# FICKLE OF FLEXIBLE? ASSESSING PARATRANSIT RELIABILITY WITH SMARTPHONES IN ACCRA, GHANA

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**ABSTRACT**

In many cities of the developing world, institutional public transportation is limited or nonexistent and inhabitants have to rely on paratransit (informal or semi-formal, non-fixed route, non-scheduled transportation systems) for their travels. While their flexibility and affordability offer clear advantages, they are often criticized for their lack of reliability in terms of variations in travel time and waiting time. The body of work on paratransit, and that work able to characterize paratransit as unreliable, is almost exclusively based on self-reported or indirect data. This paper therefore aims to fill a gap in the paratransit literature by applying concepts from the literature on transit quality of service to the field of informal transport. We use indicators traditionally applied to formal transit systems to assess the level of reliability of paratransit services in a developing country. In addition, we propose a new indicator to measure itinerary variation specific to paratransit. We find that the most appropriate unit of analysis for such research was the station, since operations on any given route are influenced by forces at the station level. The general level of variability measured through our indicators was less than expected. Although a wide range of situations was observed in our sample, most paratransit routes appear to be relatively stable in Accra.

*Keywords*: paratransit; Ghana; quality of service; reliability; smartphones;

## INTRODUCTION AND LITERATURE REVIEW

In many cities of the developing world, institutional public transportation is limited or nonexistent and inhabitants have to rely on paratransit (informal or semi-formal, non-fixed route, non-scheduled transportation systems) for their travels. Informal operations of small to mid-size vehicles for passenger transportation have been documented all over the world, particularly in Latin America, South East Asia, and Sub-Saharan Africa (*1,2,3*). While their flexibility and affordability offer clear advantages (*4,5*), these services are often criticized for their lack of safety and comfort, aggressive driving, and poor vehicle maintenance – all of which results in frequent breakdowns, added congestion, and high levels of emissions (6). In relation to their flexible nature, the lack of reliability of paratransit operations has often been highlighted (*7,8*). This lack of reliability is primarily characterized by variations in travel time, but also applies to waiting time (*9*).

Reliability has been demonstrated to be a key factor, affecting not only the perception of different transport modes, but also their level of use. In fact, a decrease in travel time variability may be more valuable to the user than a reduction of mean travel time (*10*). Reliability is also listed as one of the factors used to calculate quality of service in the Transit Capacity and Quality of Service Manual (*11*). It is generally measured by two indicators: on-time performance and regularity of headways. Research conducted on urban bus services in China suggests that improving these indicators could lead to increased attractiveness of the services for people using other modes of transportation (*12*). However, when it comes to paratransit, the operational characteristics of different systems have been described in a variety of contexts, but little data is available to actually measure the reliability of these services.

Studies have analyzed and compared the characteristics of paratransit systems in various contexts focusing on different operational variables such as passenger throughput, kilometers travelled, fare and revenue (*1*). Research conducted in Cambodia also compares moving time, standby and distance travelled by different paratransit operators (*13*). Closer to our subject, a few studies have tackled the issue of reliability in paratransit from the angle of passenger experience. Work conducted in Indonesia finds that travel time and waiting time reliability are key factors contributing to low service quality and negative passenger experience (*8, 9*). Similarly, evidence from Thailand suggests that paratransit improvement strategies should focus on relieving unreliable waiting time and in-vehicle time (*7, 1355*). Finally, data collection carried out in Nairobi suggests that paratransit routes exhibit a fair level of stability, while at the same time calling for systematic analysis (*14*) of route variability. However, none of these case studies attempts to measure or quantify the level of time or itinerary variability associated with a given paratransit route or service.

As such, the body of work on paratransit, and that work able to characterize paratransit as unreliable, is almost exclusively based on self-reported or indirect data. Researchers distributed questionnaires and conducted interviews with passengers or transport operators, but rarely collected data on moving vehicles directly. One such attempt was made in Phnom Penh by equipping vehicles with GPS trackers, but the results cannot be used to estimate service reliability since they are not associated with qualitative information (*13*). Another limitation of the existing literature is that it focuses principally on Asian countries. Naturally, paratransit has been studied on other continents as well, but not from the perspective of reliability. Germane to our research are studies on paratransit in Africa, found both in the academic (see e.g. *2*) and grey literatures. Belonging to the latter is a series of papers focusing on the informal transport business in Bamako, Abidjan, Harare, and Nairobi (*15*). These case studies provide valuable insights into the economic organization of the sector, but also rely primarily on questionnaires and interviews for data collection. In Africa as in Asia, the scarcity of work using data collected on board paratransit vehicles can be linked to the informal nature of the sector, which makes it difficult to develop large scale and systematic data collection efforts.

In 2015, we carried out a comprehensive data collection exercise to map the 315 trotro routes officially registered with local authorities (*16*). Because of the breadth of this scope, it was only possible to survey each route once in each direction (i.e. one round trip). The main limitation of the exercise was that it did not capture the dynamic and flexible nature of the paratransit network. Indeed, although trotros are bound to operate between fixed origin and destination stations, itineraries, frequency of departure, and travel time on a given route may vary greatly over time – reported in the literature (above) and observed on the ground in Accra. Operators seeking to maximize their daily revenue adopt time-saving strategies and follow transportation demand dynamically, thereby causing high variability in service provision. For instance, drivers seek to avoid congested areas by taking alternative roads, which creates both itinerary and travel time variability. These dynamics have an impact on the overall reliability of the trotro network (1*8*), although it has never been measured.

This paper therefore aims to fill a gap in the paratransit literature by applying concepts from the literature on transit quality of service to the field of informal transport. We use indicators traditionally applied to formal transit systems to assess the level of reliability of paratransit services in a developing country. In addition, we propose a new indicator to measure itinerary variation specific to paratransit. Our work differs from existing studies because of the nature of the data on which it is based. First, our data is fine-grained and consistent since it is collected firsthand onboard vehicles and at transport terminals using smartphones. Second, our data is spatialized as we track individual vehicles and tie each record to GPS coordinates in time and space. Third, our data for each route is collected consistently over one-week period, thereby making it possible to measure daily and hourly variations of traffic in Accra.

