MEASURING INDIVIDUALS' TRAVEL BEHAVIOUR BY USE OF A GPS-BASED SMARTPHONE APPLICATION IN DAR ES SALAAM CITY

L JOSEPH, A NEVEN*, K MARTENS*, O KWEKA*, G WETS*, D JANSSENS*

Hasselt University; Wetenschapspark 5, bus 6, B-3590 Diepenbeek, Belgium
Tel: +255717138930 E-mail: lucy.josephchabariko@uhasselt.be
*Hasselt University; Wetenschapspark 5, bus 6, B-3590 Diepenbeek, Belgium
Tel: + 32 (0)11 26 91 30; E-mail: An.Neven@uhasselt.be
*Technion-Israel Institute of Technology, Haifa, Israel
Tel: +972-53-821-9521; E-mail: k.martens@fm.ru.nl
*University of Dar es Salaam, P.O.BOX 35049, Dar es Salaam, Tanzania
Tel: +255 784 677 254; E-mail: okweka@yahoo.com
*Hasselt University; Wetenschapspark 5, bus 6, B-3590 Diepenbeek, Belgium
Tel: + 32 (0)11 26 91 58; E-mail: Geert.Wets@uhasselt.be
*Hasselt University; Wetenschapspark 5, bus 6, B-3590 Diepenbeek, Belgium
Tel: + 32 (0)11 26 91 28; E-mail: Davy.Janssens@uhasselt.be

ABSTRACT

The use of paratransit has been the most popular transport in many African mega cities. In Dar es Salaam (DES), the system has been the only available public transport for the majority, as the other form of public transport (state-bus) failed to operate in 1990s after a rapid increase of mobility demand. Paratransit transport (e.g., minibuses, motorcycles and tricycles) operates in different forms to cater the diversity of travel demand, both social and economic. However, the lack of adequate road connectivity and of an integrated public transport imposes heavy loads on individuals' mobility, due to limited travel options and time costs. Therefore, the recent intervention by the Tanzanian government to implement a Bus Rapid Transit (BRT) system is expected to meet the travel demand not only for individuals residing at close proximity, but also for peri-urban areas. However, not much is known about the current travel patterns, including paratransit use, which can be relevant in addressing spatial mobility demand for different individuals. This study focuses on a new method of data collection (GPS-based smartphone application) to test and capture individuals travel behaviour. The method was used to record distances, times and destinations of trips. Socio-demographic data of smartphone users were recorded in survey questionnaires. The results reveal variation in departure times, travelled destinations and trips distances that are spatially limited within neighbourhoods and away to the BRT, and along major road connecting to the Central Business District (CBD). The spatial distribution of the trips patterns shows mobility demand in both high and less connected areas. The short average distance of the trips (≤3km) considered to convey the use of paratransit modes. The GPS-based smartphone application provides an opportunity to policy makers to engage deeply with the spatial reality of local communities as a basis for transport policy improvement and toward an integrated system.

Keywords: Travel behaviour, Paratransit, GPS-based smartphone application

1 INTRODUCTION

Travel behaviour reflects the way personal activities are performed in different locations, which involves particular use of transport in various movements in time and space (Ding and Lu, 2016). Travel is a ‘derived demand’, as the individual's displacement within the space is driven by a clear motive, like going to work, school, looking for jobs and attending social matters whereby transport is the key determinant of any interaction (Neven et al., 2013; Schoenau and Müller, 2017). User characteristics (e.g., age, gender, employment) may cause variation in transport use and trips characteristics among individuals. From this aspect, low-income individuals in peri-urban areas without a car or reliable public transport may experience more serious constraints than others in performing out-of-home trips and in accessing opportunities beyond their neighbourhoods (Kamruzzaman et al., 2016). Improving the public transport system to a level as desired by individuals relatively to their socioeconomic status, is not only fundamental for their living, but also for the wider society development as well as a prerequisite of a fair transport system (Martens, 2017).

