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GPS in Pedestrian and Spatial Behaviour Surveys

Nielsen, Thomas Alexander Sick; Hovgesen, Henrik Harder

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GPS in pedestrian and spatial behaviour surveys.

Thomas S. Nielsen, Assistant professor
Department for Development and Planning, Aalborg University
Tel: +45 26 200 360, Email: tsn@plan.aau.dk

and

Henrik Harder Hovgesen, Assistant professor
Department for Development and Planning, Aalborg University
Tel: +45 96 35 84 30, Email: hhh@plan.aau.dk

Abstract.

The planning of the environment for pedestrian can be improved by using the newest gps tools for monitoring changes in human activity patters in time and space.

Using a personal GPS-device the locations and movements of respondents can be followed through a longer period of time. It will be possible to analyse how the use of urban spaces are embedded in a wider context of activity patterns (work, school etc.). The general patterning of everyday itineraries, including route choice and time spent at different locations "on the way" can also be analysed.

If the personal GPS-device is combined with an electronic questionnaire, FX. in the shape of a Personal Digital Assistant (PDA) or cell phone, a whole new array of survey-possibilities comes into being. Respondents can be asked to register their activities, evaluate – or in other ways describe the attractiveness of places – based on their actual position in the urban area. Thus a new form of integration between research into activity patterns and urban places will be possible.

The paper presents the possibilities in spatial behaviour and pedestrian-surveys with GPS and electronic questionnaires. Demonstrative mapping of test data from passive GPS-registration of Copenhagen respondents is presented. The different survey-possibilities given a combination of GPS and PDA-based electronic questionnaire are presented – together with its possible applications in the context of pedestrian surveys.

Background.

The satellite based Global Positioning System (GPS) allows for fairly accurate geographical positioning and tracking through the use of GPS-receivers on the ground. In recent years GPS-receivers have become smaller and cheaper – and increasingly integrated into a number of consumer products: onboard navigation, small computers, cell phones etc. As an offspring from this development GPS-positioning also becomes available for surveys focussing on the geographic allocation of activities, destinations etc. As a survey tool GPS-positioning is still relatively technically demanding and expensive. However the current development in fore instance the Cell phone market where GPS and PDA functionality is becoming commonly available will lower these obstacles significantly in the near future.

Early application of GPS-positioning in spatial behaviour surveys has been limited to special cases: such as the tracking of seals or other animals in order to get new knowledge of their territories and geographical flexibility. GPS-surveys of human spatial behaviour were taken on in the mid nineties when the first transportation survey with GPS-positioning of vehicles was conducted in the US. Most later applications of GPS as a transportation survey tool also uses GPS to follow vehicles (Schönefelder et. al., 2002).

The Atlanta based Geostats company have developed equipment to track and log individual persons whereabouts independent of vehicle use. This method has been used in that part of Atlanta's transportation and urban planning survey (SMARTRAQ) – that focuses on the relations between urban structure and physical exercise (Georgia Institute of Technology, 2001). It will be possible to follow the movements of the individual respondents in the neighbourhood and the immediate vicinity of the home. Information's that would be difficult to retrieve through traditional recall- and paper-based approaches.

In the Scandinavian countries recent studies of roadpricing and intelligent speed adaption (see: www.infati.dk) have employed GPS to positioning and monitor (charge) the vehicles. This have thrown of large datasets of vehicle movements through long periods of time. The data have allowed additional analysis that would previously have been very difficult to approach: fore instance the monitoring of congestions on the basis of actual driving speeds (Nielsen, 2003) and the temporal variations of travel patterns within the individual household (as opposed to the common cross sectional studies, see. Schönefelder et. al. 2002)

GPS-surveys of individuals is still few. The only GPS-based registration of individual persons spatial behavior in Denmark – known to the authors – is the assessments of exposure to air pollution – based on spatial behaviour and imissions - undertaken by the National Environmental Research Institute (Jensen et. al. 2003). The claim in this paper – is however – that GPS-positioning could be used generally to widen the possibility in spatial behaviour surveys: making them more precise and easier to handle. And to open up new analytical perspectives based on new knowledge on spatial behaviour and spatial patterns..

GPS-data.

The GPS receiver in itself allows for a capture of geographical position in terms of lat/lon coordinates and height. With a continuous registration of geographical coordinates and time – travel speed and direction can be derived.

For the experiments presented in this paper a Garmin Navtalk GSM was used as GPS-unit. It is a cell phone with build in GPS-receiver. Its cell phone dimensions make it suitable to be used as a "personal devices" to be carried around by respondents at all times.

The specific product also allowed the GPS tracks to be continuously registered – and exchanged with external media – either through SMS – allowing continuous real-time tracking - or storage of the tracks on the phone with the possibility to upload them to a computer.

