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Capturing daily urban rhythms: The use of location aware technologies

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Abstract:

Daily activities and travel often follow a natural rhythm or flow that is structured by the fixed spatial and temporal constraints. The work and home location act as pegs that define individual's activity space and it is within these spaces that activities and travel behaviour are believed to be habitual and recurring. Aggregating such individual behaviour leads to so-called daily urban rhythms. Knowledge of these daily urban rhythms is important as they are indicative of temporal and spatial user demand, that is transport or land use demand. Furthermore, knowledge of where individuals are during the various times of the day is vital for emergency planning or disaster management. While emergency evacuation is often focussed on the residential areas, this might not be where people find themselves during the day. This paper reports on a proof-of-concept study which tracked a sample of individuals over a two day period making use of their personal cell phones. The result of the research shows that cell phone records allows planners and researchers to obtain a dynamic motion picture of collective behaviour.

Keywords: Cell phones, location aware technologies, land use, transport, urban rhythms

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1. Introduction

Daily activities and travel often follow a natural *rhythm* or flow that is structured by the fixed spatial and temporal constraints. The work and home location act as pegs that define individual's *activity space* and it is within these spaces that activities and travel behaviour, for a large number of individuals, are believed to be *habitual* and *recurring*.

Aggregating such individual behaviour leads to so-called *daily urban rhythms*. Urban rhythms, for the purpose of this research can be defined as the aggregate behaviour of individuals during a day. This behaviour is expressed as the distributed population patterns dominated by residential stay during the evenings and early mornings, the daily commutes (as individuals converge and diverge, spatially and temporally on work locations), leading to concentrated activity duration at work locations during the work day, but also to semi-concentrated patterns dominated by leisure, retail and culture activities outside office hours. The implications of these phenomena are morning and evening congestions peaks, high concentrations of people in a few work locations and a fairly distributed pattern of activities in the evenings.

From a transport and land use planning perspective, knowledge of these daily urban rhythms, their temporal and spatial stability and their temporal/spatial convergence / divergence, is important. These rhythms are indicative of temporal and spatial *user demand*, that is transport or land use demand. As such, they can provide an indication of travel and activity needs (routes taken, departure time, intermediate activity sojourns, locations visited, and activity duration) which is important for transport and land use policy. Furthermore, knowledge of where individuals are during the various times of the day is vital for emergency planning, disaster management or infrastructural services planning. While emergency evacuation is often focussed on the residential areas, this might not be where people find themselves exactly during the large parts of the day. Similarly, power (electricity) might be required in the residential areas in the evenings but focussed on the retail and commercial areas during the day. Such information can be very useful to electricity utility companies for example, when and where to undertake load shedding.

Obtaining information on these daily rhythms has been difficult if not impossible. Daily urban rhythms require, in addition to information on origin and destination of the main commute trip, information on all activities undertaken during the day, their duration, location and sequence, time of departure and arrival. This paper reports on a proof-of-concept study which tracked a sample of individuals over a two day period making use of their personal cell phones. The overall aim of the research initiative was to extract dynamic spatial intelligence including complete activity-travel patterns of individuals and households and derive the collective daily urban rhythms for these individuals. Cell phones were used to record location and temporal information for individuals in five-minute intervals (called a ping). After cleaning and adding intelligence to the data, it was possible to extract a complete daily time/space profile for each individual.

The outline of the paper is as follows. The following section, a brief overview is provided of daily urban rhythms and data collection techniques. This is followed by a discussion of the methodology and a small case study focussing on a descriptive analysis and presentation of urban rhythms without ignoring issues such as accuracy and data quality.

2. Background and literature review

Traditionally, information on activity and travel behaviour is collected with a standard travel/activity diary. However, these diaries (although they have definite advantages from other perspectives) only capture static information on locations visited, modes used and in a limited number of cases, routes chosen. While delivering valuable information, the data is insufficient to derive daily urban rhythms and too outdated for adequate handling of emergencies. Location-Aware Technologies (LAT) and more specifically cell phones provide a useful alternative (or rather a supplementary technological solution) to address some of the problems associated with comprehensive data collection requirements. These technologies may augment (or even replace) complex and cumbersome travel/activity diaries which are difficult to administer, complete, and which require an accurate recording of space-time trajectories. However, the uptake of these technologies by the transport planning fraternity has been slow, with only a few studies in Europe, Japan and the USA and none in the developing world being reported. The technology is of course a relatively new phenomenon and it is really only in the last ten years or so that the technology has become established (Stopher, 2004; Wermuth et al., 2004; Wolf, 2004).

