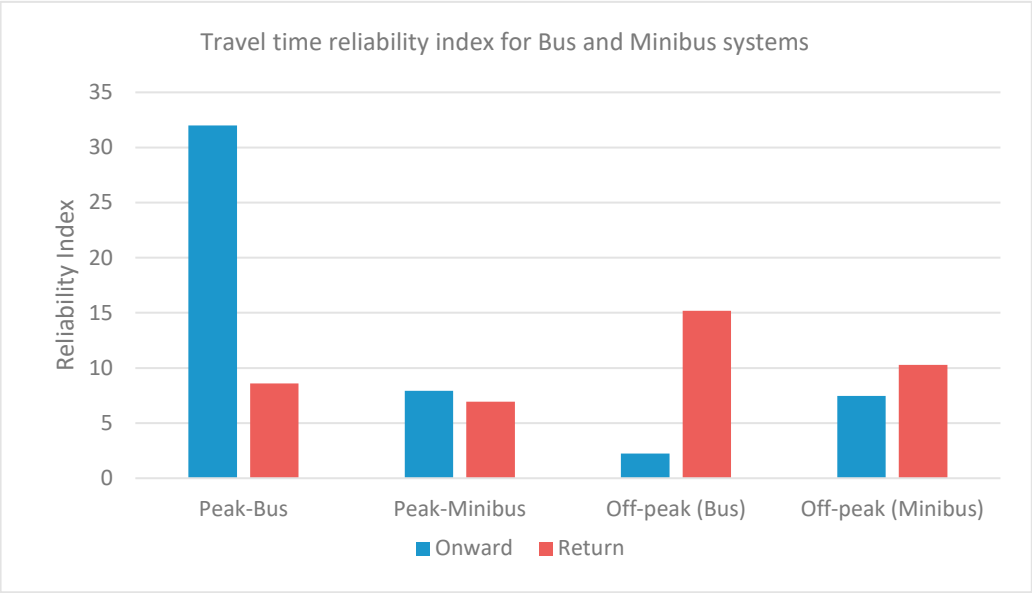


Figure 3: Travel time reliability (Statistical index) of bus and minibus

For the FHWA reliability measures, the effect of the unusual delay observed for one of the bus trips is also seen across the indicators. In terms of buffer time, it is seen that a lesser amount of buffer time is generally required for travel by bus compared to minibuses. Again, this is with the exception of the onward off-peak bus trips, where buffer time is higher due to the unusually high travel time in one of the observed trips. The buffer time index as discussed in section 3, is an indication of the percentage amount of time (from the average) that would be required to account for variability and delays. The lower the value of buffer time and buffer time index, the higher the reliability. The bus system is seen to have better reliability compared to the minibus from a buffer time perspective. The difference is however quite marginal at between 1 – 2 minutes for the various travel legs.

Planning time (or the 95th percentile travel time) is an indication of the near-worst-case travel time from a set of observations. Thus, it is the total travel time that takes into account the required buffer time. For this case, a direct comparison of planning time cannot be made between the bus and minibus systems due to the difference in route distance. However, the planning time index serves as the comparative indicator in this case since it is the normalized planning time. The planning time index in Table 1 is the planning time normalized by the free-flow travel time under uncongested travel conditions. The establishment of free-flow travel time for public transport is more complex than for private cars, as it requires detailed observation of normal operations in uncongested road conditions, which is beyond the scope of this study. For ease of analysis, the free-flow travel time was established using an assumed but reasonable free-flow speed of 40km/h. This value is less than the 60km/h free-flow speed of the roadways, but higher than the average of the observed mean speeds across the various travel legs and time periods. The free-flow travel times based on the assumed free-flow speed and the respective route distances for both modes were established to be approximately 20 minutes for buses and 17 minutes for minibuses. These values were used in computing the planning time index in Table 1. From the Table, it is seen that planning time indexes are higher for the bus compared to the minibus system for the respective travel legs and time periods. These values represent the factors of the free-flow travel time that travellers (or operators) of the system need to plan for to accommodate even the heaviest travel days.

5. Conclusion and Recommendations

The study set out to investigate and compare the travel time reliability of two major public transport modes in Johannesburg, South Africa by using existing measures proposed in the literature. A combination of the statistical reliability index and the FHWA measures were employed on travel time data collected via on-board surveys of both modes. Based on the data and the analysis presented in section 4, it is concluded that the bus system showed lesser variability in travel times and consequently, a higher travel time reliability level than the minibus for the respective travel legs. The minibus system however provides faster mobility as evidenced by the estimated average operating speeds of both modes. Among the factors attributed to this is the aggressive driver behavior of the minibus taxis, where the drivers usually make dangerous manoeuvres to avoid traffic and minimise overall delays. Although in some cases, waiting times at the start point of trips can be quite long for the minibuses as they wait for vehicles to get to capacity especially during off-peak periods, the aggressive driving and manoeuvres during the trips usually make up for those long waiting times.

In terms of peak versus off-peak period variability within each mode, it is found that the reliability of the bus system is higher for peak period compared to off-peak period only for the onward leg of the trip but lower for the return leg. A similar pattern is seen for the minibus system, where travel time reliability is higher for the peak period onward leg, but lower for the return leg. The FHWA measures like the buffer time and the planning time indexes further describe the reliability of the modes in more easily interpretable terms compared to the statistical reliability index. Buffer time as a reliability indicator can inform a traveler or operator how much additional time may be required to account for unexpected delays on days with the busiest traffic. From a commuter perspective, this could inform better presentation of travel time information than that shown purely by the standard schedules/timetables of planners and operators. From the perspective of the planner or operator, the reliability indicators could be considered in the design of schedules. Information such as the planning time for specific routes could compliment bus schedules to inform travelers on expected route travel times.

Although this study investigated one corridor, the method employed could be replicated to include any number of corridors or routes for any city. One area for improvement however is on the extensiveness of data. The study is based on a relatively small dataset with few observations. For further refinement of the results, it is recommended that more extensive travel time data be collected over a longer time frame. The key reason is that a few observations of unusual delays will have lesser effect within a large dataset with many observations compared to a small dataset.

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