Measuring individuals' travel behaviour by use of a GPS-based smartphone application in Dar es Salaam, Tanzania

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

Abstract

A range of mega-cities in the Global South have started to invest in Bus Rapid Transit (BRT) systems, as a complement or replacement for informal paratransit services, in an effort to improve the mobility and accessibility in the city. Yet, few studies have tried to analyse the impact of such systems on the mobility patterns of cities' residents, in part because traditional travel diary surveys are often too expensive to conduct and unsuitable to capture spatial mobility patterns in fast growing cities with a high level of informality in spatial development. In this study, we analyse the applicability of a new method of data collection, i.e. a GPS-based smartphone application, to capture individuals travel behaviour in fast growing mega-cities in the Global South. Our case study is the city of Dar es Salaam (DES) in Tanzania, where the first BRT line is currently being implemented. In our study, the GPS-based app was used by individuals in DES to record distances, departure times and destinations of their trips. Socio-demographic data of respondents were recorded in short questionnaires. The spatial distribution of the trip patterns shows the mobility demand in both high and less connected areas. The results reveal a variation in departure times, travel destinations and trip distances that are one the one hand spatially limited within neighbourhoods and away from the planned BRT, and on the other hand along major roads connecting to the Central Business District (CBD). The short average distances of the trips (less than 3km) reveal the characteristics 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 investments and policy improvements as steps towards an integrated public transport system.

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

1 Introduction

Travel behaviour patterns reflect 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 movements through space is typically driven by a clear motive, like going to work, school, looking for jobs and attending social matters whereby transport is the key enabler of any interaction (Neven et al., 2013; Schoenau and Müller, 2017). User characteristics (age, gender, education, employment, etc.) 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 (PT) may experience more serious constraints than others (e.g. high-income earners, car owners) in performing out-of-home trips and in accessing opportunities beyond their neighbourhoods (Adeel et al., 2016; Diaz Olvera et al., 2013; Oviedo Hernandez and Titheridge, 2016). Improving the PT system to a level as desired by individuals of different socioeconomic status is not only fundamental for their life, but also for the wider society development as well as a prerequisite of a fair transport system (Martens, 2017; Casas and Delmelle, 2014).

Traditionally, survey questionnaires and travel diaries have been the most common methods to capture individuals travel behaviour and patterns (Curtis and Perkins, 2006). However, various studies have shown several weaknesses of traditional travel diaries in the 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 trip, which may not be easy or feasible for some individuals (without time-measuring devices at their disposal, or without reading and writing skills). High chances of human errors in reporting trip distances (actual versus estimated) are possible, as the way distance is measured may also differ from one individual to another, e.g. physical versus social distances (Kamruzzaman et al., 2016). Some destinations and trips are ignored or are difficult to report (or will be misreported), especially when the place lacks a specific address or is known by multiple names. This is mostly common in the Global South, where unplanned settlements are generated by individuals themselves, lacking a professional way of land use planning, and often without postal codes or specific addresses.

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 Global South. GPS-based smartphone applications (GPS-apps) allow the recording of a multiple data on an individual’s movements in space and time, at a high level of detail (e.g. visited destinations, actual distances, times, and route-paths) with limited effort (Nour et al., 2016; Zhou et al., 2017). Although these applications are becoming more available, the utilization of GPS-apps for collecting mobility demand and patterns data in Global South, is less common.

PT in cities in the Global South is typically not a system planned in a top-down way, but rather a compilation of bottom-up initiated informal paratransit services, implying that traditional travel diaries alone may not be suitable to reveal the mobility patterns across a paratransit system in space and time (Uteng and Lucas, 2018). As in many African mega cities with a rapid growth in mostly low-income population, the use of paratransit modes by individuals is the most common way of overcoming mobility challenges in different local settings (Salazar Ferro and Behrens, 2015). Paratransit exists throughout the whole world, in both Global North and Global South, with substantial variations in degree (Gërxhani, 2004; Rizzo, 2011; Rogerson, 2016). However, paratransit is especially dominant in Global South where the demand for transport is increasing rapidly in combination with uncontrolled sprawl and unplanned settlements, unemployment, poverty and a serious shortage of resources (Agbiboa, 2016; Jabareen, 2014; La Porte and Shleifer, 2014). Paratransit refers to small passenger transport vehicles, characterized by a variety of mobility services they offer (flexible and door-to-door) to meet individuals travel demand (Behrens et al., 2015, 2017; Khayesi and Nafukho, 2016). Most paratransit modes are not subject to fixed (planned) routes and stops. The system is flexible as it can stop anywhere to drop off and pick up passengers (Kanyama, 2016). The level of flexibility varies: some vehicles have a fixed route along a main or popular corridor, while others (e.g. smaller vehicles) have a variable, demand responsive route (and only operates when a user needs it, much like a regular taxi). The size of the vehicle varies as well, with vehicles ranging from motorcycles, to 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. The lack of fixed routes, fixed stops, time schedules and smartcard ticketing systems, makes it difficult to capture the complex spatial mobility demand of different socioeconomic groups making use of paratransit services.