The continuous capture of data through SMS-messages is of course advantageous in that it allows equipment malfunctions and incorrect use to be detected and corrected. However the size of the phone bill as well as the surveillance perspective – points to the use of the devices as passive equipment without ongoing exchange of information.
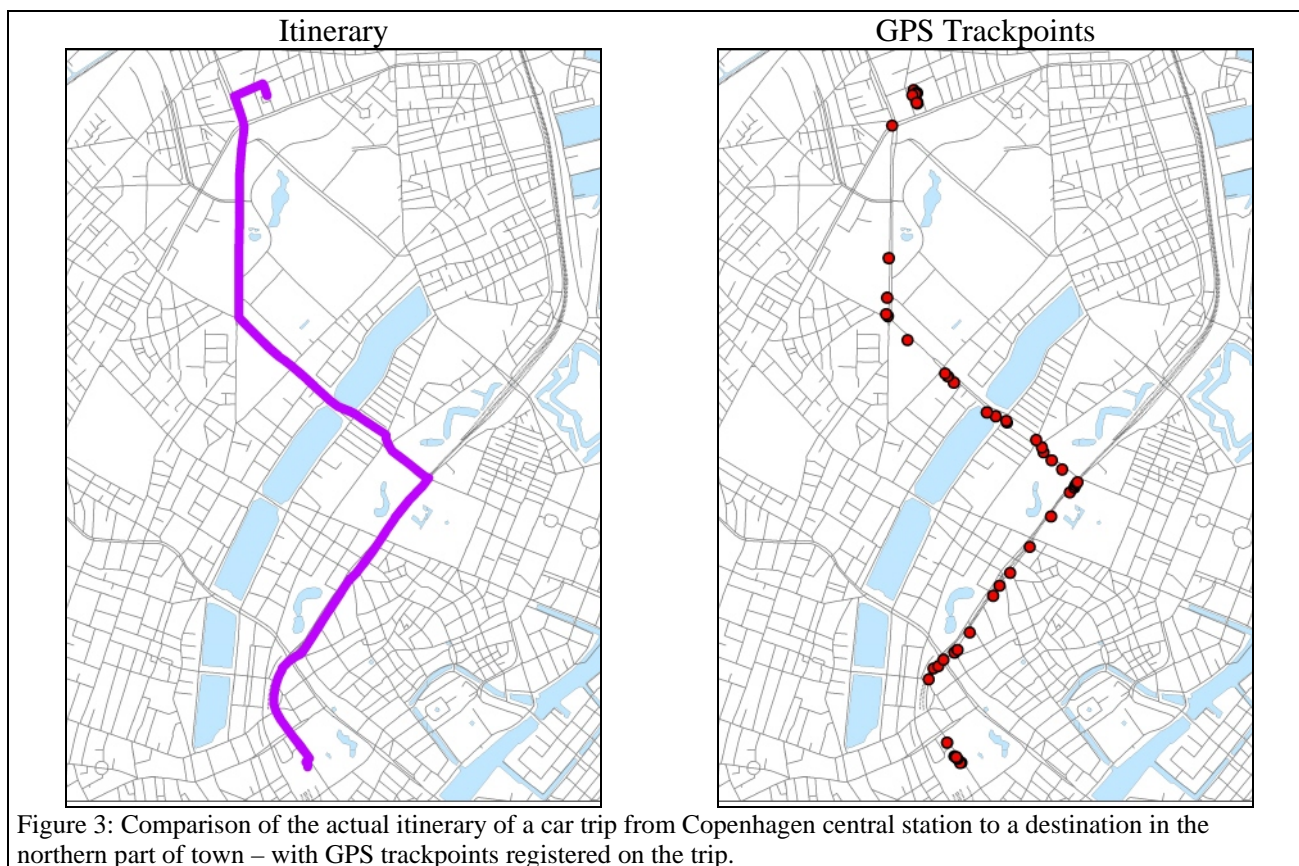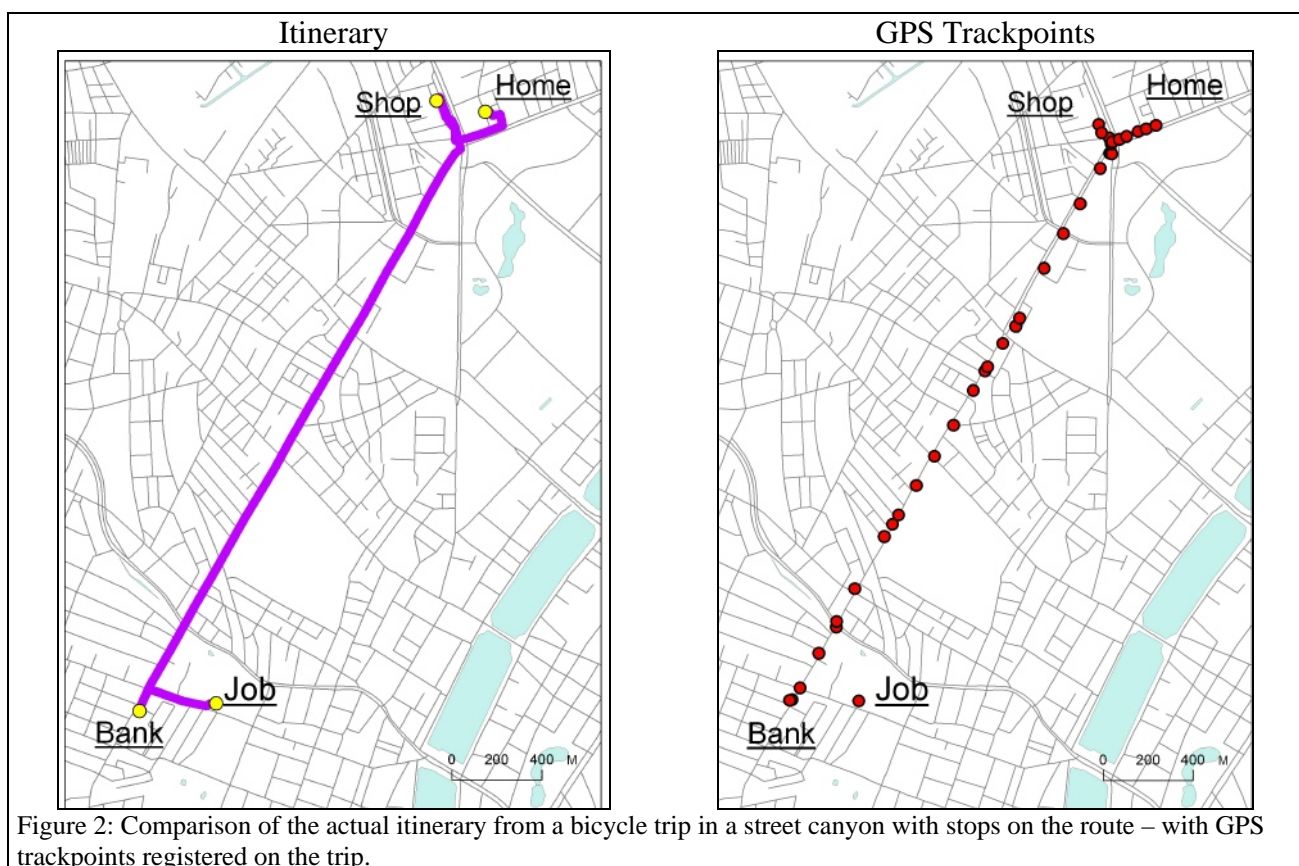

