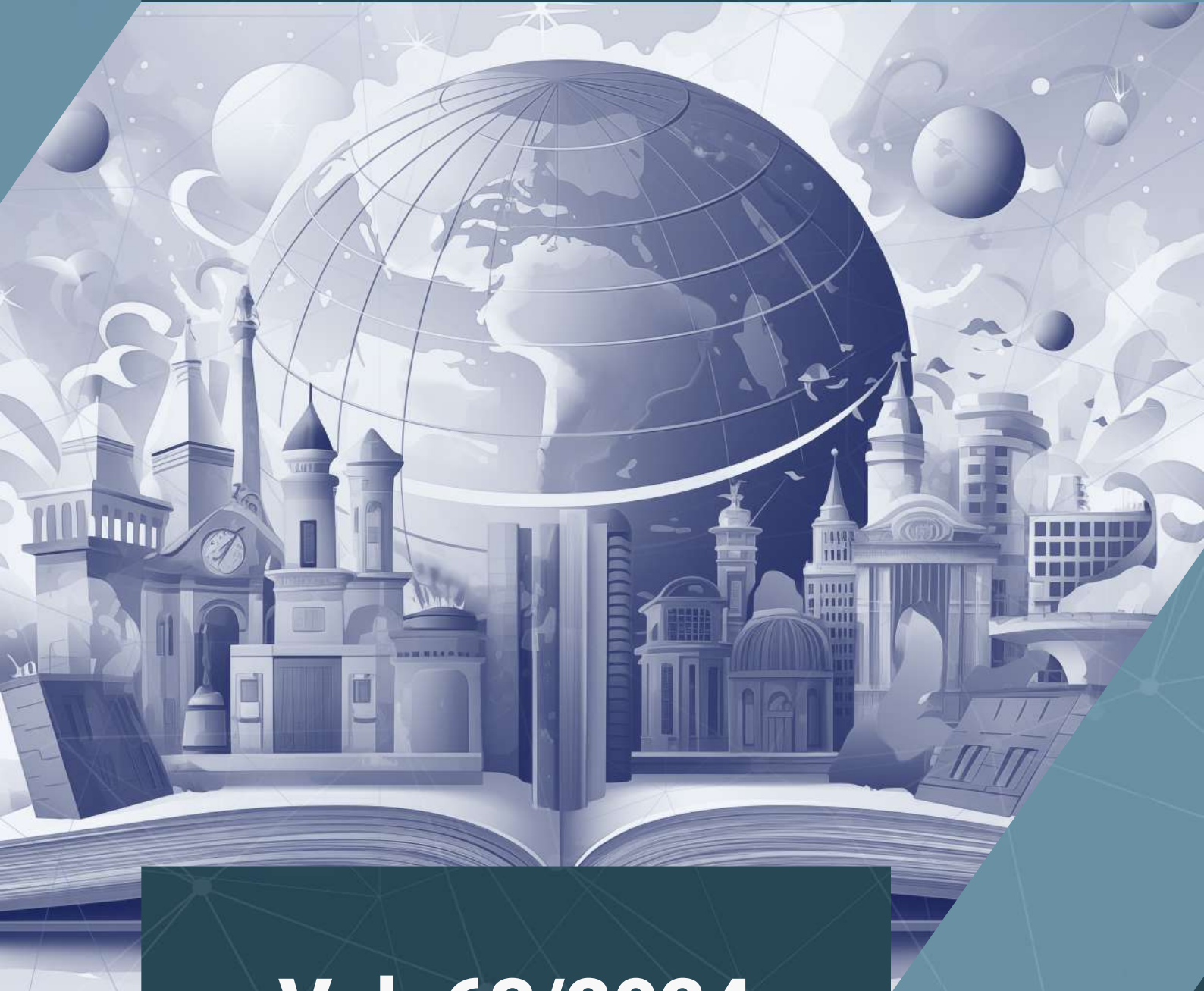




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Travel Time Reliability Analysis on Paratransit, case study: Substação-Muahivire route, Nampula - Mozambique