Traditionally, the use of survey questionnaires and travel diaries has been the most common methods to capture travel behaviour and patterns (Curtis and Perkins, 2006). However, various studies have shown several weaknesses of traditional travel diaries in travel data collection (Behrens and Masaoe, 2009; Witlox, 2007). The methods rely on the individual’s ability to remember and interpret travel times for each trips, which may not be easily for some individuals (without time-measuring device at their disposal). High chances of human errors in reporting trip distances are possible, as the way distance is measured may differ from one person to another e.g., physical *vs.* social distances (Kamruzzaman et al., 2016). Some destinations and trips are ignored or difficult to be reported, if the places lack specific addresses, or are known by multiple names which is common in developing countries where many places are unplanned. For example in Dar es Salaam (DES), Tanzania, about 75% of all residential houses are found in unplanned areas (Rasmussen, 2013).
Besides, the organization of Public Transport (PT) in the global south is consisting of complex forms in such a way that traditional travel diaries alone may not be visible to reveal its mobility contribution in space and time (Uteng and Lucas, 2018). In many African mega cities with a rapid and low-income population growth, the use of paratransit is most popular (Behrens et al., 2015). The system occurs throughout the whole world, in both developed and developing countries, with substantial variations in degree (Gërxhani, 2004; Rizzo, 2011; Rogerson, 2016). However, paratransit is especially dominant in developing countries where the demand for transport is increasing rapidly with emerged features of uncontrolled sprawl, unemployment, poverty and a serious shortage of resources (Agbiboa, 2016; La Porta and Shleifer, 2014).

The paratransit concept refers to small passenger transport vehicles that are characterized by a variety of mobility services they offer (flexible, and door-to-door) to meet individuals travel demand (Behrens et al., 2017, 2015; Khayesi and Nafukho, 2016). They go to different directions and areas, of which the routes are determined by individual passengers. They adjust their routes to serve a variety of users; so most of paratransit modes are not subject to a fixed route and stop. The system is flexible as they can stop anywhere to drop and pick passengers (D’hondt, 2009; Kanyama, 2016; Mkalawa and Haixiao, 2014). The amount of flexibility varies: some vehicles have a fixed route along the main or popular corridor, while others (generally smaller vehicles) have a variable, demand responsive route (operates when a user need it). The size of the vehicle varies as well, with vehicles ranging from motorcycles over tricycles to minibuses. As a means of transport, paratransit is oriented to overcome local travel challenges by extending its services to areas with an inadequate

connectivity by the conventional PT. However, until now there is a methodological gap to capture this complex spatial mobility of paratransit use in a case study area.
The rise of smartphone applications in transport research has created new opportunities to access a wide range of previously unavailable information about travel behaviour in developing countries, as traditional travel diaries were shown to have several weaknesses. GPS-based smartphone applications (GPS-App) allow all kinds of individuals' movements in space and time to be recorded with a high level of detail (e.g., visited destinations, accurate distances, times, and adjusted routes/paths) with less effort (Nour et al., 2016; Schoenau and Müller, 2017; Zhou et al., 2017). Although these applications are becoming more available, the use of GPS-App in developing countries, particularly in DES is less common.

In DES, as one of the mega cities in Africa (estimated population 4.5 million), the PT is provided by minibuses (*daladala*), and smaller vehicles like motorcycles and tricycles. Since the early 1990s, transport services have been dominated by these paratransit transport operators with a market share of 90%, compared to the state bus company that decreased rapidly its market share to 2% (Rasmussen, 2013). Today, paratransit is the only available travel solution for the majority of the population in DES, as many neighbourhoods live in areas with inadequate connectivity, narrow and unpaved earth roads which provide limited access to the city's trunk roads and thus to other areas in the city (Behrens et al., 2015; Kanyama, 2016; Mkalawa and Haixiao, 2014; Rizzo, 2011). During the rainy season, most of the roads become impassable, and individuals are disconnected from the daily travel opportunities which expose them into a risk of exclusion from social and economic opportunities. Efforts to improve the mobility of the inhabitants are however limited to a few places, as transportation investments are mostly done to ease traffic congestion and provide access to the Central Business District (CBD).

A new Bus Rapid Transit (BRT) system is being implemented by the Tanzanian government, which is distinguished from paratransit by use of high quality and capacity buses (150 passengers) on dedicated lanes with pre-defined schedules, and use of electronic ticketing (Ka'bange et al., 2014; Nkurunziza et al., 2012; Rizzo, 2015). The BRT system in DES which is named as Dar es Salaam Rapid Transit (DART) has specific stations and defined areas to operate. Despite the good qualities of the DART, some literature indicate that most organized formal transport systems like DART emphasize on speed efficiency, and thus offer limited travel options for most of low-income individuals (Ka'bange et al., 2014; Khayesi and Nafukho, 2016; Rizzo, 2015; Vermeiren et al., 2015). Some social contexts and local environment can be neglected, e.g., informal households and activities, and impact of climate change in transport infrastructure.