Figure 1: Garmin Navtalk GSM – cell phone, with GPS – was used in the experiments presented in this paper.

Position	Time	Altitude	Leg Length	Leg Time	Leg Speed	Leg Course
722826 6176713	19-12-2003 13:14	26.6 m	9.6 m	00:00:04	8.7 kph	188- true
722805 6176686	19-12-2003 13:14	26.6 m	34.8 m	00:00:25	5.0 kph	221- true

Table 1: "Raw"-data from passive GPS registration. Data for 2 "trackpoints". The "Position" column contains X and Y coordinates in UTM zone 32, European Datum 1950.

The GPS-receiver positions itself on the basis of signals from a large number of GPS-satellites. The precision of this positioning depends of the number of satellites that is "visible" from the position of the GPS-receiver. This is particularly important when GPS is used to monitor spatial behaviour in urban areas. The buildings block the view to the sky and makes GPS-positioning more difficult and imprecise. The dense core areas of European cities can be seen as a critical test of the use of GPS in spatial behaviour surveys (Steer Davis Gleave and Geostats, 2003).

The GPS-data that can be collected will have the character of a series of "points" – which in some circumstances almost may form a continuous itinerary – but in others may bear the marks of occasional drop outs of the GPS-signal because of buildings, vehicles or the like blocking the view to the sky.

Figure 2: Comparison of the actual itinerary from a bicycle trip in a street canyon with stops on the route – with GPS trackpoints registered on the trip.

Figure 3: Comparison of the actual itinerary of a car trip from Copenhagen central station to a destination in the northern part of town – with GPS trackpoints registered on the trip.

| Itinerary | GPS Trackpoints |

Mode of transport.
Walking
Bus no. 15
Metro (partly underground)

Figure 4: Comparison of the actual itinerary of a transit trip with metro (elevated and underground) to the centre of town where a shift to bus is made – with GPS trackpoints registered on the trip.

In the previous studies where vehicles have been equipped with GPS antenna and receiver, buildings blocking the view would be the main sources GPS drop out. In the case of GPS-receivers as a personal device – carried around by individuals – the specific location of the person holding the GPS becomes important. Positioning of GPS-devices is generally very difficult inside buildings in urban areas (only possible in low rise - relatively open neighbourhoods). As the location of a person inside a building generally implies a stationary activity this is of less importance as long as he/she is positioned entering and leaving. Some transportation modes –especially transit modes - have a similar effect: blocking the signal and causing GPS drop out.

Figures 2-4 shows the itineraries as recollected by the travellers and the GPS-trackpoints registered on the route - when 3 different transportation modes are used: bicycle, transit (bus and metro) and motorcar. The trackpoints was collected with Garmin Navtalk GSM - carried by the travellers as a personal device (in a pocket, a briefcase or the like).

Figure 2 and 3 – bicycle and motorcar obviously shows the best representation of the actual itinerary with the GPS trackpoints. For the bicycle trip the trackpoints also seems to represent the stops on the route fairly well (information on time attached to the individual trackpoints could be employed to register the duration of stay at each stop). The car trip shows a number of drop outs in the south (dense area near the central station) and in the north (area with tall buildings west of the route) – however these are at a level where reconstruction of the actual itinerary is still possible.

