ROUTE DISTANCE AND TRAVEL TIME VARIABILITY OF MINIBUS TAXI OPERATIONS IN RUSTENBURG

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ABSTRACT

Minibus taxi operations in South Africa are characterised by dynamic routing and dispatch decisions mostly made by drivers on the fly. This results in potentially large variability in the routes and travel times that passengers face. It also means that vehicles might incur large variations in operating costs and productivity across the day and across multiple days. There is little evidence available on the extent and nature of this variability in minibus taxi operations. This paper uses GPS data of a sample of taxis tracked in Rustenburg Local Municipality, to determine the route distance and travel time variabilities under real operating conditions. These measures are compared to reference routes to track variations over time for the same vehicles, delivering insights into how much variability individual drivers and vehicles face. The results show that minibus taxis operate with varying distance coverage and travel time across the day and between weekday and weekend. Individual drivers showed varying operating patterns in their distance and travel time coverage. The result indicates the complexity in operating patterns of minibus taxis, a step that is required for improving their services.

Keywords: Minibus Taxis, Route Variability, Route Directness Index, Travel Time Penalty.

1. INTRODUCTION

1.1 Background

Minibus taxis form a major component of informal public transport in the global south (ITDP, 2007). This followed a revolution in transportation in the early 1990s where majority of the private transport operators acquired minibus taxis (Kumar and Barrett, 2008). It is estimated that 80% of Africa's total motorized trips are made by minibus taxis (Agbiboa, 2020). Their services are found in several sub-Saharan African cities such as the City of Johannesburg in South Africa, Dar-es-Salam in Tanzania, Kampala in Uganda, Lagos in Nigeria, Nairobi in Kenya, as their main form of public transport (Giliomee et al., 2023, Behrens et al., 2015). Minibus taxis are commonly referred to as informal public transport mode due to their nature of operation and management. In South Africa they are managed by associations commonly referred to as trade groups and syndicates (Behrens et al., 2021, Kumar and Barrett, 2008). The associations control routes, fares, and licenses (Ngubane, 2022). At the time of this study, about 20,000 of these associations are spread across South Africa, operating between 250,000 and 300,000 minibus taxi fleet (Booysen et al., 2022). Agbiboa (2020) records that the trade unions in several other African countries are operated with semi-autonomy due to political influence.

Although they are categorised as informal, minibus taxi service formalization programs have been piloted in selected South African cities. In 2021, the Blue Dot incentive program was launched in the City of Cape Town. The program incorporated technology into minibus taxi operations and ensures minimum operation compliance, monitors services such as vehicle distance driven, vehicle performance, route management (Ribbonaar et al., 2023). The Rustenburg Local Municipality (RLM) commenced the Yarona operations in 2022, incorporating minibus taxis into scheduled bus services (Rustenburg Local Municipality, 2017). The initial success registered on the Rustenburg Rapid Transit (RRT) scheme depended on systematic planning, operation, and management strategies laid by RLM Such strategies included mapping fixed routes for minibus taxi operations. However, limited literature exists on such approaches across the African continent.

1.2 Problem Statement and Purpose

Minibus taxi route variability is the change in service pattern of minibus taxis (King et al., 2019). Route variability influences public transport users, planners, and operators as shown in the model in Figure 1. Drivers often meander within settlements to pickup and drop-off passengers (Behrens et al., 2015), a behaviour referred to as 'levy-walk behaviour' (Ndibatya and Booysen, 2020). This is observed even where operators possess route-based licences which restrict their operations to a specific corridor and continue to operate in unlicensed routes without approvals (Neumann et al., 2015). As a result, minibus taxis vary their routes over time, which may cause variations in the length of routes as well as the travel times. These variations may provide operational benefits or disbenefits to drivers. Ndibatya and Booysen (2020) recorded that minibus taxi operators often incur additional expenses when operating on informal routes, reducing profitability. The authors further added that insufficient methods exist to measure this kind of variability in informal minibus services to improve operation benefits.