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Abstract. In numerous medium-sized cities in Sub-Saharan Africa, such as Nampula, the reliability of mini-bus travel time is frequently a subject of inquiry. One contributing factor to this uncertainty is the considerable number of stops made throughout the route for passenger-related purpose, including boarding and disembarking. This study utilizes data collected during off-peak periods to scrutinize the day-to-day travel time patterns of mini-buses along the route. The route has been segmented into intervals of 500 meters each, and the analysis focuses on the duration of trips at each segment. The evaluation is based on the Coefficient of Variation (CoV) of travel time, indicating the extent of dispersion in mini-bus travel time at the segment level. The results reveal that the CoVs at nearly all segments along the route are minimal, measuring less than 15%. This suggests that day-to-day variability of travel time at the segment level is negligible. However, on road segments characterized by commercial activities, the CoVs range from 15% to 22%.

Keywords. Sub-Saharan region, Mini-bus, In-vehicle travel time, day-to-day variability.

1. Introduction

The Travel Time Variability (TTV) metric assesses the on-time performance service or the uncertainty in the arrival time of buses at stops (Sun, Arr, and Ramachandran in 2003). Its evaluation involves scrutinizing the variance in journey durations along the same route within a specific timeframe (Chang in 2010, Low, Khoo, and Khoo in 2022). Transport systems characterized by erratic travel times, exhibiting substantial variations, are generally construed as unreliable. In contrast, systems that maintain consistent travel times are deemed reliable (Roy and Basu in 2021). Consequently, travel time variability serves as a fundamental indicator of the service quality of the transport system (Low, Khoo, and Khoo in 2022 and Sun, Arr, and Ramachandran in 2003).

When public transports manifest variability in travel time, they are susceptible to failing in attracting potential travelers.

Mazloumi, Currie, and Rose (2010) assert that factors contributing to travel time variation can be categorized into two groups: Demand-related factors and Capacity-related factors. Demand-related factors encompass intrinsic traffic characteristics such as traffic flow, traffic signals, and the dynamics of passenger boarding and disembarking along the route. The latter is particularly notable in public transportation operating within the informal sector, as

observed in median-sized cities of the Sub-Saharan Africa (SSA) region (Ukam et al. (2023). Capacity-related factors involve road infrastructure conditions, including the presence of accidents/incidents, route configuration, spatial location of a route, presence of side parking, and weather conditions.

In developing countries like Mozambique, where public transport service is of paramount importance, the constrained budget available for investing in traffic surveys poses a hindrance to a comprehensive understanding of the operational dynamics of their systems. Consequently, presenting a significant challenge to effective transportation planning. However, from the last decade, smartphone usage penetration rates have increased in developing countries and, researchers have increasingly explored the use of these devices for data collection purposes (Demissie et al., 2016); resulting in numerous studies on urban mobility patterns, leveraging the data generation capabilities facilitated by these devices (Demissie et al., 2016; Mazloumi, Currie, and Rose, 2010).

This study utilizes data collected through GPS-Waypoints to analyze travel time variability on public transport in the Muahivire-Substacao route. GPS-Waypoints is a surveying and mapping application designed for Android devices, accessible through the Play Store. The application utilizes the built-in location services of smartphones and external Global Navigation Satellite System (GNSS) receivers to achieve high-precision positioning of the device (<https://www.bluecover.pt/gps-waypoints/>) (accessed on October 10, 2023).

This study commences with an examination of the factors influencing the travel time of public transport under normal traffic conditions, specifically during off-peak periods throughout the entire route. Subsequently, armed with an understanding of the factors impacting public transport travel time, the route was segmented into equal lengths (500 meters), and an analysis of the travel time pattern was conducted at these segment levels. This segmentation approach facilitates a comprehensive grasp of the dynamics of public transport operations, including key points of passenger boarding and disembarking along the route and the stop patterns at the segment level.