Figure 4 shows a transit trip – where the walking part in both trip ends is well represented together with the part of the trip on the elevated section of the Copenhagen metro (southern part of the map).

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On the part of the metro trip that goes underground there is obviously no GPS signal and therefore no trackpoints. The part of the trip by bus also seems to pose a problem – and there is only trackpoints at the point where the bus is boarded and at a single location on the route (a location on relatively high ground with and open view to the east). As a result the trackpoints contains information on origin and destination and only parts of the route. A full reconstruction of the itinerary can not be based on the trackpoints alone but would require information of the mode of transport / bus routes. Whether this is desirable depends on the focus of the study.

The effect of taking the GPS-receiver into a train resembles the effect of the bus that can be seen on figure 4. The vertical orientation of the windows and the low probability of having a view in more than one direction (because of the size of the vehicle) is probably the main reason for the transit vehicles causing the GPS to drop out.

Sample data – passive GPS-registration.

To test and demonstrate the potential for analysis of behaviour patterns a sample dataset was created. 7 "respondents" employed at the Royal Veterinary and Agricultural University (KVL) in Copenhagen agreed to carry the Garmin Navtalk with them at all times when they where outside buildings for a one week period. This should allow for a demonstrative analysis and mapping of the spatial relations for the individual respondents - and the Royal Veterinary and Agricultural University as their common activity bundle.
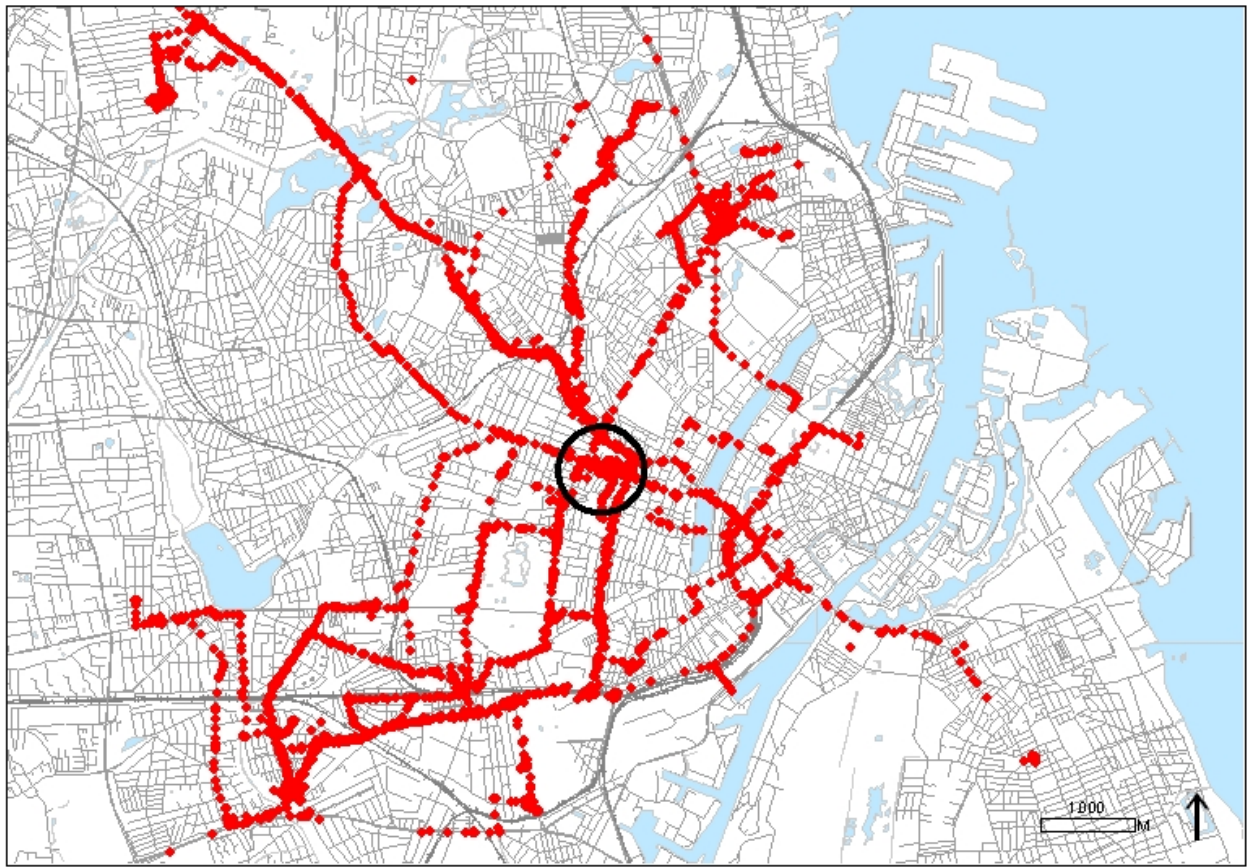
Figure 5: Trackpoints from the 7 KVL respondents "whereabouts" during approximately one week. Note that a section of the map focussing on the Royal Veterinary and Agricultural University (circle on the map) is chosen. Some of the respondents live outside the map and/or made trips to destination outside the map during the one week period.