In comparing the GPS and GSM in collecting spatial data, Kracht (2004) summarizes the accuracy and availability of GPS / GSM, technology as follow (Kracht, 2004):

Table 1: Comparison of GPS and GSM information

Technology	Information accuracy			Information availability		
	Origin	Route	Destination	Origin	Route	Destination
GPS	+++	+++	+++	++	++	++
GSM	++	++	++	+++	+++	+++
Questionnaire	++	-	++	++	-	++
+++ = good, ++ = sufficient, + = poor, - = no data						

While GPS does provide more accurate location information, information availability suffers from technological restrictions (i.e. cost, complexity, heavy systems, etc.) . As illustrated above, however, these technologies seem to be very complementary. Kracht discusses the use of both technologies in a case study in tracking individuals using all modes of travel in Berlin, Germany. As the city is well connected via various public transport modes, many trips are undertaken by public transport. Where GPS services do not always accommodate person-based in-vehicle tracking GSM could provide an alternative.

The literature, while still sparse on the subject, does reveal that there are potentially many benefits to using cell phones to collect travel behaviour, notably in a reduction in missing trips reporting, improved accuracy in the reporting of trips and activities (time and space), better routing and speed data, and the ability to capture longer periods of travel (Sharp and Murakami, 2004). The technology also provides many benefits for respondents such as low input requirements and little (if any) respondent burden (such as trying to recall activities/trips, etc.). The potential benefits of mobile phones as compared to GPS was that (i) GPS is not always an unobstructed signal (i.e. in tunnels or inner cities), especially when people are using public transport, (ii) the market penetration of mobile phones is very high (with a very high potential), (iii) mobile phones are generally cheaper than GPS and do not require additional cumbersome hardware. Other disadvantages of GPS involve the cost of equipment and deployment, and the fact that data can only be downloaded after the survey.

Cell phones, however, also have some inherent problems in data collection, notably with regard to pinpointing a location with accuracy. Complex positional algorithms supported by much additional data requirements may be required to overcome this. Accuracy is very dependent on the density of base stations and the quality of the signals in the study area. In urban areas with a higher density of base stations, resolution can be up to 50 – 100 meters. In outlying areas, the accuracy may be considerably less and in developed countries with fewer base stations, the positional data may be rather poor.

In summary the literature revealed support for the potential usefulness of cellphones in obtaining detailed activity and travel data in developed countries. While the technology potentially holds much promise for use in developing countries, many technology and data quality issues still remain. This proof-of-concept study was undertaken to address some of these issues.

3. Methodology

Data collection for activity-analysis and transport planning is no small task, especially in a developing country. Figure 1 illustrates the role of GSM technology in overcoming the main problems associated with conventional OD surveys (limited data for more comprehensive needs based analysis for travel requirements) and complex activity/travel dairies (difficult to compete and administer) while retaining on the advantages of these tools. The passive tracking capability of mobiles phones allows, theoretically, for exact spatial and temporal record of daily activities and travel. By not requiring user input, it overcomes some of the problems associated with surveys in developing countries while also providing information not previously available, such as route choice and the sequence and duration of activities.

The service provider (or partner application provider) receives the information and adds geographic coordinates and time stamps. Positional accuracy (at a first level) is provided by the 'catchment' radius of the cellphone towers (which may be divided into segments). The information is subsequently transferred to a processing unit which adds contextual information to the data and 'interrogates' the raw data with labelling algorithms and cleaning rules. A daily activity-travel path is derived and data useful for applications, such as transport planning, is then extracted.

4. Case study area, survey sample, land use and transport spatial data

As the objective of the project was primarily to consider the technological feasibility of collecting data with the GSM network, the choice of study area was not guided by whether the area and sample population was (statistically) representative of the region or general population. Rather, the study area was chosen to minimise issues such as privacy concerns, legitimacy of the exercise, financial considerations and ease of administration. The importance of these issues, however, should not be overlooked as previous researchers have pointed out (Wolf, 2004). The sample was made up of 83 employees of the Council for Scientific and Industrial Research (CSIR), all based in South Africa at the Pretoria campus in the Gauteng Province. The home location of these respondents were obtained from a questionnaire and mapped in GIS. It showed that the residential locations are spread over a rather large area with some employees having to travel considerable distances to work. During the time of the survey, several respondents undertook work related long-distance trips, like to Hartbeeshoek in North West province (distance of 120 km), Stellenbosch in the Western Cape province (distance of 1600km) and East London in the Eastern Cape province (1000km). In addition to the above spatial and temporal information, verification information was also collected (such as home locations) to compare the tracked information with respondent noted information. This included GPS coordinates and activity diaries for a few selected respondents.