Therefore, in the current study, a GPS-App was used as a new low-cost method to shed light about travel behaviour, including paratransit use, in the case study area of DES where paratransit replaces the non-existence of government supported PT. The GPS-App was used to capture individuals travel distances, departure times and frequency of trips prior to the planned DART system. The prior study intended to create a platform for comparison in the future study with DART (after the system transformed) to determine possible travel behaviour changes.

Table 1 Paratransit modes in DES and its characteristics (Kanyama, 2016; Madinda and Mfinanga, 2013)

Minibus (*Daladala)*	• Commuter minibuses and privately owned PT • Consists varying passengers' seats capacities • Some have specific routes and others do not have especially in peri-urban areas where the road is in poor condition (earth road) • No fixed schedules to be followed, but *daladala* leave the stops when it is full of passengers (difficult to determine departure times) • Approximately, 7000 daladala buses operate in DES • Routes can be adjusted or changed anytime to where there is a high demand or less congestion
Motorcycle (*Bodaboda*)	• A two-wheeled vehicle • Carrying 1-3 passengers • Fare can be shared among passengers • Privately owned • Available in congested) and non-congested areas • no fixed route • Destination is mostly determine by users/passengers
Tricycle (*Bajaji*)	• A three-wheeled vehicle • Carrying 3-4 passengers • Common in high (congested) and non-congested • Operates in all kinds of road conditions • No fixed route • Travel destination is highly determine by users/passengers

2 METHODOLOGY

2.1 Study design

Data collection was conducted before implementation of the DART system in order to capture individuals travel behaviour. Two main instruments for data collection were used; a GPS-App 'Sparrows' and survey questionnaires.

2.2 Data collection tools

The GPS-App 'Sparrows', which is developed by the Transportation Research Institute (IMOB) of Hasselt University, was capable of recording real-time based trips and stops for each individual participant. Trip specific information in terms of trip distances, trip frequency and travelled destinations were collected. To use the GPS-App, participants had to install Sparrows via the Google Play Store. The installation process was done in interactive ways with participants to confirm that the process was done properly and successfully. Research assistants and the lead researcher were involved in the installation process of the Sparrows application. After installation, data were collected automatically once the GPS of the smartphone was turned on, and participants were asked to carry his/her smartphone when making a trip. To avoid challenges related with low battery and power issue, travel data of one day were collected for this pilot study. Sparrows did not need an internet connection in order to operate, but data were transferred to the server once the internet connection was turned on. QR-codes were generated to assist in identifying each participant in the database. Survey questionnaires were used to record socio-demographic information (e.g., age, gender, employment and car ownership) of the GPS-App users. The survey also included information about modal split. These data was considered as important when linked with GPS-App data in comparing trip variation by individuals' characteristics (age, education, gender etc.).

2.3 Selection of participants

Participants of this study include diverse transport users (e.g., women, men, unemployed, employed), who were in the possession of GPS-based smartphone. Based on this selection of participants, the obtained sample size was not representative, because of exclusion of non-smartphone users. However, this small sample helped to test the effectiveness and feasibility of the GPS-based data collection method in a small geographical area with a diverse group of individuals. A total of 77 individuals who possessed smartphones were involved. With the help of local leaders in both study neighbourhoods, smartphone users were identified and requested to participate in the study. The use of local leaders was important for participants to gain trust and security towards the study.

These participants were recruited in two different locations along the planned DART system: one adjacent to the DART system (Kimara ward) and another a peri urban area (Mbezi ward), as illustrated in Figure 1. Based by this selection, we could in a later phase - i.e. after implementation of the DART system - monitor the possible travel behaviour changes on an individual level (travel behaviour before and after implementation of the DART system). Another factor for this selection was that the current plan shows an extension of unplanned residential areas in the west corridor along Morogoro road, where the DART is located. The individuals away from this main road may experience several transport challenges exposing them into risk of transport exclusion. Also, paratransit is used frequently in both study neighbourhoods, indicating that this transport mode covers different geographical locations.

