URBANISM ON TRACK

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URBANISM ON TRACK

APPLICATION OF TRACKING TECHNOLOGIES IN URBANISM

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FRANK VAN DER HOEVEN, JEROEN VAN SCHAICK, TU DELFT

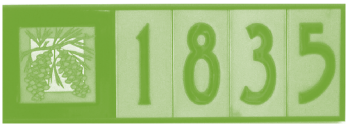
INTRODUCTION

TRACKING YOU — HOUSE NUMBERING AS A PROLOGUE TO GPS TRACKING

I once read a late 18th century account of a Swiss traveller in Austria, who expressed his shock about something we all take for granted in modern day Europe; the homes in the Austrian villages and towns he visited were all numbered! His journey must have taken place right after 1770. It was in that year that the Austrian Empress Maria Theresa decided to tag the houses in her realm by a number.

It had never had occurred to me that there had been a time when houses were not numbered. It even struck me as odd to learn that in some parts of Switzerland, house numbers still have to be implemented. How can you live without them? How can you find someone? Most of us have become fully adjusted to the idea that if you can always find someone's home by means of an address that is the combination of a street name and a house number. The use of such addresses has become the predominant way-finding strategy in Europe and other parts of the world.

Over the years, addresses and the corresponding names of those that live at them have been made available in public listings such as phonebooks. Only a few of us choose to be excluded from them. And even if you do, all the local, regional or national authorities know where to find you using their own, more complete, registers. You are notified when you need to renew your



driving licence and informed if the collection of your rubbish is rescheduled due to a public holiday. No one seriously seems to object to such use of personal data.

In recent years, the rapid development of information and communication technologies have produced a new array of identity tags such as IP numbers, mobile phone numbers and credit card numbers. Most of us are still somewhat cautious with regard to this 'new set of house numbers', and there is a valid explanation for this. The data attached to these new identity tags are a lot easier to process and share than the data that was collected in the time of Maria Theresa. It is no surprise that we frequently debate what personal data can be collected, the purposes it can and cannot be used for and the length of time it can be stored.

The use of such data is limited in Europe by EU guidelines for 'the protection of individuals with regard to the processing of personal data and on the free movement of such data for the proper use of personal data' (Directive 95/46/EC of the European Parliament and of the Council of 24 October 1995). However, no matter what the directive attempts to regulate, it cannot reverse the greatest breach of the protection of personal data that took place two centuries ago by the simple act of numbering houses. That's where it all started.

Back in 1763, Austria badly needed to pay off its debts resulting from the seven year war it had just been through, the second global conflict in history. The war had involved a coalition of Britain, Hanover and Prussia on one side and a coalition of France, Austria and Russia on the other. Austria was forced to improve its collection of taxes (http://de.wikipedia.org/wiki/Siebenjähriger_Krieg, accessed 23 July 2008).

Keeping track on which citizens it had already taxed and which it had not was vital for its capacity to wage war. The empire therefore required a systematic register of all homes and their occupants. The need to create a new army-recruiting system provided a further reason to tag homes. The empire needed to know where the men lived that could fight in its army. As the Austrian army only accepted Christian men, it was also necessary to establish who was

Christian and who not. The civil servants responsible for numbering homes and carrying out a subsequent census were quite inventive in this regard. The homes of Christian inhabitants were numbered with Arabic numbers (e.g. 36). Homes occupied by Jews were tagged with roman numerals (e.g. - XXXVI). No wonder our Swiss traveller was shocked to witness first hand the absolute power imposed by the Austrian Empress on her subjects (Tantner, 2003).

At first glance, it may seem hard to imagine that the simple numbers placed above people's front doors made such a significant contribution to the many wars waged and human atrocities committed out throughout Europe in the following two centuries. However, the fact remains that house numbers provided an improved method of collecting taxes, recruiting solders and ethnically dividing people on an unprecedented scale. A breach of privacy of a similar magnitude would be almost inconceivable in our own times.

The result of house-tagging was certainly not all negative. Taxes also generated funds for roads, bridges, healthcare and social welfare. House numbers made delivering parcels and visiting people a lot easier. Addresses provided a wealth of information for the benefit of urban and spatial planners. How would we ever be able to accommodate the spatial needs of citizens if we didn't know the size and the composition of the population of a town, a city or a region? We need to count. We need to measure. We need relevant data. And much of the data nowadays processed by Geographic Information Systems is embedded in real world addresses that are based on simple house numbers and street names. Ten years ago, our society could not have done without these addresses. It was inconceivable that a postman could deliver letters or parcels without house numbers. With an actual description of a house we might find our friends in a village. But what if our friends lived in a social housing district where all houses were the same?

During the last decade, alternative way-finding techniques have emerged and their use is spreading rapidly. The introduction of satellite navigation is the major driver for change here. Today, everyone can afford to buy a GPS handheld and start positioning any given location that he or she has access to. Such a tag contains coordinates describing givens such as latitude, longitude and altitude. These provide enough information to deliver letters or parcels to a specific building or home. Advanced software can even calculate each morning the most optimal route along which the items in a postman's bag should be delivered. It is no longer necessary for him (or her) to walk the same route day in day out. A modern GPS-assisted postman will skip streets, shorten distances, and reverse his/her tracks, all depending on the coordinates of his/her deliveries that given day.

The possibilities afforded by satellite navigation can even be taken one step further. If the tag used to deliver the parcel is dynamically linked to the actual position of the addressee, a parcel can potentially be delivered anywhere. There is no longer a need for the recipient to be at home, at work or at any other fixed location. I may be sitting on a bench in park when someone with a parcel shows up and announces a delivery for Mr. Frank van der Hoeven. At that point, it is not just my front door that is tagged. The tag will be on me.

The idea that anyone's position can be provided at any given time may sound rather far-fetched to some readers. But positioning techniques such as triangulation are already used to locate the whereabouts of subscribers to mobile phone services. As of 2007, the Dutch navigation firm TomTom tracks congestion on major roads in The Netherlands by positioning, in real time, all four million subscribers to Vodafone's mobile phone services (Farivar, 2006). Please note that four million subscribers is equal to one quarter of the entire Dutch population and that there is no technical hurdle to be crossed in increasing this number even further. All that TomTom needs to do is to include the other carriers such as KPN and T-Mobile in its scheme. With a mobile phone market penetration of over 100%, most of us will be tracked. The only reason that TomTom is not already tracking all of us is the simple fact that tracking a quarter of the population is quite sufficient to track all the congestion there is on Dutch roads. Four million users is also enough to update maps using this technique. The simple fact that a significant number of people follow a specific route each day at a specific speed indicates that the route can be travelled by foot, by bike or by car. Newly established roads will surface in the analysis the very same day that they are opened to traffic.

The experts among us will be aware that the accuracy of mobile phone positioning is not always optimal. Much depends on the density of mobile phone antennas. In rural areas, this density is relatively low. Positioning using mobile phones is therefore less accurate in remote areas than in central areas. But in this regard too, things are evolving rapidly. Mobile phones have already acquired the ability to take pictures, play music and receive and send email. Satellite navigation is set to become the next service added to our handhelds. As of April 2007, Japanese law makes it mandatory for mobile phones to identify the caller's precise location when making an emergency call (Yomogita, 2007). Such a requirement provides a much needed boost to the further integration of mobile phones and GPS services.