Building on data collected in the field by surveyors equipped with smartphones, we analyze the variability of paratransit routes in terms of departure headway, travel time and travel itinerary, out of twelve stations of origin. The next section provides a description of the case study region of Accra in Ghana and the operations of its "trotro" network. After we present the methodology that describes the scope of the study, the use of smartphones in data collection and how the data collection initiative was organized. We then present results of the three variability analyses, which is followed by a discussion of the results and concluding remarks.

## CASE STUDY AND TROTRO OPERATIONS

Accra is the capital city of the West-African country of Ghana. It has a population of approximately 2 million inhabitants, 70% of whom use informal minibus services known as *trotros* for their daily transportation needs (*16*). Trotros are generally second-hand passenger vans or retrofitted utility vehicles seating 13 to 21 passengers in addition to a driver and a conductor (or *mate*). They operate out of dedicated terminals on semi-fixed routes registered with local authorities. Operator unions run most terminals. Terminals are made up of "branches" that typically operate between 4 and 10 routes driven by thirty to sixty drivers and vehicles. We refer to these as "stations" for the purpose of this article.

Trotro vehicles are typically associated with a station of affiliation, or home station. A specificity of the trotro system (shared with other African countries) is that vehicles do not leave their home station before they are completely full. This can result in long wait times and difficulties in finding space in a vehicle outside of a terminal. Vehicles not at their home station, are however, expected to leave promptly (typically when another vehicle arrives).

At the beginning of the day and after each round trip, drivers join a queue for the route of their choice at their home station. They select a route based on two main criteria: length of the queue and expected profitability. Queues at terminals can be very long, and vehicles frequently spend more time waiting in line than driving. Therefore, it might be more advantageous for a driver to run a less profitable route (in terms of revenue per hour and per kilometer travelled) in order to save on the waiting time at the terminal. In most stations, the queuing system is formalized on a blackboard by writing down the license plate numbers of queuing vehicles for each destination. Consequently, analyzing isolated routes from different stations would not tell the full story since what happens on one route has an influence on the other routes of the same station – as such, the station is the most appropriate unit of analysis for understanding the trotro system.

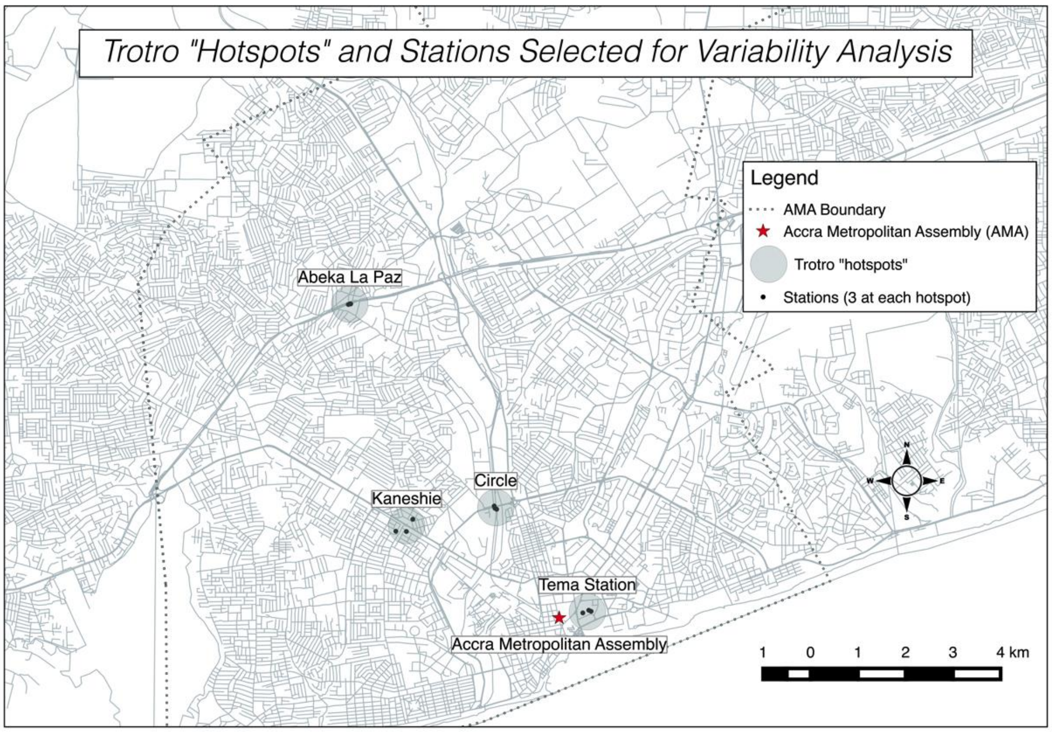


**FIGURE 1:** Accra, Ghana with location of trotro "hotspots" and stations included in the analysis

## METHODOLOGY

Previous research conducted in 2015 (*16*) led to the identification of four main "hotspots" for trotro activity in Accra. These hotspots are areas that presented a high spatial concentration of passenger boardings and alightings during our first data collection campaign. For each of these four areas, we selected three stations serving different parts of the city for in-depth data collection. Routes were chosen to exhibit different lengths (short, medium, long), as well as variation in their direction (i.e. towards and away from Accra). At each station, we met with the branch (station) executives to present our data collection project, secure their collaboration, and ask them to list the routes operating from the station. FIGURE 1 shows the location of the four hotspots from which the routes of three stations each were examined. (All maps in this paper were produced with QGIS (qgis.org).) Altogether, the routes of 12 stations were considered in this analysis. Our approach was to survey all the routes of each of the 12 stations, collecting data both at the station level and at the route level.

