
R. Ahas, A. Aasa, S. Silm, R. Aunap, H. Kalle, and Ü. Mark

ABSTRACT: The paper introduces methods and applications of the mobile positioning-based social positioning method in geography. The social positioning method (SPM) studies space–time behavior by analyzing the location coordinates of mobile phones and the social characteristics of the people carrying them. We describe the experience gained from the SPM pilot studies carried out in Estonia from 2003 to 2006. The results demonstrate that mobile positioning-based tracing is applicable in different geographical studies, as an analysis of temporal movement patterns and activity spaces. The biggest advantage of mobile positioning-based methods is that mobile phones are widespread, positioning works inside buildings, and collection of movement data is done by a third party at regular intervals. The disadvantage of mobile positioning today is relatively low spatial accuracy and surveillance fears. The boom in the generation of phones with A-GPS will improve positioning accuracy in networks.

Introduction

During the last few decades, geographers have evolved different methods to gather and analyze the space–time movement data of society and individuals. Analyses of movement patterns of persons and social groups are important in geography and urban planning, since the issues of urban sprawl, sustainable planning and smart growth are at the top of the agenda in many countries and regions today (Handy 2005). Concepts of sustainable planning and smart growth are aimed at designing energy- and time-effective settlement and transportation models which need input data from space–time movement analyses and models (Janelle et al. 1998; Timmermans et al. 2002; Miller 2005).

Space–time behavior studies are limited by data-mining methods on human motion and activities. The traditional methods of travel diaries, questionnaires, and observations are still in active use. Automatic transportation counters, street scanners, video tracking, and satellites all enable traffic flows to be described but do not give accurate characteristics of the moving subjects. There is growing interest in GPS and mobile phone tracing experiments in behavioral studies in new millennia (Ahas and Mark 2005; Axhausen et al. 2002; Dykes and Mountain 2003; Mountain and Raper 2001; Ratti et al. 2006; Ahas et al. 2007a). Both methods have advantages and disadvantages. GPS tracing has digital output and good preciseness, but GPS applicability is limited in areas with reduced visibility, in forests, cities, and houses. Mobile positioning has higher potential for tracing experiments as phones have become widespread in most countries and they have also become traceable inside buildings. Mobile positioning is limited by lower accuracy. Booming new generation of mobile phones with A-GPS, which integrates best functions of phones and GPS, has opened great data potential for geographical research in a broader sense. Positioning data are digital; it is easy to trace many people at the same time, and it is possible to analyze their movements in real time.

In this paper we introduce methods and results of pilot studies of using the positioning data of personal mobile phones in research into human space–time behavior. This method is called the social positioning method (SPM) (Ahas and Mark 2005; Ahas et al. 2007a) and it describes individuals' movement patterns using the positioning coordinates of their personal communication devices combined with the owners' personal/social attributes. First pilot studies of the social positioning method were carried out by the Institute of Geography,
University of Tartu, and Positium Ltd during 2003 and 2004 (Ahas and Mark 2005). Those pilot studies provide a basis for demonstrating and discussing the potential and shortcomings of SPM.

The most important problems of SPM are related to data security, as well as concerns about unauthorized personal surveillance (Froomkin 2000; Lilian and Konstantinos 2003). These problems can be solved with further development of location-based services (LBS) and relevant legal and organizational regulation. Today mobile positioning can be applied only by obtaining participants' personal acceptance.

Mobile Positioning in Geographical Studies

The methods of using location coordinates of mobile phones have been discussed in geographical research by several authors. Many geographers have mentioned the potential of location-based services (LBS) of mobile communications in geographical research (Dykes and Mountain 2003; Mountain and Raper 2001; Rauhal et al. 2004). Still, the majority of studies using mobile phones are limited to tracing the movement of mobile phones (“moving dots”) and do not integrate the social characteristics of phone owners, because personal data are strictly protected and very sensitive information (Saitoh et al. 2001; Spinney 2003). Such studies use anonymous LBS info (number of phones = cars in highway sector or area) for transportation, management, and civil engineering studies, and the information from this type of research has also been used in marketing and tourism studies in several countries.

Collection of positioning data is technically possible in the majority of mobile networks in Europe. The biggest problems lie in getting the operators to offer infrastructure for case studies and in obviating the tricky ground of “tracing/surveillance experiments.” Operators do not want to lose the clients’ trust. Many operators accept LBS-based services and experiments as a potential source of generating additional income from expensive infrastructure. Normally, they charge clients per every positioning event, and experiments can generate tens of thousands of positioning events daily. For operators it is most important to get the verified acceptance of individuals to participate in a study which will be traced by a third party (such as scientists). Applications of mobile positioning are developing along with improvements in the preciseness of positioning.