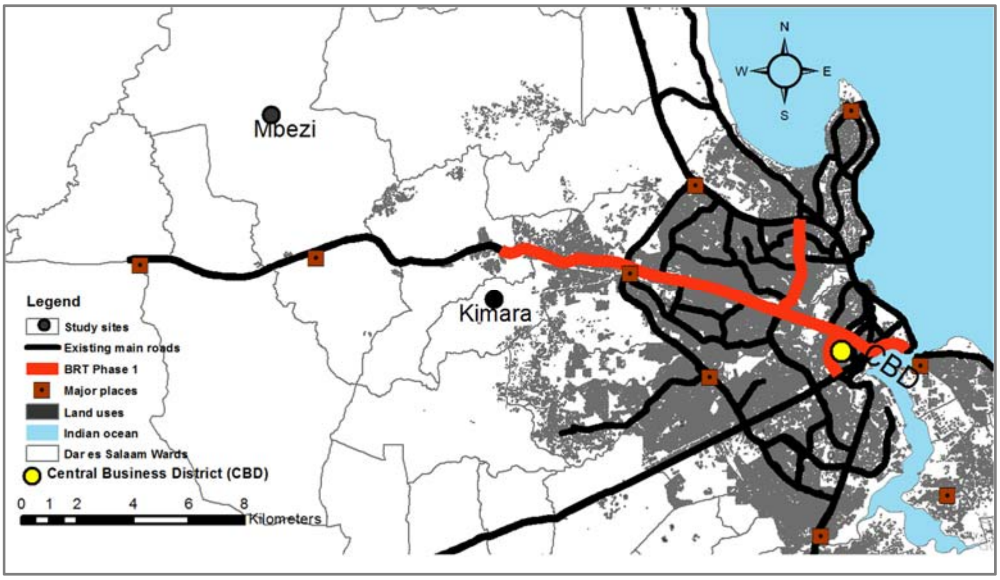

Figure 1 Main roads and location of the planned BRT line

2.4 Data analysis

This study utilized quantitative data from the GPS-App (travel data) and the survey questionnaires (socioeconomic data). Data were analysed and presented by using ArcGIS 10.3 and IBM SPSS statistics 24. Other datasets from secondary sources included ESRI online Base maps (Open Street maps of DES), roads and wards shapefiles from Tanzania National Road Agency (TANROADS) and National Bureau of Statistics (NBS). These datasets were used to facilitate GIS spatial analysis (overlaying, joining and merging) of different datasets.

The GPS traces of the individual movements were in the form of points and lines, representing stops and trips. These datasets were analysed in GIS technology to visualize original trips and stops, to identify patterns, and for further spatial statistical measurement (Chen et al., 2011; Du, 2000, Liu et al., 2015). ArcGIS 10.3 was used to measure spatial data about average distances, departure times and average number of trips (frequency).

Density analysis in GIS was performed to identify concentrations of trips along different road network. One-day trip data generated by individuals were used to compare and measure trip variations among individuals. IBM SPSS statistics 24 was used to perform descriptive statistics between sociodemographic variables and trips. The outcomes of the various geo-processing analysis (e.g., spatial density) in ArcGIS, and the SPSS analysis, were presented in figures and tables.
ArcGIS analytical tools for spatial density analysis of trips include selection tools (select by attributes using query builder expression: “place” = ‘Mbezi’, or ‘Kimara’). From these selections, the output feature class of the selection were used as input datasets for line density analysis. Other parameters in line density tool were set in default to allow ArcGIS identifies places with high and low concentration of trips. The model (Figure 2) below was created in ArcGIS to illustrate procedures involved to create density maps presented in the results.