In fact this Japanese law comes close to the resolution that was signed by Maria Theresa two centuries earlier. The Austrians made tagging 'your front door' mandatory. The Japanese are making tagging 'you' mandatory. While in Austria the empress's objective was to expand her power over her subjects, all the Japanese authorities want at this time is to provide emergency services where they needed. Hopefully this is a much encouraging difference.

URBANISM ON TRACK

While the application of tracking technologies has developed substantially in social sciences and transportation sciences in the last decade, it has failed to make a significant impression in the scientific field of urbanism and spatial planning. The chair of Urban Design and the chair of Spatial Planning at the Delft University of Technology noted this shortcoming while working within the framework of the EU-sponsored Spatial Metro project and the Network Cities research programme. In a joint effort, on 18 January 2007, they held an international expert meeting on the application of tracking technologies in urbanism. The Delft School of Design sponsored and facilitated the expert meeting. The starting point of *Urbanism on Track* was the exploration of the current and future possibilities and the limitations in the application

of tracking technologies in urban design and spatial planning processes. The expert meeting *Urbanism on Track* aimed to address the subject from the viewpoint of multiple disciplines. The book *Urbanism on Track* shows a preliminary crystallisation of the ideas presented at that meeting. As such, *Urbanism on Track* documents the early stages of the application of tracking technologies. Practices or applications are as yet far from mature, but the documentation of this relatively early stage of technological development is what makes the book particularly relevant.

Urbanism on Track demonstrates a state of the art in a highly dynamic field of research and as such only represents a snapshot of our times. It provides insight in the challenges and bottlenecks we are currently facing, while it reflects the enthusiasm for new developments. The initiative *Urbanism on Track* is intended to live on in future meetings and, who knows, new books.

This book contains three parts. The first part deals with the basics; what is GPS tracking, what is different about using GPS in an urban environment, how can we process and visualise GPS-obtained data, and what do we know about the relationship between human spatio-temporal behaviour and navigation?

The second part takes a closer look at some of the first experiments urban researchers carried out with GPS as an emerging tool: the Danish field tests, the EU-sponsored Spatial Metro project, MIT's Real Time Rome and the Sense of the City project that was implemented in Eindhoven.

First, the third part discusses true applications such as replacing paper travel diaries, travel demand management and collaborative map generation. This part concludes with an agenda for structurally embedding research using tracking technologies in urbanism. This part concludes with an agenda for the structural embedment of research using tracking technologies in urbanism.

A BRIEF SYNOPSIS OF ALL CHAPTERS

Tracking and navigation, the basics

Shoval introduces us to the world of GPS tracking and presents two cases in which he used GPS-obtained data for his research on the outdoor mobility of elderly people with cognitive disorders and research on the user-density of an Israeli heritage site.

Van der Spek provides an overview of the demand and availability of a range of tracking technologies.

Nijhuis explains how to use GPS tracking data in Geographic Information Systems (GIS) for the visual representation, analysis and modelling of complex spatial environments within the context of urban planning and design.

Millonig and Schechtner provide a survey on current research on human spatio-temporal behaviour aimed at the development of pedestrian navigation systems, including route choice behaviour, localisation technologies and the adoption of location-based information systems. Linked to these topics, they outline three related projects performed at arsenal research and the Vienna University of Technology.

First pilots with tracking

Hovgesen, Nielsen, Bro and Tradisauskas report on their experiences in tracking visitors in public parks in Denmark as part of their Diverse Urban Space (DUS) research project. The work involved the testing of equipment within small-scale and large-scale surveys.

Van der Spek describes the results of a pedestrian observation study that was conducted among others in Norwich, Rouen and Koblenz within the framework of an EU-sponsored network.

Sevtsuk and Ratti present the results of a survey conducted in Rome, Italy in January 2007 and analyse how accurately and reliably mobile phone positioning data describes the actual presence of vehicles and people on city streets. They moreover question whether mobile phone data predict additional over-time variations in mobility patterns which is lacking in traditional fixed predictors.

Leestemaker and Van Berlo discuss the development of tools, based on multiple media, to observe, map and analyse changing patterns in human time use. Within this framework, they present the dynamic 3D maps of Sense of the City and argue that geo-referenced databases, geographical information systems and the application of chrono-geographic models are within reach.

Integrating tracking into urbanism and spatial planning research

Bohte, Maat and Quak argue that paper travel diaries can be replaced by methods based on the Global Positioning System (GPS). Such methods are potentially more accurate and less of a burden on respondents than paper diary methods. Especially when GPS data are placed in a GIS application subject to further interpretation, the possibilities in using GPS are promising.

Janssens, Hannes and Wets discuss how knowledge developed through the use of new tracking technologies can impact the spatial planning process and the kind of spatial interventions that can be expected as a result of new tracking technologies. Their focus is on travel demand management.

Edelkamp, Pereira , Sulewski and Costa look at the possibilities of fundamentally changing 'map-making' (cartography) in light of tracking technologies. They propose a general architecture for a collaborative map generation system and discuss in some detail the technical challenges for each module, as well as its current solutions. They address filtering, map-matching, updating and aggregation, steps for the construction of the maps, and some efficient algorithms and data structures that are used to compress, process and query maps once they have been generated.

Van Schaick analyses the assumptions underlying the application of tracking technologies. On the basis of his findings and the results of the expert meeting *Urbanism On Track*, he synthesises an agenda for the application of tracking research in the context of urban design and planning.

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2

NOAM SHOVAL, HEBREW UNIVERSITY OF JERUSALEM

THE GPS REVOLUTION IN SPATIAL RESEARCH

INTRODUCTION

In recent years, the rapid development and availability of small, cheap and reliable tracking devices has led to a growing amount of spatial research using such technologies. GPS devices offer researchers the opportunity for continuous and intensive high resolution data collection, never before possible in spatial research. The ability to collect time-space data in such high resolutions in time (seconds) and space (metres) for long periods of time opens up the possibility of drawing new lines of inquiry and creates opportunities to formulate new research questions that could not be previously asked. Could the potential impact of tracking technologies in the spatial sciences be compared one day to the impact of the introduction of high-resolution digital platforms in other fields, such as MRI in medicine, the electron microscope in chemistry and biology, or the Ikonos earth observation satellite in remote sensing? Perhaps this 'prophecy' is a truly wild exaggeration, but perhaps not.

Although there is a Russian GPS Global Positioning System (Glonass) in operation, the best known and most commonly used is the United States Department of Defense's (DOD) GPS, officially referred to as NAVSTAR: Navigation System with Timing and Ranging. Both systems were originally conceived as military navigation systems. The American system became fully operational in 1994 (Kaplan, 1996); it was initially available to military personnel only, with the DOD deliberately degrading the satellites' civilian signal in order to deny civilians access to its system. In May 2000 the DOD terminated, as it was known, the Selective Availability (SA) procedure, opening up the system to individuals and for commercial applications across the globe. In recent years, GPS devices using the American system have become relatively cheap. They have various uses in civilian navigation, and GPS has become an embedded feature in many new cellular phones (also chapter 3).