### Smartphones and digital technologies in data collection

To carry out this project, we used a methodology based exclusively on the use of smartphones for data collection and data transmission. Over two months, we deployed a team of 12 surveyors equipped with entry-level smartphones and power banks. Two apps were installed on the phones: the first app, developed by the TRIP Lab at Concordia University and called DataMobile, runs in the background of the phone and records geographic coordinates at regular intervals; the second, TapLog is freely available, and was used by surveyors to log preselected variables along their way (departure and arrival time, location of stops, notes on the vehicle etc.).

Before the start of each week, a survey plan was communicated to the surveyors for the coming days, containing the geographic coordinates of the station of origin, and a schedule of the routes to be recorded for every day of the week. This was done through an instant messaging app, making it easy to share instructions with all the surveyors at the same time without having to communicate with them individually. At the end of their shift, surveyors sent their data to a centralized email address over the 3G network. This organization limited the need for physical meetings with the surveyors and saved many unnecessary trips to the project office. Leaving out paper records also eliminated any form of transcription work, which is both time-consuming and a source of errors. Data was then shared with the team working overseas through a cloud storage service. Taking advantage of the time difference with Ghana, it was then possible for the Canadian team to review and signal any missing information before the start of the next day of data collection.

**Two levels of data collection**

For each route, our ambition was to record the largest possible number of round trips during a 15-hour time window to capture variations in operating conditions throughout the day. Collectors were organized in two shifts, from 6AM to 2PM and from 1PM to 9PM, with one hour of overlap to ensure data continuity. Collectors boarded the first available vehicle and stayed on it until the last stop, both passively and actively recording information along their way. As many as six round trips per surveyor were recorded on short routes, and as few as one on the longest routes. The minimum number of trips recorded per direction and per route was four, while the maximum was over twenty. In total, data for over 1,200 trips were recorded in both directions (outbound from the home station and inbound) of 65 (130 route legs i.e. inbound and outbound) different routes (20% of registered routes in Accra).

While each route was only surveyed for one day, data on departures at the station level was collected for one full week at each station. This was done by a static coordinator in charge of recording all vehicles departing from a station. For each departure, the following information was logged: route number (i.e. destination), license plate, and seating capacity of the vehicle. In addition to this role, shift coordinators were also responsible for dispatching collectors at regular intervals and providing them guidelines as needed. During a period of six weeks, over 15,000 departures were logged out of the twelve different stations with varying levels of activity (340 to 2,700 departures per week).

## RESULTS

We chose three different aspects of trotro services to analyze for variability. Headway variability was chosen to answer the question “how much variation is there in how long a passenger need to wait to make their trip?” Travel time variability was chosen to answer the question “how much variation is there in how long it takes to get to a destination?” These first two will have implications for how much time people have to devote to a given trip. Finally, route itinerary variability was chosen to answer the question “how much variation is there in the roads that are used for a given trip?” This indicator has implications for whether or not the route is likely to go to the desired destination, as well as the likelihood of being able to board a trotro when outside of a station.

**Departure headway analysis**

FIGURE 2 presents fitted polynomial regressions illustrating the hourly and daily evolution of headway for all routes and stations taken together. (Inclusion of all data points, up ~2,000 per graph, made figures difficult to read, so are not included.)

Weekdays exhibit similar headway profiles, with short intervals between vehicles during the morning peak followed by a sharp increase in headway times. A plateau is observed in the middle of the day. These results illustrate the existence of a strong classic peak-hour phenomenon in Accra. On weekends, intervals between vehicles are longer on average and peak effects are less pronounced. On Sundays in particular, headways remain long throughout the afternoon, as movement around the city is limited outside of religious functions happening in the morning. While these results indicate a fair level of variability in departure headway (and thus in waiting time for passengers) between different hours of day and days of the week, they are presented at an aggregate level that doesn't reflect variations between routes and stations.

In order to cast light on headway variability at a finer scale, we also ran fractional polynomial regression analyses for all routes by station. Station 1 was chosen as an example to present the results of this analysis because it has the highest number of departures recorded per week (over 2,700) and serves different types of locations.

