AN ANALYSIS OF CROSS-BORDER MINIBUS TAXI MOVEMENT PATTERNS USING GEOGRAPHIC INFORMATION SYSTEM (GIS): CASE STUDY OF ROUTES BETWEEN SOUTH AFRICA AND ITS NEIGHBOURS

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ABSTRACT

The paper analyses the cross-border movement of minibus taxis on routes that serve South Africa and three of its neighbours, Botswana, eSwatini, and Mozambique. It uses geographic positioning system (GPS) data instead of the traditional manual methods of collecting data to determine the movement pattern of cross-border minibus taxis. The movement patterns of cross-border minibus taxis were recorded. The data were subsequently mapped and analysed using ESRI® ArcGIS 10.6 to identify hotspots of the three origins and destinations. The analysis allowed for the determination of passenger waiting times at the rank facilities, stoppages along the routes due to factors like law enforcement operations, informal stops, border post activities, and total travel time and speed of the minibus taxis.

The results reveal that Johannesburg is the main hotspot of passenger activities followed by Maputo, Mbabane and Gaborone. Moreover, the results indicate that most passengers travel in the morning (between 06:00 to 08:00), hence waiting time is shorter compared to the afternoon-evening period (15:00 to18:00) where the waiting time is longer. The early travels are generally due to the limited time the minibus taxis must leave the station. The movement patterns are influenced by peak (weekends and holidays) and off-peak (weekdays) periods. In contrast, cross-border minibus drivers' behaviours were to some extent influenced by the presence or absence of traffic law enforcement officers along with the route network. The paper proves that using the use of GPS and Geographic Information Systems (GIS) technologies to analyse the movement patterns of cross-border minibus taxis can efficiently map the movement patterns and trends of cross-border minibus taxi operations.

1. INTRODUCTION

With technological advancements including the advent of the fourth industrial revolution (4IR), various opportunities enable improvement in the flow of cross-border road transport movement effectively and efficiently. The development of innovative ways in Application Programming Interface (API) as well as mobile-based travel applications, leveraging big data usage and Artificial intelligence (AI) can improve road transport performance (Berryhill, et al., 2019). However, there is no formal platform for determining the cross-border minibus taxi (MBT) travel patterns and trends that the regulatory authorities can rely on for planning and law enforcement purposes (Pophiwa, 2017; Yesefu, 2016). In light of the challenge, it is difficult for regulatory authorities to effectively manage cross-border MBT travel patterns. Consequently, informal rank facilities are mushrooming and the industry is characterised by several other illegal operations (Yesufu, 2021).

The Geographic Information Systems (GIS) applications are used around the globe in tracking the movement patterns of public transport. The GIS application has been used in several studies. Li et al. (2019) analysed taxi trajectory data and considered five traffic factors namely pick-ups, drop-offs, ratio of pick-ups to drop-offs, pick-up probability, and drop-off probability. The study was divided into weekdays-weekends and developed an Area Crossing Index (ACI) which reflected the taxi cardinality and accessibility showing ridership per hour. Zhang et al. (2017) assessed intra-urban taxi mobility over a period of twelve months examining taxi trajectory in Harbin, China. The study used multivariate spatial point pattern analysis to describe and model the spatial dependence, and infer significant positive spatial relationships between the taxi picked up points (PUPs) and the dropped off points (DOPs). In South Africa, Van Zyl and Labuschagne (2008) tracked the MBT movements in Cape Town for public transport regulatory purposes. In the study, a passenger counter designed for MBTs was used and the GPS used a combination of image and sensor equipment. The GPS logged the routes travelled by taxis and the data was subsequently plotted using MapInfo. The application of GIS-derived information was successfully utilised in the analysis of movement patterns of public transport.

Notwithstanding the efforts made in prior studies, the absence of real-time data negatively affects the effective planning of the cross-border road passenger transport sector. This makes it difficult for various regulatory authorities to effectively function, inter alia; the Cross-Border Road Transport Agency, Customs & Excise Division of the South African Revenue Services (SARS), Immigration, South African Police Service (SAPS), Port Health and Department of Agriculture, and Forestry and Fisheries (Ferreira et al., 2013; Lu et al., 2018; Khumalo, 2014). To model cross-border road transport networks and gather data on MBT movement patterns, there is a need to analyse their operations (Zhang and Xu, 2021). However, such activities are marred by various complexities in that the route network comprises many links and nodes. The challenges are intertwined in integrated planning, socio-economic activities, and developing comparative analyses of the hard and soft road transport network systems (Pérez et al., 2015).

2. METHODOLOGY

2.1 Study Area

Three road networks in the SADC region connecting from Johannesburg are considered. The road networks connect three cities namely (1) Maputo (Mozambique) highlighted in green colour; (2) Mbabane (eSwatini) highlighted in red colour, and (3) Gaborone (Botswana) highlighted in black colour as shown in Figure 1. Johannesburg is the largest city in South Africa with an estimated population of 5.6 million in 2019 (World Population Review, 2022c). It is the country’s wealthiest province and is regarded as Africa’s economic powerhouse with established economic nodes (Gauteng City-Region, 2022). Park City taxi rank facility is located in Johannesburg central business district and caters for cross-border passenger movements.

Maputo is the most populous city with about 1.1 million people recorded in the year 2019 (World Population Review, 2022d). Maputo's closest border crossing into South Africa is Ressano Garcia/Lebombo which connects with Johannesburg using the N14 route. Junta taxi rank is one of cross-border road passenger facilities in Maputo. Mbabane is the capital city of eSwatini, although Manzini is the largest city in terms of population and it is where most trips start and end. According to World Population Review (2022a), the population of Mbabane is estimated to be 76 218 people. There is a Bus Rank taxi facility situated in Mbabane central business district that serves passengers intending to cross the border.

The city’s closest border crossing to South Africa is Ngwenya/Oshoek connecting to Johannesburg on the N17 route and is the busiest border post between the two countries.

Gaborone is the capital and largest city of Botswana with a population of about 232 000 as of July 2019 (World Population Review, 2022b). The city’s Bus Stop taxi rank is a facility that connects some passengers to South Africa using the Tlokweng/Kopfontein Border using the R49 route.