Therefore, in the current study, a GPS-app was used as a low-cost method to shed light about mobility demand and patterns, including paratransit use, in the case study area of Dar es Salaam (DES), where paratransit replaced the non-existence of government-supported PT, in different spatial settings. The GPS-app was used to capture individuals' travel distances, departure times and frequencies of trips and destination of their trips.

2. Background on case study city

In Tanzania, the emerging land use development indicates a mismatch with the professional planning standards, lacking an equitable distribution of basic infrastructure services like transport, water and electricity (Msigwa, 2013). Most of urban planning standards and regulations inherited from the colonial time have proven to be outdated and inappropriate to cope with increasing urban challenges like poverty issues, unemployment, housing and mobility demand for low income households, etc. (Kombe, 2005; Lusugga Kironde, 2006; Mkalawa and Haixiao, 2014; Rasmussen, 2013). Today, unplanned settlements and activities are the most emerging feature shaping the urban land use pattern. Tanzania's commercial capital, Dar es Salaam (DES), is one of the rapid growing mega cities in Africa (with an estimated population 4.5 million), where about 75% of all residential houses are built in unplanned neighbourhoods and settlements (Rasmussen, 2013). PT is provided by minibuses (*daladala*), and smaller vehicles like motorcycles (*bodaboda*) and tricycles (*bajaji*). Much of its use occurs in the sprawling unplanned areas outside the Central Business District (CBD), both high and low-density areas, often also far away from major roads (i.e., the planned or officially designated roads). 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 which saw its market share decline rapidly to 2% (Rasmussen, 2013) due to a rapid increase of mobility demand and a failure to adjust its services to the new demand. At the time of the study, paratransit is the only available travel solution for the majority of the population in DES, as many neighbourhoods are located in areas with inadequate connectivity by regular PT, due in part to narrow and unpaved earth roads (not engineered) which provide limited access to the city's major roads and thus to other areas in the city (Behrens et al., 2015; Kanyama, 2016; Mkalawa and Haixiao, 2014). During the rainy season, many of these unpaved roads become flooded and impassable, and individuals are disconnected from their 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 considered the most important (i.e., the major destinations), as transportation investments are mostly done to ease traffic congestion and provide access to the CBD (Figure 1).

A new Bus Rapid Transit (BRT) system is currently being implemented by the Tanzanian government, which is distinguished from paratransit by use of high quality and capacity buses (with 150 passengers) on dedicated lanes, with pre-defined schedules and by use of electronic pre-paid tickets (Ka'bange et al., 2014; Rizzo, 2015; Roy, 2005). The planned BRT system in DES, named Dar es Salaam Rapid Transit (DART) and also shown in figure 1, has dedicated stations, separate lanes and fixed routes and destinations. The DART is promoted by the Tanzanian government and the World Bank (as a financial agency) to meet the mobility demands of individuals, by changing the current PT (paratransit) to a more innovative system (Fox, 2014). Despite the opportunities of the planned DART, previous studies indicate that most planned PT systems like DART emphasize speed and efficiency, and thus offer only limited travel options for most of the low-income individuals residing in the often vast neighbourhoods around the urban core (Ka'bange et al., 2014; Khayesi and Nafukho, 2016; Rizzo, 2015; Salazar Ferro and Behrens, 2015). This study, analyses the applicability of a GPS-app to capture individuals travel behaviour before implementation of the DART system. The study intends to create a platform for comparison in a future follow-up study, after DART is implemented, to determine possible travel behaviour changes of individuals. Two different locations were selected along the planned DART corridor: one adjacent to the DART system (Kimara), and another one a peri-urban area (Mbezi), as illustrated in Figure 1.