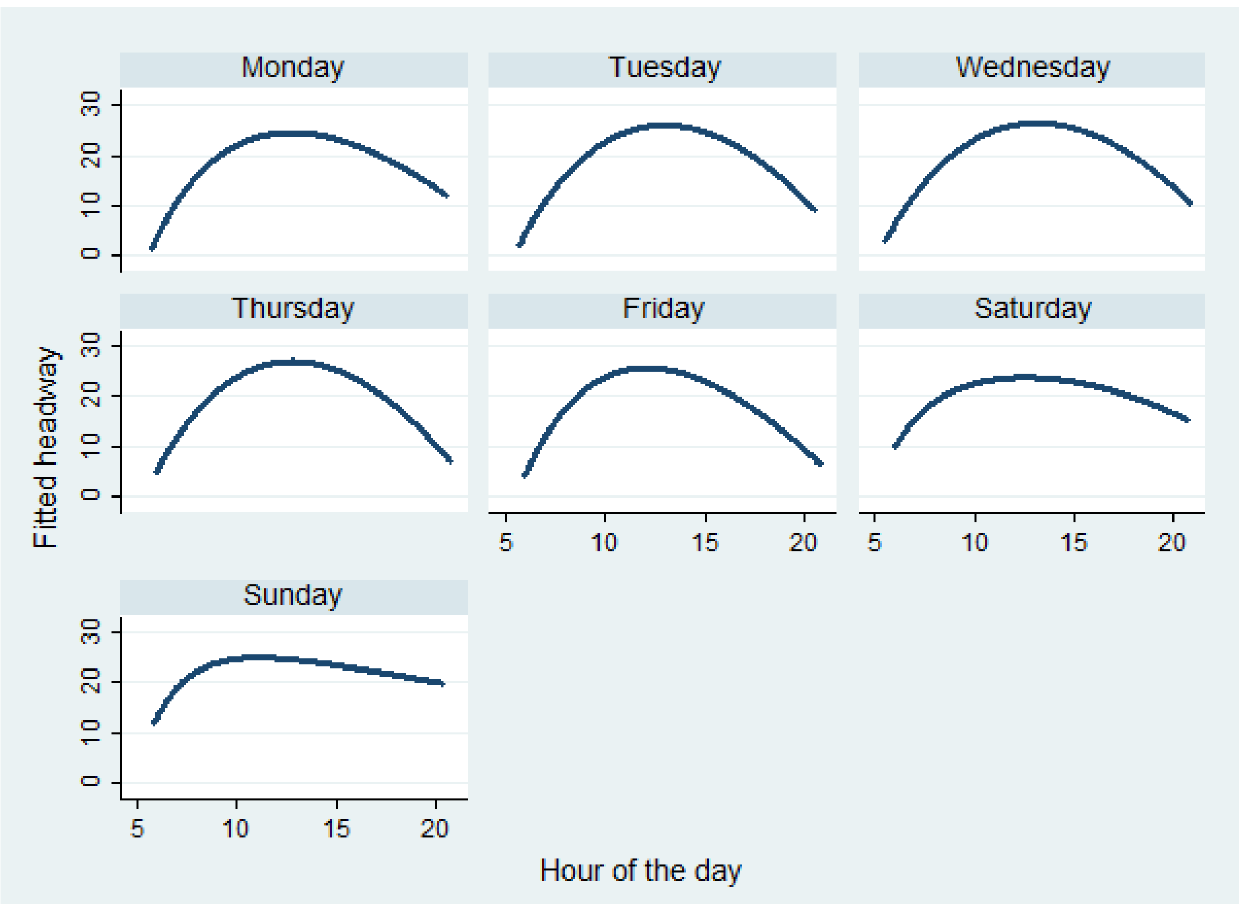


**FIGURE 2:** Trip departures

FIGURE 3 presents variations in headway at different times of the day for the 6 routes operating from Station 1. Contrary to the previous analysis, data for all days of the week is analyzed together since we focus on differences between routes of the same station rather than between days of week (adding or removing week-end days did not affect the shape of the results). As can be observed from the shape of the curves, these routes have very different activity profiles throughout the day, falling in three main categories. Route A and B exhibit similar trends, with short intervals in the early morning, gradually increasing in length as the day progresses. The shortest headway between departures on these routes is found soon after the start of data collection, between 6 AM and 6:30 AM (collection at this terminal started at 5:30 on average, as it was possible for the coordinator to get there very early). These two routes have a teaching hospital and a mortuary located side by side as their final destination, which explains their high level of similarity. The nature of these destinations also explains their activity pattern: patients going to the hospital have to get there early in the morning if they want to receive treatment, as long queues are frequent. Therefore, travel demand is high in the morning and does not increase again since there would be no point going to the hospital this late in the day.