GPS is a one-way broadcasting system. The satellites send a signal, which is then picked up by essentially 'passive' receivers (Zhao, 1997). This means that in order to track the device, it must be able to send data via an external communication protocol (for example via SMS or GPRS). Alternatively, the device could have the ability to store the obtained locations in time and space on an internal hard disk or a memory card that will later enable data retrieval. The accuracy of Global Positing Systems varies greatly and is dependent on the nature of the terrain, (open rural as opposed to dense urban), weather conditions and the extent of the GPS receiver's exposure to the sky. The receiver will provide an accurate reading only if it is directly exposed to the satellites' signals. Any obstruction, regardless of whether this partially or fully blocks the signal, can result in an imprecise reading. However, a regular GPS device can obtain a location with a deviation of about 3-5 metres on average (Shoval & Isaacson, 2006).

At the time of writing (January 2008), a whole new generation of GPS receivers have just entered the market. The new generation is designed to be more sensitive than the current generation of GPS receivers, allowing them to pick up signals in more challenging environments. Furthermore, the new devices are also lower voltage, allowing them to work longer without the batteries needing to be changed or charged. See Illustration 2.1 for an example of three new small GPS loggers with low energy consumption. This low energy requirement enables the devices to function for several days and to keep the data obtained during this period of time. All three devices are currently on sale for less than 70 Euro.

Illustration 2.1 Three new GPS loggers. From left to right: Royaltek RGM-3800, i-Blue 747, BT335.

SOME EXAMPLES OF IMPLEMENTATION FOR SPATIAL RESEARCH

To date, research into time-space activities using tracking technologies – for example, the Global Positioning System – has been largely limited to transport studies, and specifically to studies tracing the spatial routes of motorised vehicles (see for example Zito et al., 1995; Quiroga & Bullock, 1998; Murakami & Wagner, 1999). Analogous studies focusing on the spatial activities of pedestrians have, however, been rarer. One possible explanation for this state of affairs is that gathering data from pedestrians by this means is more complicated than doing so for motorised vehicles (cf. chapters 5, 6 and 7). Whereas for a car the advanced tracking system is simply one more accessory, which, easily installed will not affect the nature of the data collected, in the case of pedestrians the tracking system has to be both small and 'passive' so as not to disrupt or affect the subject's normal behaviour. These requirements were difficult to meet until recently when small, lightweight and highly sensitive receivers with long operation times began to appear on the market.

Below, I wish to present, very briefly, two cases regarding the implementation of tracking technologies in spatial research. The first case relates to the sophistication of a location kit that is used to collect data for research focusing on the outdoor mobility of elderly people with cognitive disorders. This kit enables the researchers to measure not just the time-space activity of the research subjects, but also the level of their participation in the study. The second case relates to the ability to 'pixel' environments using the high-resolution nature of the GPS-obtained data.

The Use of Advanced Tracking Technologies for the Analysis of Mobility in Alzheimer's Disease and Related Cognitive Disorders [1]

This project addresses the measurement of mobility of elderly people with mild cognitive disorders by taking advantage of advanced tracking technologies (see the following website for more information: http://geography.huji.ac.il/sentra/index.html, accessed 24 July 2008). In this project we track people for one month, and due to the features of the tracking kit used, know at any given moment whether the research subject is participating in the research by carrying the GPS device about, as opposed to leaving it at home when going out. This system consists of a GPS receiver with a GSM modem, an RF transmitter that resembles a watch and is worn on the wrist (see **Illustration 2.2** for the elements of the kit) and a monitoring unit located in the home. The waterproof RF transmitter allows us to know whether or not a research subject has the GPS device with him, while the multiple sensors in the 'watch' also indicate whether it is being worn on the wrist. The GSM modem sends

Illustration 2.2
Elements of the location kit of the SenTra project.

Personal Watcher
RF component

STaR Monitoring Unit
GPS Reciever
GSM modem
RF component

Home Monitoring Unit
RF component

the obtained data to the project server and enables us to monitor the location kit from a distance, for example to obtain an indication of the charge level of the batteries.

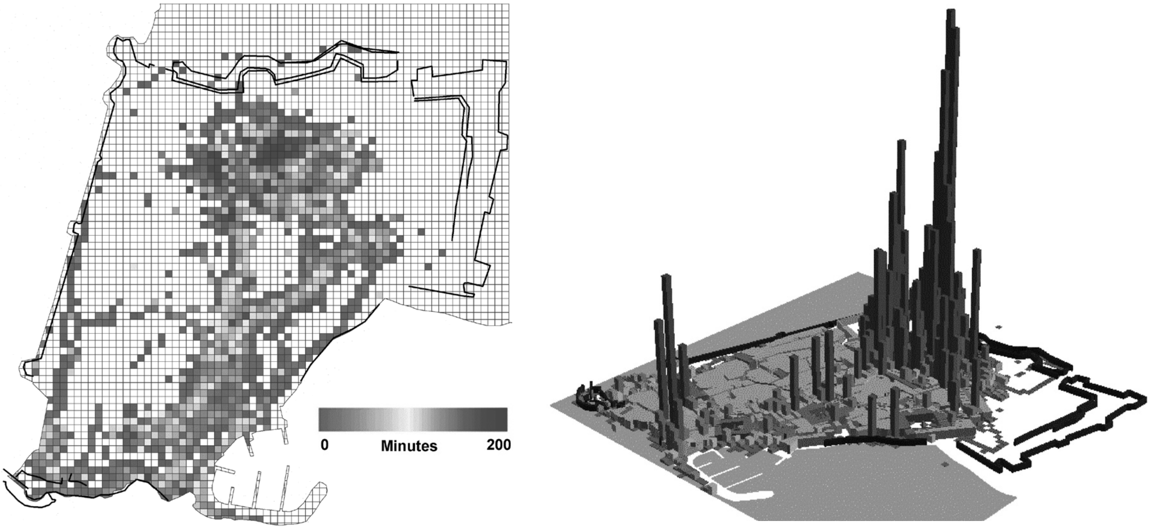
The data obtained in this project are used to develop typologies of out-of-home activity in order to explain differences in mobility based on a wide range of socio-structural, personality-related and environmental variables. Those typologies will be based upon a wide range of geographic variables that could only be defined due to the high resolution nature of the data collection. One type of variable is related to the places of activity considered as 'nodes' (for example: the number of nodes visited per day, the time spent at them, their location in space and their type). The other type of variable is related to routes taken from one place of activity to the other, considered to be 'tracks' (examples are: walking versus driving, walking speeds and walking distances and number of walking trips per day). In addition, the research aims to assess the impact of the use of advanced tracking technologies on the quality of life of dementia patients and caregivers, as well as evaluating its potential as a diagnostic tool. The explicit consideration of ethical aspects involved in the use of tracking technologies is a substantial component throughout the project.