5. Accuracy and quality of the data

Generally, the tracked path compared well with the GPS tracked path and the activity diaries collected. In some instance cellphone records proved more accurate data as some respondents omitted short, incidental trips (such as stopping at the local video store). However, in some instance recorded activities were wrongly coded as activities when in fact it was "noise" in the data. Nearly all the respondents 'recognised' their daily activity pattern from the maps and could verify the various locations visited (i.e. work, home and other).

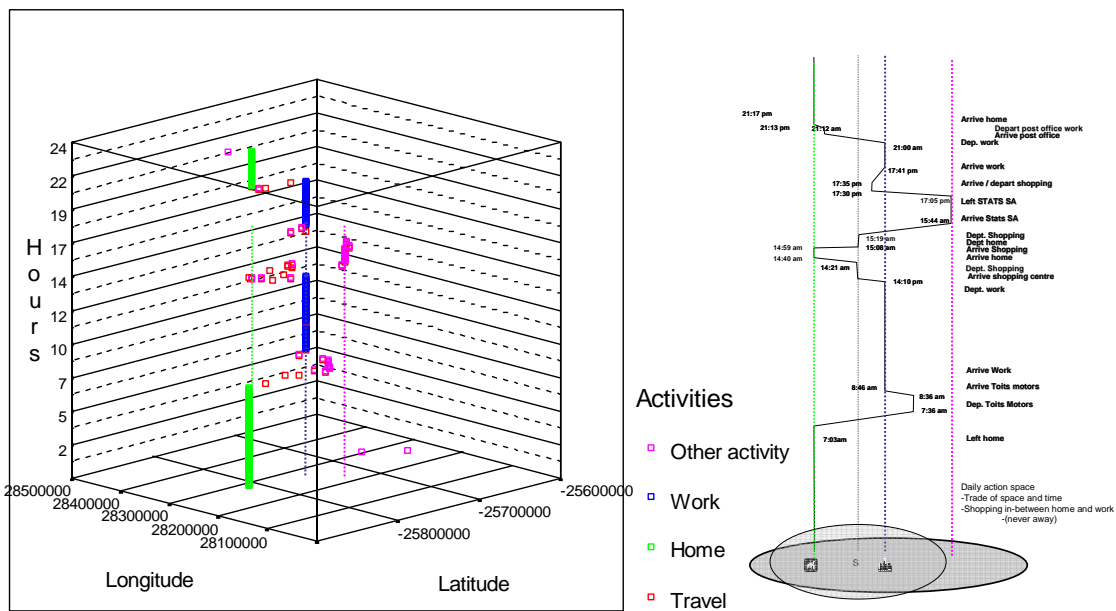


Figure 3 compares the cellphone tracked records with an activity/travel diary of a respondent. In this instance the match between the two is very high with even a short incidental stop on the way to home (i.e. a short 5-minute stop at the post office) capture and recorded as an 'Other Activity'. Figure 3 also shows two 'noise' locations in the data. These can be relatively easily cleaned, other inaccuracies are harder to fix, but have relatively little effect on the overall picture.