The remainder of the paper is structured as follows: the second section comprises a literature review, providing insights into related works on the reliability of travel time in public transport services. Following this, the third section details the materials and methods employed, elucidating the processes involved in data processing and analysis. Subsequent sections, the fourth and fifth, present the results and engage in a discussion of the findings, respectively. The manuscript concludes with a summary and recommendations in the sixth and seventh sections.

2. Literature review

Travel time is defined as the duration it takes for a traveler to traverse from an origin point "A" to a destination point "B." In the context of public transport analysis, travel time can be disaggregated into distinct components, including waiting time, in-vehicle time, and transfer time (Carrion and Levinson, 2012). Waiting time pertains to the period a traveler spends at a station, awaiting the arrival and departure of a bus. In-vehicle time encompasses the duration spent traveling within the same vehicle, commencing from the moment the vehicle departs from point "A" until it reaches point "B." Transfer time denotes the time required for a traveler to transition between vehicles or modes of transport at an intermediate station.

As stated by Carrion and Levinson (2012), the prevailing traffic conditions significantly impact travel time. For instance, in the absence of traffic, vehicles can move at

free flow speed, reducing the overall travel time. However, heightened demand on traffic may introduce additional time requirements to complete the same trajectory. These variations in travel time can be categorized as either predictable or unpredictable. When travelers can anticipate travel time, they can plan their trips with a certain level of confidence. Conversely, unpredictable travel time erodes confidence in planning, as the duration becomes uncertain (Fu, 1999; Noland and Polak, 2010).

In the literature, Carrion and Levinson (2012) and Durán-Hormazábal and Tirachini (2016) propose two approaches for analyzing travel time variability (TTV): the scheduling model and the mean-variance model. The scheduling model utilizes the Preferred Arrival Time (PAT), which represents the average time interval required to complete the trip, to evaluate travel time variability (Low, Khoo, and Khoo, 2022). In contrast, the mean-variance model measures travel time variability based on observed data, irrespective of whether instances are of short or long duration (Durán-Hormazábal and Tirachini, 2016).

Numerous studies on the reliability of travel time have predominantly utilized scheduling models, where the on-time arrival, departure, and headway regularity of buses at each stop are valued by travelers (Low, Khoo, and Khoo, 2022; Mazloumi, Currie, and Rose, 2010; Yu, Yang, and Wang, 2010). This approach is reflective of scenarios where public transportation operates within a formal sector. In such systems, the number of stops along the route is pre-established and fixed, and factors contributing to variations in travel time include fluctuations in traffic volumes, traffic incidents, traffic control devices, work zones, and weather conditions (Chang, 2010; Lin, Zito, and Taylor, 2005; Ukam et al., 2023; Yu, Yang, and Wang, 2010).

However, in many developing countries, particularly in cities across sub-Saharan Africa, public transportation predominantly operates in an informal manner (Abraham et al., 2021; Demissie et al., 2016). This mode operates without a fixed timetable, allowing buses to stop at any point along the route as necessary for passenger-related purposes such as boarding and disembarking (Sietchiping, Permezel, and Ngomsi, 2012). The scheduling approach is deemed inappropriate for this context. These stops, perceived in two distinct ways within the bus operational system—problematic due to their contribution to travel time variability and convenient as they grant passengers flexibility—are not only tolerated but viewed as essential and intrinsic to the transport system by bus users, including both drivers and passengers in Nampula city.

Literature also suggests that in reliability analysis of travel time, the value attributed by travelers to the reduction of time variability in the schedule model is lesser than that given to the reduction of travel time variability in the mean-variance model. This implies that among travelers, the average time to travel from point "A" to "B" has less significance than the day-to-day variability of travel time.

While the significance of passenger-related stops in public transport operations for travel time variability (TTV) is acknowledged, there is currently a paucity of comprehensive studies analyzing the characteristics of these stops and their impact on day-to-day trip fluctuations. One possible explanation for this gap in research may be the challenges associated with collecting data on travel time and bus stops along the route.