'Pixelating' Urban Environments

The high accuracy of GPS enables the micro-analysis of environments using various methods. Having examined the behaviour of the participants as individuals, we can now aggregate the information collected to achieve a better understanding of how people consume space. Thanks to the high resolution of the data obtained by GPS, it is possible to actually pixelise places to very small units of observation. In the case of the World Heritage Site of Akko (Acre), Israel, the town's urban space was divided into squares measuring 10 by 10 metres, and the total number of signals picked up by all the GPS receivers of all the participants per square counted (for more details see Shoval, 2008). Obviously, the size of the grid's square depends on the size of the urban space studied, with larger scale studies requiring larger squares and smaller ones smaller squares. In a recent study in the Mini-Israel Miniature Park, the chosen resolutions were 4 by 4 metres and 2 by 2 metres.

Illustration 2.3a and 2.3b depict which areas in the town boast high levels of concentrated tourist activity and which suffer from a dearth of tourists. Indeed, looked at as whole, the map exposes a marked spatial imbalance between the town's sites; an imbalance rooted in the way Akko's tourist industry developed over the years. The illustrations also reveal which of the possible routes linking Akko's various centres of activity are most commonly used.

Illustration 2.3a and 2.3b
Visualisations (2D and 3D) of aggregative analysis of visitors' activity in the Old City of Akko (Acre).



Intensity of Activity in Old Acre Cell - 10 x 10 m

Intensity of Activity in Old Acre Cell - 10 x 10 m

CONCLUSION

Advanced tracking technologies could do much to facilitate and indeed improve empirical research in the field of urban studies. Firstly, these technologies can track subjects in time and space over long periods of time, and do so passively, thus reducing the burden placed on the subjects to a minimum. Secondly, they provide researchers with a far more accurate database than before, and moreover a database marked by an extraordinarily high degree of temporal and spatial resolution. These technical advantages could, in turn, serve to advance current but also open up a great many new, previously unfeasible, lines of inquiry in urban studies. Advanced tracking data collection methods could, for example, be used to improve our understanding of retail and consumption geographies, or to measure and assess the vitality of city centres (Ratti et al., 2006; cf. chapters 7 and 8). They could also be exploited to investigate the phenomenon of urban segregation in its various manifestations. To date, owing to the data available, most such studies have tended to focus upon residential type spatial segregation. Now, with digitally-based tracking methods, it will be easier to explore production, consumption and recreation-based spatial segregation as well.

While these technologies' huge, albeit as of yet potential, value as tools for gathering data on spatial-temporal behaviour is more than apparent, there are nevertheless several issues that have to be dealt with by researchers before they can be fully and effectively exploited. Firstly, there is a logistical problem that relates to the difficulties involved in distributing and collecting the tracking devices during the experiment. Often complicating the research design, it is nonetheless a problem that could be solved with a little imagination. The second issue is mainly a moral and an ethical one, specifically the way in which these devices may impinge upon individuals' right to privacy. As Levy has noted, 'In the future our cell phones will tag and track us like FedEx packages, sometimes when we are not aware' (Levy, 2004: 81; cf. chapter 1). Indeed, tracking technologies raise serious concerns regarding infringements on privacy and add a geographical dimension to the 'surveillance society' (Lyon, 2001) and the abilities to better track the 'digital individual' (Curry, 1997). This is not a new issue, as even today commercial mobile phone companies can identify the location of their cell phone users (Foroohar, 2003), and often use this knowledge to bombard customers with unwelcome information about nearby functions and events (Curry, 2000; Fisher and Dobson, 2003). The question of the mobile phone users' privacy is one that most countries' legal systems, including that of the United States, have failed to tackle fully and as such is a question of considerable and global importance (Renenger, 2002). There is also another complication: do people, once they know they are being tracked, change their behaviour, and if so how?

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3

STEFAN VAN DER SPEK, TU DELFT

TRACKING TECHNOLOGIES *AN OVERVIEW*

There is a growing demand for knowledge about processes in our cities, specifically the understanding of people's actual behaviour. Advanced Tracking Technologies offer the ability to give both actual and detailed insight into both people's individual and collective travel behaviour. The collected information can be used in urban analysis to map behaviour, feed prediction models, for simulation tools and for human behavioural sciences.

The use of emerging technologies such as GPS tracking, mobile phone tracking and RFID is replacing existing methods and adding features to traditional instruments in the field of urban design and planning. Advanced tracking technologies have already been used in other fields – those of sociology, geography, transport planning logistics, and biology have been using tracking technology in their research since the 1990s (Spek, 2006; http://en.wikipedia.org/wiki/GPS_wildlife_tracking, accessed 22 Nov. 2007).

This chapter gives an overview of tracking technologies relevant to urban design and planning. Firstly, the need for advanced technology is explained, followed by an explanation of available techniques. The chapter concludes with examples of the application of tracking technologies in practice

DEMAND FOR TRACKING TECHNOLOGIES

Understanding processes in the city is a pre-requisite for 'good' urban design (Schaick, 2008). Traditional urban planning and city analysis methods only offer partial insight into these processes. Counting, observation and mapping methods such as those developed by Gehl Architects over decades and practiced in cities like Copenhagen, Melbourne, Adelaide, London and Rotterdam (Gehl, 2007) could benefit from new advanced approaches showing the whole picture, including patterns of movement. Melbourne and London have already installed automatic people counters, extending the duration of measuring from several days to '24x7' as presented respectively at Walk21 (Melbourne, Oct. 2006; http://www.walk21.com, accessed 11 July 2008) and by Transport for London at the Connected Cities Conference (London, Sept. 2007; http://www.connectedcities.eu, accessed 11 July 2008). These counters effectively measure the intensity of pedestrian activity at a limited number of locations. However, these studies lack insight into actual, individual travel patterns.

Travel diaries might give insight into actual behaviour, but depend on the accuracy of people's minds (see chapter 11). A case study in Delft showed that the ability of people to reproduce a walked route on a map is inadequate. The actual walking pattern based on GPS tracks deviated repeatedly from the drawn map (Spek, 2006).

Prediction models such as Space Syntax predict pedestrian activity based on 'Centrality' (http://www.spacesyntax.org, accessed 11 July 2008). The structure and form of the street network forms the basis of the hierarchal position in the network. In real estate, these 'hot spots' which attract pedestrians can be recognised on the basis of their functions i.e. the location of fashion & luxury as well as rental prizes as shown by Kickert (2007a, 2007b).

Advanced tracking technologies can add accurate and detailed insight into the actual journey of a person in terms of *location in time and space* and in terms of *duration and distance*, e.g. travelled route, travelled distance(s), mode(s) of transportation, destination(s), departure and return time, time spent travelling and time spent at destinations. Using GPS, Mobile Phones, RFID, Bluetooth or video, it is possible to record individual travel behaviour and even extend it to collective behaviour, namely patterns of use.