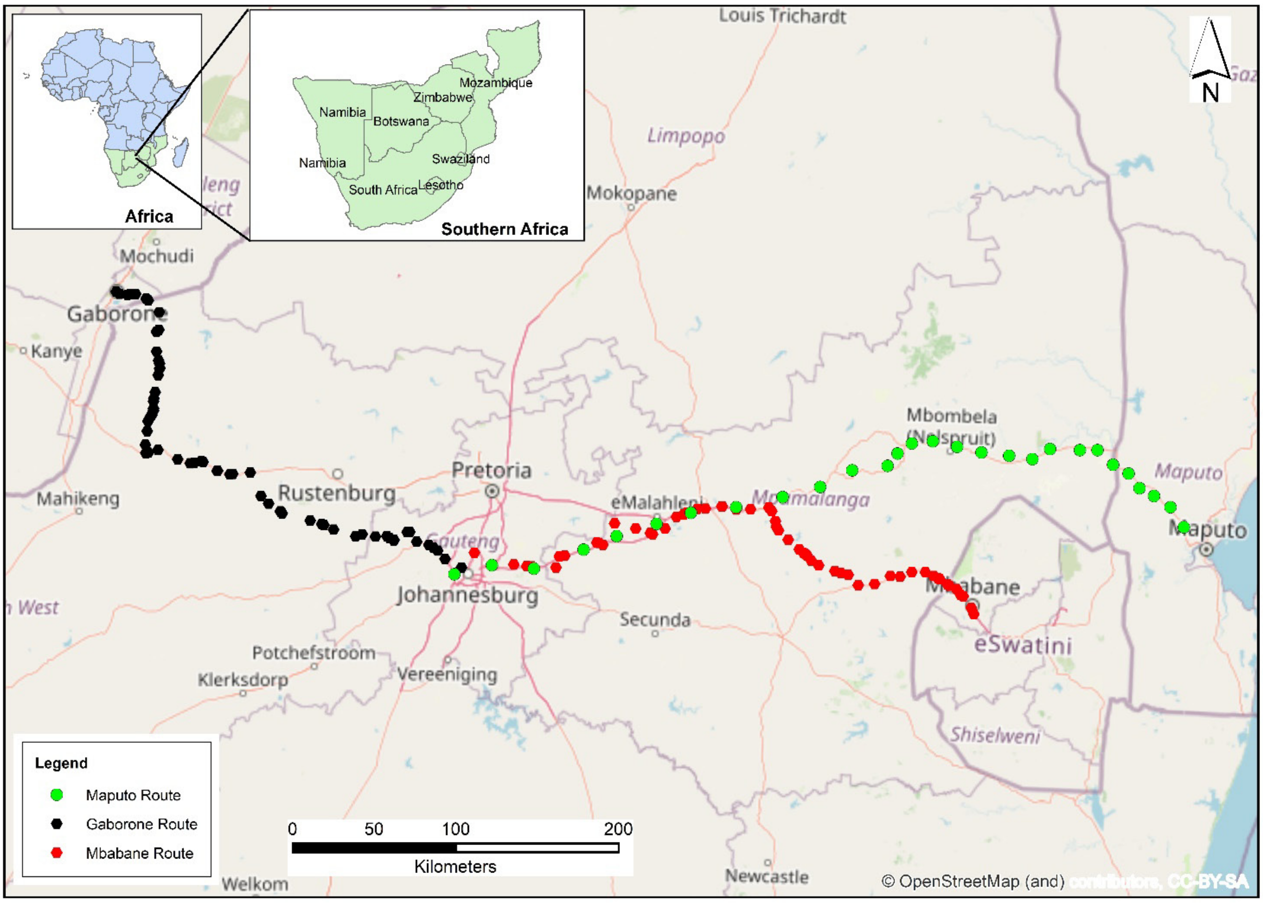


Figure 1: Routes of cross-border MBTs to Johannesburg from Maputo, eSwatini and Gaborone

2.2 Data Collection and Analysis

Figure 2 summarises the three methods and techniques of data collection and analysis. The qualitative and quantitative methods included interviews of taxi rank queue marshals and data collected using GPS and GIS techniques respectively (Mbuh et al., 2019).

Part A involved collecting data via 12 face-to-face interviews with taxi rank queue marshals and observations. The two methods were utilised in order to develop a holistic understanding of cross-border MBT operating patterns from points-of-origin to destinations. Interviews recorded cross-border MBT passenger arrival times, waiting times, and departure times from rank facilities. Five peak periods dates and five off-peak periods dates were chosen for data collection for the three routes to assess differences in different periods. The interviews and observations were conducted during peak periods (holidays and weekends) and off-peak periods (non-holidays and normal working days).

A purposive sampling technique was chosen to interview cross-border taxi rank queue marshals. The technique uses the judgment of an expert in selecting cases with a specific purpose in mind (Tongco, 2007). This was conducted specifically targeting the taxi rank queue marshals. Cross-border taxi rank queue marshals monitor the number of passengers against the available cross-border MBTs in the rank facility. To ensure the seamless operation of this process, the taxi rank queue marshals estimate the demand for cross-border MBTs within the rank facility, and requests for more cross-border vehicles to be sent from the holding area to meet the demand in the rank facility. To analyse data for Part A, two statistical techniques were performed viz. simple regression analysis and cluster/hotspot analysis.