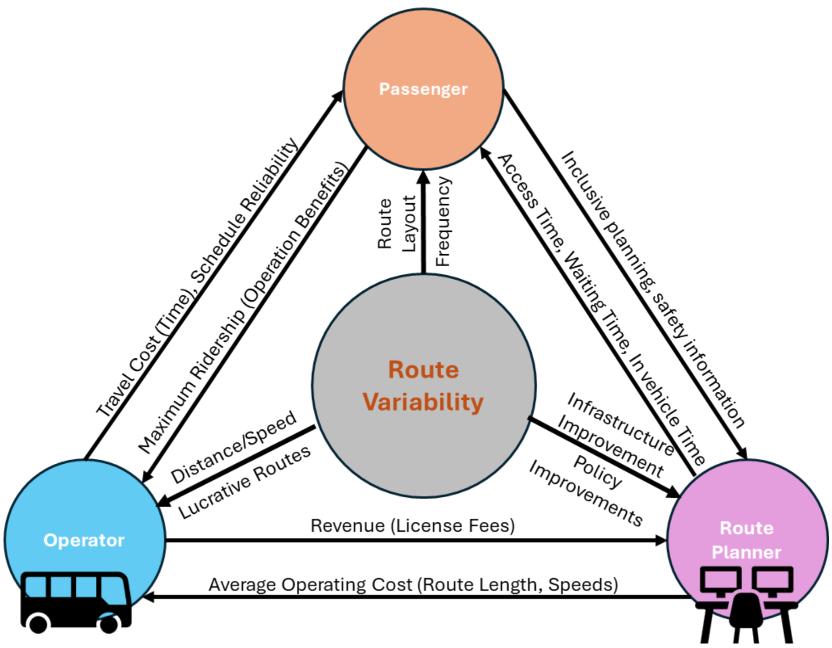

Figure 1: Triangular model describing route variability and its significance within public transport

Route variability therefore carries profound implications for operators within the triangular model in Figure 1 (Akgol et al., 2020; Du Preez & Venter, 2022). Understanding route variability may help operators to evaluate their operations, make service improvement decisions, or justify for a move towards rationalized routes. The purpose of this study is to measure variability in route and travel time. This helps in identifying operation benefits or inefficiencies among individual drivers and over a given period. Route and travel time variations reflect drivers' choices across a given day, by comparing the variability among minibus taxis. This improves management of fleet and controls daily operational costs.

1.3 Paper Outline

The paper comprises of four main sections, introduction, literature, methods, findings and analysis, and conclusion. Introduction section provides a general background about minibus taxi operations in South Africa. Literature section outlines relevant studies on variability and their respective methods. Methodology section describes the steps of achieving the objective of the study with the results provided under findings and analysis. The conclusion section outlines the main findings and evaluates if the objective has been achieved.

2. LITERATURE

2.1 Minibus Taxi Service Pattern and Variability Measurement

Minibus taxis operate with flexible routes choices (Coetzee et al., 2019) deviating from main service routes (Akgol et al., 2020). According to Zhao et al. (2022), movement of minibus taxis in space is influenced by the type of infrastructure such as road condition, topography of the area of operation; demand distribution, income levels, features such as space coverage, travel distances. These characteristics are claimed to influence their frequency across routes during peak and off-peak hours (Behrens et al., 2021).

King et al. (2019) studied the daily patterns of minibus in the city of Cape Town using on-board data collected through the WhereIsMyTransport App and roadside counts of vehicles. The study measured variability of minibus taxis. The results of trip duration, fullness factor, average distance travelled, and average waiting time was found to vary along different routes used by minibus taxis. Giliomee et al. (2023) suggests that minibus taxi drivers go where they please in an unscheduled manner, advising that their spatio-temporal movement can accurately be measured and modelled by capturing GPS data with minimum of time, speed, latitude, and longitude data fields. The author in the absence of GPS data, used street maps from google earth to model route variability. The results were found to vary across various routes.

Ndibatya and Booysen (2021) modelled variability of individual minibus taxis using GPS data. Their trajectory paths were found to follow a levy walk behavior across different routes. The study also proposed methodology for modelling ranks in minibus taxi operating areas where ranks are not available.

Table 1 summarises several studies for measuring variability in public transport. The method provided by Ciscal-Terry et al. (2016) were adopted during this study. The indicators used are route directness index (RDI) and travel time penalty (Tp).