According to Harsha, Mulangi, and Kumar (2020), studies focusing on bus travel time variation necessitate substantial data on the movement of buses within the network. Some investigations conducted in Melbourne and Brisbane in Australia, Alberta in Canada, and Surat and Chennai in India have utilized data collected through the Automatic Vehicle Location (AVL) system for analysis. The author notes that most of these studies have been

conducted in homogeneous traffic conditions with lane discipline, while studies in heterogeneous traffic conditions with weak lane discipline are comparatively scarce.

Given that the AVL system is not available on the buses used for public transportation services in Nampula, this study employs GPS-Waypoints to collect data for analysis. The data is gathered by repeatedly recording observations of trips on the same route under normal traffic conditions (off-peak, sunny days) over a span of nine days (weekdays).

This study concentrates on the off-peak period primarily because, in Nampula, even during non-peak hours, traffic conditions exhibit chaotic and heterogeneous characteristics with weak lane discipline.

The primary objective of this study is to assess the impact of stops for passenger purposes along the route on the variability of in-bus travel time. While waiting time at stops or stations is undeniably significant for the overall reliability of public transport, this study deliberately narrows its focus to in-vehicle time. In-vehicle time refers to the duration after the bus has initiated its journey. The waiting time at stops is intentionally excluded from the analysis due to its direct influence on variations in in-vehicle travel time, as noted by Chang (2010).

3. Materials and methods

3.1. This study utilizes two datasets for analysis.

The first dataset is acquired through the GPS-Waypoints app. A surveyor boards the mini-bus at the starting point (origin) and remains on board until the final destination, covering the entire trajectory of the Substação-Muahivire route in Nampula city, as illustrated in Figure 1. The app is activated as the mini-bus commences its journey and deactivated upon reaching the destination. It records the spatio-temporal location of the mini-bus at every 3-second interval from the moment of activation, capturing data such as latitude, longitude, altitude, along with the date and direction of movement.

The second dataset consists of a manual record of every instance where the mini-bus came to a stop along the route, irrespective of the reason for stopping. This dataset includes information on both the location of the stop and the reason for the stop.

These two datasets have been integrated into a unified dataset, as outlined in Table 1. The data collection occurred during off-peak periods over a span of nine days.

The Substação-Muahivire route has in total approximately 12 km and connects two residential areas, traversing through Nampula city center.

Direction	latitude	longitude	Altitude	Date	Hour	Time interval	Reason for Stop	Local
In	-15.1412	39.29395	419.7567	2022/08/24	14:45:02	3	SP	
In	-15.1412	39.29395	419.7567	2022/08/24	14:45:05	3	SP	
In	-15.1412	39.29395	419.7567	2022/08/24	14:45:08	3	SP	
In	-15.1413	39.29393	420.557	2022/08/24	14:45:23	3		
In	-15.1413	39.2939	420.657	2022/08/24	14:45:2	3		

		3		4	6			
In	-15.1413	39.2939 3	420.657	2022/08/2 4	14:45:2 9	3	SP	Destin e
In	-15.1413	39.2939 3	420.657	2022/08/2 4	14:45:3 2	3	SP	Destin e
In	-15.1413	39.2939 3	420.657	2022/08/2 4	14:45:3 5	3	SP	Destin e
...



3.2. Analytical procedure

Two distinct analytical procedures were employed for the analysis of mini-bus travel time.

In the first procedure, the study concentrates on comprehending the impact of road friction factors on bus travel time. This involves defining travel time measures and subsequently analyzing the factors influencing travel time at the entire route level. The focus is on understanding the comprehensive factors affecting travel time for the entire route.

The second procedure involves analyzing the reliability of travel time, building upon the results obtained from the friction factors. However, in this case, the analysis is conducted at the road-segment unit level, rather than the entire route level. This approach allows for a more detailed examination of the factors influencing travel time.

3.2.1. Procedure 1: Effect of the road friction factors on bus travel time (Route level)

Travel time measures

The provided data details the spatio-temporal location of the mini-buses along the route, encompassing longitude and latitude, as previously mentioned. Utilizing the Haversine equation, the distance covered by the mini-buses at each 3-second interval was calculated.