To model the relationship between time spent at the rank facility against the departure time in different cities, the simple linear regression analysis was performed. Simple linear regression is a statistical method used to infer the relationship between two continuous quantitative variables (Zou et al. 2003). The average waiting time and time of the day were used as dependent and independent variables respectively. The estimations were done using the following linear regression equation:

$$\acute{Y} = a + b\mathrm{X} \quad (1)$$

Where;
Ý is the dependent variable (waiting time)
x is the independent variable (departure time)
b is the slope of the line
a is the y-intercept

A Cluster/Hotspot analysis was computed to assess the busiest rank facility in the study area. The Hotspot Analysis tool in the ArcGIS software was used to calculate the Getis-Ord Gi* statistic for each feature in a dataset (Getis and Ord, 2010). The statistics result in z-scores and p-values displaying features with either high or low values which cluster spatially (Getis and Ord 2010). Notably, a feature with a high value may not necessarily be a statistically significant hotspot. Therefore, for a feature to be a statistically significant hotspot, it should have a high value, and should be surrounded by other features with high values (Unwin and Unwin 1998; Getis and Ord, 2010). Furthermore, for a location to be identified as a statistically significant positive z-scores there should be a large z-score value, and this will represent more concentration or clustering of high values (hotspot). On the other hand, for statistically significant negative z-scores, the smaller the z-score, the more intense the clustering of low values (coldspot) (Unwin and Unwin 1998; Getis and Ord, 2010). The Getis-Ord local statistics are given by Equation 2.

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{x} \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\frac{\left[n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right) 2\right]}{n-1}}} \quad (2)$$

Where;
$\boldsymbol{x_{,j}}$ is the attribute value for feature ***j***, $\boldsymbol{w_{i,j}}$ is the spatial weight between features ***i*** and ***j***, ***n*** is equal to the number of features.

Part B describes the data collection and analysis relating to the movement patterns of the cross-border MBTs along the route from their points of origin to their final destinations for return trips. Data collection involved using the GPS to record the speed, distance, and stationery time stamps. To analyse the data, pattern analysis was used to map the movement patterns and travel behaviours of the MBTs. Field tracks recorded from the field trips were imported into the ArcGIS 10.6 platform and converted to feature class were analysed. Tracking analysis was achieved by using different symbology options designed to bring visualised events in the tracking data. Time windows were created to display data in different colours. These display the paths of tracked objects using track lines and show the movement of MBTs (Kapler and Wright 2005). The tracks were then matched to the road network using the road layers. In this step, each trajectory was divided into segments based on the constraints of the stationary and motion periods.

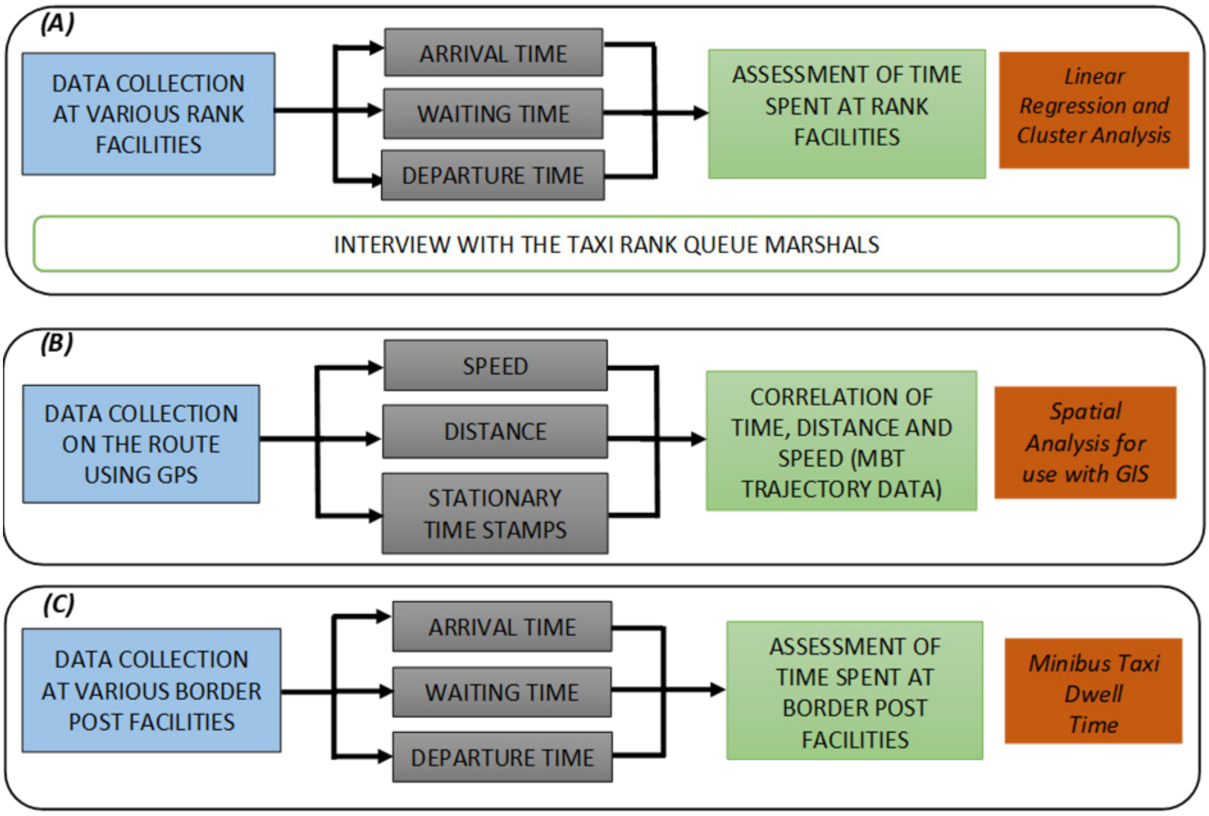


Figure 2: Flow Chart Illustrating data collection and processing in Parts A, B, and C

Part C shows the data collection at the border posts of the three countries. Dwell time was used to compute the time spent in the border post during peak and off-peak periods. It involves the assessment of dwell time patterns using a graphical method (Christoforou et al., 2020). Calculations are based on the difference between the departure time and the arrival time of the MBT. This is done considering each direction separately, the outbound and inbound route. Dwell time are produced, allowing for the variation in these parameters to serve as a function of the border posts and of the period observed (Christoforou et al., 2020). The segregated dwell time for each border is given by Equation 3.

$$\left(Exit^{\text{TM}}\ Border\ Post\ Side_a - Arrival^{\text{TM}}\ Border\ Post\ Side_a\right)$$

And $$(Exit^{\text{TM}}\ Border\ Post\ Side_b - Arrival^{\text{TM}}\ Border\ Post\ Side_b) \quad (3)$$

Where;

$Border\ Post\ Side_a$ (Outbound) = first side of the border; and

$Border\ Post\ Side_b$ (Inbound) = second side of the border.