ADVANCED TRACKING TECHNOLOGIES

Within advanced tracking technologies, a distinction can be made between two types of tracking technologies, namely global technologies and context-dependent technologies. Context-dependent technologies are limited to a location based on the available infrastructure or the technical limitations of the equipment. Only GPS can be used globally, preferably in the open sky or outdoor conditions. Mobile phones are dependant on the availability of a communication network. Video and infrared are limited to the reach of the sensors and RFID and Bluetooth to the location of the receivers. These tracking technologies differ from context-dependent technologies such as automatic counters based on sound, vibration, infrared or laser. The following paragraphs give an overview of current technologies in use.

GLOBAL POSITIONING SYSTEMS (GPS)

The Global Positioning System

GPS is a system for global navigation and orientation. The system utilises a network of satellites in orbit. These satellites transmit precise microwave signals to earth. A GPS device has the ability to receive these signals and compute its position. At least four satellites are necessary in order to accurately determine a geographical position (http://en.wikipedia.org/wiki/Global_positioning_system, accessed 21 Nov. 2007).

GPS devices are mainly known as navigation or orientation instruments. The devices are the basis for e.g. marine and car navigation systems such as TomTom® or outdoor orientation equipment. Today, GPS devices also function as Location Based Services (LBS) indicating the location of Points of Interest (POI). The GPS technology was developed by the United States military (NAVSTAR/ DOD). Since 2000 when the Selective Availability (SA) was disabled, the technology has been made more widely available to the public. Today, accuracy is around three to five metres in the open field. Russia and India are developing their own GPS system, GLONASS. China is developing COMPASS. In addition, Europe is building its own global positioning system, Galileo (http://en.wikipedia.org/wiki/Global_positioning_system, accessed 21 Nov. 2007). This system should have been completed in 2008 but is facing serious delays. It is now expected to be operational in 2011-12. Technology using external reference points can make GPS far more accurate by disabling atmospheric effects and other errors. These systems are known as GNSS Augmentation, Differential GPS or EGNOS/WAAS (http://en.wikipedia.org/wiki/High_Sensitivity_GPS, accessed 11 July 2008).

GPS data logging

Using GPS technology it is possible to obtain accurate and detailed insights into the actual behaviour of a person, vehicle or animal with a GPS device attached to them. For tracking research the device should either have the ability to store position data in a log file which can be read out later and projected onto a map in a Geographical Information System (GIS) (http://en.wikipedia.org/wiki/Geographic_information_system, accessed 30 Nov. 2007; see chapter 4), or the ability to send the location data real time to a server or application within a specific time interval.

The technology will give insight into the used route, the covered distance, the visited locations, the speed, the used mode of transportation, the exact departure and return times as well as the time spent on specific locations or destinations.

GPS devices

Although they started out as large, unmanageable devices, today GPS devices are the size of mobile phones or even smaller. New chipsets such as the Sirf III (2006) and MTK (2007) have highly improved their fixation time and accuracy (http://en.wikipedia.org/wiki/SiRFstar_III, accessed 21 Nov. 2007).

Of course, GPS-tracking has its issues too. Firstly, the main issues of GPS devices are the time taken to determine its position (Time to First Fix), the drainage of batteries, their size, weight, accuracy in built-up environments due to multipath effects (e.g. reflection of signals on glass facades) and their lack of reception indoors or underground. (http://en.wikipedia.org/wiki/Global_positioning_system, accessed 21 Nov. 2007)

Secondly, conditions in cities are far from ideal for using GPS technologies. Buildings block the reception of satellite signals, signals bounce off buildings, small streets have limited reception and people naturally enter buildings. Especially slow modes such as walking generate more problems in dense urban environment. (http://en.wikipedia.org/wiki/Global_positioning_system, accessed 21 Nov. 2007)

Finally, carrying GPS devices may trigger other, aberrant behaviour.

Nevertheless, GPS technology is developing relatively rapidly. Software to analyse, filter and map GPS tracks is under constant development too. New hardware and firmware are improving the capabilities of existing devices. This development makes GPS ideal for replacing traditional stalking and observation methods with advanced technology. (http://en.wikipedia.org/wiki/Advanced_GPS, accessed 11 July 2008)

The devices are in development and so far, not specifically designed for tracking research, although some specific data loggers have been recently introduced. These loggers were developed for the automatic positioning of photographs on a map. Other uses are fleet management, e.g. delivery trucks, cabs and emergency services. (http://en.wikipedia.org/wiki/Location-based_service, accessed 13 Dec. 2007; http://en.wikipedia.org/wiki/GPS_tracking, accessed 21 Nov. 2007)

Mobile Phone tracking

Mobile phones can be traced based on the cell tower the mobile phone is allocated to, but also using techniques to pinpoint the phone on a location on the map. Based on the direction of arrival or triangulation, the general position of mobile phones can be determined by comparing the relative signal strength from multiple cell towers (http://en.wikipedia.org/wiki/Mobile_phone_tracking, accessed 22 Nov. 2007). However, this process is time consuming, expensive and there are privacy issues.

Another way of using mobile phones is to determine the intensity of use of the network (see chapter 8), indicating the number of people at a specific location. This method was used in Rome by MIT and was presented at the Biennale in Venice in 2006. The question is whether active calling or sending a text message is representative for the amount of people. So far, mobile phone tracking is less accurate than GPS tracking (Shoval and Isaacson, 2006). Mobile phone tracking works on a higher scale, showing the location of the mobile phone or the densities of mobile phones within an area during a period of time.

Hybrid Mobile Phone: A-GPS and E-GPS

Some mobile phones already have GPS ability onboard or make use of assisted GPS technology (A-GPS; http://en.wikipedia.org/wiki/Assisted_GPS, accessed 11 July 2008). This new technology enables the quick fixation of the position, probably even inside buildings. The Assistance Server is able to roughly position the location of the mobile phone, speeding up the GPS fixation process. Enhanced GPS (E-GPS, due 2008; http://en.wikipedia.org/wiki/Enhanced_GPS, accessed 11 July 2008) will succeed A-GPS using the assistance for augmentation to determine the position even faster and far more accurately. Another advantage of the combination of mobile phone tracking and GPS is that accurate position data can be sent to a server automatically or even real-time.

Radio Frequency Identification (RFID)

RFID makes use of active, passive and semi-passive tags (transponders) in combination with readers (receivers). Passive tags have no power and only reflect information at short distances, less than a few metres. Active tags have a power source for the chip and can broadcast information at greater distances, around 500 metres. Semi-passive tags have a power source for the chip and are ten times more sensitive then passive tags (http://en.wikipedia.org/wiki/Radio-frequency_identification, accessed 21 Nov. 2007).

A recent development in plastic tags makes RFID useful for retailers and tracing objects or people. Examples are tracing goods or people in buildings and public transport chip cards, such as TfL Oyster Card (London), OV-Chip (Netherlands) and Smart Card (Singapore). The use of the system is limited to the location of the receivers and the range of reception (Shoval & Isaacson, 2007; Shoval, 2007); a predefined and prepared environment is required with a view to using RFID for tracking purposes.