Social Positioning Method

The social positioning method (SPM) uses the location coordinates of mobile phones and the social identifications of the people carrying them for the purpose of studying the space–time behavior of society (Ahas and Mark 2005; Ahas and Laineste 2006; Ahas et al. 2007b). The SPM data collection method allow working in real time. The term “social positioning method” has so been coined because the method focuses on the study of the space–time movement of identified persons with social attributes, not on unidentified moving “dots,” as is the case in several traffic experiments. To collect data on the positioning of individuals one needs to secure the personal consent of each participant, as is the case in any other study or query. In addition, the SPM method uses personal data obtained from a positioning contract and/or a special questionnaire seeking information on the social characteristics and travel behavior of respondents. Mobile phones allow researchers to ask additional questions via text messages or phone. Using location coordinates, the questions can be made automatic and location specific. For example, if a person enters a park, we can ask with a text message what transportation he/she has used or the reason for the visit.

We have successfully been testing SPM in pilot studies with small samples, in cooperation with 2 major network operators EMT and Elisa in Estonia. Some of the results from these studies have been applied in planning projects in Tallinn during 2004, 2005 and 2006. There is a new positioning experiment organized by Positium, Ltd. and Tartu University to collect the positioning data of foreign tourists in Estonia since 2004. As of June 2007, a database of over 30 million location points have been collected (Ahas et al. 2007c).

Technical Solutions of Mobile Positioning

Positioning data can be defined as active and passive. Active mobile positioning data are collected using mobile tracing, and the location of a mobile phone is determined with a special query using radio waves (Positium 2006). Passive mobile positioning data are location data stored automatically in the databases of mobile operators when a person uses a mobile phone (call activity).
Such data can be log files or the billing memory of an operator such as the Home Location Register in the Ericsson software used in the EMT network in Estonia (Ahass et al. 2007c).

The technical solutions for mobile positioning are different for different network standards (Adams et al. 2003). These solutions can be handset-, network-, or satellite (mostly GPS) based. Handset-based solutions for mobile positioning use special software in the phone to triangulate the location coordinates of the radio coverage cells and the network antennae. New handset-based methods combine GPS and network-based positioning methods. The phone can submit collected location coordinates via a radio signal (SMS, GPRS etc) to an operator, an independent server, or another phone.

Network-based methods use different positioning techniques to find phone locations in a network, i.e., cell identity, triangulation, angle, and arrival time of radio signal. Most commonly used methods use unique ID for individual network cells—the cell global identity (CGI). As network cells can be relatively large (ranging between 0.002 km² to 100 km²), the exact location in a cell is determined by timing advance (TA) or the angle of a radio signal. For example, the commonly used positioning methods today are the Cell Global Identity + Timing Advance (CGI+TA) and the Enhanced Observed Time Difference (E-OTD) methods. Most network base-methods use additional hardware or radio signal queries, which makes them expensive. Furthermore, their precision is much lower than that of satellite-based GPS.

Not surprisingly, satellite-based positioning methods are applied more and more in mobile positioning. The fastest developing mobile positioning methods are based on a combination of mobile positioning and the satellite-based GPS system; they are the network-assisted GPS (A-GPS). The GPS system has been specifically designed for positioning, as accurately as possible anywhere on the globe. GPS needs visual contact with satellites, but mobile positioning also works in buildings, cities, and the forest. A-GPS, which combines those advantages, is a rapidly developing technology. In Asian mobile networks, phones with GPS and A-GPS services are becoming standard. In European and American networks, the boom in A-GPS and phones with GPS is beginning. The European Union and its partners are developing the Galileo navigation system to serve as the basis for A-GPS in GSM networks after 2009.

A-GPS is the most spatially accurate method of determining location; with a 1-10 m accuracy range it undoubtedly is the positioning method of the future. With other more widespread methods, such as Cell Global Identity (CGI+TA) and Enhanced Observed Time Difference (E-OTD), practical precision falls within the range of 50-5000 m. In practice, the precision of positioning depends to a large extent on the density of the communication network. Although the precision of positioning is not very high today, it still enables the study of various patterns in the space–time movement of society.

Case Studies with SPM in Estonia

The main data source for the analyses in this paper was the SPM pilot study in Tallinn, the Estonian capital, on 18-22 February 2004, with 117 respondents and a positioning interval of 30 min. The objective of the SPM study was to map activity spaces and space consumption of residents of the city centre of Tallinn and commuters living outside the city and working in the city centre. We also used the results and experiences of two other SPM experiments in Estonia: one conducted on 10-15 March 2003 in Tallinn with 22 participants and a four-hour positioning interval, and the other on 17-18 April 2004 in Tartu with 26 participants and a five-minute positioning interval.

The collection and analysis of the social positioning data were conducted by Positium, Ltd which is currently developing SPM applications in cooperation with the Institute of Geography, University of Tartu. The pilot studies utilized the EMT network which has technical and organizational capabilities for location-based services using the CGI+TA method. During the experimentations, EMT used ERICSSON, Ltd’s MPS system for mobile positioning, enhanced by PinPoint Mgine software developed by ReachU, Ltd.