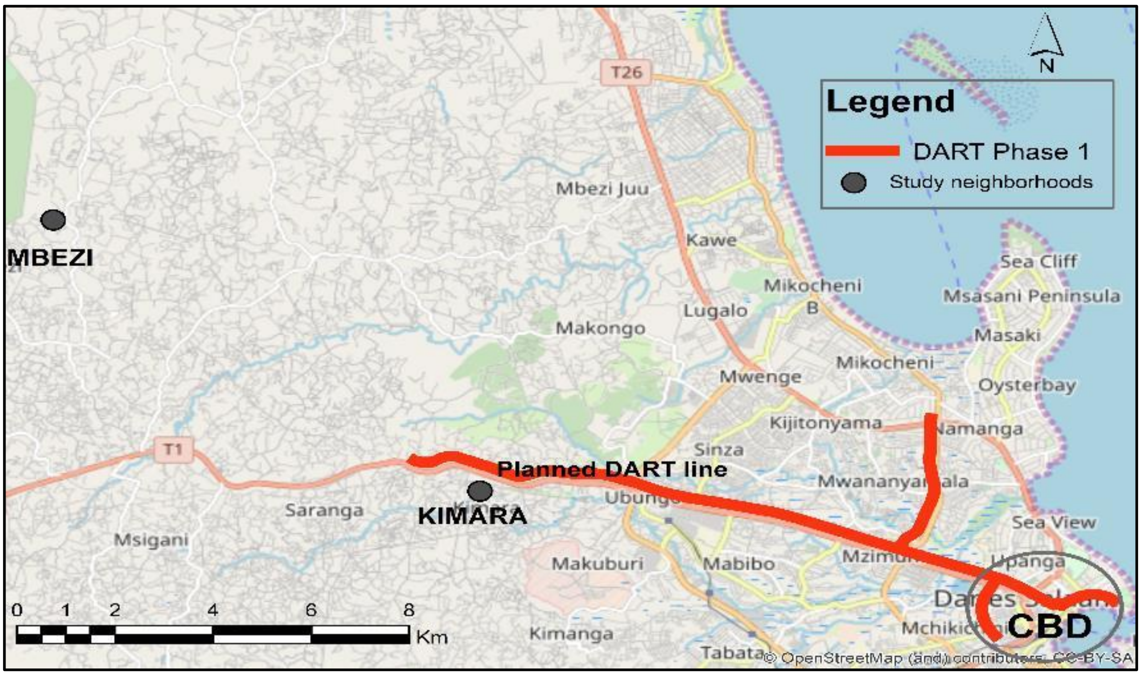

Figure 1 The two study areas Mbezi (peri-urban) and Kimara (adjacent to the planned DART line)

3 Method and materials

3.1 Experimental design

The data collection was conducted before completion of the implementation of the DART system, around February 2016 when the construction of DART lanes and bus stations was in the final stage. This study aims to reveal the spatial mobility demand of individuals by use of the GPS-app (trip patterns, trip distances and departure times), before implementation of the DART service; on the one hand as insights for understanding the spatial contribution of paratransit services, as well as on the other hand to provide a basis for a follow-up study in which possible changes in travel behaviour after the actual experience with the DART system can be determined.

One of the important trends over the past years has been the use of new technologies for collecting data (Ciscal-Terry et al., 2016; Lee et al., 2016; Montini et al., 2015; Vlassenroot et al., 2014). The primary focus of some technologies has been data collection itself, e.g. infrared sensors to determine vehicle occupancy, satellite imaging to assess change in land use, or in-vehicle enabled GPS devices to monitor vehicle movements. Most recent emerging technologies like GPS-apps have important positive impacts on the collection of data for individual trips, rather than of vehicle trips (Papinski et al., 2009). As self-reported paper-and-pen travel studies were shown to have an overstatement in reporting durations and distances for various trips, many travel studies in Africa have tended to omit them in favour of simpler instruments, emphasizing on specific trips considered important by passengers (Behrens and Masaoe, 2009). In the present study, two main instruments for data collection were used to collect travel data from individual participants: a GPS-app called 'Sparrows' and short questionnaires.

The GPS-app 'Sparrows', developed by the Transportation Research Institute (IMOB) of Hasselt University, was capable of recording trip specific information in terms of trip distances, trip frequency and travelled destinations, as important variables for understanding individuals' mobility demand and patterns. To use the GPS-app, participants had to install Sparrows via the Google Play Store, which was done in interactive ways with the research team (assignment of QR-code with an ID-number for each participant) to confirm that the installation of the GPS-app was done properly and successfully. After installation of the GPS-app on the smartphone, data were collected automatically (in a passive way), once the GPS of the smartphone was turned on when a trip was made. Participants were asked to carry his/her smartphone during a day when at least one out-of-home trip was made. Previous studies have shown some challenges regarding the use of electronic devices (GPS devices, mobile phones, GPS-apps, etc.) for data collection, including battery consumption, (Lee et al., 2016; Papinski et al., 2009; Vlassenroot et al., 2014), requiring frequent charging of the battery. Considering the local challenges of electricity and low battery life spans of some smartphones, travel data of one day was collected in the study, mainly to test the feasibility of this innovative data collection method (GPS-app) in Global South (Olson and Wagner, 2015). Sparrows did not need an internet connection in order to operate, but data were transferred to the server of the research team once the internet connection was turned on.