The map on figure 5 shows the joint trackpoints from the 7 KVL-respondents inside a section of central Copenhagen focussed on the Royal Veterinary and Agricultural University.
The point data may be given a treatment to illustrate the intensity of points – fore instance using a spatial statistic like kernel density estimation. The kernel density estimates on the map figure 6 is presented as an example of how the continuous pattern of interaction might be represented on the basis of trackpointdata (calculations with Crimestat – program by Ned Levine and associates, 1999).

If the individual trackpoints is taken to represent a unit of time then the map (figure 6) would represent the allocation of the respondent's time. Given the GPS drop out inside buildings and the tendency to drop out inside busses and trains this condition is not fulfilled on figure 6. However – the important point is that the allocation of time can be mapped on the basis of the GPS data (in the simplest way: by adding the time passed since last trackpoint as a z-variable to each trackpoint).
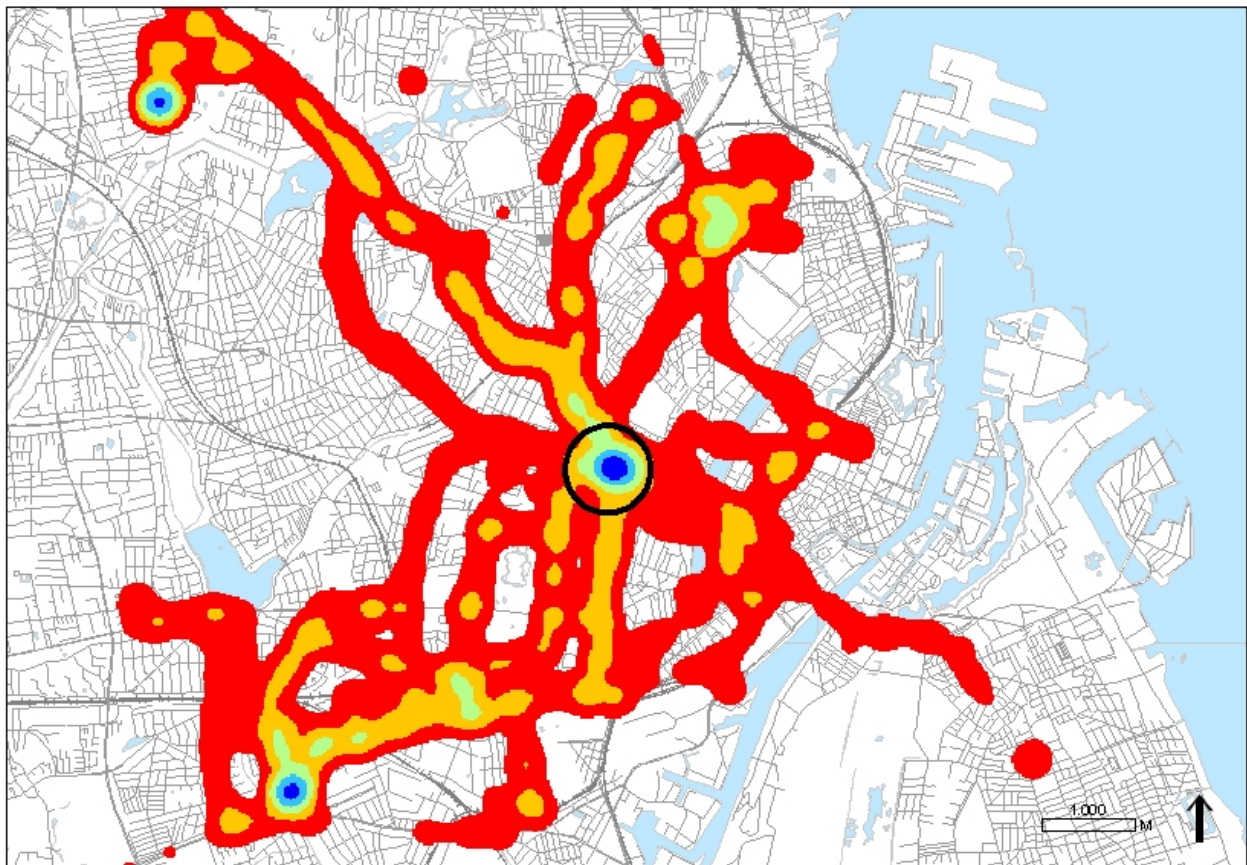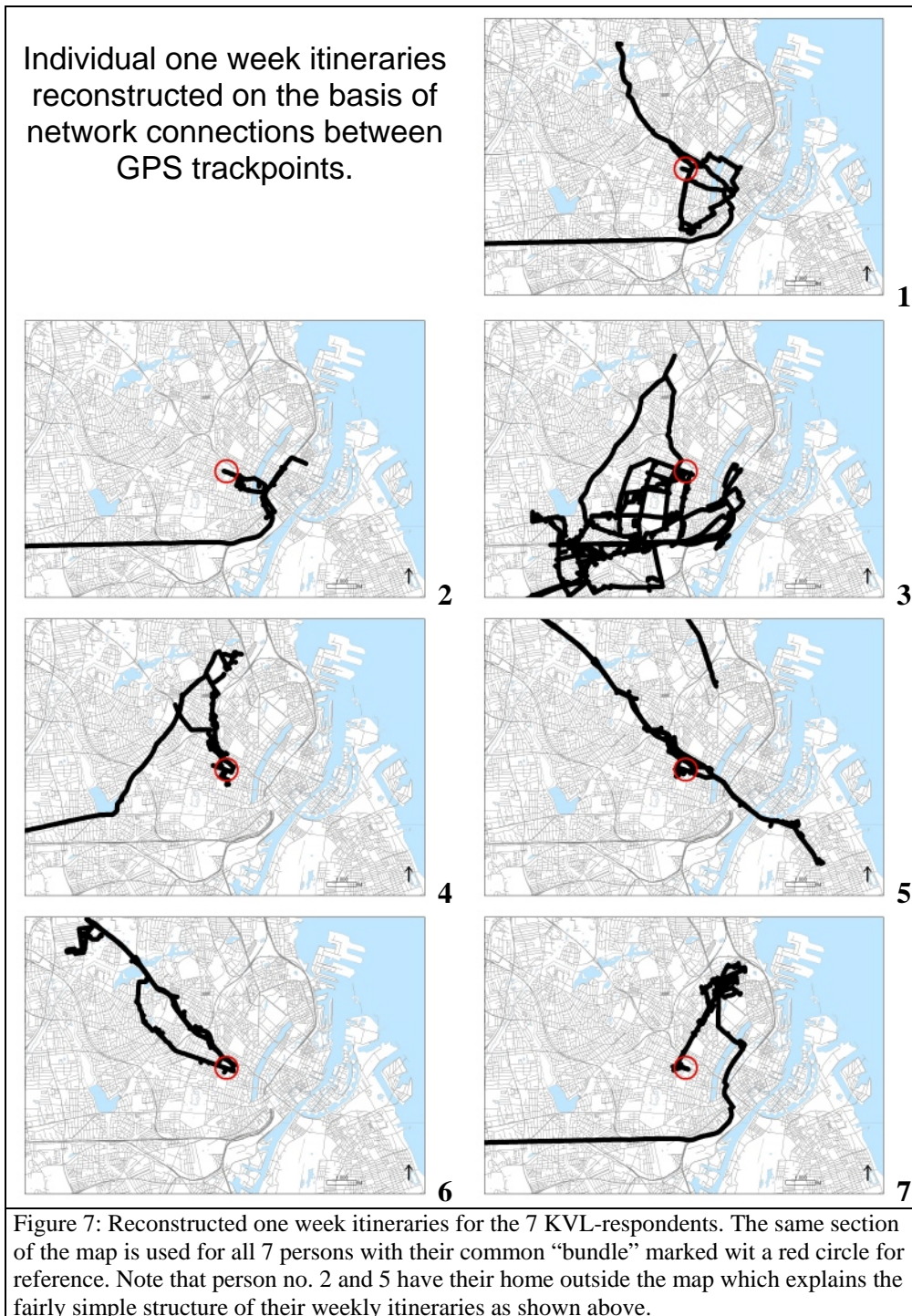
Figure 6: Kernel densities: densities of trackpoints on the map when each trackpoints is taken – not to be a point – but to "decline" gradually (normal-distributed with SD = 50 meter). This technique may be a means to overcome the gaps between the trackpoints – and to map continuous patterns of spatial interaction. Blue colours represent a high density of trackpoints – red a low density – and blank zero density. The circle marks the location of the Royal Veterinary and Agricultural University (KVL).