The size of the sample and the number of positioning events was limited by the budget allocated for the experiment. The sample reflects the sex-age distribution of Tallinn’s population, derived from the 2000 National Population Census (ESA 2000). The sample was proportionally divided into two groups: one was comprised of 91 residents of the central part of the city, and in the other were 26 commuters, e.g., persons working within the city centre but living outside Tallinn. To balance the sample, the quotas of commuters were divided equally between the main commuting routes of the Tallinn region.

The participants were selected in January and February 2004 by three agents who used EMT
phonebooks and made enquiries in offices and public institutions in the city centre. They were asked to sign a special contract enabling the recording of the positioning of their personal mobile phone on the days of the experiment; and they filled in a special questionnaire describing their social background and travel behavior. As a personal feedback, participants received, after the experiment, a record of their digital tracks overlaid on the map of Tallinn. Among the 117 persons participating in the experiment, 47 percent were male and 53 percent were female, corresponding to the actual population sex ratio of the city. In terms of age groups, the sample had 10 percent more participants in the 20 to 39 year age group than the mean age for all Tallinn recorded by the 2000 national census. This is due to the fact that there is a larger proportion of younger and well paid residents living in downtown Tallinn than elsewhere in the city. The most time-consuming aspect of the selection process revolved around the need to assuage fears of privacy invasion.

Tallinn has an area of 158 km² and a population of 400 000. The biggest residential areas in Tallinn are Lasnamäe, Mustamäe and Ülemiste, where people are living in apartment buildings built between the 1960s and 1990. A significant part of the population is also located within the city centre—14 778 inhabitants. The compact medieval old town in the centre of Tallinn is on UNESCO’s world cultural heritage list. Urban agglomeration around Tallinn extends 50 to 70 km from the core of the city (Tammaru et al. 2004). In suburban areas, the residential areas and shopping centres have been extensively developed. The population of Greater Tallinn is 550 000 inhabitants, and a large number of well paid employees commute daily to work and back using mostly cars but also (to a lesser extent) trains and buses. During the last fifteen years the number of cars in Tallinn has almost doubled, reaching 319 cars per 1000 inhabitants in 2004.

The analysis of the SPM data were managed and performed in the environment of MS Access, Excel, and Statistica programs. Spatial analysis was performed using the GIS program packages ArcInfo, Surfer and Idrisi.

**Anonymity and Participants’ Safety**

The most sensitive aspect of the SPM is the protection of privacy and security. Positioning can open to public delicate aspects of personal life and can cause psychological disturbance. Hence, the positioning experiment was performed only with the written consent of the phone carrier. Where a business phone was used, the consent of the employer was additionally obtained. The participants were informed by the agents about data security, analysis, and applications in urban planning. Every positioning event was followed by a SMS message to the participant informing them that, “you have been positioned by Positium service.” There were no serious misunderstandings, and the participants were happy to participate in the experiment.

**The Efficiency of SPM in Data Mining**

An important part of the current study is related to the testing and the development of the social positioning method. Data obtained using SPM are similar to space–time movement data gathered by GPS, Moby drive, travel diaries, questionnaires, and video tracking. They consist of two or three location coordinates (x,y,z), time (t), personal features, and the respondent’s transportation information. The SPM survey is not a revolutionary data collection method, but it does have some advantages resulting from the potentially higher frequency and quantity of data, the digital origin of the data, and an independence from respondents’ “memory bias.” These advantages of SPM data exist because mobile phones are very popular and most people like to carry their mobile phone with them at all times. Also, people carefully check the battery level of their mobile phones, unlike with GPS tracing experiments where battery checks are less ubiquitous.

**Preciseness of Mobile Positioning**

The precision of positioning and readiness of mobile operators is improving continuously with the development of location-based services. This notwithstanding, the majority of networks (except A-GPS) have problems with the relatively low accuracy of mobile positioning. We verified the positioning accuracy for 717 location points with a special GPS device during our field experiments. These special accuracy checks demonstrated that 52 percent of measurements made in urban areas had an error smaller than 400 m and for 99 percent the error was smaller than 1200 m. In rural areas, 26 percent of points had smaller error than 400 m and 50 percent of points had an error smaller than 2600 m.

There are limits to precision and data quality in today’s mobile positioning, but the current accu-
racy level still allows us to study several aspects of urban geography and planning. Our study shows that, because of low precision of positioning it is difficult to analyze movements in a given house or at street level, as planners and architects would normally like to do. But the SPM data make it possible to do so at the level of a transportation region or a block level. As precision of positioning is directly dependent on the density of the mobile network, the scale and accuracy of the data analyses can be connected with the operator’s network cells. The network is very dense, cells are small, and positioning is more accurate in city centres, and we can use a smaller raster for analysis. We used such a “cellular carpet” in our analysis, which was determined for Tallinn by the EMT mobile network using the Voronoi diagram (Pang and Shi 2002), and this spatial coverage fits well with data quality requirement (Figure 1). In central Tallinn, the network cells are 0.4 km² on average (smallest cells near 200 m²), and mean positioning accuracy ranges from 50 to 200 m. In suburban areas, the network cells are on average 0.5 to 1 km² and accuracy ranges from 100 to 400 m. The network cells in Estonian rural areas have the average size 49 km² with an positioning accuracy of between 300 and 2500 m. If we use such a cellular carpet for analysis, this dimension is the right scale for spatial analyses of data. We can zoom in on city centres but be general in dispersed settlement areas. Still, we have to consider that these network (cell) areas are not fixed, but are flexible radio coverage areas that depend on the strength of the signal, visual contact, and the number of users in an area.