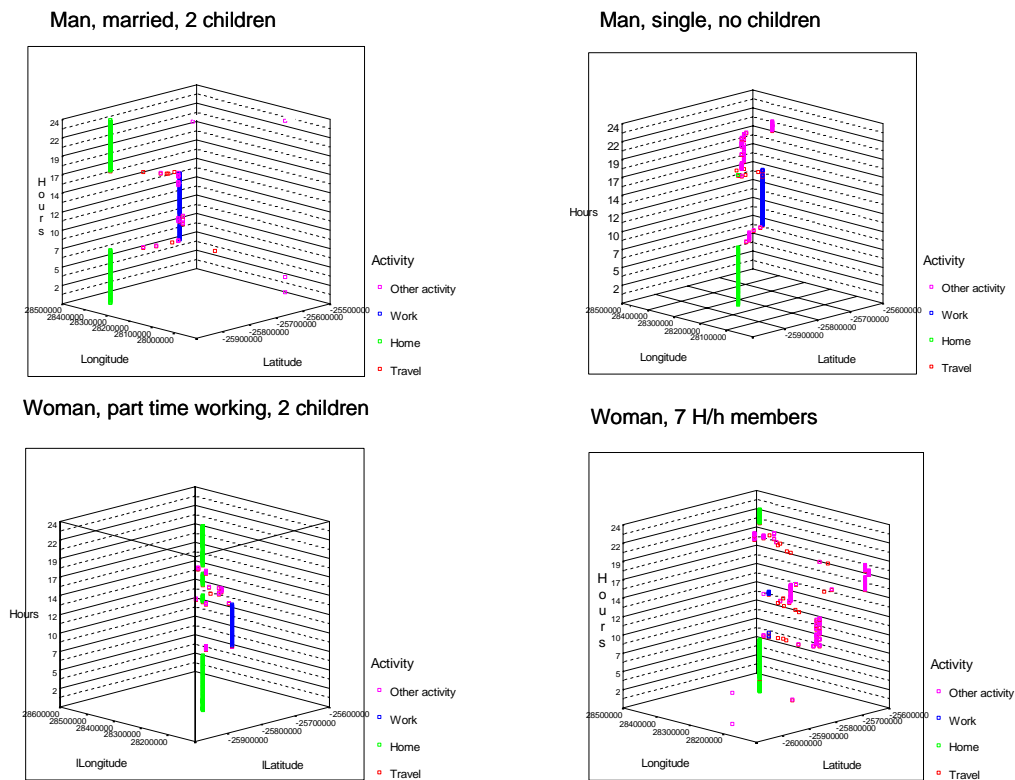


Figure 3 Interpreted temporal / spatial path for four respondents

Apart from the above mentioned noise where a cell phone is suddenly and usually only for a very short period picked up a relatively far removed tower, two more types of inaccuracies can be distinguished:

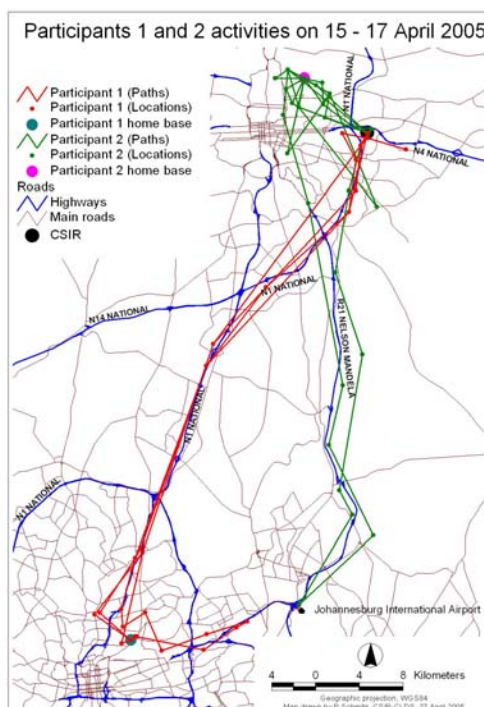
Cells can, especially in relatively sparsely populated areas, cover quite a large area which means that the centre of the cell can be several kilometres removed from the actual position.

Due to atmospheric conditions signal strengths may vary slightly which can cause a stationary cell phone to be frequently “handed over” between a small group of neighbouring towers, thereby seemingly moving around in circles.

In this study we will further ignore these effects apart from removing the obvious noise, but a in follow on study GPS measurements need to be included to properly assess the effects of all these inaccuracies on results.

6. Interpreted activity and trip patterns

The interpreted spatial and temporal paths for 4 individuals are plotted in Figure 4. The interpreted



pattern shows the home origin, work destination and other activity locations. Both figures show that the interpreted signal points are intuitively appealing. That is, stationary points at night and during early morning are classified as *home* while points during working hours are classified as *work*. Points between home and work are classified as ‘other activity’ while points with significant space between them are classified as moving.

Figure 4 Cell phone records overlaid with road network

From the classified points, it was also possible to derive some descriptive statistics such as the number of out-of-home activities and trips per day, work duration, home duration, total daily travel time, travel time for work as well as departure and arrival time distributions, etc. Longer term tracking exercises allows researcher to explore longer terms daily rhythms in activity and travel behaviour.

Interpreted activity / travel pattern data can subsequently be mapped in a GIS and overlaid with various other feature data layers, including the (satellite) land use classification data, transport zones information, a land use map and the transport zonal data. Important attribute data can be appended to each record, relating for example to land use, neighbourhood, closest street, transport zone the individual belongs to, etc.

7. Descriptive analysis and presentation of urban rhythms

Securing information on individual's location for five minute intervals during the day holds significant advantages over traditional recording instruments (such as paper-based dairies). Continuous location information allows researchers to plot and identify the continuous, aggregate pattern of movement and activity engagements.

Figure 5 shows for the survey population the variation in distance from the home and work anchor points during the day. The two lines are almost mirror images intersecting at 7:30h and 17:00h; indicating that commuting takes place at a normal time of day. The intersection points show at what time the average respondent is halfway between home and work. The slope in the distance curves seems less steep in the evening indicating that respondents may be either more inclined to do shopping and other activities at the end of the workday or that traffic congestion is worse in that timeframe. (Krygsman, S. C., Arentze, T., and Timmermans, H. J. P., 2004).