Short questionnaires were used to assist in recording socio-demographic information of the participants such as age, gender, educational level, employment status and vehicle ownership. This information was relevant in describing and making interpretations of the differences and similarities in the spatial mobility demand by socio-demographic characteristics (Behrens and Masaoe, 2009; Dodson et al., 2010). The questionnaire also included general information about the use of travel modes (modal split) and preferred travel mode(s) by activity type. The socio-demographic information about the participants and their transport usage was linked with the trip information from the GPS-app, to analyse the trip variation by individual characteristics (age, employment, gender, vehicle ownership etc).

3.2 Participants

As mobility (or making movements in space and time) or the decision to make out-of-home trips, is influenced by socio-economic characteristics, a diverse sample of participants was recruited. Participants of this study included diverse transport users (both women and men, unemployed and employed, different age categories, low and high educational level, etc.) who were in the possession of a GPS-based smartphone. Based on this selection of participants, the obtained sample was not completely representative, because of exclusion of non-smartphone users. However, the present study provided crucial insights in the effectiveness and feasibility of an GPS-based data collection method to identify mobility patterns of individuals in fast growing countries (Global South) with a high level of informality in spatial development. With the help of local leaders in both study neighbourhoods, smartphone users were identified and were willing to participate in the study. A snowballing technique (i.e., using already participating smartphone users to identify and recommend other smartphone users whom they know) was used to identify other individuals residing in the study neighbourhoods who possessed a smartphone and were willing to participate. In total, 77 smartphone users participated in the study. The use of local leaders of the studied neighbourhoods was helpful and important for participants to gain trust, interest and security towards the study.

The study participants were recruited from two different locations along the planned DART corridor: one adjacent to the DART system (Kimara), and another one a peri-urban area (Mbezi), as illustrated in Figure 1. The individuals of this peri-urban area, away from the major road, may experience additional transport challenges exposing them into a risk of transport exclusion due to lack of PT connections. Paratransit was used frequently in both study neighbourhoods, as this transport mode covers different geographical locations. This selection of study neighbourhoods enabled us to analyse the travel behaviour of individuals in different spatial settings; but also makes it possible in a later phase - i.e., after implementation of the DART system – to monitor possible travel behaviour changes of individuals by using the GPS-app.

3.3 Data analysis

This study utilized quantitative data from the GPS-app (one-day travel data of individuals) and the questionnaires (socio-demographic data), which were analysed 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 shapefiles from the Tanzania National Road Agency (TANROADS), and the National Bureau of Statistics (NBS). These datasets were used to facilitate the 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 ArcGIS 10.3 to visualize original trips and stops, to identify mobility patterns (in terms of average distances, departure times and average number of trips), and for further spatial statistical measurement (Chen et al., 2011; Du, 2000; Liu et al., 2015). Density analysis in GIS was performed to identify the concentrations of trips along different road networks. IBM SPSS statistics 24 was used to perform descriptive statistics between socio-demographic variables and trips.

4 Results

4.1 Socio-demographic characteristics of participants

Table 1 presents the socio-demographic characteristics of participants in terms of gender, age, educational level, vehicle ownership and employment status. The table shows that vehicle ownership in both neighbourhoods was minimal (16 car-owners), causing that a large number of participants (n=61) depends on paratransit modes. A high number of individuals has a lower educational level (primary and secondary), especially in Mbezi (peri-urban area). Individuals with a higher educational degree were mostly employed as full-time professionals in public and private sectors, travelling to specific destinations (their workplace) and having specific work schedules. Self-employed individuals included those engaged in small entrepreneurships and medium business (Rizzo et al., 2015), such as petty traders, street vendors, shoe shiners, etc.; both with or without permanent workplaces. Unemployed individuals included those either searching for a job (e.g. completed secondary schools) or not (e.g. housewives). In both neighbourhoods most of the participants were in the age group between 20-45 years, with a limited number of individuals of age above 46, which can be explained by the fact that the use of smartphone technology is also influenced by age.