3. RESULTS

3.1 Cross-Border Rank Facilities Activities

The results in Figure 3 illustrate different periods, i.e. 5 days during holidays or weekends and 5 days during the normal working days/non-holidays. The average waiting times (60 minutes intervals) were calculated for all different rank facilities from the different cities. It can be observed that during the morning times, between 06:00 and 08:00 which is the busiest time of the day, the average number of passengers exceeded 50 people. In contrast, in the period between 15:00 and 18:00, there were fewer activities at all rank facilities analysed with an average of fewer than 20 passengers. During the afternoon between 12:00−14:00, there was a slight increase in activities at taxi rank facilities (30−50 people on average) compared to the late afternoon period (15:00 and 18:00) but lower than the morning period. Normal working days show a uniform trend of a generally low number of passenger activities during different times of the day. Overall, weekends or holidays recorded generally high activities at the cross-border taxi rank facilities compared to normal working days or non-holidays. In addition to that, high activities were recorded in the morning than in the afternoon on both normal working days or non-holidays and weekends or holidays.

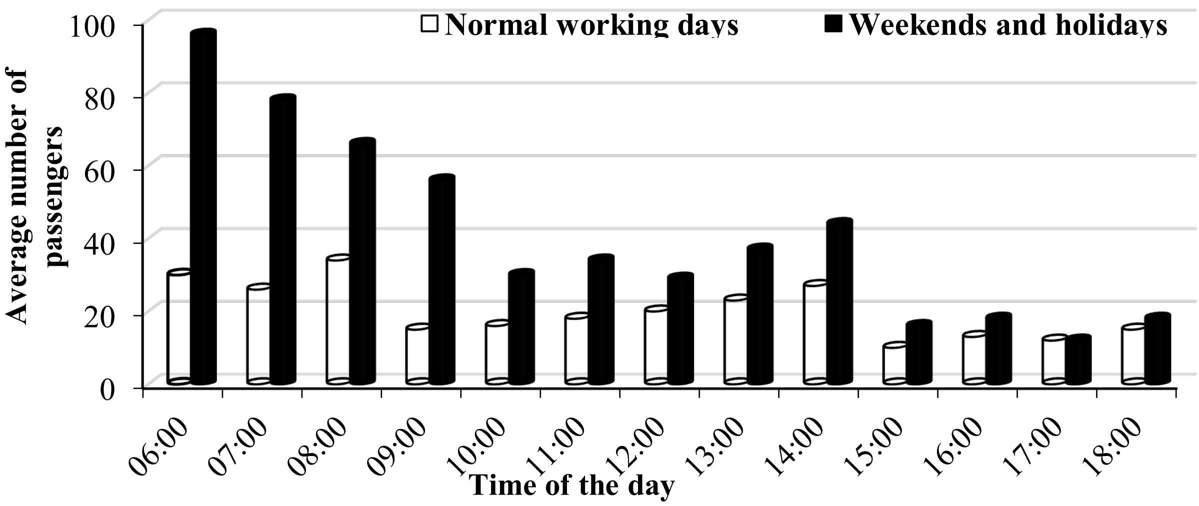


Figure 3: Average number of passengers arriving at cross-border rank facilities

A comparison of waiting times for different rank facilities was conducted to see which rank facilities resulted in longer passenger waiting times. The results show that Johannesburg and Mbabane ranks achieved an average waiting time below 40 minutes. Moreover, for the same cities, normal working days and weekends or holidays also achieved approximately similar waiting times below 40 minutes. Passengers spend more time at the taxi rank facilities in both Maputo and Gaborone which both recorded more than 60 minutes (Figure 4). The recorded longer waiting times were experienced during the week, which is a normal working day compared to weekends/ holidays. Overall, the results show that activities at cross-border taxi rank facilities represent the least waiting time during weekends and holidays compared to normal working days.

Figure 4: Average waiting time (mins) in different cities

Data collected from cross border taxi rank marshals shows that there is no relationship between departure time and waiting time, although it takes longer time for the cross-border MBT to be full during the week than during weekends or holidays. Moreover, there is no relationship between normal working days and weekends or holidays with the former resulting in more waiting time than the latter. Such observations were recorded from all the cross-border rank facilities. In terms of departure time and arrival time of the cross-border MBT, the paper established that there is no timekeeping in tracking the movement of the cross-border MBT as it is an informal mode. Thus, the cross-border MBT can only leave the rank facility when it is full. In line with the results, it is noted that passenger preference for MBT affects departure times, with some passengers preferring a certain seating capacity design. This results in more time being spent at the platform. Such behaviours are noted at all different cross-border taxi rank facilities.

Further analysis of the activities at the rank facilities is presented in Figures 5a, b, c, d. The results show the relationship between average waiting time and time of the day for the cross-border MBT as well as passengers' activities in all rank facilities. The highest correlation is recorded from the Junta taxi rank facility in Maputo with R^2 = 0.79, this is followed by the Park City taxi rank facility in Johannesburg with R^2 = 0.61. The Bus Stop taxi rank in Gaborone retained R^2 of 0.43 which was the third-highest coefficient of determination. Closely followed by Bus Rank taxi facility in Mbabane which recorded R^2 = 0.42 making it the lowest coefficient of determination comparing all other cross-border rank facilities.