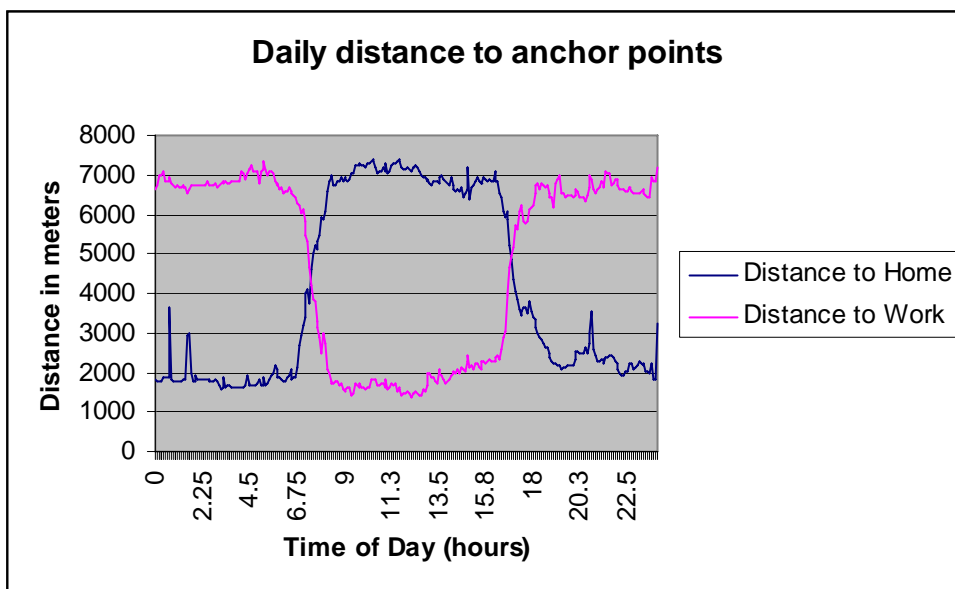


Figure 5: Aggregate daily distance to anchor points¹

This is also reflected in figure 6 where a score of 1 represents any position on a straight line between home and work location. It shows that there is a considerable deviation not only during commuting times but during the whole office hour period indicating a very mobile workforce and a second period

¹ The ragged shape of the lines is to some degree due to inaccuracies in the determination of the cell a phone is located in; this is a point of concern that required further attention in future research.

between 20:00h and 22:00h where other activities take respondents away from the home location.

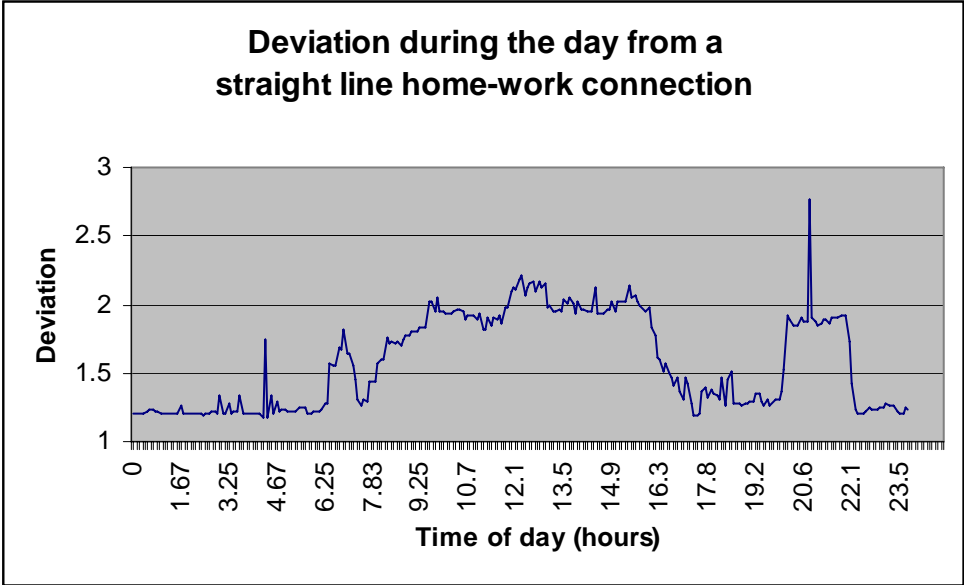


Figure 6: Deviation from the straight line between anchor points

Admittedly the sample population is very biased, but figure 6 clearly illustrates that it is too simple to assume that everybody will be at the work location during office hours. Maps can also be constructed to show the position of each phone with respect to the anchor points at any specific time. Figure 7 shows the positions at 18:00 hours and 19:00h, when most respondents are returning to home. Anchor lines are used to link the actual position to the home location to give an indication of distance still to go. Although the picture has clarified by 19:00h a significant number of respondents has still a considerable distance to go.