Characteristics	Kimara (adjacent to BRT/ n=43)	Mbezi (peri-urban / n=34)
Gender (M/F)	20/23	18/16
Age (<35/35-45/>45)	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

Table 1 Socio-demographic characteristics of the participants

4.2 Travel modes of participants

The results on the use of travel modes (modal split), collected via the questionnaires and shown in Table 2, enable to compare the use of travel modes by socio-demographic characteristics and by study area (Kimara and Mbezi). Individuals were allowed to indicate multiple travel modes in the questionnaire, as more than one travel mode was used to meet the mobility demand because individuals were not directly connected with the major roads; making it not possible to link one specific travel mode to a specific profile. The table was not representative to generalize the results, but it gives useful information about the distribution of travel mode across individuals. In both neighbourhoods, the use of paratransit modes (daladala, motorcycles and tricycles) was more common than private car and walking. In general, the use of a private car was only possible for individuals with a middle and high income, who were full-time professional workers; while walking was not attractive due to unsafe roads and the lack of sidewalks. Individuals involved in part-time jobs, or who were self-employed (mostly small entrepreneurs) or unemployed, mostly relied on paratransit as the only available mobility option to reach different destinations. The use of tricycles and walking was higher for individuals residing close to the major road (Kimara) than those living in the peri-urban area (Mbezi), where walking was inconvenient because of the long distance (more than 3km) from the major road, and tricycles were limited used because of the unpaved road condition. The distribution of travel mode by gender showed that the most preferred travel mode for male was the motorcycle, while for female this was the daladala minibus. The data also showed a variation in travel modes by educational status: most individuals with a higher education had the option to make use of a private car, while individuals with a lower educational status (mostly engaged in petty trading, street vending, or unemployed) relied on paratransit as the only available travel modes for their out-of-home trips; which is related to their employment status.

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

Table 2 Modal split by study area and individuals' characteristics

4.3 *Average number of trips and trip distances*

Table 3 presents the trip characteristics (in terms of average number of trips and travel distances, and range (minimum and maximum values), captured by the GPS-app, across different socio-demographic characteristics. The results indicate that the number of trips in Kimara and Mbezi were almost similar, but the variation by trip distances was much higher, as longer trip distances were made in Mbezi (reflecting longer distances to different opportunities). The variation by trip distances among individuals in general was shown to be much higher. While the average number of trips was similar between male and female, the average distances were slightly higher for females, showing that most of them were participating in different activities outside their neighbourhoods. In terms of age groups, the highest average number of trips was observed in the age group younger than 35, while the highest trip distances were observed between 35-45 years, capturing the working class. The highest average trip distances were observed for full-time workers, as they typically travel longer distances because most public offices are located away from their neighbourhood. Contrary, trips conducted by self-employed or unemployed individuals were short (<3km), because most of their activities were conducted within their own neighbourhood. Car-owners were also shown to be more advantaged to travel longer distances as compared to non-car individuals, especially when PT is inadequate.

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)
Area	Kimara	3.08 ±1.80 (1-8)	3.06 ± 2.85 (0.1-16.6)
	Mbezi	2.96 ±2.18 (1-9)	4.20 ± 4.06 (0.1-18.5)
Gender	Male	2.99 ± 1.97 (1-9)	3.0 ± 2.5 (1.0-12.4)
	Female	3.06 ± 1.98 (1-8)	4.0 ± 4.1 (0.2-18.5)
Age	<35	3.22 ±2.04 (1-8)	2.03 ± 1.89 (0.1-7.4)
	35-45	2.78 ±1.93 (1-9)	4.83 ± 4.09 (0.2-18.5)
	>45	3.15 ±1.94 (1-7)	4.24 ± 3.50 (1.1-12.4)
Employment	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)	1.6 ± 2.4 (0.2-8.1)
	Unemployed	2.25 ± 1.4 (1-6)	1.6 ± 2.4 (0.2-8.1)
Car-ownership	Car-owners	3.5 ± 1.9 (2-8)	5.4 ± 4.5 (1.3-18.5)
	Non-car	2.9 ± 1.9 (1-9)	3.0 ± 2.9 (0.1-16.6)