Selecting the Time Interval

One important issue in SPM studies is the selection of the optimal positioning interval. The type of interval selected depends on the research objectives and scale of the experiment, transportation devices used by respondents, and available finances. We have used intervals of 4 hr, 30 min, 5 min, and 1 min in experiments with different objectives. Most end users prefer to work with positioning data with as short an interval as possible, but the interval is actually dependent on positioning costs. As mobile positioning is part of the services of mobile operators, the current market price is between 0.03 and 0.6 EUR per positioning event in networks in the Baltic Sea region. The costs of positioning with a 1-min interval are 60 times higher than those with a 1-hr interval. This easy mathematics raises the question of the determination of the optimal interval for positioning.

First we have to consider the objectives of the study and the transportation means used by respondents. This positioning interval is different for walking and using a car or a bicycle. Figure 2 shows the best positioning intervals for tracking a person with a car and walking a short distance in the city, using as a benchmark one-day positioning in Tartu with a 5-min interval and a GPS reference. The SPM analysis in Figure 2 indicates that a 5 minute interval is too short for tracking driving car in a city like Tartu. Therefore we selected interval 15 minutes for experiments and Tallinn had a similar optimal positioning sequence.

We also studied the spatial accuracy of this same 5-min-interval experiment fragment in Tartu (Figure 3). The SPM-modelled route for different (5, 10, 15, 30 min) positioning intervals in relation to the actual route in Tartu are presented on Figure 3. The
Figure shows that the 5-min interval is best and the 30-min interval loses most of the road points. The 5-min interval is relatively accurate for spatial movement studies in the GSM network using the CGI+TA method.

Figure 4 shows that when the objectives of the project are clearly identified, and the respondents’ transportation device as well as the best positioning interval are known, the results obtained with low accuracy and low “cost” intervals are acceptable. The figure shows correlations between the automatic traffic counter on the Vabaduse-Sõbra crossing in Tallinn and the SPM data collected using a 30-min interval.

Correlations are especially high (R=0.81) if we eliminate local movements (due to walking or antennae change bias) by using a minimum speed limit filter for SPM data to eliminate movements smaller than 500 m per 30-min interval. The strong relation shows that the SPM data are relevant and can be used as a valuable supplementary tool to determine traffic flow. More importantly, the personalized SPM data enables one to add “a face to the traffic flow”—the social characteristics which, until recently, could only be guessed or indirectly assessed on the basis of conventional traffic counts and scanners.

Analysis of SPM Method

The gathering and analysis of SPM data have much in common with methods and tools developed in geography and GIScience studies of space–time behavior and activity spaces. These studies have been prominent in geography since the postulation of the time–geography paradigm by Hägerstrand (Hägerstrand 1968), and their precept has been rediscovered in the last decade in connection with civil engineering and planning applications (Bromley et al. 2003; Newsome et al. 1998; Timmermans et al. 2002). The increase in the number of studies of space–time behavior is also due to booming GIS methodology environment and new electronic/digital data sources available for analysis (Kwan 2000; Longley 2002; Raubal et al. 2004; Miller 2005).

Temporal Rhythm of Social Behavior

The social positioning method makes it possible to map and analyze temporal rhythm and variability of social space because the timelines of location changes are well documented and stored in a database. We found
in our positioning experiment that the proportion of people who change their location during the day varied from 10 to 30 percent in the mornings and evenings to 70 percent during the work day peaks (Figure 5). As could be expected, commuters were more active movers, and there was a general increase in movement on Friday afternoon and a decrease on Sunday morning. On work days, mobility was highest between 9 a.m. and 11 a.m. and between 4 p.m. and 6 p.m. The least activity occurred between 11 a.m. and 12 a.m. and at 3 p.m. Mobility decreased as people started to arrive home, after 7 p.m. Little mobility was observed before noon on weekends. The residents of the city centre moved less than the commuters. The difference (up to 10 percent) was greatest between 8.30 a.m. and 9.30 a.m. and between 4.30 p.m. and 7.00 p.m. On weekends, the city centre inhabitants were quite active between 9 a.m. and 3 p.m., with up to 75 percent of the sample being in motion. The commuters were more active on weekends, between 3 p.m. and 6 p.m.

The temporal rhythm of the participants’ consumption of space is described in SPM by the distance that a person covers during a 30-min period between two positioning events. The mean distances of the participants in our study are presented in Figure 6. As can be seen from the statistics of space consumption, the differences between the relative journey distances of the commuters and the city center residents were considerable. On work days, the commuters covered between 1000 and 4000 m during a 30-min period, compared with 200 to 300 m by the city center inhabitants.