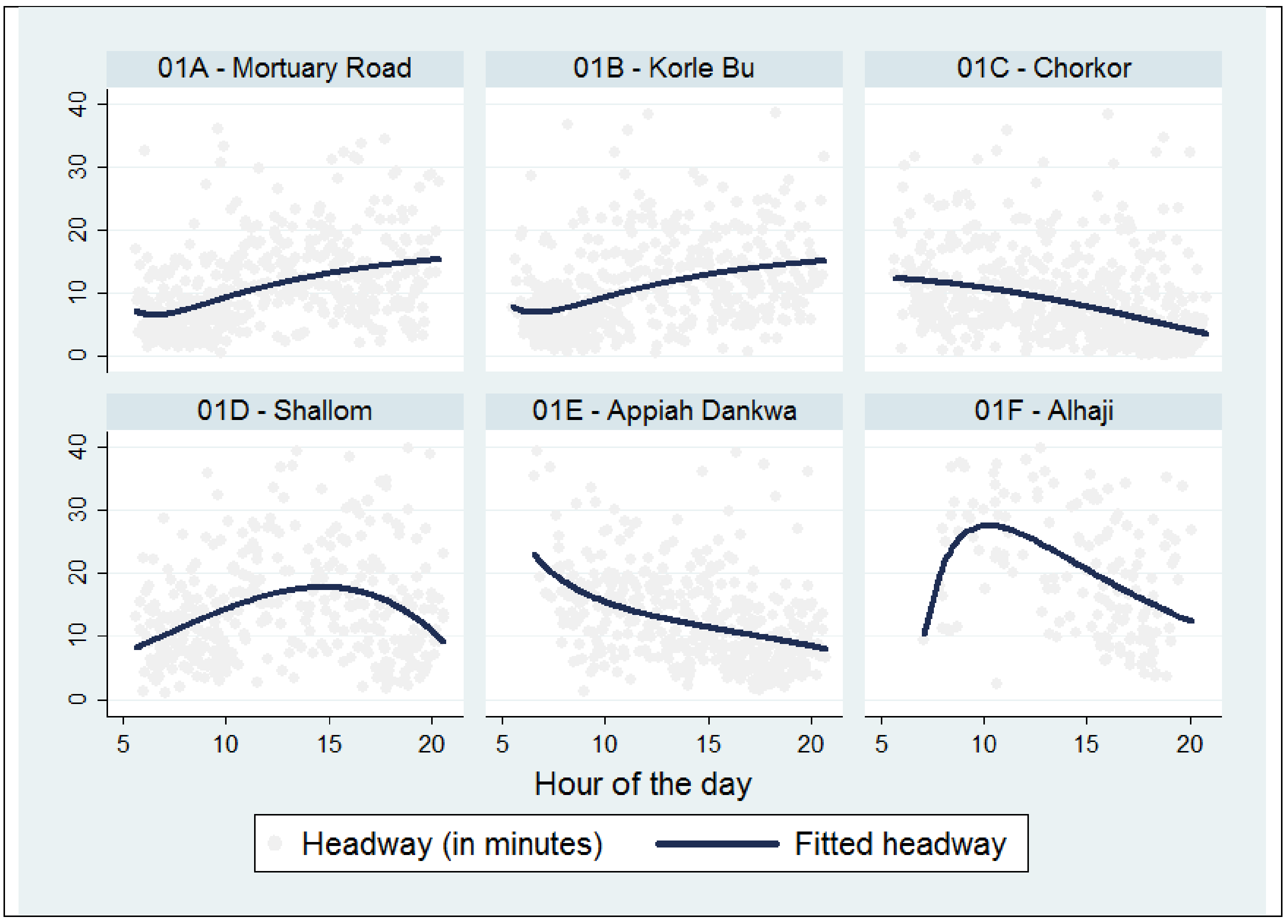


**FIGURE 3:** Departures at Station 1

Routes C and E exhibit the opposite profile from routes A and B. Intervals between departing vehicles on these routes are relatively longer in the morning and decrease as the hours go by. This trend is particularly marked for route E, which has little activity in the early morning and only comes to life after 10 AM. Route C presents very short headways overall, with an almost linear decrease in average waiting time from morning to evening. These results can be explained by the mostly residential nature of the neighborhoods served by these two routes. Transportation demand towards residential areas tends to be lower in the morning and gradually increases as passengers return from their daily activities. This translates into longer average headways in the morning, and shorter waiting times in the afternoon. Overall, we note that the activity profiles exhibited by the routes of Station 1 are varied but complementary. Indeed, as business is slow on routes C and E in the morning, more vehicles are available to serve routes A and B, which are particularly active at that time of the day. The reverse phenomenon happens in the afternoon. This confirms that trotro operations have to be analyzed at the station level to understand the dynamics of their allocation mechanisms. These dynamics evolve with the hour of the day and can be explained by economic considerations.

Operators have to make a delicate trade-off between the revenue that they expect from a round trip of a route and the cost that is associated with it. Revenue for the outbound trip can be estimated by multiplying the number of seats by the nominal fare for the route, since the vehicle will only leave the station when it is full. Estimating fares for the return trip is more difficult as the "fill and go" rule does not apply to it. The cost of making a trip on a route includes the time spent queuing, the number of kilometers travelled, and the time spent on the road – in both directions. Before choosing their next destination, drivers carefully consider all these variables, assessing present and expected demand, as well as conditions on the road.

## Travel time variability

The second type of variability examined is travel time variability. Travel time was inferred from TapLog data that had time stamped entries for the departure and arrival of a trip. It was calculated as the difference between departure and arrival times. Altogether, data collectors undertook 1,524 trips. Of these, travel time variability analysis was only conducted on those trips that departed and arrived from their expected terminals. There were also some trips for which there was incomplete TapLog data. This resulted in 1,208 trips for 123 route legs available for travel time variability. The indicator used to quantify the amount of variability of travel times on the routes was the standard deviation of travel time. FIGURE 4 provides summary results for all of the routes.

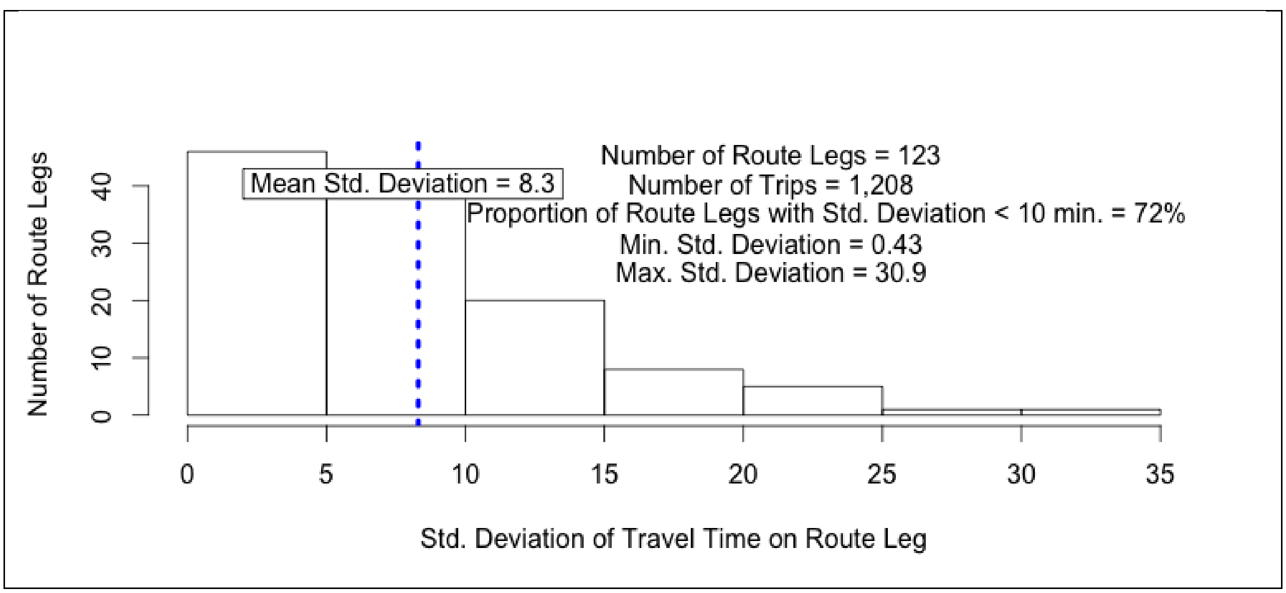


**FIGURE 4:** Standard deviation of travel time on route legs

Average standard deviation across route legs is 8.3 minutes, and 72% of route legs show standard deviations of less than 10 minutes. These figures, while relatively high, hide some even greater variation. Some route legs had standard deviations of travel times of up to 31 minutes! Some of the variations in travel time are systematic, in the sense that they are regular. Travel times are longer on average during peak period travel (6:00-9:00 and 16:30-20:00), and in particular, when a route leg is moving in the same direction as congested traffic. E.g. towards the center of Accra in the morning, and away from the center in the afternoon. In fact, there is an average difference of 5 minutes in travel times (t = 2.5, df = 320, p-value = 0.01) in these circumstances. Another type of travel time variability was hypothesized – that between outbound (leaving from the home station) and inbound (returning to home station) trips.