This approach allowed for the identification of instances when the mini-buses were in motion or stationary. These instances were then utilized to determine three measures of travel time: Total travel time (TT), Effective moving time (EMT), and Dwelling time (DT), as summarized in **Error! Reference source not found.**

a) Total travel time (TT) refers to the cumulative time taken by a mini-bus to complete a trip, measured from its departure from the origin until its arrival at the destination, irrespective of any stoppages along the route.

b) Effective moving time (EMT) represents the cumulative time during which the mini-buses were actively in motion throughout the trip.

c) Dwelling time (DT) is the cumulative time spent when the vehicle comes to a stop along the route after initiating the journey, regardless of the reason for the stoppage.

With each travel time measure (TT, EMT, and DT) estimated for every trip, and considering the small sample size (less than 30 observations), the Shapiro-Wilk test was applied to assess whether each measure follows a normal distribution. The results indicate that the samples for TT and DT follow a normal distribution, as evidenced by their respective *p-values* of 0.092 and 0.412.

Upon confirming that the samples for TT and DT are normally distributed and under the assumption that the average travel time and dwelling time on this route are unknown or undefined, a *one-sample t-test* was employed to assess whether the available data samples within each of these measures (TT and DT) are drawn from the same population. In other words, the test aimed to determine if there is a significant difference within the samples of each measure. The null hypothesis posits that the observed data are sampled from the same population, implying they share the same mean. However, the results of the *one-sample t-test* reject the null hypothesis, indicating a statistically significant difference in both total travel time observations (TT) with a *p-value* of $2.2e-16$, and dwelling time (DT) with a *p-value* of $1.9e-11$.

The findings of the *one-sample t-test* suggest that variability in day-to-day travel time on the Substacao-Muahivire route cannot be overlooked; there is a statistical significant variation on day-to-day travel time, even during off-peak periods.

ID	Date	Direction	TT	EMT	DT
			(minutes)		
1	8/18/202	In	42.4	28.2	14.2
2	8/18/202	Out	39.3	29.1	10.2
3	8/24/202	In	41.5	32.5	9.0
4	8/24/202	Out	42.9	31.3	11.7
5	8/25/202	In	42.8	30.0	12.8
6	8/25/202	Out	41.6	32.0	9.6
7	8/26/202	In	43.4	31.9	11.5
8	8/26/202	Out	42.7	30.4	12.3
9	8/27/202	In	42.3	33.8	8.5
10	8/27/202	Out	47.7	32.5	15.2
11	8/28/202	In	42.7	29.0	13.7

12	8/28/202	Out	42.5	30.6	11.9
13	8/29/202	In	39.0	30.9	8.1
14	8/29/202	Out	41.9	33.0	8.9
15	8/30/202	In	41.4	33.2	8.3
16	8/30/202	Out	38.9	30.2	8.7
17	8/31/202	In	44.3	40.9	13.5
18	8/31/202	Out	38.2	30.1	8.1