Commuters start their morning journeys earlier, traveling distances of between 2500 and 3500 m per 30 min during the morning peak hours. By 11 a.m., the commuters’ movement decreased to the level of the city center residents’ movement, traveling distances of close to 1000 m within a 30-min period. From 3 p.m., the beginning of the end of work day, the commuters’ mobility rapidly increases to up to 4000 m per 30 minutes and remains high until 10 p.m.

On work days, the mobility of the city center residents was relatively stable, increasing from 300 m at 7 a.m. to 1000 m at 10 p.m. This group became highly mobile after 4 p.m. and continued to be so until after 10 p.m., indicating some similarity to the mobility of the commuters.

*Figure 4. Correlations (R=0.81) between SPM database (movements over 500 m per 30 min) and the automatic traffic counter on the Vabaduse-Sõbra crossing in Tallinn, Estonia, during the 18.02-23.02 experiment.*

*Figure 5. Percentage of people changing their location during 30 min time intervals within the sample of 117 participants. [A=work days, B=weekends.]*

Vol. 34, No. 4
On weekends, the mobility patterns peak at noon, and the differences between the city center residents’ mobility and that of the commuters are no greater than the differences found for work days. On weekend mornings, especially on Sundays, the mobility of people is low, although there are still a few residents and commuters who leave home early on weekend mornings. A considerable increase in mobility occurs after 11 a.m., reaching maximum levels after 3 p.m., at which time the commuters cover an average of 3000 m during a 30-min period and the city center residents cover an average of 1500 m. During weekend evenings the movements of both groups are at a minimum after 10 p.m.

The number of kilometers traveled is the highest on Friday afternoons, when the number of people in motion is the highest and mean journey distances exceed 3000 m. On weekends there are less people in motion but they cover longer distances than they normally do—up to 4000 m per 30 minutes on average.

We also studied space consumption in different regions of Tallinn by spatially mapping data between transportation regions. We found that by late morning, the population from the greater Tallinn is concentrated in the city centre, with the maximum number of people (75 percent of the sample) reaching downtown Tallinn between 10 a.m. and 11 a.m. The proportion of the sample in the other parts of the city increased to up to 15 percent during the same time period, leaving less than 10 percent of the sample outside the city. From 6 p.m. onward, the number of people in downtown Tallinn gradually decreased, and the proportion of the sample outside the city increased, reaching 20 percent by 9 p.m. Between 8 p.m. and 9 p.m., the number of people in the centre was at its minimum (58 percent of the sample), increasing to about 65 percent by late evening. The diurnal rhythm of space consumption is different on work days and weekends (figure 7). The centre of Tallinn was busiest on work days (70 percent of the sample) and on weekends the area outside Tallinn was more popular among the participants (30 percent). This result is logical and corresponds to the results of journey distances described earlier.
Spatial Variability of Activity Spaces

Analysis of Distances

Distances covered on the way between anchor places (home, work, school) or between simple route markers (selected points) of every day travel are important parameters for describing spatial activities. We analyzed two parameters based on distances in respondents' travel: cumulative sums of daily movements and distances from the city centre obtained with an SPM data set.

Cumulative sums of distances covered during the day are good for analyzing daily movements with regard to covered distance, speed, and time of movement (Figure 8). Those movement curves are also best for describing and comparing lifestyles, as shown in Figure 9, with mean values for all traced commuters and city center residents. Summarized movement distances also help to analyze the rhythm of different days, as we can distinguish the morning rush, lunch break, and end of work in the movement curves. Such details of daily movements are more visual on personal movement curves, because averaging blurs out special and personal movement features. Cumulative movement sums and curves can be very valuable indicators of our lifestyle. The averaged movements of city centre residents and commuters show that on work days (Wednesday, Thursday, and Friday), the commuters cover almost twice the distance (50-70 km) than do residents (20-40 km) (see Figure 12). Saturdays are very similar (46 km) for commuters and residents but on Sundays, evening commuters travel more. The rise angle of the cumulative curve shows the speed of respondents. Cumulative sums of kilometers between anchor places are also good variables for further statistical analyses of personal movement characteristics.

The second parameter we studied was distance of respondents from city centre during the day. There is a possibility to analyze distances from different 0 points, or such anchor points as home or work. We selected the city centre as the 0 point of analyses (Town Square of Old Tallinn), as this helps to describe the respondents' lifestyle. The averaged values of distances from city centre for residents and commuters are different, as are their daily rhythms (Figure 10. The commuters start and

---

Figure 8. Daily cumulative movement sums of one city centre resident and one commuter during positioned days.

Figure 9. Mean values of daily cumulative distances covered by city centre residents and commuters.

Spatial Variability of Activity Spaces

Analysis of Distances

Distances covered on the way between anchor places (home, work, school) or between simple route markers (selected points) of every day travel are important parameters for describing spatial activities. We analyzed two parameters based on distances in respondents' travel: cumulative sums of daily movements and distances from the city centre obtained with an SPM data set.