Video monitoring

Video can be used for specific locations, only showing the behaviour of people at a determined location. Feasible locations are public spaces such as squares or interior public spaces such as train stations as shown by Arsenal (Vienna) (see chapter 5). Sophisticated software is available for automatic recognition and analysis, e.g. as used by the Faculty of Civil Engineering at Delft University of Technology to monitor and analyse pedestrian behaviour. Video analysis was, for example, used during the 2008 European Football Championship, measuring the distance the football players walked during a match.

Bluetooth monitoring

Bluetooth is a technique for short range communication between devices. Today, most mobile phones, laptops and handhelds are equipped with Bluetooth.

Some cities have installed a network of Bluetooth information systems delivering Location-Based Services (Furbach, Marun & Read, 2008). Using the connectivity logs, it is possible to 'track' the visited locations of Bluetooth devices, similar to tracking mobile phones based on cell towers, and similar to tracing RFID tags based on a network of RFID receivers.

URBANISM ON TRACK?

For years now, tracking technologies have been used in fields other than urbanism for tracking research and other space-time related studies. Nonetheless, tracking is a growing business in the field of urban design and planning.

The first well-known tracking experiment was carried out in Amsterdam in 2000 by Waag Society (Kustermans, 2006; http://www.waag.nl, accessed June 2006) as part of an art exhibition. Participants were equipped with a GPS and information was collected real-time, resulting in a new map of Amsterdam. This project re sulted in 'Sense of the City', Eindhoven 2006 (http://www.senseofthecity.nl, accessed July 2008).

Tracking technologies can be used on different scales for different purposes. On the largest scale, the University of Tartu operates using their mobile phone based technology which measures activity in the phone network throughout the whole country, Estonia (Ahas, Aasa, Mark, Pae & Kull, 2007; Ahas, Aasa, Roose, Mark & Silm 2007). MIT measured the densities of mobile phones in Manhattan (Shoval, 2007), Milan and Rome (see chapter 8).

Well known is the use of GPS tracking technologies in activity pattern research. In this case, people carry a GPS device with them each time they leave the house for a fixed period of time, usually a week. Here the GPS device replaces the activity agenda, offering very accurate and detailed insight into individual movement. Examples of these kind of travel surveys have been carried out by iMOB (see chapter 11), OTB at TU Delft (Verbree et al., 2005; see chapter 10) and Aalborg University (Nielsen & Hovgesen, 2004; http://www.spacetimeman.net, accessed 11 July 2008). Urbanism at TU Delft carried out a small test tracing fifteen families in the Dutch new town of Almere for a period of one week.

On a lower scale, GPS tracking has been used to observe people in an open-air museum in the Old City of Akko and Old Jaffa in Israel by Shoval and Isaacson (2006, 2007; see chapter 2). In Denmark, Hovgesen and Nielsen used GPS tracking to observe people in several parks in Aalborg and in the city centre of Copenhagen (see chapter 6). TU Delft developed a method of using GPS technology to observe pedestrian behaviour in three historic European city centres within the Spatial Metro project - Norwich (UK), Rouen (F) and Koblenz (G) (Spek, 2008; http://www.spatialmetro.org; see chapter 7).

Another interesting project applying GPS- based research in urban design is CityWare (UCL). This project compares the outcome of movement behaviour research to the physical environment and relates it to Space Syntax theory (http://www.cityware.org.uk, accessed 11 July 2008). Finally, the collection of global GPS tracks delivers a unique tool to develop maps based on actual use. An example is OpenStreetMap (http://en.wikipedia.org/wiki/OpenStreetMap, accessed 21 Nov. 2007; http://openstreetmap.com/, accessed 21 Nov. 2007).

CONCLUDING REMARKS

On the basis of this chapter, three brief conclusions can be drawn. Firstly, tracking technologies provide rich grounds offering a wide range of techniques for research in urban design and planning. Secondly, particular types of tracking technologies need to be applied to particular (urban) contexts and particular types of research questions. Finally, the scale of a study, the control of its context and the deployment of tracking devices are the key to selecting a particular technique.

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4

STEFFEN NIJHUIS, TU DELFT

APPLICATION OF GPS DATA IN GEOGRAPHIC INFORMATION SYSTEMS

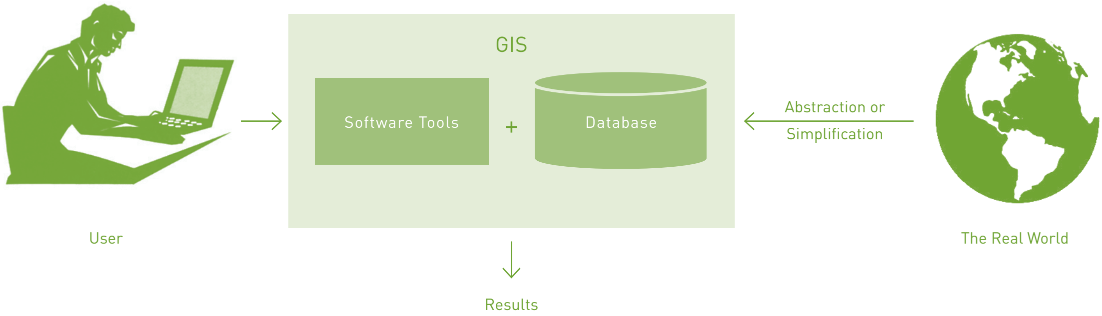
INTRODUCTION

Urban planners and designers depend on spatial-oriented information and knowledge to comprehend a situation and to find design opportunities and solutions for spatial problems. Geographic location, spatial patterns and the distribution of features or events across an urban landscape inform many people of the decisions that planners either make or help others to make. As we will see in this chapter, a Geographic Information System (GIS) provides urban planners with a platform on which they can deal with these complex spatial environments and represent, analyse and model them. It also generates new insights through advanced spatial analysis and helps to increase efficiency and flexibility in the planning process. Parallel to GIS, handheld Global Positioning Systems (GPS) are becoming increasingly available, opening the way for various applications in spatial research. The linking up of GPS and GIS in particular has proved to be a powerful instrument for urban analysis. This chapter is an introduction to the use of GPS tracking data in GIS for the descriptive and comparative analysis of pedestrian movement behaviour and the exploration of space-time activity patterns. The first part of the chapter addresses some key concepts of GIS into urban planning and design. It will address a number of fundamental GIS tools for delineation and the analysis of spatial patterns and relationships. The second part elaborates on the analysis of spatial patterns using GIS in combination with GPS. GPS tracking data will be explored by mapping *movement* and *density* in order to comprehend and monitor pedestrian behaviour in city centres, with Rouen as a case-study.