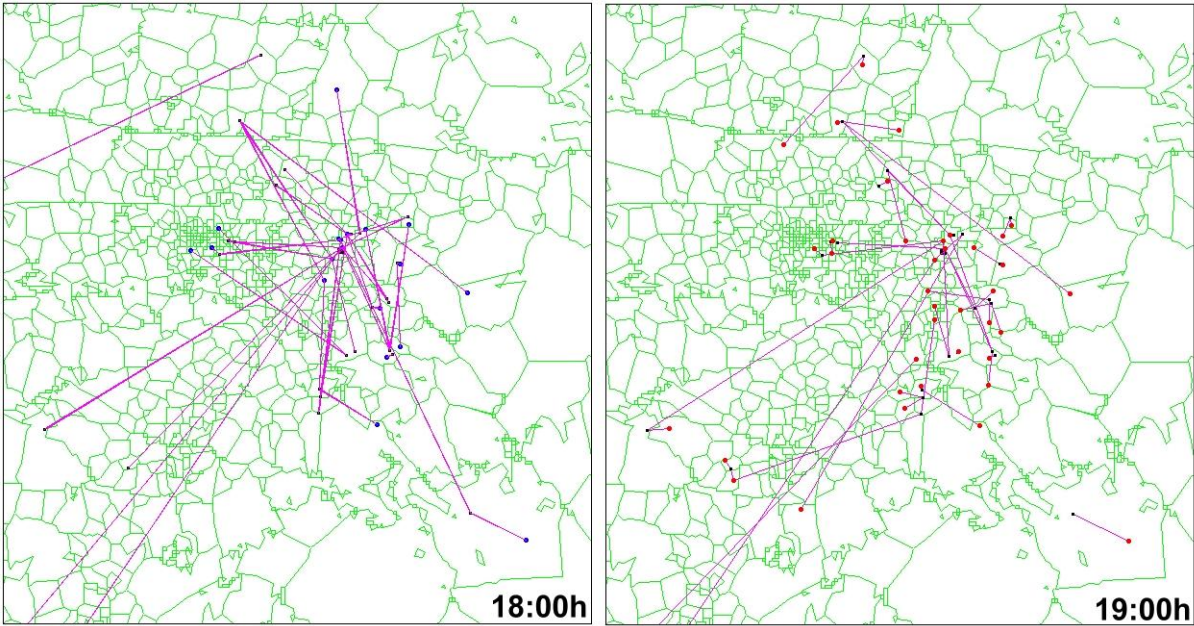
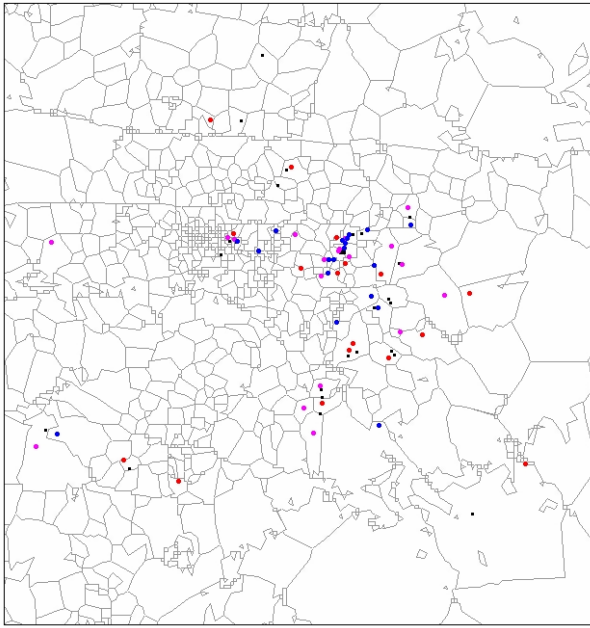


Figure 7: Cell phone position at 18:00h and 19:00h and anchor points (home locations)



The varying positions in time can also be drawn in a single map. Figure 8 shows the respective locations at 19:00h, 19:30h and 20:00h when a major part of the respondents relocates from the home to the work location. However too many “snapshots” in a single map easily obscure the overall picture and a better understanding of the daily urban rhythm can be gained by combining a detailed series of similar maps at chronologically ordered points in time into a dynamic map or a movie.