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

4.4 Departure times of trips

The temporal dimension of making trips was again influenced by socio-demographic factors. A correct understanding of the departure times is however difficult for unscheduled modes of transport, mostly common in (Global South) cities with a high level of informality, or for unplanned activities. The use of a GPS-app, by which the outdoor trips were automatically recorded in real-time, enabled to capture the actual departure times when individuals made trips. As presented in Table 4, the departure times of individuals (i.e. the departure time of the first trip they made during that specific day), were distributed almost throughout the day, by which trips were made from the early morning hours (03:00) to the late evening hours (23:59). In both neighbourhoods, out-of-home movements occurred at different times, but Kimara (adjacent to DART) was more advantaged (with more transport options available) to travel in different hours than Mbezi (peri-urban).The temporal characteristics by gender show the variation between males and females, where 15.8% of males made their first out-of-home trip between 03:00-05.59, as compared to 7.7% of females in the same time slot. For self-employed individuals (e.g. street vendors), trips were conducted throughout the complete day, as most of their activities depend on individual decisions (e.g. start time of their own business); while full-time professional workers have specific working days and hours (8:00-16:00 for public offices). The results are not representative but show the ability of the method to detect the actual departure times when individuals decide to travel out-of-home (including non-work trips).

Departure (Time)	Area Kimara/Mbezi	Gender M/F	Car-ownership Car/non-car	Employment Full-time	Part-time	Self-emp	Un-emp
03:00-05:59	8/1	6/3	2/7	2	2	3	2
06:00-08:59	10/5	5/10	1/14	3	3	8	1
09:00-11:59	9/6	6/9	4/11	4	3	7	1
12:00-14:59	7/9	9/7	3/13	2	4	6	4
15:00-17:59	7/9	10/6	6/10	6	2	7	1
18:00-23:59	2/4	2/4	-/6	1	-	4	1
Total individuals	(43/34)	(38/39)	(16/61)	(18)	(14)	(35)	(10)

Table 4 Departure times of trips

4.5 Visualization of performed trips and destinations

The travel data collected from the GPS-app allowed a visual presentation, through mapping all visited places where individuals participated in their activities (their destinations), and the routes taken to reach these places. Figure 2 shows a heat map, visualizing the performed trips and different spatial locations (the destinations of the trips). The concentration of destinations and trips along the major road (i.e., the planned designated road) displayed a linear pattern. There are however also many performed routes which are extending from the major road, reflecting additional routes generated by paratransit modes via unpaved roads, in order to serve the individual mobility demand in different spatial locations. The GPS data provided useful insights that individual trips were not always limited to major roads but were also performed via unplanned roads by paratransit modes as a way of responding to the local situation (because of lack of direct PT connections, unpaved road conditions and narrow paths).

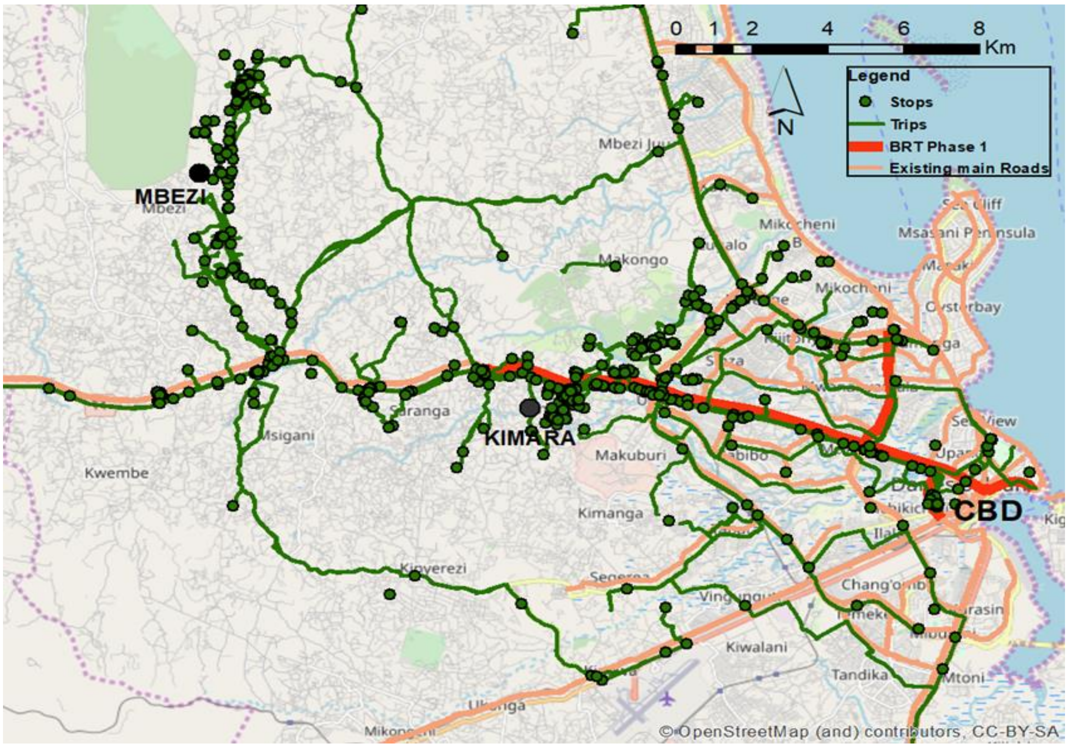

Figure 2 Visualization of performed trips (green lines) and destinations (green dots**)**