Reconstruction of itineraries.

Given the present state of the GPS-technology – the trackpoints that can be attained from a person's movement over a longer time span is unlikely to be continuous. If a continuous itinerary is desirable – fore instance for mapping purposes – it will have to be reconstructed on the basis of the trackpoints and some predefined transportation network.

As a demonstration a rough reconstruction of continuous itineraries on the basis of network relations between points was attempted for each of the seven respondents (figure 7). The reconstruction is rough because is uses simple airline distance to assign trackpoints to the network – and roads as transportation network.

Individual one week itineraries reconstructed on the basis of network connections between GPS trackpoints.

Figure 7: Reconstructed one week itineraries for the 7 KVL-respondents. The same section of the map is used for all 7 persons with their common "bundle" marked wit a red circle for reference. Note that person no. 2 and 5 have their home outside the map which explains the fairly simple structure of their weekly itineraries as shown above.

The reconstruction could be made better through assignment of trackpoints to the network on the basis of projections of direction or the like (see: Cederholm, 2000) and through the inclusion of travel speed as a proxy for travel mode - and relevant additional transportation networks. Whether this is necessary depends on what aspects of travel and spatial patterns – at what scale - it is desired to represent on the maps. As a representation of the patterning of spatial behaviour within an urban area of the size shown on the maps above – the "rough" approach will probably be adequate in many cases.

Extending the GPS-survey.