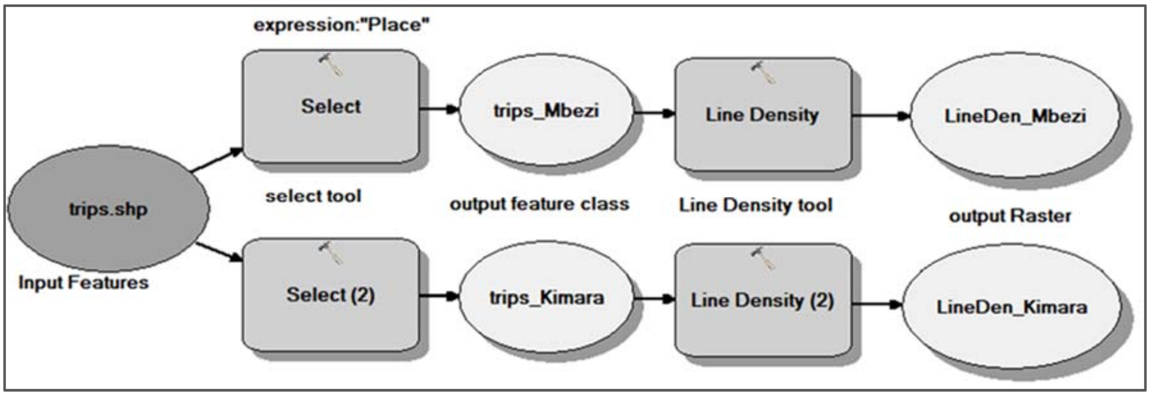

Figure 2 ArcGIS analytical tools for spatial density

2.5 Socioeconomic characteristics of the participants

Table 2 presents the socioeconomic characteristics of the participants based on age, gender, education, vehicle ownership (any travel modes not only car) and employment status. The results show that vehicle ownership among individuals is minimal. Educational levels of the participants include a higher number of individuals’ with secondary education (39) as compared to higher (23) and primary (15) education. Self-employed individuals include those engaged in small and medium business (Rizzo et al., 2015) such as petty traders, street vendors, shoe shiners, and tailors etc., with or without permanent work-places. Full-time and part-time employees were those in public and private sectors. Unemployed individuals include those either searching for a job or not.

Table 1 Socio-economic characteristics of the participants

Characteristics	Area	Area
	Kimara (adjacent to BRT)	Mbezi (peri-urban)
Gender (M/F)	20/23	18/16
Age (<35/35-45/46+)	21/17/5	11/15/8
Education (Primary/Secondary/Higher)	6/19/18	9/20/5
Vehicle ownership (Yes/No)	8/35	8/26
Employment(Full/Part-time/Self/Unemployed)	13/10/13/7	5/4/22/3

3 RESULTS

3.1 Modal split.

This section compares the use of various modes of transport by socioeconomic factors of the individuals (age, gender and education) and between study locations (Mbezi and Kimara) along Morogoro main road. This information help to understand modes availability between the two neighbourhoods, and which individuals make use of various means of transport. In both study neighbourhoods, the use of paratransit transport is common as compared to private car and walking. As already shown in the previous section that vehicle ownership among participants is limited, which means most of individuals depend on paratransit modes such as *daladala* bus, tricycles, and motorcycles. Despite this, there is variation in modal split between the two neighbourhoods and among individuals (Table 3).The number is higher because of multiple responses from most of participant in different modes.

Table 2 Modal Split by locations and individuals characteristics (survey data)

Modes	Area (Kimara/Mbezi)	Gender (M/F)	Education (Primary/Sec/Higher)	Age (18-25/26-35/36-45/46-55/56+)
Daladala	33/22	26/29	12/31/12	3/23/24/4/1
Motorcycle	28/25	30/23	14/27/12	0/24/21/6/2
Tricycle	34/8	20/22	9/19/14	3/20/14/4/1
Car	10/6	10/6	2/2/0/12	0/1/9/6/0
Walking	11/3	8/6	1/8/5	1/10/2/1/0)

3.2 Individuals' characteristics and travel variations

This section describes trips characteristics from GPS-App in relation with socio-economic data (age, gender, and work status, and car ownership) from the survey questionnaires. The main purpose is to describe variation in trips distances, and number of trips by different groups. Table 4 shows variation of trip characteristics for each category based on average lengths and number of trips. The highest average number of trips of 4 is observed in the age group younger than 25, and the lowest average number of trips of 2.25 is observed in the unemployed category (highlighted values in Table 4). In a similar way, the highest average trip lengths of 18.5km is observed in full-time employed and car-owners individuals. This particular data provide evidence that GPS-App is a feasible technique in measuring different trip distances made by different individuals. This is important because trip distances may also determine the way individuals make use of different transport modes.