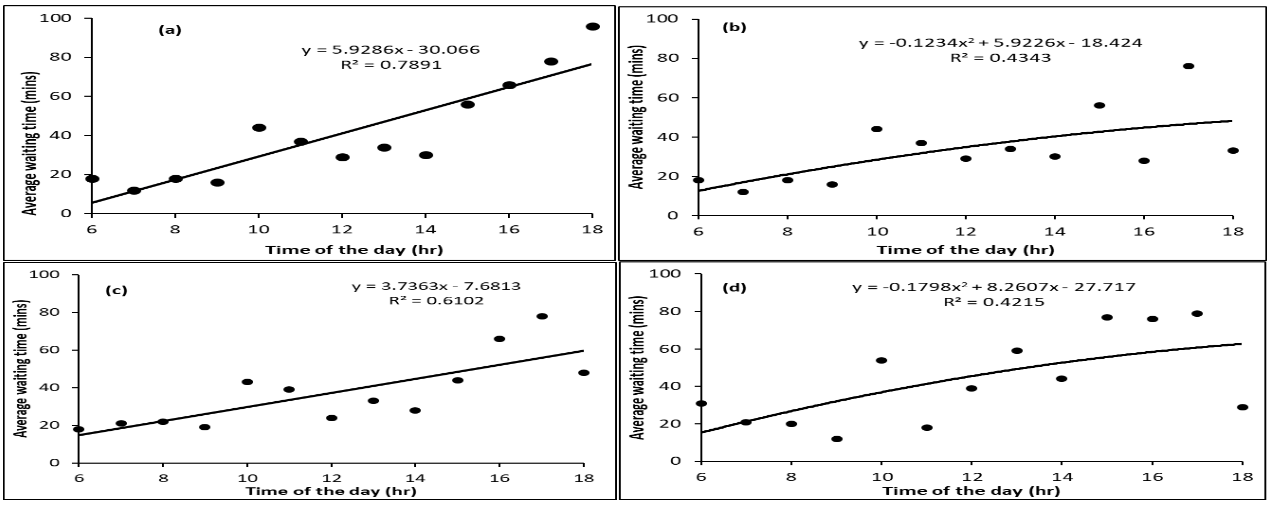


Figure 5: Correlation of the average waiting time and time of day in different cities; (a) Maputo, (b) Gaborone, (c) Johannesburg, and (d) Mbabane

Cross-border MBTs departing early in the morning around 06:00 have short waiting times for passengers at all cross-border rank facilities. In contrast cross-border MBT departing late around 18:00 take a longer time to be full, especially in Maputo with an average of 100 minutes of waiting time compared to Johannesburg with an average of 40 minutes.

The hotspot analysis show high activities in the Park City taxi rank facility followed by the Junta taxi rank facility compared to other cities. In contrast, the Bus Rank taxi facility and Bus Stop taxi rank show the least activities and fewer passenger counts. This signifies coldspots (Figure 6). Thus, the clustering shown in the output is the average count of the number of people at the taxi rank facilities. The headcount was done for the cross-border passenger. The results show a lot of activities in Park City taxi rank since most people come to Johannesburg from neighbouring countries for better economic prospects.

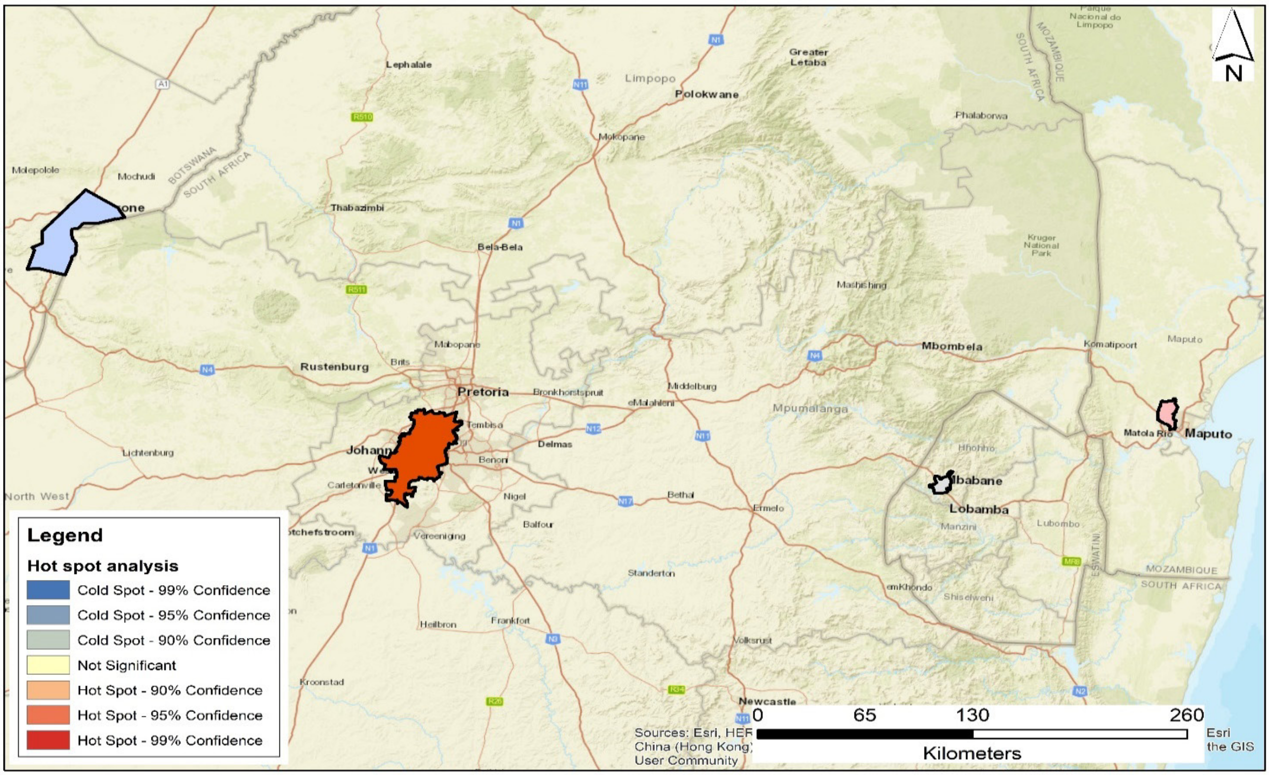


Figure 6: Hotspot and coldspot analysis

3.2 Cross-Border MBT Movement Patterns

The cross-border MBT routes comprise stoppage and moving patterns. As a result, the GPS points of cross-border MBTs are divided into stationary and moving points (stationary time stamps). Every stationary point becomes the potential stoppage location which requires analysis to verify whether it is the real stoppage location.