The value of GPS-positioning as a tool for data capture can be greatly enhanced when it is combined with a Personal Digital Assistant (PDA) or a similar feature allowing the collection of additional data in full integration with GPS-positions. From the field of urban planning and planning studies one could think of Francis Stuart Chapin Jr´s Activity based approach (1974). Following Chapin planning where to rest upon studies of activities in time and space. Unfortunately the "space" part of the approach was never fully implemented – and was later left out from most studies concerned with the use of time (time use has generally been taken as synonymous with "activity pattern"). The likely reason for this was probably the difficulties associated with the collection and handling of spatial behaviour data. As a consequence spatial behaviour at the everyday level has only been studied when it was unavoidable as fore instance in transportation studies concerned with travel from zones of origin to destination zones. The GPS-positioning eases the scientific access to the spatial part of activity patterns. The integration of GPS positioning with an electronic questionnaire (PDA) will allow for registration of the activities undertaken, trip purposes and similar qualities that requires a dialogue with the respondents.

The GPS integrated PDA-interface - with the screen sizes now commonly available – allows for different approaches to electronic questioning. These will briefly be commented on in the following - taking the study of spatio-temporal activity patterns as point of departure.

Self administered questionnaire.
The PDA may be used as a self administered questionnaire where respondents could register changes of their main activities through the day. As registration should happen real-time it is of course very important to find the balance where respondents are not overburdened – but details on time use still satisfactorily high. Thus a direct implementation of the full range of time use categories used in fore instance Eurostat standard (2000) will not be possible. One would realistically have to rely on main categories with the necessary differentiation on "target areas".

| 0 Personal care |
| 1 Employment |
| 2 Study |
| 3 Household and family care |
| 4 Volunteer work and meetings |
| 5 Social life and entertainment |
| 6 Sports and outdoor activities |
| 7 Hobbies and games |
| 8 Mass media (reading, TV etc.) |
| 9 Travel and unspecified time use |

Table 2: Eurostats main activity categories (Eurostat, 2000)

Temporal questioning.
Another way to organise the time use survey would be to question the participants periodically on what they have been doing within the previous time "period". To limit the burden on the respondents the time spans will have to be relatively long (probably one hour). The temporal questioning will impose a relatively rigid structure on the data – but would be relatively simple and overcome some problems with the forgetfulness of the respondents.

Place or behaviour dependent questioning.
The self administered as well as the temporal questioning is basically a direct substitution of pen and paper for a digital PDA-based registration with its obvious advantages in terms of data handling and dataset construction. The GPS-positioning is of course added - but not really integrated in the methodology. It is also possible to integrate the GPS-positioning in the questioning – either on the basis of pre-defined areas in which pre-defined questions are asked when the respondents is leaving or entering - or on the basis of a distinction between whether the respondents is mobile or stationary at the moment.

The pre-defined areas may be a number of specially designated areas: CBD, Parks etc. - or a grid covering a larger area. The delimitation of areas will be preloaded to the PDA and the questioning will be coded (taking error margins into account) to question about their activities in the area when they are leaving the area. Given the knowledge of the specific location and a deliberate delimitation of areas the questioning may be targeted to the specific area (spending in the CBD/urban core or leisure activities in the park etc.). This approach is especially suited to address narrow questions on area-problems, customers, use-contexts and the like.

A distinction between mobility and stationarity could be employed as a means to capture actual locations of activities through the day. The continuing GPS-positioning makes it possible to register when the respondent have not moved more than x meter in x minutes – and to use this information to question the respondents about their doings.

The integration of information on behaviour (mobility-stationarity) and in some cases specific places – into the questionnaire format – holds a potential to develop very reliable GPS/PDA-based accounts of activity patterns. However the structure of the questioning and database build up must be rethought in comparison with the "traditional" activity/time use survey.

New data items.
The market for PDAs and cell phones with similar functionality already promises a wide range of additional functionality that will widen the survey possibilities. Pictures, video clips and sound may be taken/recorded by respondents – and related directly to the other information in the database: positions, activities etc. The taking of pictures may fore instance be build into the "questionnaire" – and may be prompted with a relevant task description in designated areas. It must
of course be kept in mind that these functionalities will add to the need to educate the respondents on how to participate in the survey. On theses grounds it may be have limited use in general surveys – but could be of great use in smaller more targeted surveys.

GPS in pedestrian surveys.

In the context of pedestrian surveys the use of GPS-registration can be seen as advantageous on a number of grounds. Foremost the GPS is a means to attain detailed registration of routes and activity allocation. GPS-registration allows surveys of pedestrian behaviour in all types of outdoor spaces. The registration is also relative independent of scale or area delimitation. The respondents whereabouts can be monitored in relatively closely defined areas (fore instance a park or a housing development) as well as at the urban or regional level. Precision for small area studies may also be greatly enhanced through the employment of DGPS-correction - yielding precision as high as +/- a few meters. Thus it should be possible to judge on what side of the street at person is walking etc.

New perspectives for analysis also seems to open up with the employment of GPS-registration: Use context (location within activity schedule and routes) of urban parks. Visual exposure of the population to greenery (interesting from a health or quality of life perspective). And analysis of spatial patterning of behaviour and spatio-temporal rythms (could be part of micro-level pedestrian modelling - see fore instance Michael Batty, 2003). This will allow new insight to be gained and new representations of spatial patterns to be presented.