As was discussed above, trotros leaving from their home station are typically not allowed to leave until they are full. When at a non-home station, on the other hand, trotros are required to leave as soon as another trotro arrives. The result is that a trotro leaving a non-home station is likely to have space for passengers, whereas a trotro leaving its home station simply won't have any space for additional passengers. It was hypothesized therefore that inbound route legs would be more likely to vary their itineraries and travel time as they try to collect additional passengers. This hypothesis was not borne out in the statistical analysis – it was not possible to reject the hypothesis that there was no difference in travel times between inbound and outbound route legs.

**Variation in itinerary**

The last type of variability examined is that related to route itinerary. Calculating this required developing a measure of similarity of the trips for a given route. In the development of this measure we were inspired by the literature on route choice modeling (see e.g. Bovy et al. (*16*)) in which it is necessary to quantify the similarity between alternative routes. The basic measure they use for this is the length of common route. Since we were comparing several trips of the same route leg, it was necessary to have a composite measure of how similar each trip was with all other trips. As a result, the measure we used was the average shared proportion of trips for a given route.

$$TVI_r = \frac{\sum_i^{t_r} \sum_j^{t_r} P_{ij}}{t_r^2 - t_r} \forall j \neq i \qquad (1)$$

We call this the Transit Variation Index. $r$ indexes routes and $t_r$ indexes the number of trips for a given route. If all trips of a route have an identical itinerary, this will result in a *TVI* of 1, whereas if no trips share any portion of their itinerary, this will result in a *TVI* of 0.

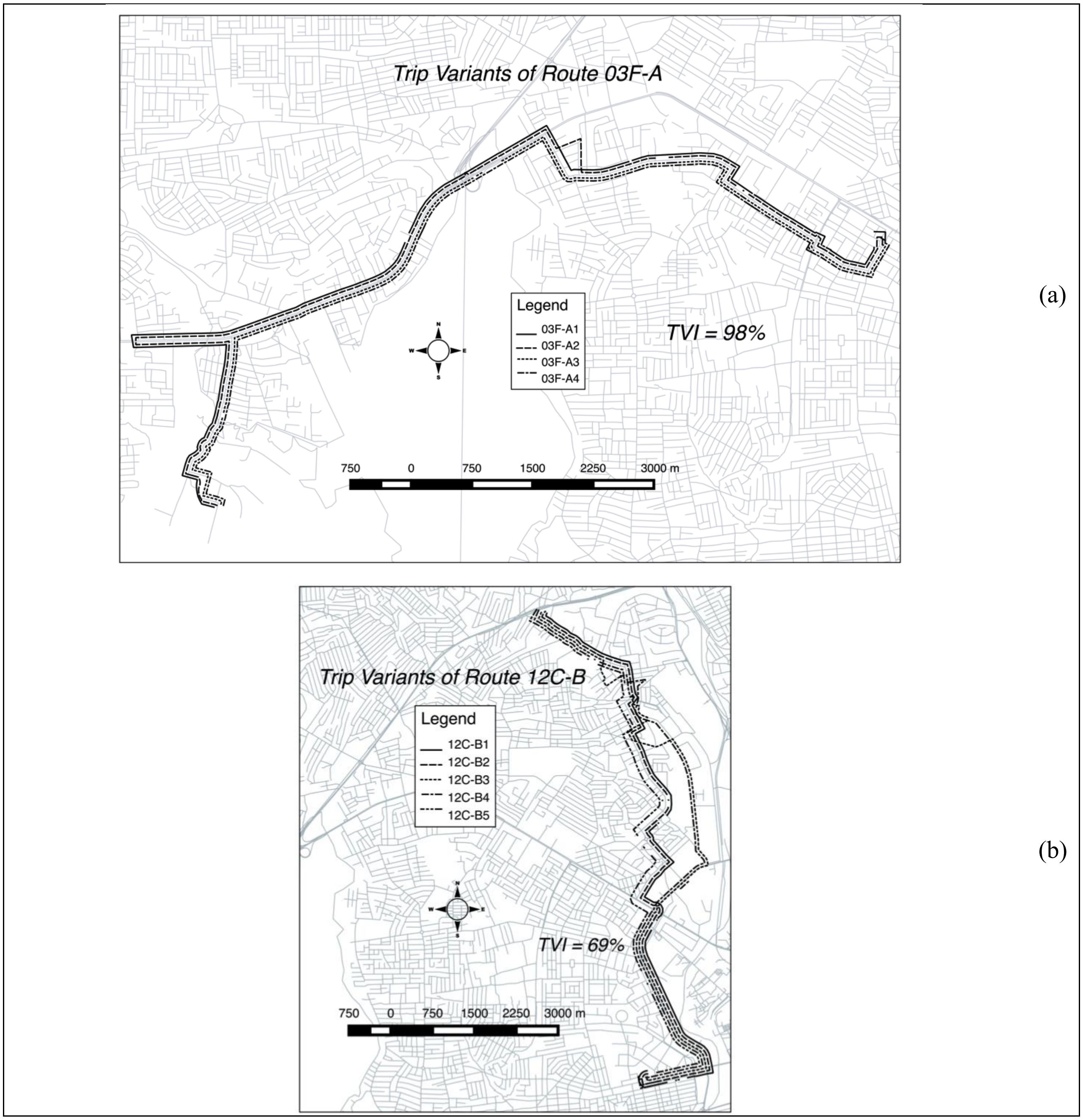


**FIGURE 5:** Trip variants of route legs 03F-A (a) and 12C-B (b)

**FIGURE 5** shows examples of the trips for two route legs, 03F-A and 12C-B as well as their TVI. The itineraries of the trips have been slightly offset to allow for a visual comparison of their differences. 03F-A is one of the least varying route legs that was observed. This can be seen both in the similarity of the itineraries of the different trips, as well as by the TVI of 98%. In contrast, route leg 12C-B with 5 trips shows a fair bit more variation in itineraries used. This is reflected in the lower TVI of 69%. These two route legs were used because they had a limited number of trips (making it easier to represent them in a map) and because they showed a breadth of variation in their trips. TVI was calculated for all of the 120 route legs in this analysis. The results are summarized in FIGURE 6.