Table 3 Travel variation by individuals' characteristics (GPS traces and survey data)

Characteristics		Average number of trips Mean ± Std. Dev (Min-Max)	Average trip distances (Km) Mean ± Std. Dev (Min-Max)
General (N=77)		3.03 ± 1.97 (1-9)	3.57 ± 3.46 (0.1-18.5)
Gender	(M)	2.99 ± 1.97 (1-9)	3.0 ± 2.5 (1.0-12.4)
	(F)	3.06 ± 1.98 (1-8)	4.0 ± 4.1 (0.2-18.5)
Age	(≤ 25)	4.0 ± 1.5 (3-6)	2.0 ± 2.5 (0.3-5.8)
	(26-35)	3.1 ± 2.1 (1-8)	2.0 ± 1.8 (0.1-7.4)
	(36-45)	2.7 ± 1.9 (1-9)	4.8 ± 4.0 (0.2-18.5)
	(46-55)	3.4 ± 1.9 (1-7)	4.5 ± 3.7 (1.1-12.4)
	(+55)	3.4 ± 1.9 (1-7)	4.5 ± 3.7 (1.1-12.4)
Work	(Full-time)	3.5 ± 1.9 (1-8)	6.0 ± 4.9 (1.6-18.5)
	Part-time	3.5 ± 2.7 (1-9)	2.4 ± 1.8 (0.1-6.7)
	Self-employed	2.7 ± 1.6 (1-8)	3.3 ± 2.5 (0.1-10.5)
	Unemployed	2.25 ± 1.4 (1-6)	1.6 ± 2.4 (0.2-8.1)
Car	(Non-car owners)	2.9 ± 1.9 (1-9)	3.0 ± 2.9 (0.1-16.6)
	Car owners	3.5 ± 1.9 (2-8)	5.4 ± 4.5 (1.3-18.5)

3.3 Temporal dimension of individuals' trips

The temporal dimension of trip-making is determined by individual decisions to travel. The way in which individuals decide when the trip to be made (starting time of the trip) differs from one individual to another. Understanding of start time at which the trips were made is relevant in determining operating hours of PT taking into account that individual trips are driven by complex factors ranging from social to economic demand. In Table 5, the temporal trip characteristics by gender show the variation between males and females. About 15.8% of male made their trip between 03:00-05.59 am as compared to female in the same time slot (7.7%). For self-employed individuals, trips are conducted throughout the entire day. This table also shows when individuals actually conduct their trips, which is important in transport provision. The table also present interesting findings about the GPS-App in extracting temporal dimension (actual time and day) of the trips made by individuals.

Table 5 Temporal dimension of trip making by individuals

Departure	Gender	Employment status					
Time	M/F	Full-time	Part-time	Self-employed	unemployed		
03:00-05:59	6/3	2	2	3	2		
06:00-08:59	5/10	3	3	8	1		
09:00-11:59	6/9	4	3	7	1		
12:00-14:59	9/7	2	4	6	4		
15:00-17:59	10/6	6	2	7	1		
18:00-23:59	2/4	1	-	4	1		
Total (individuals)	(38/39)	(18)	(14)	(35)	(10)		
Day	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Total(trips)	97	215	302	222	298	340	198

3.4 Visualizing original trips and stops

The GPS traces represent stops and trips of individual's movements in space and time. The stops are represented by point features for all locations, and trips/pathways were represented by linear features. Visualization of original GPS traces of individuals' trips and stops spatially is an added value of the GPS-App to provide evidence of where exactly individuals' movements occurred. Figure 4 shows a heat map used to visualize original stops and trips in ArcGIS 10.3. The figure shows a concentration of stops and trips along the road networks, displaying a linear like pattern. There are also many paths/routes extracted from individuals' trips, extending from major roads that are not actually similar with existing planned road networks. This may also reflect additional possible paths/routes generated by paratransit modes to serve individual mobility demand.