The disadvantages of GPS-based datacollection in pedestrian surveys is the costs of data collection and the need to hand out and retrieve the GPS-units.

The price of the GPS-units will in many cases make it unrealistic to equip a large number of respondents with one each. Thus larger surveys will probably demand that a number of GPS-receivers is "recycled" among respondents through a period of time.

The need to hand out and retrieve the GPS-receivers makes it obvious to contact respondents at home or at work – or some other "activity bundle" to which the respondents is attached. Other approaches could be to hand out GPS-equipment on site and have respondents mail the equipment back.
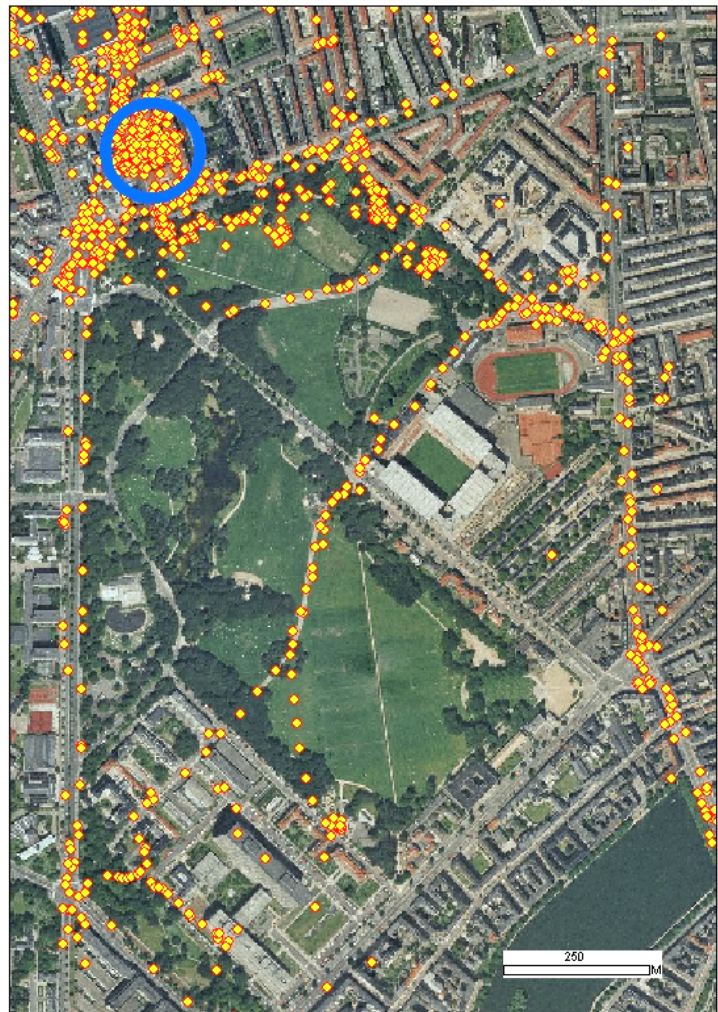

Figure 8: trackpoints from one week for 5 respondents living within the blue circle. The map is focussed on the nearby park. The heaviest use can be located to the sections of the park closest to the home. The rest of the park is only occasionally used as part of a route. The data was collected in the late winter (February) and it should be kept in mind that the pattern of park use is likely to be significantly different in the summer months.

References.

Batty, Michael (2003), *"Agent based pedestrian modelling"*, Centre for advanced spatial analysis, Working paper 61, University College London

Cederholm, Peter (2000), "Integrating GPS with Dead Reckoning Sensors", *Surveying and Land Information systems*, vol. 60, no. 4

Chapin, Francis Stuart (1974), *"Human activity patterns in the city. The things people do in time and space"*, John Wiley and sons, New York/London/Sydney/Toronto

Eurostat (2000), *"Survey on time use, Activity coding list, Final draft"*, DOC E2/TUS/5/00

Georgia Institute of Technology (2001), *"Americas Auto dependent urban form: Researchers in Atlanta studying land use and transportation alternatives to decrease traffic congestion and improve quality of life"*, Press release April 19, 2001

Jensen, Hertel, Berkowicz, Hvidberg, Loft and Raaschou-Nielsen (2003), "Menneskers eksponering en vigtig brik mellem luftforurening og helbredseffekter", *Miljøforskning*, no. 57

Ned Levine & Associates, 1999, *"Crimestat"*, Program created under grant from National Institute of Justice (grants 1997-IJ-CX-0040 and 1999-IJ-CX-0044), http://www.icpsr.umich.edu/NACJD/crimestat.html

Nielsen, O. A. (2003), "Analyse af trængsel og hastigheder v.h.a. GPS-data", *Trafikdage* 2003

Schönefelder, S., Axhausen, K., Antille, N. og Bierlaire, M., (2002),,,Exploring the potentials of automatically collected GPS data for travel behaviour analysis – A Swedish data source", *Arbeitsberichte Verkehr- und Raumplanung*, 124, IVT, ETH, Zurich.

Steer Davies Gleave and GeoStats LP (2003*), "The use of GPS to improve travel data. Study report*", Prepared for DTLR New horizons programme