The route length between Johannesburg to Maputo is 547km and it takes approximately 7h15m. On average the Maputo to Johannesburg route recorded more stops (10 stops) outbound compared to the other trips (Table 1). The consistent stationary locations were observed on the tollgates, the service station for fuel and refreshments. It should also be noted that these were the average stops during the peak and off-peak times.

Table 1: Number of stationary locations along the route from Johannesburg to Maputo (outbound) and from Maputo to Johannesburg (inbound)

Johannesburg to Maputo - Outbound		Maputo to Johannesburg - Inbound	
Stops	**Activities**	**Stops**	**Activities**
1	Fuel Service Station	1	Matola Maputo Tollgate
2	Middelberg Tollgate	2	Moamba Tollgate
3	Machado Tollgate	3	Lebombo/ Ressano Garcia border
4	Traffic Inspection/ Police Stop	4	Traffic Inspection/ Police Stop
5	Nkomazi Tollgate	5	Nkomazi Tollgate
6	Driver checking the car	6	Traffic Police
7	Fuel Service Station (close to border)	7	Machado Tollgate
8	Lebombo/ Ressano Garcia border	8	Middelberg Tollgate
9	Moamba Tollgate		
10	Matola Maputo Tollgate		

The route length between Johannesburg to Mbabane is 364km and it takes approximately 4h15m. On average the Johannesburg to Mbabane route records fewer stops (5 stops) compared to the inbound journey (Table 2).

Table 2: Number of stationary locations recorded along the route from Johannesburg to Mbabane (outbound) and from Mbabane to Johannesburg (inbound)

Johannesburg to Mbabane - Outbound		Mbabane to Johannesburg - Inbound	
Stops	**Activities**	**Stops**	**Activities**
1	Middleburg Tollgate	1	Traffic Inspection/ Police Stop
2	Traffic Inspection/ Police Stop	2	Oshoek/ Ngwenya Border Post
3	Machado Tollgate	3	Caroline Town
4	Caroline Town	4	Fuel Service Station
5	Oshoek/ Ngwenya Border Post	5	Machado Tollgate
		6	Middleburg Tollgate

The route length between Johannesburg to Gaborone is 372km and it takes approximately 4h35m. The Johannesburg-Gaborone route recorded, on average four stops both during peak times and off-peak times and this is the least travel time compared to the other routes (Table 3). There was a constant base station for traffic police and that is where cross-border MBTs stop during random law enforcement.

Table 3: Number of stationary locations recorded on the route from Johannesburg - Gaborone (outbound) and from Gaborone - Johannesburg (inbound)

Johannesburg to Gaborone - Outbound		Gaborone to Johannesburg - Inbound	
Stops	**Activities**	**Stops**	**Activities**
1	Fuel Service Station	1	Kopfontein/ Tlokweng Border
2	Traffic Inspection/ Police Stop	2	Traffic Inspection/ Police Stop
3	Swartruggens Tollgate	3	Swartruggens Tollgate
4	Kopfontein/ Tlokweng border post	4	Fuel Service Station

There are more stops along the route during peak time due to law traffic enforcement operations. During off-peak times, the cross-border MBT only stop at the tollgate and fuel service stations. Furthermore, the information recorded represents the average stops during the peak and off-peak times. Generally, traffic law enforcers stop the cross-border MBTs to check for road permits, drivers' licences, and the roadworthiness of the vehicles and trailers.

Speed trajectories were recorded from the route network between Johannesburg and Maputo, Mbabane as well as Gaborone, both during weekends and holidays as well as on normal working days (Figure 7).