Figure 8: Positions at different times

The final map (figure 9) again illustrates that the usual assumption of people moving straight from home to work (left hand picture) in the morning rush hour does not do justice to the actual travel behaviour as can be seen (right hand picture) when all movements at 5 minute intervals are displayed

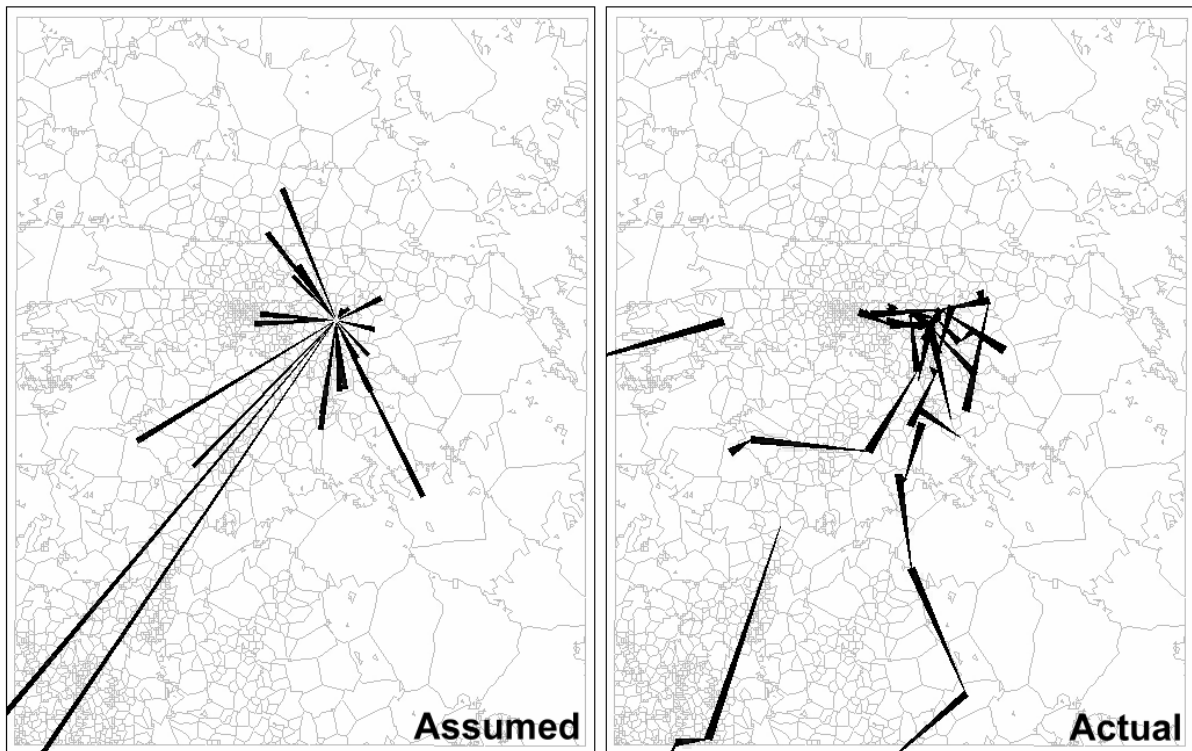


Figure 9: Assumed and actual movement in the morning rush hour

An obvious next step would to allocate the actual flows as displayed in figure 9 to the transport network to get an indication in variation of traffic loads over time during the day, but this requires a larger and more representative sample and a better understanding of the accuracy issues described in a previous paragraph.

8. Concluding discussions and directions for future research

This paper presented the findings of a *proof-of-concept* study to obtain detailed information on individuals' daily travel and activity patterns using cellphone tracking. The proliferation and adoption of consumer devices such as GSM technology (and Assisted-GSM in the future) offers the opportunity to leverage existing hardware and software already in the hands of study participants for collecting detailed travel behaviour information and at the same time overcoming the well-known problems with complex and burdensome activity-travel diaries, specifically in a developing country (Wolf, 2004).

The proof-of-concept study showed that it is possible to obtain individual-level travel behaviour data from cellphones. However, while information such as the origin and destination of trips (and the linking thereof to transport zones) can be 'extracted' from cellphone data without significant labour and technological intervention, obtaining a more richer description of individuals' entire daily activity and travel patterns proved considerably more complex requiring (at least initially) much more methodological innovation.

To extract detailed daily activity and travel patterns entailed a complex (iterative) process relying on labelling rules and algorithms to clean, verify and ultimately transform the raw data to travel pattern data. Applying the rules and algorithms to the data resulted in a very real activity and travel path for each individual from which valuable relevant information (departure time, arrival time, activity duration, activity sequencing, etc.) could be extracted for use in conventional transport modelling studies and more advanced activity-based research.