Cumulative sums of distances covered during the day are good for analyzing daily movements with regard to covered distance, speed, and time of movement (Figure 8). Those movement curves are also best for describing and comparing lifestyles, as shown in Figure 9, with mean values for all traced commuters and city center residents. Summarized movement distances also help to analyze the rhythm of different days, as we can distinguish the morning rush, lunch break, and end of work in the movement curves. Such details of daily movements are more visual on personal movement curves, because averaging blurs out special and personal movement features. Cumulative movement sums and curves can be very valuable indicators of our lifestyle. The averaged movements of city centre residents and commuters show that on work days (Wednesday, Thursday, and Friday), the commuters cover almost twice the distance (50-70 km) than do residents (20-40 km) (see Figure 12). Saturdays are very similar (46 km) for commuters and residents but on Sundays, evening commuters travel more. The rise angle of the cumulative curve shows the speed of respondents. Cumulative sums of kilometers between anchor places are also good variables for further statistical analyses of personal movement characteristics.

The second parameter we studied was distance of respondents from city centre during the day. There is a possibility to analyze distances from different 0 points, or such anchor points as home or work. We selected the city centre as the 0 point of analyses (Town Square of Old Tallinn), as this helps to describe the respondents' lifestyle. The averaged values of distances from city centre for residents and commuters are different, as are their daily rhythms (Figure 10. The commuters start and
end their day 15 kilometres or more from the city centre; during lunch time they are close to the city centre, within a range of 5-10 km. City center residents have the opposite spatial relationship with the city centre. On Saturdays and Sundays the commuters stayed far away from the city, being at least 20 to 35 km away.

**Personal Activity Spaces**
The study of the spatial dimension and spatial variability of personal activities or activity spaces is an important aspect of geographical studies. SPM data allows 3D visualization, comparison, and analysis of the spatial movement of persons with different movement characteristics or lifestyles (Figure 11). Still, the mapping of activity spaces is a limited method, allowing mostly just a visual analysis. Visual analysis is good for studying the activity spaces of a few persons or it can be applied for simple samples of respondents. For more complicated analyses, space–time movements need to be disaggregated into statistical parameters or spatial densities (Newsome et al. 1998).

We analyzed the daily space consumption in anchor points by commuters in greater Tallinn (Figure 12). As we can see, the division of time spent at home and at the work is very logical. The movement at other places was highest in the afternoons, and this was the main difference between commuters and residents. Commuters spent 10-25 percent more time than residents in other places, with the biggest differences occurring during the afternoon hours (2 p.m. to 6 p.m.). Also, the commuters spent more time at home on Saturday mornings (7 a.m. to noon).

The analysis of spatial densities with positioning data shows the mobility differences of distinct social groups. Mobile positioning offers many possibilities here, as it collects location points during the day with constant frequency. We analyzed the location differences of workers and specialists/managers (Figure 13) during their spare time (before and after work). The profile line ran along the city’s major highway. The results show that managers use the city space much more extensively compared to workers, who are more static. Specialists and managers were more concentrated in the eastern part of the city centre, where numerous office buildings are situated, whereas workers with simple jobs were more evenly spread over central Tallinn. During

![Figure 10. Mean distance from city centre (Raekoja square) of all positioned city center residents and commuters.](image)

![Figure 11. 3D representation of personal activity tracks of a commuter in greater Tallinn on February 18 to 23, 2004.](image)
working hours, besides the concentration in the centre, specialists were also found in the residential areas of west Tallinn, which could be explained by the relatively flexible working hours, while workers were tied to fixed working places and hours. The temporal distribution of the participants’ movements shows also that managers/specialists are more mobile during non-office hours. Managers and specialists were very often found on the streets and highways surrounding the city. Workers living and working in the city had fewer activities involving travel during work days, and also out of office hours.

Statistical Analysis of Activity Spaces

The dependence of the daily movement of people on social features or life styles can be studied with statistical methods. The space–time behavior of individuals is a very complicated matter to study, because daily movement comprises many different parameters. The cumulative sums of daily movement distances reported earlier in this paper is a good characteristic for statistical analysis. One other possible approach is to generalize space–time movement patterns into confidence ellipses of activity spaces (Newsome et al. 1998; Schönfelder and Axhausen 2003). The confidence ellipses of activity spaces are described using the following parameters: length of primary and secondary axis, orientation, and area. In this research, the activity space ellipses were calculated in an ESRI ArcView 3.1 environment, using the freeware extension VISAR (Schwarze and Schönfelder 2001).