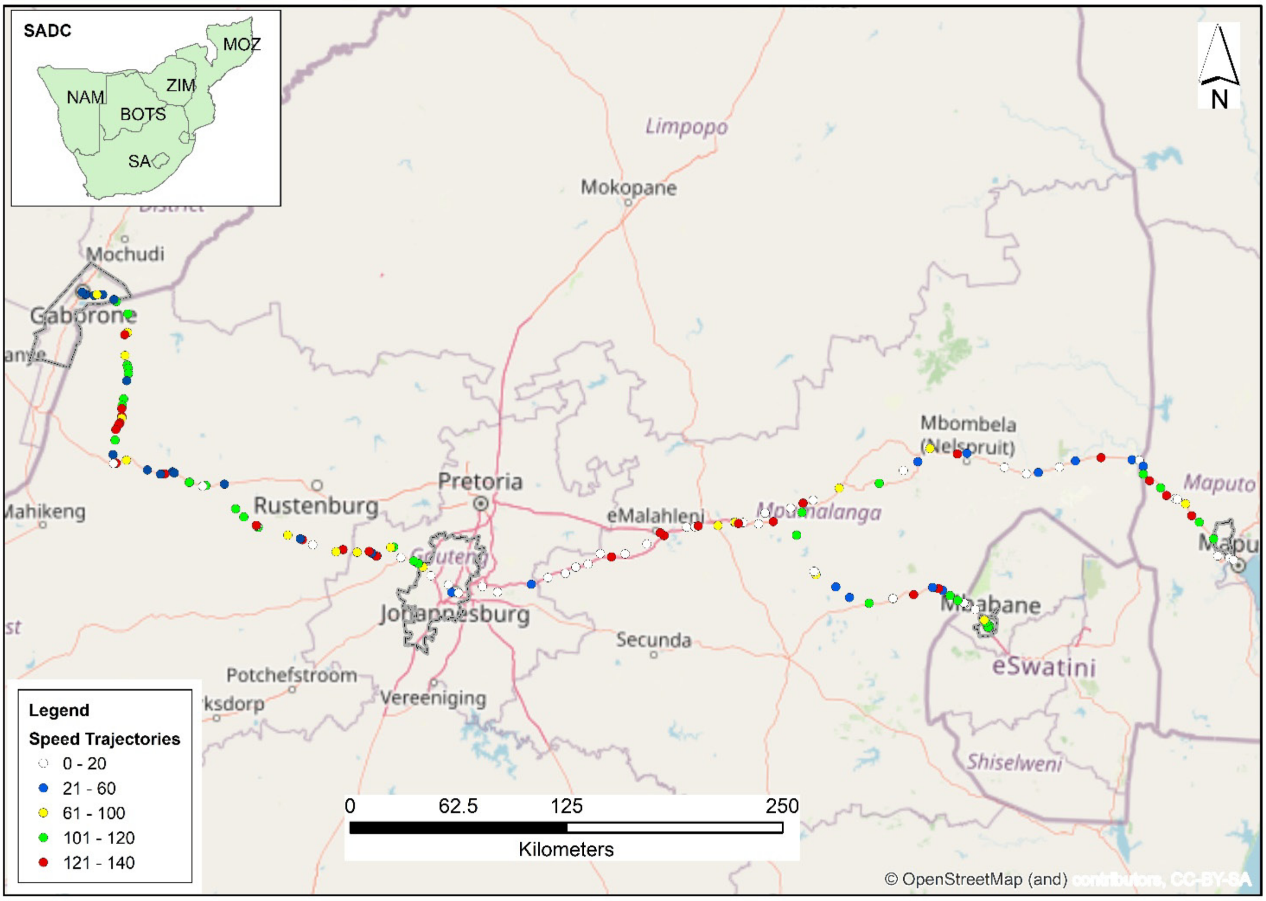
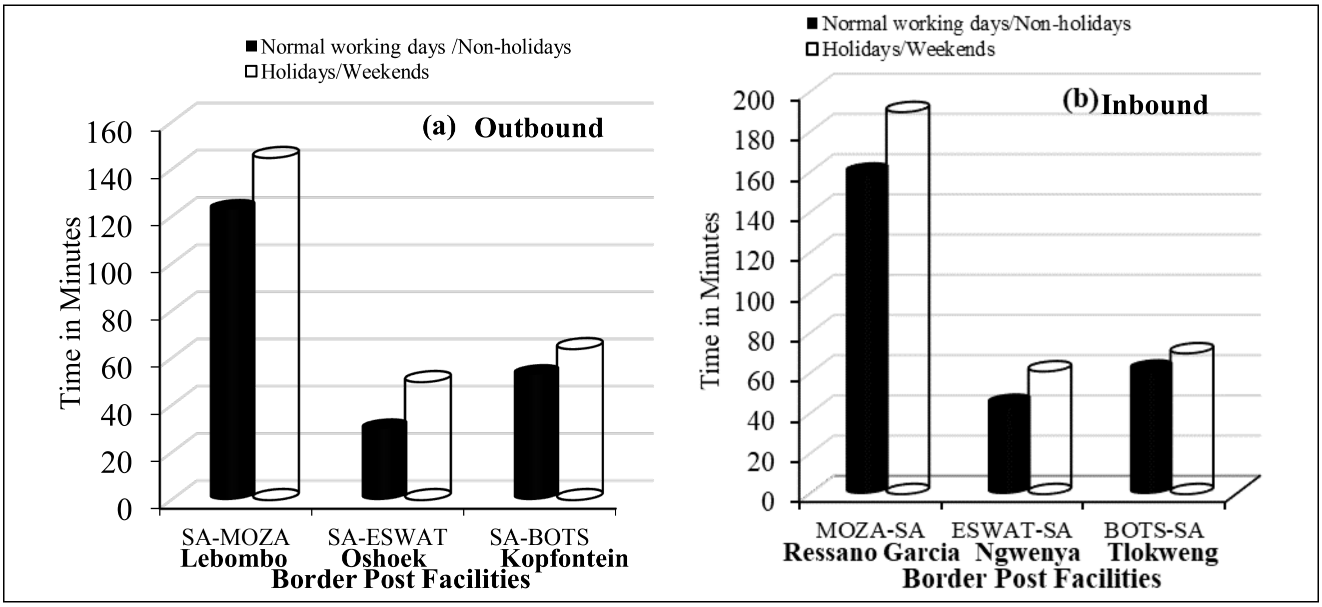


Figure 7: Illustration of the speed traps in kilometres per hour along the different routes

The speed profiles as recorded from GPS devices are used to differentiate between the different routes of the study. On the route to Maputo, there are fluctuations in top speeds throughout the trip with high and low speeds recordings. The top speed was recorded at 133 km/hr for the trips. There were more stationary times recorded during the off-peak period on the route to Mbabane and the return journey to Johannesburg. Most high speeds were recorded on the route to Mbabane than on the return journey. Movement patterns from Johannesburg to Gaborone show a top speed of 135 km/hr and was recorded on the journey to Gaborone from Johannesburg. Low speeds were recorded during off-peak periods and the route to Gaborone showed that there are more stops during peak periods. The speed gradually moves below 60 km/hr when the cross-border MBT crosses the border to Gaborone and continues to maintain the low speeds when the cross-border MBT departed Gaborone then increases the speed after crossing the border.

3.3 Border Post Activities

Border post facilities have different processing regulations for passengers. Operations at border post facilities are affected by the number of passengers per mode. The results shown in Figure 8a represent the outbound route networks. Lebombo border facility obtained a longer waiting period compared to other border posts in both periods. Kopfontein border post was second from the Lebombo border. The border post with the least time transit is Oshoek. The general outlook of the outbound activities shows a constant trend of longer waiting times during holidays or weekends compared to the normal working days.



*SA = South Africa, *Moza = Mozambique, *Bots = Botswana, *eSwat = eSwatini

Figure 8: Average passenger waiting time at the border post facilities (a) inbound, (b) outbound

Figure 8b above shows a similar trend of higher waiting time on the Ressano Garcia border. The border facility process time at Ngwenya and Tlokweng was almost similar to the outbound journeys. Overall, holidays or weekends still recorded higher waiting times compared to the normal working days. The route between South Africa and Mozambique resulted in more waiting times. This was followed by the border post between South Africa and Botswana. Then lastly the border posts between South Africa and eSwatini recorded the least waiting time. It should be noted that the reported results are for the average time considering both the inbound and outbound trips and during holidays and normal working days.

4. DISCUSSION

This study was aimed at using advanced GPS- and GIS-based techniques to assess cross-border MBT movements patterns and trends on the routes between South Africa, Botswana, eSwatini and Mozambique (Li et al., 2019;). Numerous studies have applied GIS technology in mapping movement patterns of taxis (Van Zyl and Labuschagne 2008; Dibatya et al. 2016; Zhang et al., 2017; Coetzee et al., 2018). Our study was different from the mentioned studies because it applied GIS technology to map movement patterns and travel trends of cross-border minibus taxis which have different operations to local taxis.