While the exercise was generally a success, the researchers did experience some problems in cleaning and labelling the raw data and several areas for further research are considered. These include improving the cleaning and labelling rules and algorithms, improving location accuracy (through triangulation and/or signal strength determination), allocating movement points to routes and integrating the data with various other contextual layers.

Furthermore, a need was also identified to replicate the exercise with larger and preferably a randomly drawn sample with a variety of work destinations. In addition, it is recommended that cellphone tracking is undertaken together with more conventional household surveys (to verify the tracked information and inform the rules and algorithms). Information on home and work locations and other daily activity engagements can be used to verify the tracking data and provide information on individual socio-demographic characteristics not available via cellphone tracking.

Cellphone data collected by way of passive tracking only provides locational and temporal data. When used in transport and land use studies, the data should still be supplemented with GIS layers of land use and other spatial features. Depending on the application (e.g. retail services, transport, logistics) cellphone data will have to be supplemented with additional data, such as home interviews, telephone

surveys and respondent stated and revealed preference surveys. Cellphone tracking, however, does take care of one of the more complex data requirements, i.e. accurate temporal and spatial activity and (possibly) route location information. It is also possible to use cellphone tracking as add-on surveys with other more routine surveys such as OD and national travel surveys. The cellphone information can then be used to identify under-reporting of trips/activities (and hence be used to derive correction factors for the larger, conventional surveys), obtain accurate location information and correct for incomplete, missing, or inconsistent trip details.

The area holds much promise as consumer driven services are driving location based services and leading to improvements in the accuracy and quality of service. The integration of GPS in cellphones is an area of continuing technology improvements which promises to provide a wealth of information for users of cell phones, personal digital assistants and other mobile devices. Similarly, these services will provide transport planners and other infrastructure researchers with the detailed information required to make more informed decisions.

The research illustrated that it is possible to use cellphone technology to address the critical data needs of developing countries. However, as illustrated by several technology projects in developing countries, no technology is a single panacea for all data and research requirements (or activity-based data requirements). The technology requires careful implementation and appropriate business models. Furthermore, the integration of the technology in transport information collection and transport planning requires an understanding of where the technology ends and transport planning begins.

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9. References

Asakura, Y. and Hato, E., 2005. 'Tracking survey for individual travel behaviour using mobile communication instruments'. *Transportation Research Part C 12*, Elsevier, pp. 273-291.

Bhat, C. R. and Koppelman, F. S., 2000, "Activity-based travel demand analysis: History, results and future directions", TRB, Washington, D.C.

Kitamura, R., 1997, "Applications of Models of Activity Behaviour for Activity-Based Demand Forecasting", Texas Transportation Institute, ed., *Travel Model Improvement Program*, Washington, DC. pp. 119-150.

Kracht, M., "Tracking and interviewing individuals with GPS and GSM technology on mobile electronic devices", Seventh International Conference on Travel Survey Methods, Costa Rica.

Pas, E. I., 1990, "Is Travel Demand Analysis and Modelling in the Doldrums?," In Developments in dynamic and activity-based approaches to travel analysis, Avebury Grower Publishing Company, pp. 3-33.

Pas, E. I., 1995, "The Urban Transport Planning Process," In The Geography of Urban Transportation, 2 edn, S. Hanson, ed., The Guildford Press, New York, pp. 53-77.

Pipkin, J. S., 1986, "Disaggregate Travel Models," In The Geography of Urban Transportation, S. Hanson, ed., The Guilford Press, New York.

Sharp, J. and Murakami, E., 4 A.D., "Travel Survey Methods and Technologies Resource Paper", NATIONAL HOUSEHOLD TRAVEL SURVEY CONFERENCE: Understanding Our Nation's Travel, Transportation Research Board, Washington, DC.

Stopher, P., 2004, "GPS, Location, and Household Travel," In Handbook of Geography and Spatial System, 1 edn, D. A. Hensher et al., eds., Elsevier, Oxford, pp. 433-449.

Timmermans, H. J. P., 2000, "Theories and models of activity patterns," In Albatros: A Learning-Based transportation Oriented Simulation System, European Institute of Retailing and Services Studies (EIRASS), Eindhoven, pp. 6-70.

Wermuth, M., Sommer, C. and Kreitz, M., 2004, "Impact of new technologies in travel surveys," In Transport Survey Quality and Innovation, P. Stopher & P. Jones, eds., Pergamon, Oxford, pp. 455-482.

Wolf, J., "Applications of new technologies in travel surveys", August 2004, International Conference on Transport Survey Quality and Innovation, Costa Rica.