Confidence ellipses are analogous to the confidence interval of a univariate distribution as the smallest possible sub-area in which the true value of the population should be found with a certain probability (e.g., 95 percent). The size of the area of the ellipse is therefore an indicator of the dispersion of visited locations. The ellipses are computed using the covariance matrix of all points of a person:

\[
S = \begin{pmatrix}
    s_{xx} & s_{xy} \\
    s_{yx} & s_{yy}
\end{pmatrix}
\]
Where each covariance is defined as:
\[
s_{xx} = \frac{1}{n-2} \sum_{i=1}^{n} (x_i - \bar{x})^2
\]
\[
s_{yy} = \frac{1}{n-2} \sum_{i=1}^{n} (y_i - \bar{y})^2
\]
\[
s_{xy} = s_{yx} = \frac{1}{n-2} \sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})
\]

The determinant of the covariance matrix (generalized variance) is:
\[
|S| = s_{xx}s_{yy} - s_{xy}^2
\]

And the ellipse size A is:
\[
A = 6\pi|S|^{\frac{1}{2}}
\]

The arithmetic mean of all the unique locations weighted by the frequency of visit can be considered as the centre of the ellipse (Srivastava and Schönfelder 2003). The main advantage of activity ellipses analyses is the possibility to generalize a great number of movement points offered by the SPM or GPS methods.

The analysis of the movements of the 117 respondents studied in Tallinn demonstrated that the character of motion is dependent on certain personal characteristics (Table 1). The longer axis of the ellipse expresses the distance between the main locations (work–home) and the intensity of the day-to-day use of the route between them. This variable is significantly (p < 0.01) dependent on the place of residence of the participant, which determines also the general pattern of lifestyle of the participant (Figure 14): commuter or resident of the city centre (Table 2). The length of the home–work route is dependent on the profession and the education of the participant (P < 0.02). Results show that workers and less well educated people travel a much shorter distance to work in Tallinn than managers and specialists. This phenomenon can be explained by the fact that highly paid and educated specialists can afford to live outside of the city, as it is the trend in Tallinn today. The residences of workers performing edu-

<table>
<thead>
<tr>
<th>Factor</th>
<th>Explanation</th>
<th>Number</th>
<th>Factor</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential area</td>
<td>Old town and the centre</td>
<td>31</td>
<td>Education</td>
<td>Primary</td>
</tr>
<tr>
<td></td>
<td>3 districts near centre</td>
<td>60</td>
<td>Secondary and professional school</td>
<td></td>
</tr>
<tr>
<td>Out of city borders</td>
<td></td>
<td>26</td>
<td>University</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>&lt;19</td>
<td>8</td>
<td>Marital status</td>
<td>Single</td>
</tr>
<tr>
<td></td>
<td>20...39</td>
<td>81</td>
<td></td>
<td>Married</td>
</tr>
<tr>
<td></td>
<td>&gt;40</td>
<td>28</td>
<td>Children</td>
<td>0</td>
</tr>
<tr>
<td>Gender</td>
<td>Male</td>
<td>55</td>
<td>Education</td>
<td>1-2</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>62</td>
<td>Salary (EUR)</td>
<td>&lt; 320</td>
</tr>
<tr>
<td>Occupation</td>
<td>Managers and specialists</td>
<td>69</td>
<td>Workers</td>
<td>320-641</td>
</tr>
<tr>
<td></td>
<td>Workers</td>
<td>19</td>
<td>Retired, pupil, student</td>
<td>641-962</td>
</tr>
<tr>
<td></td>
<td>Retired, pupil, student</td>
<td>29</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Resident/commuter</td>
<td>91</td>
<td>Resident</td>
<td>&gt;962</td>
</tr>
<tr>
<td></td>
<td>Commuter</td>
<td>26</td>
<td>Commuter</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Participants/respondents by social groups.
Advantages and Disadvantages of the SPM Method

The analysis of the data collected during the experiment showed that the social positioning method is useful and operational in many fields of study. Some of the results, such as space–time movement patterns of the commuters and city centre residents, have great applicability, and SPM data have relevance to earlier studies in this field (Weber and Kwan 2002). Still, the data collected with the SPM method and our analysis enable us to discuss methodological aspects and relevancy of data collected by SPM. Some of the results are more difficult to obtain by conventional methods, such as the rate and time of activity of commuters’ journey distances during different days of the week. Such data could be obtained by travel diaries or GPS, but with some limitations, as it is difficult to monitor exactly the activity between the starting point and the destination of the journey with travel diaries or to track movements with GPS inside buildings and street canyons. Mobile positioning traces such travel details and timing easily. Mobile positioning is also very good for recording movements between anchor points with a regular time interval. Positioning is proceeded by a third party, which makes it free of memory bias or mistakes.

The advantages of SPM are also connected with the potential number of respondent, as the majority of society has the technical readiness to be tracked—they have mobile phones. The preciseness of mobile positioning is a problem today but during the next five years, A-GPS will become standard in most networks and positioning accuracy will increase. However, the possibility of using mobile positioning for data collection presents a serious problem due to fear of surveillance and an uncomfortable feeling about the transparency limits expressed by a number of potential respondents. The great number of possible positioning points per respondent raises also the costs of experiments, as network operators charge per every point. However, if we compare the costs of SPM with those of conventional methods (travel diaries or questionnaires), the estimated double costs of SPM per respondent can give us 8 to 10 times more digital location points free from memory bias.