GIS IN URBAN PLANNING AND DESIGN

Geographic Information System (GIS) has received very wide acclaim as important and powerful tool for spatial research, design and planning (e.g. Stillwell et al., 1999; Longley & Batty, 2003). GIS offers planners and designers a platform on which they can represent, analyse and model complex spatial environments. It can also provide new insights through advanced spatial analysis and help to increase efficiency and flexibility in the process. There are many definitions of GIS, and it is difficult to find a single definition that encompasses the multiplicity of GIS use. It is perhaps easiest to think of GIS as an integrated system of components; information about the real world that has been abstracted and simplified into a digital database of spatial and non-spatial features which, in conjunction with specialised software and hardware, and coupled with the expert judgment of the urban planner, gives insight into the spatial environment and produces solutions to spatial problems (see **illustration 4.1**) (Maantay & Ziegler, 2006). In this perspective, it is very important to realise that computers and software cannot make sense of the data without the user's expertise.

Illustration 4.1 The components of GIS (source: Maantay & Ziegler, 2006)



Mapping and spatial analysis

Maps are a very important component in GIS and are used as both the raw materials and final products in research and design projects. Maps are intended to convey information, as well as abstractions, simplifications and representations of reality. Map-makers organise information on maps in order to view knowledge in a new way or to increase knowledge (cf. chapter 12). As a result, maps suggest explanations, and while explanations reassure us, they also prompt us to ask more questions and to consider other possibilities. To ask for a map is to say, "Tell me a story" (Turchi, 2004). While mapping is an important component of GIS, GIS is more; it combines mapping with information technology, and thereby transfers the control of the mapping process from the cartographer to the planner or designer. In this sense, GIS offers urban planners a platform on which they can deal with complex spatial environments and represent, analyse and model them. Mapping and spatial analysis are intimately linked, as different scholarly studies have pointed out (e.g. Cross, 2006; Steenbergen & Aerts, 2002). However, it is a common idea to think of spatial analysis as something different from mapping, and substantially more sophisticated. "GIS is just a mapping machine" is a statement frequently heard, implying that if sophisticated GIS software is used only to display data in a visual form, it is somehow being underutilised. In fact, the earliest GIS – the Canada Geographic Information System – had no display capacities at all in its original design, and could only produce numerical output in table form (Goodchild, 1999). The Spatial Metro project illustrates, among other studies, that within GIS, mapping and spatial research are very much interwoven (also see chapter 7).

Layering and attribute database queries

For planners and designers, GIS is a way to combine, analyse, and visualise the various kinds of (spatial) information that describe a geographic area. This implies that the application of GIS meets specific needs, but always involves typical tasks within GIS technology such as *creating maps, reconciling map scales and projections, layering*, *handling non-spatial attribute database queries*, *linking the map to other images*, *connecting GIS and CAD,* and *three-dimensional GIS applications* (Maantay & Ziegler, 2006).

Layering is a fundamental feature of GIS. In the late 1960s, Ian McHarg, a visionary landscape architect and a key person in GIS development, introduced a layering system – the 'layer cake' model – for environmental planners in his seminal work *Design with Nature* (1969). He used tracing paper overlays to reveal the cumulative effect of various environmental conditions on an area. This approach is nowadays a widely used technique among designers and planners, and a useful tool to explore how different elements interact with one other within the same geographic area. Layering within GIS offers the opportunity to interact with different levels or elements of urban geography such as land use, topography, geology, demographics, transportation, etc. (see **illustration 4.2**). In the case of the Spatial Metro project for example, we can interact with the layers of pedestrian behaviour, urban layout and attractors to explore spatial correlations. The layers can be overlaid on each other in any combination and can be analysed using logic operators such as *within*, *containment*, or *intersection*. With these topological operators, we are able to run queries on geographic features from different layers that meet certain criteria in terms of *adjacent to*, *connected to*, *contained by*, or *containing*.

GIS data is composed of both spatial and non-spatial information. Non-spatial data is commonly referred to as attribute data and is a database table. The database table is the basic building

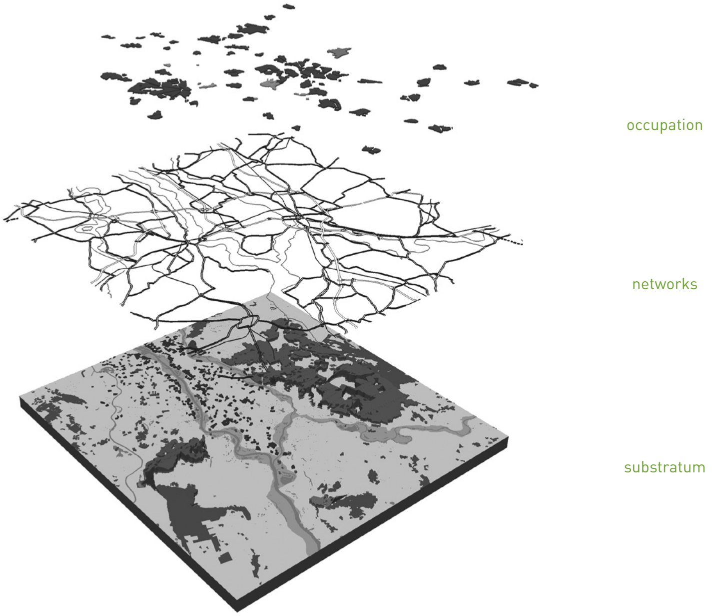


Illustration 4.2
'Layer cake' model
(source: Van Uum & Nijhuis, 2007)

block of all attribute *DataBase Management Systems* (DBMS) such as Microsoft Access or SQL Server. An attribute database can be queried through *non-spatial attribute database queries* using logical operators (in Standard Query Language). These queries are useful for measurements and statistics and allow quantifying specific patterns and relationships. The GIS can perform standard database management tasks such as redefining, reclassifying, and altering attribute data. In addition, a linkage to external DMBS is possible to perform data analysis in terms of selection (query), measurement and statistics. Through ODBC connections or middleware such as the ESRI Spatial Database Engine (SDE), the GIS provides direct access to external DBMS. The database tables can also be incorporated into a *relational database* that is capable of combining, managing and updating information that is stored in several tables. In fact, the GIS itself is a DBMS because it links the attribute database to the spatial database that produces maps, and can manage data stored in more than one database table (Mitchell, 2005; Maantay & Ziegler, 2006).

Advanced spatial analysis

At the heart of GIS is spatial analysis. Without spatial analysis capabilities, GIS would be a computerised mapping and spatial database storage utility. Jack Dangermond, landscape architect and the founder of ESRI [1] stated that "The real heart of GIS is the analytical part, where you explore on a scientific level the spatial relationships, patterns and processes of geographic, cultural, biological and physical phenomena". This implies a wide range of possible applications in urban planning and design, since spatial relationships and patterns are key concepts for understanding urban structure and configuration (Lynch, 1960; Hillier, 1996; Alexander, 2002).