4.6 Spatial concentration of trips

Low and high spatial concentrations of trips were mapped in ArcGIS 10.3, based on a natural break classification (7 density classes) and displayed by using bilinear interpolation for continuous data. A smooth and continuous map was created in Figure 3, with a colour variation indicating high (red) and low (dark blue) concentrations of trips along the major road. The figure displays the performed routes in density maps for Mbezi (left, peri-urban area) and Kimara (right, close to DART). In Mbezi, the highest concentrations of trips occurred in the junction between the major road (where the planned DART is located) and the peri-urban local road. In Kimara, the highest concentration of trips occurred mainly along the major road itself (where the planned DART is located). The high concentration of trips on both maps may indicate a limited spatial connectivity, as individuals were forced to use only the available major roads to facilitate their mobility demand. The concentrations of trips on some (smaller) roads revealed a spatial diversity in travel demand among individuals. The results of the density analysis were not meant for statistical testing, but to provide a visual identification of the mobility patterns which were not only taking place along major roads, but also in peri-urban areas with limited transport facilities and connectivity. The high and low-density travel patterns helped to distinguish travel demand of individuals in different spatial settings.

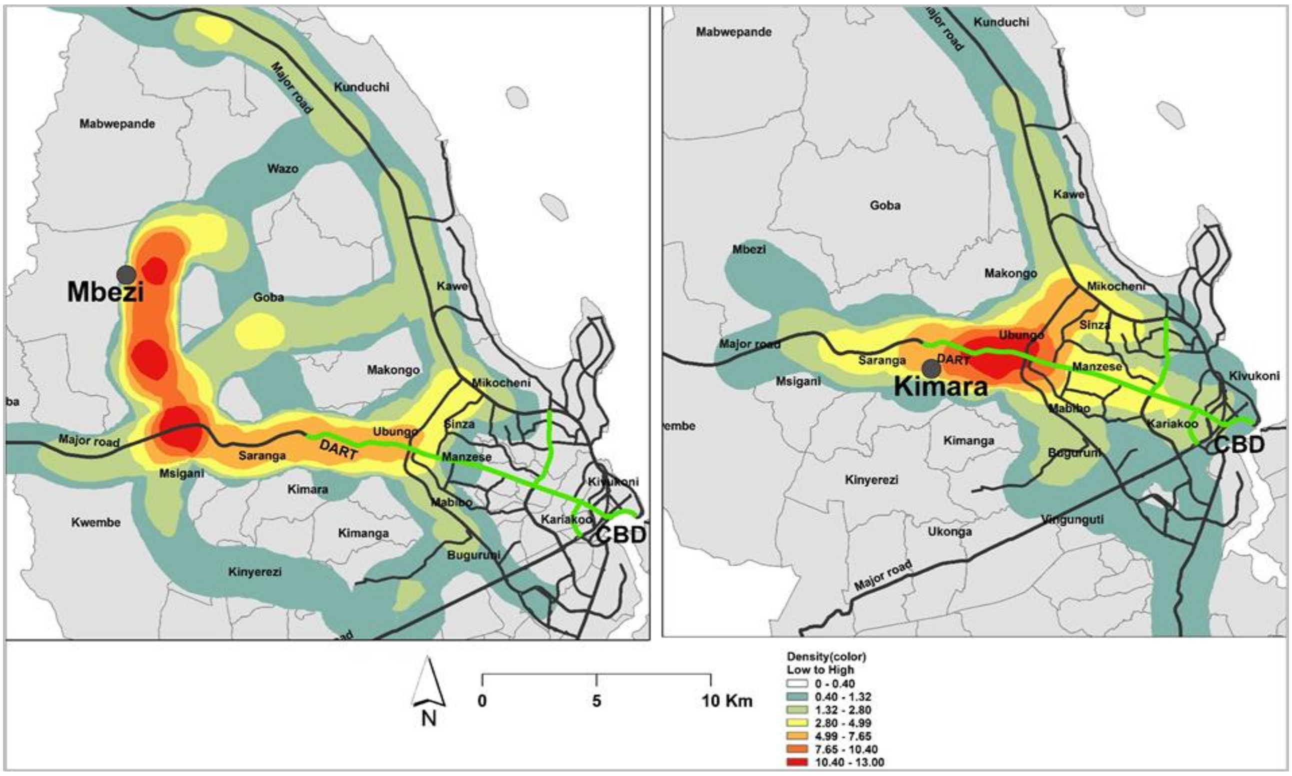

Figure 3 High and low spatial concentration of trips

5 Conclusion and discussion

The present study provided insights into the applicability of a GPS-app in revealing individual travel behaviour in Global South with a high of level of informality in spatial development, where paratransit modes are the main means of motorized transport. A GPS-app was used specifically to reveal the mobility demand and patterns of individuals in DES residing in proximity to a major road (Kimara) and individuals living further away from such a road, in a peri-urban neighbourhood (Mbezi). Despite the substantial differences in distances from a major road, the travel data collected by the GPS-app showed that both groups of respondents depend on this major road to get access to their most important service centres in DES. The mobility demand of individuals living in the peri-urban area was challenged by a lack of direct routes, limited travel options, and unpaved local roads. The spatial distribution of trips shows many destinations at a substantial distance from the major road, providing evidence that paratransit modes extend their services to serve the mobility demand of individuals without a private car (mostly low-income individuals). The mobility demands and patterns of individuals not adjacent to a major road were characterized by the use of many unpaved, not-planned roads; which may lead to recommendations to redefine major roads to serve the diverse mobility demands in different destinations. This spatial information is vital, particularly for planners who seek to meet the mobility demand of individuals outside the direct area around a major road and outside the city centre, in order to reduce their mobility constraints (Hrelja et al., 2017). The high trip density patterns along the major road indicated that the mobility demand of individuals was mostly limited to this specific road, and that there is a need for enhancing the first (origin) and last (destination) mile connectivity for accessing the planned DART system for individuals residing and commuting further away from the major road.