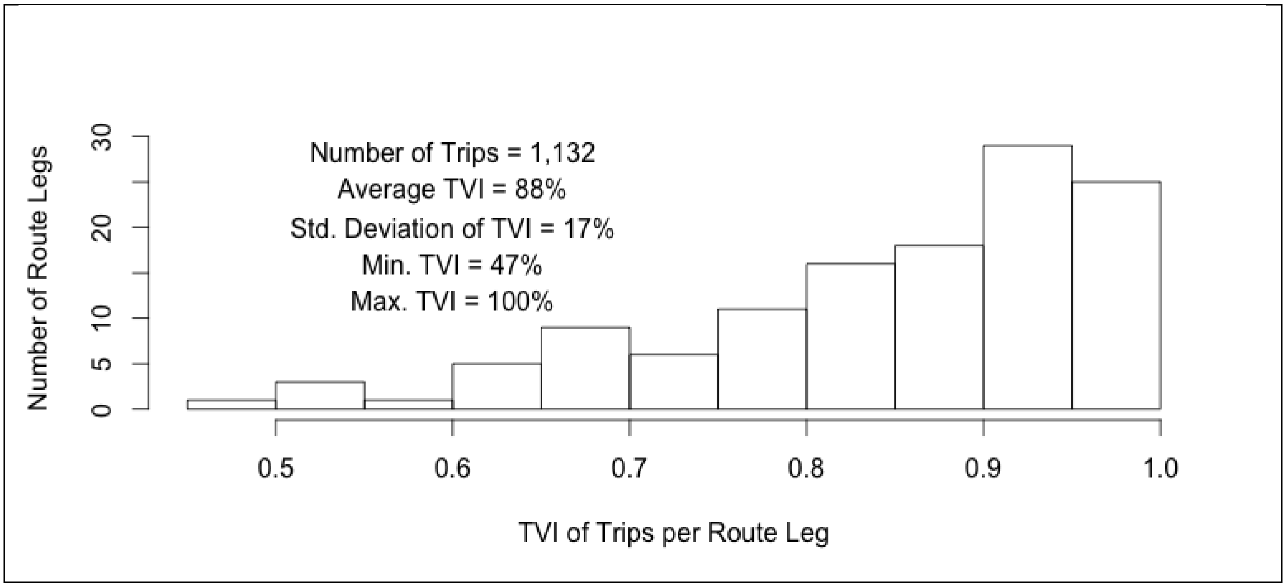


**FIGURE 6:** Summary of trip itinerary variation across all route legs

Complete data was available for 1,132 trips on 120 route legs. Altogether, there is relatively little variation in trip itineraries with the average TVI being 88% and modal TVI being between 90% and 95%. This of course hides a fair bit of variation in observed TVI which is observed at its lowest at 47%, but 100% at its maximum.

The hypothesis that inbound and outbound routes may vary was also tested for route itineraries. That is, it was hypothesized that the itineraries of inbound routes vary more than outbound routes as the trotros try to get more passengers when they leave their non-home station. As it turns out, it was found that inbound trips were less similar to other trips from the same route with average similarities of 82% whereas outbound trips had average similarities of 85% ($t = 2.2$, $df = 116$, $p\text{-value} = 0.02$). It is interesting to note that overall travel time is not different, while their itineraries are.

These figures capture another type of variation related to route itineraries that are heard in complaints from users. That is, whether or not routes were actually completed. Unlike for travel time variation trip itinerary variation included route legs even if they did not depart or arrive from their expected terminals. This does not always happen either due to mechanical break downs (a result of the old age and poor condition of many vehicles), or because the driver decided to change destination along the way to serve a more profitable one. Overall, incomplete trips were observed 113 times in all of the trips (1,524) for which some data were recorded, i.e. in 7% of trips.

## DISCUSSION

The results presented above indicate variability in the operation of trotro services, although not as much as might have been expected. Headway between vehicles varies across the hours of the day and the days of the week, following classic peak hour patterns, with some times of day having very short headways. Travel times are relatively constant on the same route leg, although they can vary quite a bit. They are also longer during peak periods than in the off-peak. Route itineraries are relatively stable (average TVI of 88%), but as with travel times they can show a considerable amount of variation. Interestingly, inbound trips vary more than outbound trips. Yet, these figures hide important disparities between routes and stations. The headway profiles of different routes operating from the same station can be very different, as illustrated above with Station 1. Similarly, some stations operate routes with limited fluctuations in travel times, while others have routes with very unstable travel times. Finally, some routes have less than 50% of their itinerary stable across trips and others use the same path consistently over time.

What does this mean in terms of reliability? From the passenger's perspective, the unpredictability of waiting times at the station, time needed to reach a destination, and itinerary followed by their vehicle, can be distressing. It makes it difficult to efficiently plan trips and schedule activities, reach a destination on time, and make good use of one's time in general. This could in turn limit access to economic and social opportunities for the population. High variability is also likely to negatively impact paratransit user's experience. In Accra, most trotro passengers can be considered as captive users since no other mode of transportation is equally affordable. Nevertheless, improving the predictability of trotro services could also contribute to making trotros more attractive to people who rarely or never use them. That is not to say that we should always consider variability as a synonym of unreliability when it comes to paratransit. Unreliability, applied to scheduled transport services, would be characterized by systematic deviations from an established time-table. In the case of trotros there is no official time-table, although most stations have regular hours of operation. Passengers' expectations when it comes to waiting or travel times are informed by their own experience, which can be considered as a kind of informal schedule. Regular passengers would therefore not be surprised by shorter waiting times and longer travel times during peak hours, for instance. To some degree, variability can therefore not be equated with unreliability since it is characteristic of the system that has been integrated by users.