Table 1: Summary of existing studies on variability of public transport

Reference	Metrics of Variability in Public Transport	Mode of Public Transport	Application
Wong (2013)	• Specific times for every stop (arrival and departure). • Headway variation. • Intersection stops.	Scheduled bus services	Route planning and developing transit routes and provision of priority access for buses
National Academy of Sciences (2013 pg. 4-5)	• Speed variations. • Route frequency. • Stop locations. • Vehicle headways.	Scheduled bus service	Used in transit capacity and quality of service design (TCQSM)
Büchel and Corman (2020)	• Travel time variability. • Headway variability. • Passenger wait time. variability* • Punctuality of vehicles (Frequency).	Scheduled bus services	Analysis of vehicle bunching to determine oversupply and undersupply using travel time, headway, and dwell time comparisons along routes.
King et al. (2019)	• Route geometry. • Trip duration. • Fullness factor* • Route frequency.	Minibus taxis	Used for journey planning computations for minibus taxis
Strathman et al. (1999)	• Running time • Headway • Ontime performance	Scheduled bus services	Used for monitoring service reliability of scheduled bus services.
Ciscal-Terry et al. (2016)	• Travel time penalty • Route Directness Index	Bus services	Used for measuring travel time compliance of drivers when they select different routes instead of the shortest route.

3. METHODS

3.1 Study Area

The study was conducted in Rustenburg local municipality (RLM), a category B local municipality. The RLM is in the Northwest province of South Africa. The municipality covers an area of 3,423 km^2 of Bojanala district with a population of 600,000. There are 35 operational public transport companies using buses and minibus taxis. Over 3212 minibus taxis operate on both local and long-distance routes under 22 associations. An estimated 3.4% of the minibus taxis operated as metered services in the central business district (CBD), Waterval and Boitenkong. The minibus taxis and buses took up 51% of the total ridership share, 17% by non-motorized transport and 32% by private vehicles (Draft Integrated Development Plan, 2024). The Yarona quality bus service, a scheduled bus system commenced operations in RLM in 2022. The bus services operated on a 33.3 kilometers of trunk corridor with dedicated bus lanes. The integrated system accommodated both buses and minibus taxis (Rustenburg Local Municipality, 2017). The minibus taxis in the RLM either operated as scheduled services or unscheduled taxis services (Chetty et al., 2024). Both the scheduled and the unscheduled minibus taxis under the Yarona quality bus management were tracked by GPS at a frequency of 10 seconds.

3.2 Data Sources

Primary data sources included route characteristics such as the types of road and traffic conditions, other public transport operators along the routes, and taxi rank. Secondary data consisted of trip data extracted from the RRT website, GIS maps, and high frequency routes. Raw GPS data was downloaded for 7 consecutive days for 10 unscheduled taxis so-called "mop-ups" representing 21% of the tracked minibus taxis, between 05:00 and 19:59 hours daily. The mop-ups are unbranded, and they are allowed to choose routes and frequencies freely. The mop-up operations were also considered unaffected during this period by the fear of being tracked by GPS devises as confirmed by the RLM control team. The data obtained for analysis is therefore a representative of the population in the case study area.

3.3 Methodology

Route directness index (RDI) and travel time penalty (Tp) were the two indicators used for measuring variability of minibus taxis. The method was adopted from (Ciscal-Terry et al., 2016). The RDI measures the extent by which a minibus taxi deviates from the reference routes by means of comparing their distances as a ratio. The Tp measures the costs in terms of travel time changes when minibus taxis deviate from reference routes. Figure 2 shows a graphical representation of the reference route and the actual minibus taxi route.

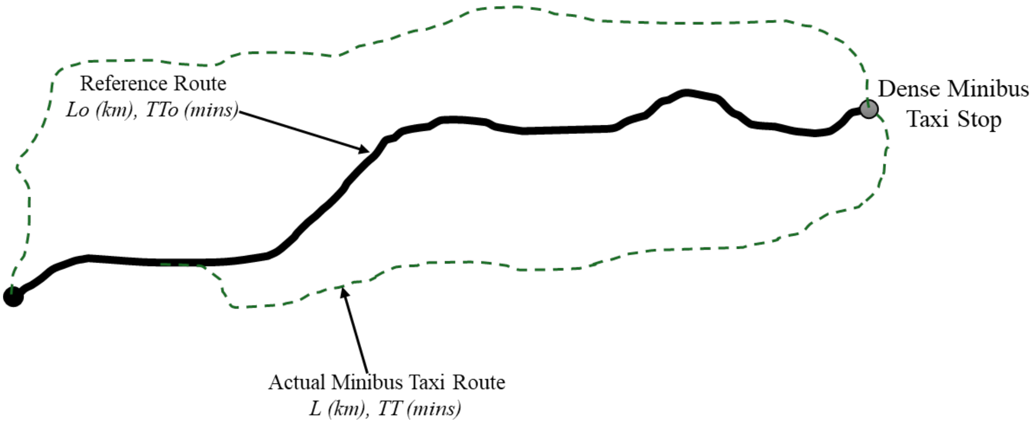

Figure 2: A graphical representation of minibus taxi reference route and the actual route taken

The RDI is a unitless index and is computed from Eq. (1). The values of RDI are > 0, but RDI can be > 1. If RDI > 1.0, it shows that the actual route taken by minibus taxi is longer than the reference route and if RDI < 1.0, it indicates that the actual route taken by minibus taxi is shorter than the reference route.

$$RDI = \frac{L\,(km)}{L_0\,(km)} \tag{1}$$

Where:

L is the actual minibus taxi route (km) and
Lo is the reference route length (km).