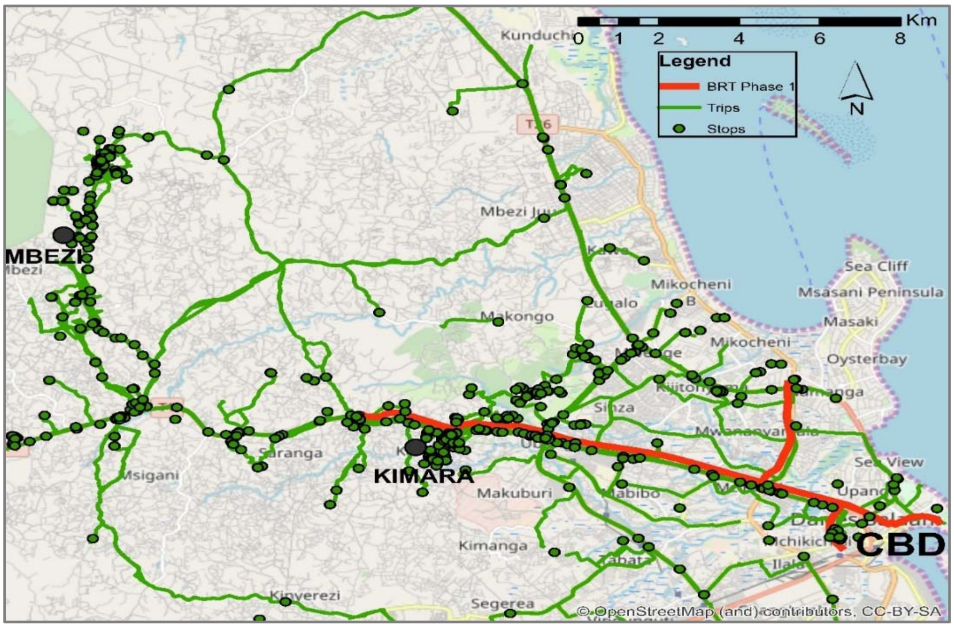

Figure 3 Visualizing original trips (green lines) and stops (green dots)

3.5 Extracting travel patterns from GPS-App

Using the line density tool in ArcGIS 10.3, low and high spatial concentration of trips observation were mapped based on natural break classification (7 classes), and displayed using bilinear interpolation for continuous data to capture all paths. A smooth and continuous map was created with colour variation indicating high (red area) and low (dark blue) concentrations of trips. Figure 5 displays generated routes paths by GPS-App in density maps for Mbezi (Map A) and Kimara (Map B). The high and low concentrations of trips occur in some sections of the roads (including where the planned DART is located), and in the peri-urban road as for the case of Mbezi. Low concentrations of trips in some roads/paths reveal a spatial diversity in travel demand among individuals. The result of the density analysis is not for statistical testing but provides a visual identification of mobility patterns. The high and low density travel patterns help to distinguish travel demand of an individual from those of groups (occurred in major road). The mobility patterns of outside the planned networks shows that the paratransit services are operating in areas where there is demand for transport.