4.1 Cross-Border Rank Facilities Activities

Analysis of activities at rank facilities showed that on average there were more people during peak hours of the day (06:00-08:00) compared to other times of the day. This could be explained by the fact that most of the passengers prefer to travel in the morning, especially when using cross-border MBTs. The trend of high activities at the rank facilities is further noticed during weekends or holidays, thus it shows that majority of the passengers prefer to travel during the morning time between countries for various reasons. Such cross-border movement observations were also reported in the study by Thoso and Chibira (2016) who analysed South African long-distance passenger transport. The design of the rank facility has an impact on the waiting time due to the lack of proper circulation space for vehicle flow thus the rank tends to be congested during weekends or holidays.

Further analysis of the travel time showed that there was a high correlation between waiting time and the arrival time of cross-border MBTs at the Junta taxi rank facility in Maputo (R^2 =0.78) compared to the Park City taxi rank facility in Johannesburg (R^2 = 0.46). This could be attributed to more waiting in the evening and less waiting time in the morning (Figure 5) and therefore the graphs cannot be a parabola. A closer look at the clustering of activities at the rank facilities (Figure 6), shows more activities and high demand at the Park City taxi rank facility. A lot of passengers are present at the Park City taxi rank facility looking for transport to travel to either Botswana, eSwatini, or Mozambique (Moyo and Nshimbi 2017). The waiting time is higher in Maputo than in Johannesburg during normal working times because passengers approach the taxi rank facilities at different intervals, meaning those who arrive early will spend more time at the rank facility platform until the cross-border MBT is full and then it can move.

4.2 Cross-Border MBT Movement Patterns

Cross-border MBTs movement patterns were analysed from the point of origin to destination (inbound and outbound) through Johannesburg-Maputo; Johannesburg-Mbabane; Johannesburg-Gaborone. It was observed that cross-border MBT movement patterns are consistent with periods where the drivers increase their travelling speed during weekends and holidays. In most cases cross-border MBT movement patterns are dependent on the driver’s behaviour along the route networks and the condition of the SADC road infrastructures. For instance, on narrow roads after crossing the Ngwenya border, potholes in Maputo lead to the MBTs resulting in speed reduction and stray cattle on Botswana roads. Furthermore, strict road traffic control regulations on the border between eSwatini and South Africa were consistent with a speed reduction. Observations from the study show that some of the drivers increase speed regardless of whether it is a peak period or an off-peak period. In some instances, some drivers increase the speed when they realise that it is getting dark. Overall, the output of the study showed that there are more stationary locations (Table 1; Table 2; Table 3) during the peak period, which is mostly due to the presence of law traffic enforcements officers and police, especially during holiday times.

There have been some highlights on how GPS tracking data can be utilised in conjunction with contextual spatial information to mine and understand cross-border MBT travel behaviour (Li et al., 2019). The process of monitoring the cross-border MBT assisted with an understanding of operator route adherence. To the best of our knowledge, this is an attempt to look for potential GPS tracking data in the cross-border MBTs which are largely for quantity operations (Pophiwa, 2017). Some of the notable studies which successfully utilised GPS tracking for public road transport showed that vehicle trajectories can be effectively mapped with GIS applications (Barrile and Postoriono, 2016). Barrile and Postoriono (2016) study conclude that trajectories followed by vehicles can be mapped and used to monitor traffic congestion and the same observations were noted in the study.

4.3 Border Posts Activities

The cross-border MBT movement patterns were observed at the different border post facilities, and it was noted that a longer waiting time was recorded on Mozambique to South Africa borders, especially inbound movement (Figure 8). There are various reasons which can be attributed to the long waiting time at the Mozambique-South Africa border. Some of the reasons include the following; (a) Most of the passengers will not have proper travelling documents which allow them to cross-borders, from one country to another, hence this results in delays at the border post, (b) There is a lot of passengers between the border post who are looking for better economic opportunities such as buying and selling of goods as well as presence of bogus agents, thus pressure is put on the border facility, (c) Immigration put under pressure with large number of passengers arriving or departing at the same time, and (d) Lack of synchronised systems from one border officer to another as well as replication of processes from one country to another (Kwanisa et al., 2014). The South Africa-Botswana borders recorded the second-highest delays, and it was followed by the South Africa-eSwatini borders. It was observed that few people are travelling between eSwatini and South Africa. This could be attributed to the proximity of the two countries and informal crossing which result in people crossing by foot.

5. CONCLUSION

This study utilised advanced GPS- and GIS-based techniques to analyse cross-border MBT movements patterns on the routes between South Africa and Mozambique, eSwatini, and Botswana. With the analyses of activities at the rank facilities across different cities, it was observed that more activities at the rank facilities were recorded during the morning periods than any other time of the day. This was consistently recorded throughout the study period in both peak and off-peak times. Across different routes, more travelling time was recorded during weekends and holidays. Overall, activities observed at different border gates showed that the Maputo border post resulted in a long processing time compared to other border gate facilities.

GPS and GIS technologies will improve the collection, management, and reporting of cross-border road passenger transport data. It is therefore imperative to develop data management capabilities that improve the quality of cross-border road passengers and MBT operators. The most noteworthy outcome of this research is the information on cross-border passenger waiting time at the rank facilities, informal stops, stoppages through law enforcement operations, border posts and the movement patterns of the cross-border MBTs. There must be a synergy of all these variables for the MBT movement patterns to be effective and efficient on the route network.

It is not possible to understand cross-border MBT movement patterns using rank surveys only. The results of the study reviewed that utilising GPS tracking can be an essential tool in monitoring the cross-border road transport network. This will aid in the passenger's decisions on which time is better to plan on travelling from one country to another because most people would want to avoid idling at the rank facilities while they can be running some errands. It is critical to introduce such innovative ways to improve cross-border road passenger transport efficiency in developing nations coupled with investment and integration of big data from different stakeholders.

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