Travel time penalty, Tp is a change in travel time resulting from the use of alternative routes instead of reference routes. The Tp is determined using Eq. (2). The Tp can either be a positive reflecting higher travel times or a negative reflecting less travel time.

$$T_p = TT - TTo \tag{2}$$

Where:

> TT is the actual route travel time when a minibus taxi makes a trip; and
> TT_o is the reference route travel time, both measured in minutes (mins).

3.3.1 Data Input 1

The Mop-up GPS tracking data formed the first set of data in the analysis process. The GPS data was downloaded in excel and cleaned to remove unwanted data items. Trips were identified from the data in two directions, outbound trips and inbound trips. The directional trips were identified by splitting a minibus taxi round trip into two, using the furthest distance as a break point. The travel distances and the corresponding travel times were determined for each trip.

3.3.2 Data Input 2

The second source of data for the analysis included high frequency routes, referred to as reference routes. The reference routes are most frequently used routes by all the tracked minibus taxis in Rustenburg. The reference routes were obtained through a method proposed by Angurini and Venter (2025). The authors joined a sample of 1069 trips from all tracked minibus taxis with road network data. Minibus taxi frequencies were determined by counting number of minibus taxis for each road segment. The frequencies were categorised into bands of 8 veh/h and plotted in QGIS. The reference routes were determined by intuitively tracing the frequency bands along the various road segment to obtain the reference routes. The layout of the reference routes is shown in Figure 3.

Table 2 shows the lengths, Lo, and Fig. 4 shows the average travel time, TTo of the reference routes. The average travel times have been aggregated per direction instead of per route. The morning period was defined between 05:00 to 09:59, off-peak between 10:00 to 14:59 and afternoon peak between 15:00 to 19:59 hours.

3.3.3 Route Mapping

Route mapping is the process of plotting the actual route against the reference route. The mapping helps to determine the closest reference route to the actual route to enable realistic estimation of RDI and Tp as shown in Figure 5.

Figure 3: Minibus taxi reference routes (Angurini & Venter, 2025)

Table 3: Route lengths (km) for high frequency (reference) routes

Period	Attributes	24.1 -32.0 veh/h	16.1 -24.0 veh/h	8.1 -16.0 veh/h
Morning Peak Outbound	Start Location	Rustenburg Taxi Rank		
	End Location	R3	R7	R7
	Route Length	6.316	8.221	8.216
Morning Peak Inbound	Start Location	R7	R7	R3
	End Location	Rustenburg Taxi Rank		
	Route Length	6.212	7.099	4.750
Mid Off-peak Outbound	Start Location	Rustenburg Taxi Rank		
	End Location	R5	R5	Unknown
	Route Length	5.927	6.859	5.276
Mid Off-peak Inbound	Start Location	R8	R8	R8
	End Location	Rustenburg Taxi Rank		
	Route Length	6.826	7.319	7.162
Afternoon Peak Outbound	Start Location	Rustenburg Taxi Rank		
	End Location	R4	R6	R1
	Route Length	6.380	4.724	7.065
Afternoon Peak Inbound	Start Location	R4	R4	R6
	End Location	Rustenburg Taxi Rank		
	Route Length	6.485	6.181	5.292