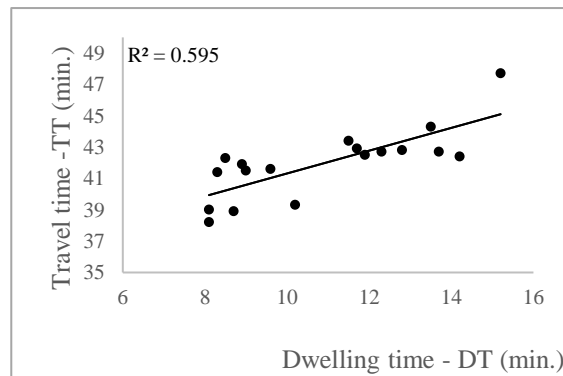
3.2.2. Factor affecting the travel time

As elucidated in the 3.1. section, instances where the mini-bus came to a stop along the journey were meticulously documented. This comprehensive documentation included the identification of factors (X's) causing the stoppage. The cumulative time spent during these stops in each trip is denoted as dwelling time (DT). Noteworthy factors identified for mini-bus stops encompass: Passenger-related stops (PRS): Encompasses all stops associated with the boarding or disembarking of passengers; Traffic light control (TLC): Designates every stop prompted by a red traffic light; Intersection (Inter.): Signifies every stop required for the passage of other vehicles at an intersection; Vehicle mechanical problems (VMP): Indicates stops resulting from mechanical issues with the vehicle; Congestion (Cong.): Refers to non-recurrent congestion that sporadically occurs during off-peak periods.

These factors serve as key contributors to the dwelling time experienced by mini-buses along the Substacao-Muahivire route.

In the urban network of median-sized cities such as Nampula, the travel time of mini-buses can be considered a linear function of dwelling time, as illustrated in **Error! Reference source not found.** Consequently, the time spent for each specific factor was aggregated, as depicted in **Error! Reference source not found.** Subsequently, a multivariate regression analysis (Equation 1) was employed to quantify the influence (β) of each factor (X) on dwelling time.

The results of the regression analysis indicate that, among all factors, only passenger-related stops (PRS) exhibit a statistically significant effect on dwelling time (DT, $\beta = 552.06$ secs, $p\text{-value} = 2.2e-16$). The impacts of all other factors are deemed negligible, as detailed in Table 3. This outcome suggests that, the primary factor affecting the variability of the DT of the mini-buses on day-to-day bases is the passenger-related stops.



$$y_i = (\beta_0 + \beta_1 X_1 + \dots + \beta_n X_n)_i + \varepsilon$$

Variables	Coefficient - β	P-Value
Constant	6.80	0.7907
PRS (Passenger-related stop)	552.06	2.2e-16*
(TLC) Traffic light control	42.20	0.2126
(Inter.) Intersection	-0.80	0.9880
(VMP) Vehicle mechanical problem	56.20	0.5093
(Cong) Occasional traffic jam	18.40	0.6783
n	42	
R-sq.	0.91	
Adj. R-sq.	0.90	
DF	41	
p-Value	2.2e-16	