Variability in the three characteristics of paratransit studied in this article can be explained by two main factors. The first is congestion on the road network: strong peak hour effect combined with insufficient road capacities results in frequent traffic jams affecting paratransit services as well as private cars. This has an effect on travel time (as the commercial speed of vehicles decreases), choice of itinerary (trotro drivers use alternative routes), and on the frequency and distribution of departures across routes, (since drivers would rather go against the traffic than towards it). The second factor explaining variability is the search for profitability on the part of the operators. Because they seek to maximize their passenger throughput and optimize the ratio between fares collected and time spent on the road (or kilometer travelled), operators have no interest in providing constant services over time or destinations. Rather, they seek to match an evolving demand, while minimizing their cost. In the absence of regulation imposing a minimum level of service on registered routes, it is likely that coverage will remain uneven both spatially and in time. At last, we have to keep in mind variability is also a mark of a flexible system, which presents clear advantages. In terms of itinerary, for instance, drivers can adjust the course of their journey based on the destinations of the passengers that are on board. Similarly, the number and location of the stops are based on passengers' requests. Paratransit offers more demand responsiveness than regular transit and can serve some of the needs that formalized systems can't.

## CONCLUSION

This paper aims at testing the claim that paratransit operations are often unstable, if not unreliable. To do so, we assessed the variability of trotro services in Accra based on three indicators. Two of these indicators – evenness of headways and travel time regularity – are standard measures for quality of transit services. Our third indicator – variation in itinerary – was designed to capture the flexible nature of paratransit routes. This research therefore makes a methodological contribution by pioneering measures of reliability adapted to the specificities of paratransit systems. It also illustrates how digital technologies can be leveraged to carry out an ambitious survey with limited human and financial capacities. Using smartphones for data collection and collaborative tools to coordinate all stakeholders, 12 collectors were able to record over 1,100 trips and 15,000 departures in six weeks.

While we could build on data collection tools and protocols developed through previous experience, finding the right level of analysis was not obvious from the start. This led us to study the inner workings of paratransit operations in Accra, seeking to understand the governance, economics and technical characteristics of the system. We found that the adequate unit of analysis was the station, since operations on any given route are influenced by forces at the station level. The dynamic nature of departure distribution was highlighted as one of the key mechanisms in trotro operations. Contrary to what was expected, the general level of variability measured through our indicators was not very high. Although a wide range of situations was observed in our sample, most paratransit routes appear to be relatively stable in Accra. Further research, tying this data to spatial information on land-use, would be necessary to better understand the determinants of transport demand and supply in the field of paratransit.

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**REFERENCES**

1. Shimazaki, T. and M. M. Rahman (1995) Operational characteristics of paratransit in developing countries of Asia, *Transportation Research Record*, 1503, 49–56.

2. Behrens, R., D. McCormick and D. Mfinanga (2015) *Paratransit in African Cities: Operations, Regulation and Reform*, Routledge.

3. Salazar Ferro, P. (2015) Paratransit: a key element in a dual system, *Technical Report*, AFD/Codatu, Paris.

4. Cervero, R. (2001) Informal transit: learning from the developing world, *ACCESS Magazine*, 1 (18).

5. Salazar Ferro, P. (2015) The challenge of finding a role for paratransit services in the global south, *Technical Report*, AFD/Codatu, Paris. Paper presented at the 2015 Codatu Conference on The Role of Urban Transport Policies in Developing Countries.

6. Cervero, R. and A. Golub (2007) Informal transport: A global perspective, *Transport Policy*, 14 (6) 445–457.

7. Tangphaisankun, A., F. Nakamura and T. Okamura (2010) Influences of paratransit as a feeder of mass transit system in developing countries based on commuter satisfaction, *Journal of the Eastern Asia Society for Transportation Studies*, 8, 1341–1356.

8. Joewono, T. and H. Kubota (2007) Exploring negative experiences and user loyalty in paratransit, *Transportation Research Record: Journal of the Transportation Research Board*, (2034) 134–142.

9. Sumaedi, S., I. Bakti and M. Yarmen (2012) The empirical study of public transport passengers' behavioral intentions: the roles of service quality, perceived sacrifice, perceived value, and satisfaction (case study: paratransit passengers in Jakarta, Indonesia), *International Journal for Traffic and Transport Engineering*, 2 (1) 83–97.

10. Bates, J., J. Polak, P. Jones and A. Cook (2001) The valuation of reliability for personal travel, *Transportation Research Part E: Logistics and Transportation Review*, 37 (2) 191– 229.

11. Kittelson & Associates, Federal Transit Administration, Transit Cooperative Research Program and Transit Development Corporation (2003) *Transit Capacity and Quality of Service Manual*, vol. 100, Transportation Research Board.

12. Chen, X., L. Yu, Y. Zhang and J. Guo (2009) Analyzing urban bus service reliability at the stop, route, and network levels, *Transportation research part A: policy and practice*, 43 (8) 722–734.

13. Phun, V. K., I. Lim and T. Yai (2015) The characteristics of paratransit operation and fare in Phnom Penh, *Journal of the Eastern Asia Society for Transportation Studies*, 11 (0) 1307–1327.

14. Klopp, J., J. Mutua, D. Orwa, P. Waiganjo, A. White and S. Williams (2014) Towards a standard for paratransit data: Lessons from developing GTFS data for Nairobi's Matatu system, paper presented at the *Transportation Research Board 93rd Annual Meeting*, no. 14-5280.

15. World Bank & Economic Commission for Africa (2001) Profitability and financing of urban public transport microenterprises in Sub-saharan Africa: An overview of the regional study conducted in Abidjan, Bamako, Harare, and Nairobi, *Technical Report*, SSATP Working Paper number 54, World Bank.

16. Saddier, S., Z. Patterson, A. Johnson and M. Chan (2016) Mapping the jitney network with smartphones in Accra, Ghana: The Accramobile experiment, *Transportation Research Record: Journal of the Transportation Research Board*, (2581) 113–122.

17. World Bank (2015) Rising through cities in Ghana: Ghana urbanization review overview report, *Technical Report*, The World Bank, MLGRD and SECO.

18. Poku-Boansi, M. and K. K. Adarkwa (2011) An analysis of the supply of urban public transport service in Kumasi, Ghana. Journal of Sustainable Development in Africa, 13 (2) 28–40.