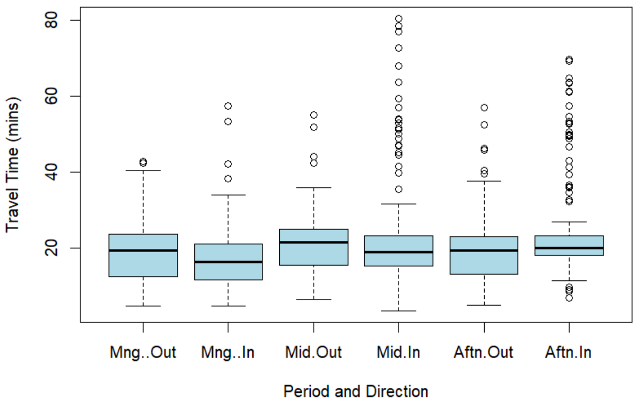

Figure 4. Average minibus taxi travel times on reference routes

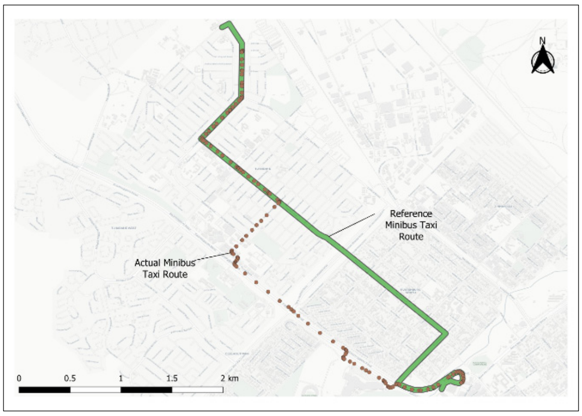

Figure 5. Mapping of actual route against the reference route

4. RESULTS

4.1 Weekly Variation

Figure 6 shows the box and whisker plots of RDI split into weekday and weekend. The average weekday RDI is 0.846 while the average RDI for weekends is 0.860. The difference between the two is statistically insignificant. More taxis operated wih RDI<1.0 on weekdays than on weekends. This result indicates that some of the drivers kept their routes shorter on weekdays but chose longer ones on weekends. Minibus taxis M9 and M10 operated with higher average RDI > 1.0 while M38, M46 and M59 with R<1.0 on both weekdays and weekends. This suggests that some drivers have a tendancy of consistently using longer routes. Minibus taxis M15 and M23 show wider range of distances driven on weekdays and maintain route lengths with minor deviations on weekends.

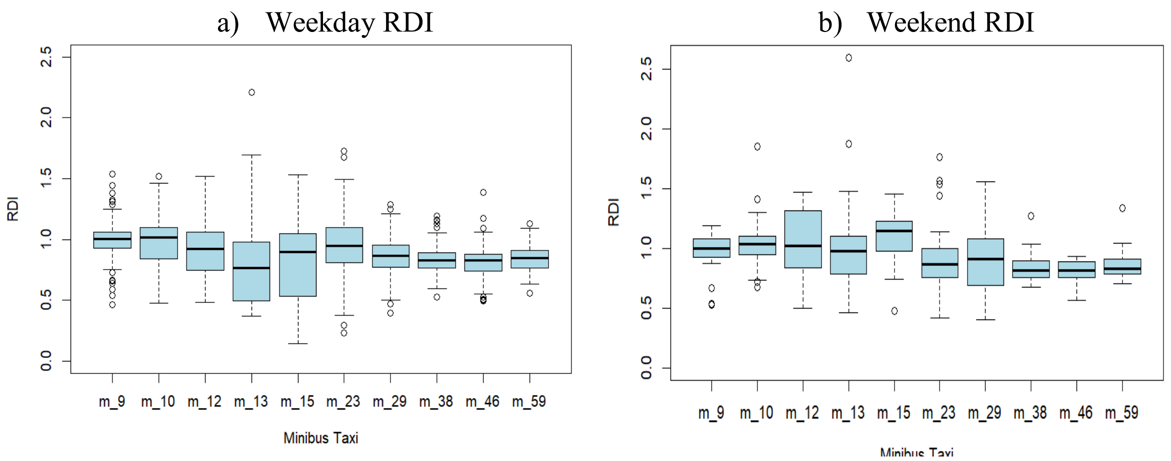

Figure 6: Weekly distribution of RDI for various minibus taxis

Figure 7 shows the box and whisker plot of travel time penalties for the various minibus taxis across the week. The average Tp is -1.639 mins on weekdays and -0.507 mins on weekends. The sampled minibus taxis generally operated with average travel time savings compared on both weekdays and weekends. The average time savings were 69% more on weekdays compared to weekends. The travel time penalty results therefore suggest that minibus taxis operated with lower speeds on weekends. Minibus taxis M9 and M10 that had RDI>1.0 operated with travel time penalties. The penalty can be attributed to the additional kilometers covered by the vehicles.