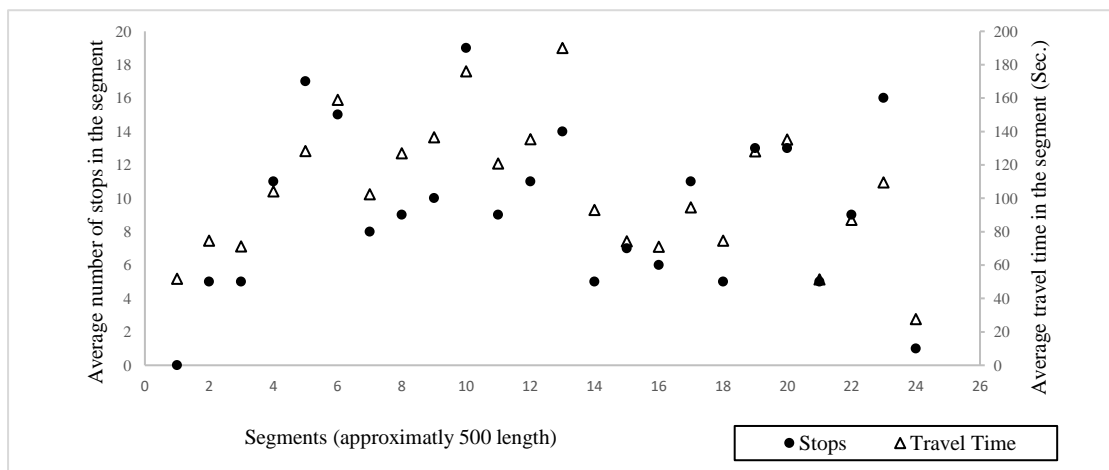
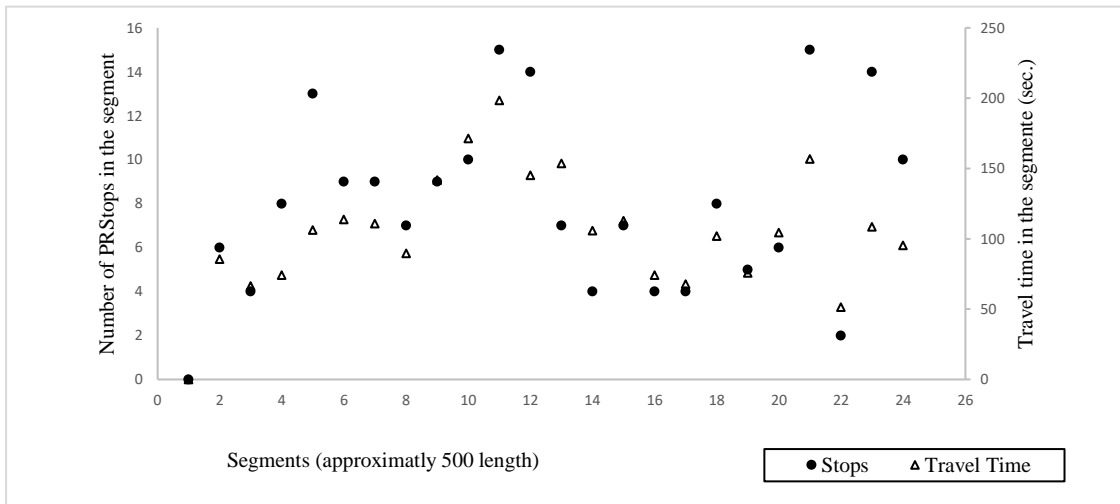
Although it is acknowledged that mini-buses may come to a stop anywhere along the route for passenger-related purposes, this study argues that these stops are not randomly distributed. Specific road segments along the route exhibit a notably higher likelihood of mini-buses coming to a stop compared to others, even though these stops are contingent on passenger demand.

In contrast to the previous analysis that considered friction factors on mini-bus travel time for the entire route, the subsequent approach delves into the analysis of travel time variability at the level of road segments.

3.2.3. *Procedure 2: Reliability of the travel time (Road-segment unit level)* **PRS vs travel time at road-segment level**

The route (Substation-Muahivire) was partitioned into segments, each approximately 500 meters in length, yielding a total of 24 road-segment units. Subsequent to the identification in the prior analysis that only the PRS wielded a noteworthy influence on dwelling time, and considering the positive correlation between dwelling time and travel time, the PRS and travel time data for all nine days were aggregated for each road-segment unit. This aggregation process resulted in 48 samples.

The aggregation of these two variables reveals a consistent trend. As the number of PRS increases at road-segment unit, the travel time also increases, **Error! Reference source not found. & Error! Reference source not found.** In other words, the extended travel time is observed in segments with



Day-to-Day variability of the Travel time

In this section, we evaluate day-to-day variability at the road-segment unit to gain insights into the distribution of travel time. The extent of dispersion in the travel time data directly influences the variability in day-to-day trip duration. While the variability in travel time at the route level might not be effectively captured under fluctuating passenger demand (PRS) along the entire route, the assessment at the road-segment unit level is deemed more reliable. This is because factors influencing travel time, such as land use and passenger demand, exhibit variations along the route.