Applications of the Social Positioning Method

The social positioning method opens up opportunities for new applications and research directions, such as real-time mapping and analysis. Currently there is a limited number of end users for real-time geography, but public administrations and businesses will need such information to measure the “social barometer” of their cities or on the streets they operate on, and, armed with this knowledge, govern or operate better. Dynamic city management and dynamic architecture will be technically possible with SPM, if streets or houses can “see” and recognise people using the “social barometer.” Mobile positioning methods together with video surveillance cam-

<table>
<thead>
<tr>
<th></th>
<th>Major Axis</th>
<th>Minor Axis</th>
<th>Angle</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential Area</td>
<td>Yes***</td>
<td>Yes***</td>
<td>-</td>
<td>Yes***</td>
</tr>
<tr>
<td>Age</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Gender</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Occupation</td>
<td>Yes**</td>
<td>-</td>
<td>-</td>
<td>Yes*</td>
</tr>
<tr>
<td>Education</td>
<td>Yes**</td>
<td>Yes**</td>
<td>-</td>
<td>Yes**</td>
</tr>
<tr>
<td>Marital Status</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Children</td>
<td>-</td>
<td>-</td>
<td>Yes*</td>
<td>-</td>
</tr>
<tr>
<td>Pay</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Resident/Commuter</td>
<td>Yes***</td>
<td>Yes***</td>
<td>-</td>
<td>Yes***</td>
</tr>
</tbody>
</table>

Table 2. Significance of the effect of social characteristics of the studied 117 participants on activity–space ellipse parameters determined by the Kruskal-Wallis test. (** - P < 0.01; * - P < 0.1).
eras are a possible direction in this field (Ahas and Mark 2005).

Another application of mobile positioning is in public participation leading to a broader participatory democracy (Al-Kodmany 2001). The documented entering time into some area or object (park, bridge, supermarket) by a person can be used as an indirect sign of spatial presence or consumption of some functions of space. SPM is one possible tool for registering spatial presence (Ahas et al. 2005). Additionally, entering an area can lead to interactive votes or questionnaires concerning opinions or needs. This is possible because telephones can recognize space, and space can recognize telephones.

Yet another interesting application of SPM is recording “personal digital memory tracks” (Ahas et al. 2005). There is a growing number of people who want to save a history of their movements, and using the digital memory of phone location is the cheapest and most convenient way of keeping a record of spatial movement. The normal positioning frequency for digital memory tracking ranges from one to three hours. With a frequency of two hours all important daily movements are visible, amounting to 4380 positionings annually, which is financially affordable at current positioning prices. Digital memory tracking can also be used for geographical analysis.

Motion Patterns of Commuters and Residents

Despite the relatively small sample (117 participants) and only five days of experimentation, it was to draw some conclusions about human time-space behavior in Tallinn, particularly those of commuters and city center residents. First, the obvious was established, namely that the character of movement by commuters and city center residents is quite different. The main differences are in the use of urban space and in the temporal rhythm of daily movement. Compared to the movement of an average commuter (who covered 55 km a day during the experiment), the average resident moves only 31 km a day. The analysis of all the positioning events made during five days of the experiment shows that the resident moves on average 2266 m in 30 minutes, while the commuter moves 4426 m. This difference can be attributed to differences in lifestyles and in the environmental footprints of people working in the same area, or even in the same office. The observed differences in movement between commuters and city center residents is also likely to impact utilization of resources and infrastructure. For Tallinn, where suburbanisation and sprawl continue unabated, this means that solutions to transportation problems should be taken into account the source of these problems, the commuters. SPM analysis would be a good method to estimate and calculate personal motion costs and regulation measures in Tallinn and other growing cities.

Conclusions

The results of the SPM experiments demonstrated here confirm that the method is suitable for geographical studies. Because activity spaces can easily be determined, and with fair accuracy, using mobile positioning, the method is most suitable for studies of commuting and suburban lifestyles, by helping to analyze day-to-day routine. We were successful in describing the daily life rhythm of different areas in the greater Tallinn.

The social positioning method has several advantages, such as the possibility to collect large quantities of data, establish a routine positioning interval by third body, and customize the digital format of data. A very important result of the current study is the finding of strong correlation (r = 0.81) between automatic traffic counters and corresponding SPM data, which demonstrates the credibility of the method. The method’s disadvantages lie in the precision of current positioning methods and fear of privacy invasion. The rapid development of techniques and methodology for location-based services calls for an analysis of the various risks involved and public discussion of surveillance regulation, both of which may influence a possible power shift in society. The advances in regulation have to ensure that personal freedom is not affected.

ACKNOWLEDGMENTS

The authors wish to thank the Tallinn Department of Planning, EMT, Ltd., Positium, Ltd., and all the people who participated in the experiment. This project was funded by the Target Funding Project No. SF0180052s07 of the Ministry of Education and Science, Estonia, and Grant ETF 7204.

REFERENCES


Positium Ltd. 2006. About Positium Ltd. [www. positium.ee; last visited August 26, 2006].