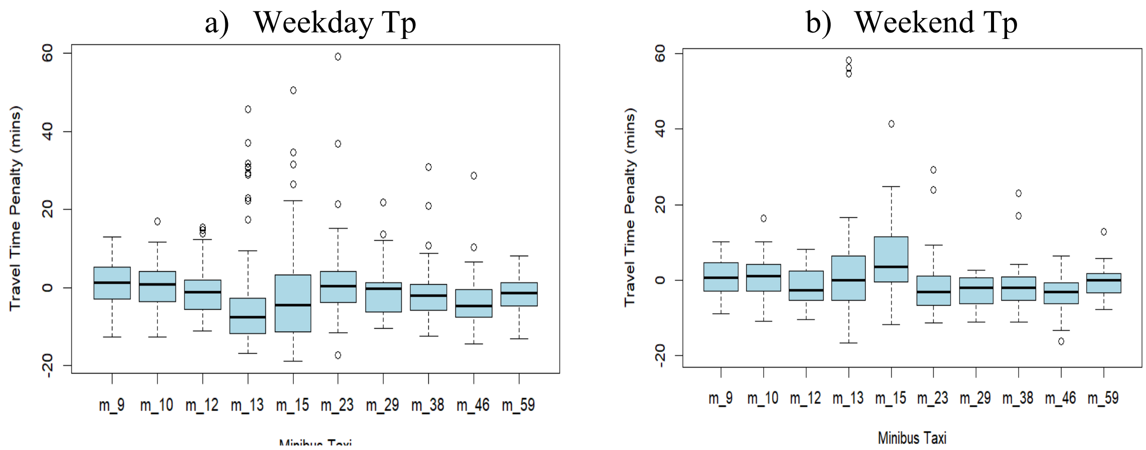

Figure 7: Weekly distribution of TP for various minibus taxis

4.2 Daily Variation and Comparison

Figure 8 shows the cumulative distribution of RDIs for the various minibus taxis. The vertical dotted line at RDI value of 1.0 meets the cumulative curves at a corresponding cumulative probability value. The portion of the curves to the left of the vertical line indicates that minibus taxi trip lengths were shorter than reference route lengths and the portion to the right were longer. Minibus taxis recorded shorter route length, about 76% of the trips in the morning peak outbound. This was attributed to express trips on arterial roads with targeted destinations. The proportion of shorter routes selected reduced to 15% in the inbound direction. Apart from off-peak inbound direction with a proportion of 45% shorter routes, minibus taxis registered less than 25% shorter routes in the mid off-peak and afternoon peak. This was mainly due to scattered trip destinations and intensive passenger searching activities across Tlhabane area in off-peak hours and afternoon peak. During this period, drivers become sensitive to cost such as fuel than time.

Minibus taxis M38, M46 and M59 made several shorter trips with RDI values <1.0. This suggests that these minibus taxis make several short trips across the day. Some of the minibuses make alternate short and long trips. For instance M13 made shorter trips in the morning peak and off-peak but longer trips in the afternoon peak.