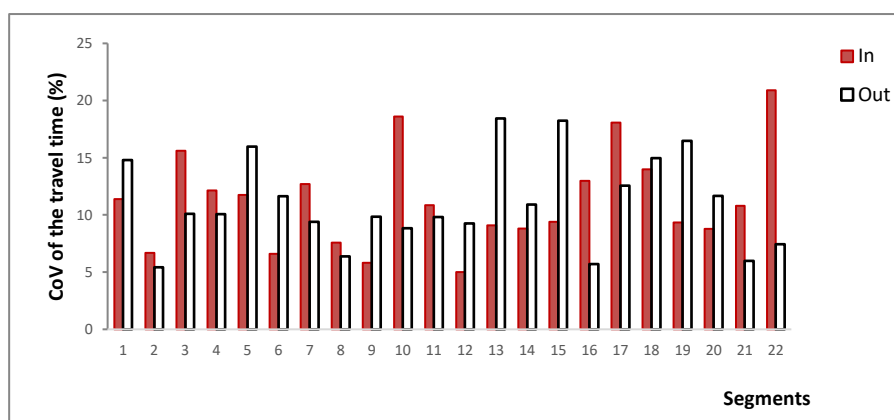
The variability of travel time is quantified by the ratio of the standard deviation to the mean of the observed data, commonly referred to as the Coefficient of Variation (COV). A lower COV indicates minimal dispersion in travel time durations, suggesting a consistent day-to-day travel time pattern. Conversely, a higher COV signifies greater dispersion in the travel time data, implying a less consistent travel time pattern.

Understanding the pattern of travel time at segment level is of paramount importance when deciding allocates stops along the route.

4. Results

The Coefficients of Variation (CoVs) for travel time at the road-segment unit level, in both inbound and outbound directions, exhibit negligible values. Approximately 50% of the road-segment units in both directions demonstrate a CoV of less than 10%. Another 30% of the road-segment units have CoVs ranging from 10% to 15%, **Error! Reference source not found.**

It is noteworthy that only a sparse number of road-segment units present CoVs surpassing 15%. Notably, these segments are primarily localized areas distinguished by the presence of roadside informal markets.



5. Discussion

Two distinct procedures were employed to evaluate the variability of mini-bus travel time along the Substation-Muahivire route, both conducted at different levels of spatial aggregation and focusing specifically on in-vehicle travel time during off-peak hours.

In the initial procedure, the aim was to comprehend the impact of road friction factors on mini-bus travel time along the entire route. The normality of three travel time measures, including total travel time and dwelling time, was assessed using the Shapiro-Wilk test. While both total travel time and dwelling time demonstrated normal distribution, indicating an anticipated travel time interval for completing the entire route, the one-sample t-test revealed significant differences in the travel time data despite their normal distribution. Subsequently, employing multivariate linear regression, it was discerned that the PRS emerged as the sole factor influencing mini-bus travel time during off-peak periods. PRS, influenced by passenger demand and the characteristics of land use along the route, exhibited a non-uniform distribution pattern throughout the route, affecting the likelihood of mini-bus stops for PRS-related purposes.

In the second procedure, the route was subdivided into segments of uniform lengths (500 meters). At each segment unit, travel time variability was scrutinized based on the Coefficient of Variation (CoV). In the majority of segment units, travel time variability was negligible. However, in certain segments characterized by roadside commercial activities in land use, a substantial variation in day-to-day travel time patterns was observed.

6. Conclusions

The variability in mini-bus travel time during off-peak hours on the Substation-Muahivire route is notably influenced by passenger-related stops (PRS). Mini-buses have the flexibility to stop at any points along the route, and the occurrence of stops is contingent on both passenger demand and the characteristics of land use.

When scrutinizing travel time variability, aggregating data for the entire route may not readily capture the impact of land use. Conversely, aggregating data at the segment level provides a more comprehensive understanding of travel time variability.

The outcomes of this study present an opportunity to enhance the quality of mini-bus services in Nampula city. It is essential to acknowledge a limitation of this study, which is its exclusive focus on the off-peak period. Further research extending the analysis to peak hours could contribute to a more holistic understanding of mini-bus travel dynamics.

7. Recommendations

A suggested enhancement to this analysis involves expanding the scope to encompass additional time periods, such as morning peak, afternoon off-peak, and peak hours. This broader temporal examination would provide a more comprehensive understanding of the factors influencing mini-bus travel time throughout various segments of the day, allowing for a more robust assessment of the service dynamics and contributing to a more holistic improvement strategy for mini-bus services in Nampula city.

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