Previous studies on travel behaviour in Global South cities provided little to no information on the spatial distribution of trip making, as the traditional method of travel surveys cannot or did not capture the travel behaviour patterns. The GPS-app can therefore be considered as a powerful tool in revealing both the spatial and temporal dimensions of making trips in real local environments (including areas with unscheduled routes or unplanned areas); as well as of individuals without specific work schedules. The trip characteristics generated by individuals indicated that there is variation in terms of trip distances and number of trips made among individuals; and also revealed the contribution of paratransit modes in serving the spatial demand of transport, in line with previous studies describing trip characteristics by paratransit (Guillen et al., 2013; Woolf & Joubert, 2013).

The GPS-app used in the present study made it possible to gain insights about the travel behaviour of individuals in terms of number of trips, departure times and trip distances; as well as performed routes and travelled destinations. Travel mode detection and trip purpose detection, both important parameters of travel behaviour as well, was however not possible with the current GPS-app. In this study, short questionnaires were used to complement the data of the GPS-app with general information about use of travel modes, which could however not be linked to the trips recorded by the GPS-app. Extracting modes and certainly trip purposes in the setting of DES is difficult, as there are no comprehensive land use data and only little previous knowledge on trip making behaviour (unlike in countries with regular travel behaviour surveys). Further research needs to be done to test the feasibility of a GPS-app in travel mode detection, including paratransit modes without fixed schedules or stops, in order to capture the complete mobility demand of individuals and for a longer duration. The use of GPS-app along with a simplified prompted recall survey (for example web-based annotation, that takes literacy issues into account (e.g. simple visual objects), can be considered for detecting trip purposes and travel modes. As the smartphone belongs to individuals themselves, the costs of detecting travel data via this method is low. Individuals' commitments are highly needed to yield rich travel data, as the data are constantly recorded as individuals take along their smartphones all the time. Some incentives (like mobile internet bundles) can be considered to increase the motivation and commitment of the GPS-app users. Privacy issues of individuals should be taken into account; as well as local challenges (e.g. regular electricity cuts, making it difficult to charge smartphones) implying that the GPS-based smartphone method should rely on apps with a low battery consumption.

Although the current study only involved a small number of participants and only made it possible to derive some parameters of the travel behaviour (but not the travel mode or trip purpose), the potential and applicability of an innovative GPS-based smartphone method in understanding the mobility demand, including the paratransit contribution, in a (developing) case study area in the Global South characterized by a high level of informality in spatial development, was shown to be valuable. The method can provide decision-makers and other key stakeholders with the necessary data to improve PT policies, and to monitor its impacts across a diverse range of target social groups. The study also provided a baseline for further research to monitor changes in spatial mobility demand of individuals after the introduction and extension of the DART system.

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