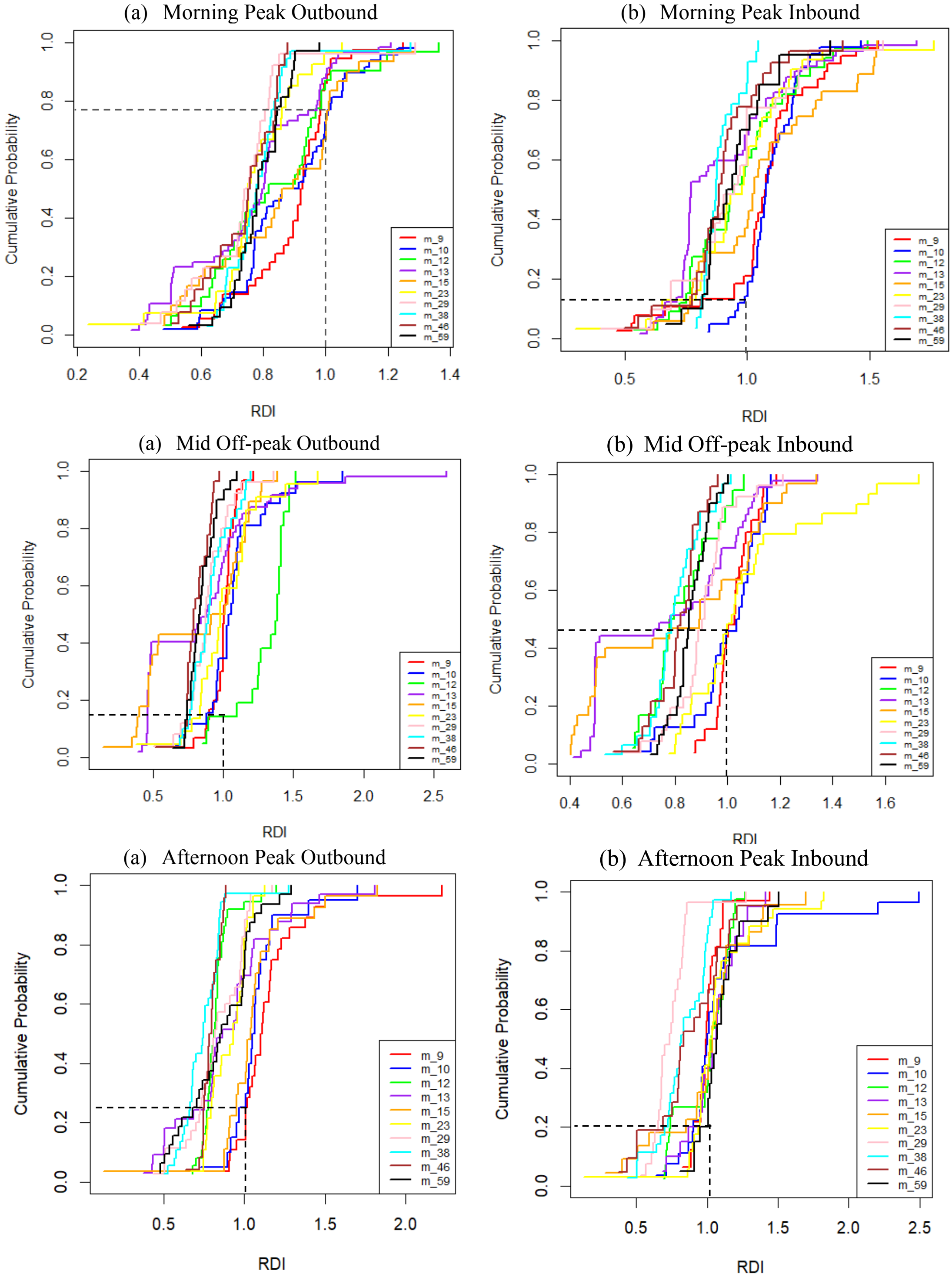

Figure 8: Comparative cumulative distribution of RDI for the minibus taxis

Figure 9 shows the cumulative distribution of Tp for the different minibus taxis in the morning peak, mid off-peak and afternoon peak periods. The graphs show that 28% of the trips made by minibus taxis occurred with time savings in the outbound direction and 32% in the inbound direction. During the mid off-peak periods, 53% of the trips in the outbound direction and 34% in the inbound direction occurred with time savings. In the afternoon peak hour, 38% in the outbound and 25% in the inbound occur with time savings. This shows that minibus taxis make more savings in outbound direction than in the inbound. This is attributed to passenger searching during the off-peak periods.

Minibus taxis M10 and M38 operate with more travel time savings than the rest of the minibus taxis across the day. M9 incured travel time penalties in the morning peak but operated with travel time savings in the afternoon peak. This suggests that some of the drivers tend to balance up operation costs across the day.