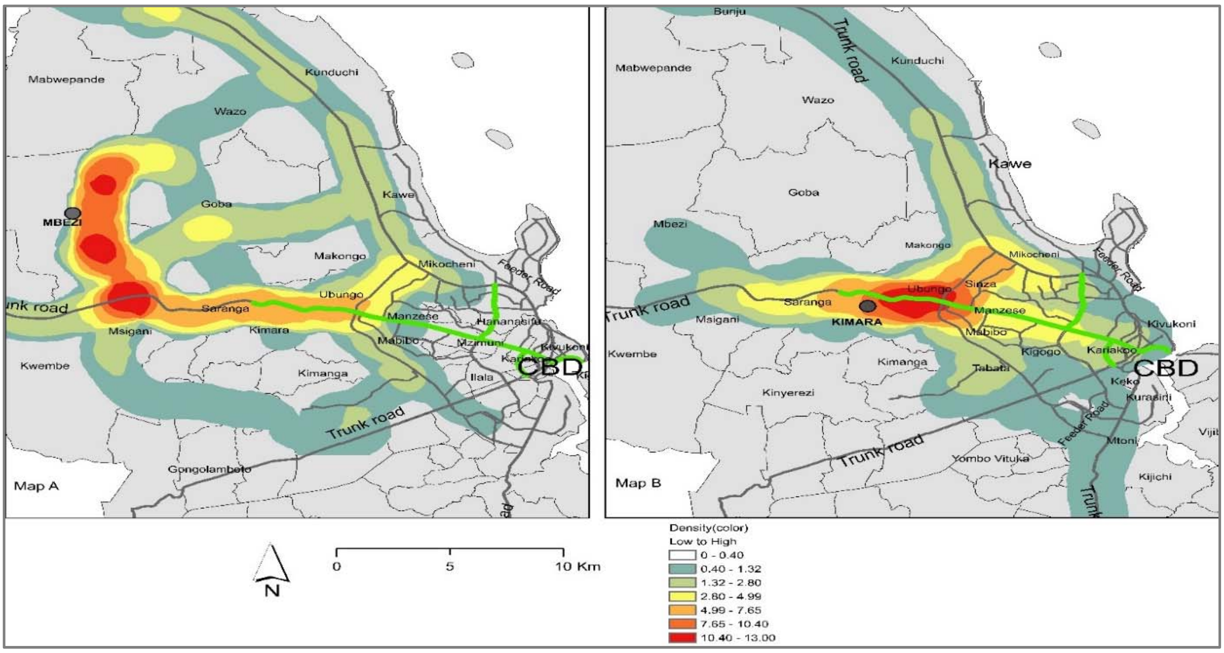

Figure 4 High and low spatial concentration of trips paths/routes

4 DISCUSSION AND CONCLUSION

The results presented provide insights in the ability of the GPS-App, in revealing individuals travel behaviour in developing countries where individual travel is mainly by paratransit. The method helps in understanding spatial mobility demand in both major roads (higher functional network) and local streets. This method is also powerful in capturing real travel behaviour of individuals in different spatial-temporal dimensions of trip-making e.g., real-times, day (when an individual decides to make a trip), distances, and locations. The original trips and stops extracted with the GPS-App reveal some paths that are not typically matching to the planned road network, showing that spatial mobility of the individuals are not only driven by the planned road network, but also unplanned road network extended and defined by paratransit. This information is important, particularly for planners who seek to meet travel demand to consider mobility away from planned road network as other lines of inquiry which could be relevant in understanding individual interaction with social needs.
The real-temporal dimension of trip-making includes late-hours night trips and early-morning trips. This is another strength of the GPS-App in revealing actual temporal demand of transport for different individuals. Paratransit transport provides a mobility solution for individuals without a private car, to travel anytime they wish, as the system considers mobility as a service that can be accessed at any time by any individual.
The reliance on traditional travel survey data for decision making may underrepresents paratransit trips in unknown addresses and undefined routes which are common in unplanned cities like DES. The spatial distribution of paratransit service (i.e., actual operating hours or schedule) remains unclear (unknown) in previous studies as the traditional method of travel survey did not capture the complex inherent behaviour like adjusted routes/paths and spatial area of paratransit service that could be precisely compared with these findings.
The trips characteristics indicate that there is a slight variation among individuals in terms of trip lengths, travelled destinations, and alleyways. The spatial patterns of the trips are largely limited to a few places along the major road and within neighbourhoods. Besides, the average trip lengths show that more short trips (≤3km) were made than long trips (>3km). The results reveal possible contribution of paratransit modes in spatial demand of the transport, which is in line with most of studies describing trips characteristics by paratransit transport modes (Guillen et al., 2013; Woolf & Joubert, 2013).

The high trip density along the trunk road and outside main road show that there is a need for enhancing first and last mile connectivity for efficient PT and minimizing barriers for individuals commuting away from the planned DART system. The linear travel pattern indicates that road connectivity can be one of the influencing factors of this pattern (e.g., roads.). However, lack of clear patterns for some trips and stops may also indicates other areas of transport demand. The findings presented offers methodological contribution of the GPS-App in capturing spatial mobility demand in areas with complex forms of public transport (e.g., paratransit).

5 LIMITATION

The findings contribute to the knowledge gap on the way a GPS-based data smartphone application can be relevant in capturing actual trip paths, destinations and real times and distances. The spatial related travel patterns generated by individuals travel behaviour, is a new alert in redefining transport road networks to serve diversity in travel demand. The results reveal the travel intensity of paratransit occurring outside the trunk areas, especially for non-car users.

Although the study involved a small number of participants, we believe it is informative to the potential of the GPS-based smartphone method in understanding paratransit services in a case study area. The method can provide decision-makers in government with the data they need to improve public transport policy towards BRT, and monitor its impacts across a range of target social groups.

The methodological recommendation is that GPS-App can be adapted to capture travel behaviour data for appropriate modal integration. Although this GPS-App is largely quantitative, it is practicable in the context of ongoing and real-life situations. The study provides a baseline for further research to monitor individuals travel behaviour change after DART system.

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