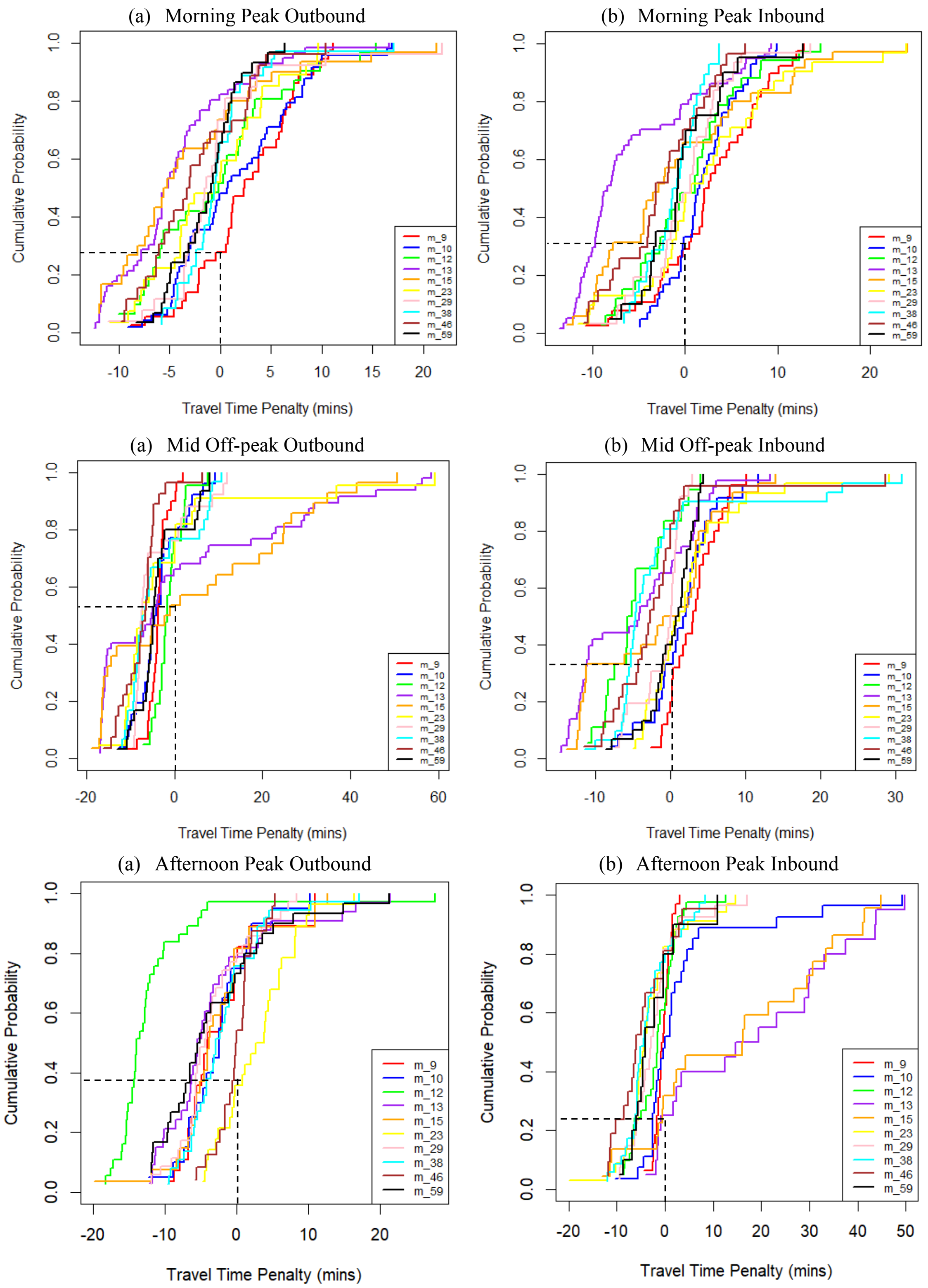

Figure 9: Comparative cumulative distribution of T_p of the minibus taxis

5. CONCLUSION

The results from the route distance and travel time variability studies indicate that route variability exists both in space and in time and among the individual minibus taxis. Variability results indicate that whereas there is no significant changes in route lengths, some of the minibus taxis still encounter travel time penalties when they make deviations. This was evident on weekdays where minibus taxis made more savings.

Variability among individual minibus taxis indicates that some minibus taxis operate with additional costs while others operate with savings within the same network. The costs are associated with extra kilometers covered (Bokor, 2010) some of which are on unutilized routes with low ridership benefits. These operations were found to influence additional travel time. Buehler and Pucher (2011) suggest that such services can be cut off from the system and minibus taxi operators utilize lucrative routes and maintain operations within such reference routes. The observed individual minibus taxi variability suggests that some drivers have a predictable trend of only selecting either shorter or longer routes. This was also evident among several other drivers where both longer and shorter route lengths were selected. The RDI and Tp approach can be adopted in South Africa to test the compliance of drivers across different route choice scenarios. Although the study focused on tracked minibus taxis, there were other untracked minibus taxis operating on the network. These were never captured in this analysis. During the study, it was assumed that minibus taxi operations remain unchanged for fear of being tracked using GPS. There might be changes in minibus taxi operations such as biased route selection to avoid penalties. The RDI and Tp were only quantified by distance and time respectively. The actual monetary costs associated with with their deviations was never estimated.

5.1 Recommendation

The study focused primarily on driver behaviour and route efficiency. The study did not consider how these variations affect passenger experiences such as waiting times, reliability, and affordability. Further studies should be undertaken to incorporate these cost drivers evaluating the economic impact of route deviations and identifying optimal operational strategies to strengthen the outcome of the paper

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