Spatial analysis is a process for looking at geographic patterns in spatial data and relationships between features. The actual methods of analysis can be simple – making a map, for instance, or more complexly, involving models that mimic the real world by combining many data layers. The range of geo-spatial analysis methods that are available through GIS consists of the principles of data exploration and spatial statistics, physical surface and field analysis, and network and location analysis. These contain the basic concepts: mapping *where things are*, mapping *most* and *least*, mapping *density*, finding what's *inside* or *nearby*, mapping *change* and *movement*, and mapping *visibility* (Mitchell, 1999; Smith et al., 2007). These analysis concepts and tasks are useful in their own right but can often serve as building blocks for more advanced spatial analyses. By adding analytic capability, in terms of modelling and simulation – e.g. the integration of cellular automata-based, agent-based models and other expert-systems – GIS can be used for advanced spatial analysis (Batty, 2007; Longley & Batty, 2003; Batty et al., 1999). Possible applications of GIS include virtual cities, agent-based pedestrian modelling, the identification and measurement of urban sprawl (Longley and Batty, 2003), the exploration of architectural composition (see **illustration 4.3**) (Nijhuis, 2007) and web-based decision support systems for community planning (Brail & Klosterman, 2001).

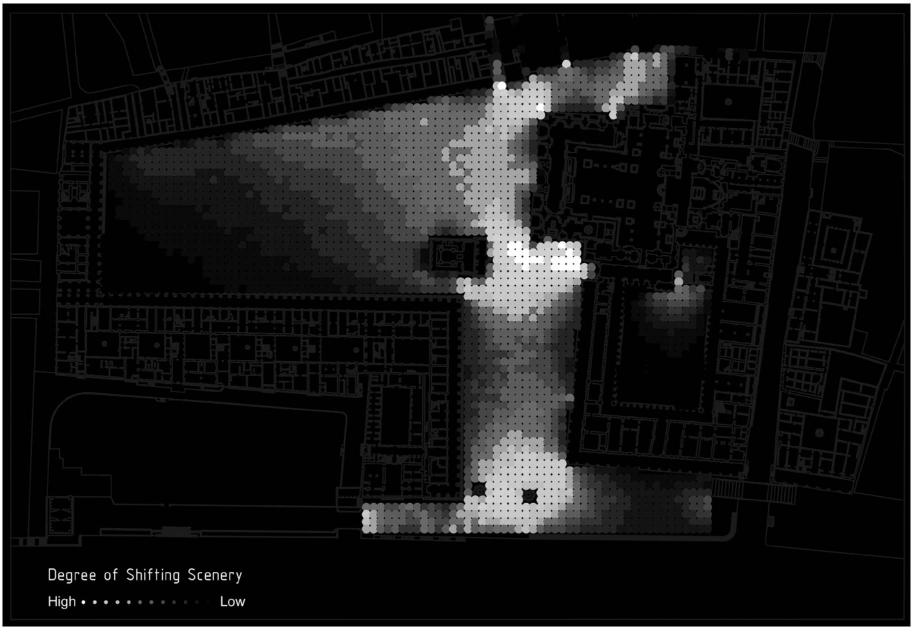


Illustration 4.3 Exploration of the architectonic composition of Piazza San Marco, Venice, Italy (source: Nijhuis, 2007)

The focus in the rest of this chapter will be on the analysis and visualisation of tracking data derived from global position systems (GPS) within the context of urban planning and design. Within the framework of the Spatial Metro project by Spek (2008; chapter 7), this chapter will elaborate on the concepts of analysing *Movement* and *Density* within GIS to comprehend and monitor pedestrian behaviour in city centres.

PATTERNS IN SPACE AND TIME

In the field of spatial and urban research, two different fields of research using GPS can be distinguished, namely travel surveys and activity patterns (Spek, 2006). The first field is related to travel diary research – research in the field of travel choice behaviour, mostly on a regional or metropolitan scale. The second field covers the analysis of activity patterns on different scales. Here, the relationship between activity and space-time is crucial. The focus of GPS research in the Spatial Metro project (Spek, 2008) is the monitoring of patterns and intensities of pedestrian movement on the scale of the city centre, and is therefore part of the second field of research. This research depends on large amounts of GPS data derived from extensive field surveys. To visualise the tracking data, we can use standard GPS visualisation software or specially designed applications as in the projects *Amsterdam RealTime* (Ross, 2006), *GPS drawing* (see **illustration 4.4**) (Pryor and Wood, 2002) or *The Urban Tapestries* (Moed, 2006). However, for scientifically-based research in terms of analysing spatial patterns, intensities and relationships, this software is usually not sufficient or lacks flexibility. Instead, off-the-shelf GIS software [2] is a great deal more suitable. The linking up of GIS and GPS within the context

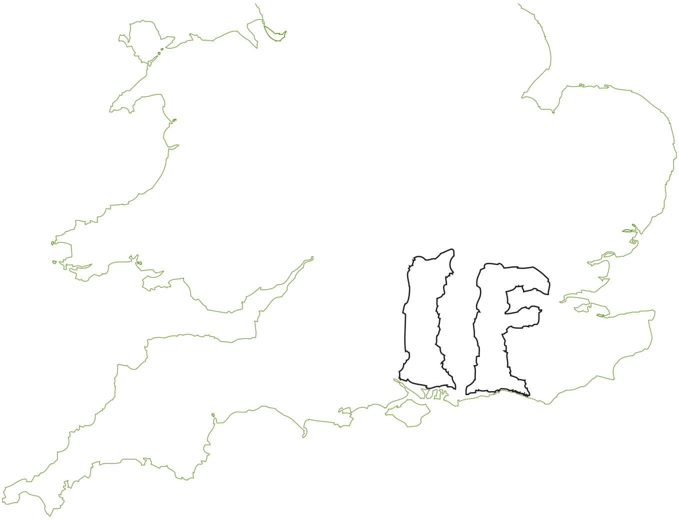


Illustration 4.4 GPS Drawing: The worlds largest "IF" (source: www.gpsdrawing.com)

of urban design is not only for the purpose of the visualisation of tracking data, but also to analyse the data and derive spatial patterns and correlations from it. Parallel to GPS, technology for determining the geographic location of cell phones is becoming increasingly available. This opens the way to a wide range of applications, collectively referred to as Location-Based Services (LBS) and in combination with GIS, these will also become a powerful tool for urban analysis (e.g. Ratti et al., 2006; cf. chapter 8). However, the topic of this chapter is the application of GPS data in GIS for the purpose of urban planning and design. GPS data derived from Spatial Metro field surveys in the city centre of Rouen (France) are used to illustrate the application of the analysis concepts of *movement* and *density*.

MAPPING CHANGE AND MOVEMENT

By mapping where and how people move over a period of time, insights can be gained into the movement behaviour of pedestrians in the city. There are three different methods of analysing change or movement within GIS which are applicable to GPS data: 1) *time series*, 2) *measuring change* and 3) *tracking map*. A *time series* (1) is effective for showing the change of patterns of movement during a certain time span or mapping change in the magnitude or the type of the pedestrians. It is possible for example to map the change of location of individuals or groups throughout a day or the presence of more or less visitors at a specific location. To *measure and map change* (2) the difference in value between two dates or times is calculated and displayed as an amount, a percentage, or the rate of change and is very useful for comparative study. The *tracking map* (3) shows the position of a person or persons at various times. It is useful for showing the incremental movement of pedestrians. It can be visualised as individual points (each feature at each date or time [3] or as a line connecting the points. This 'time-line' represents the path of movement. There is also a possibility of visualising tracking maps dynamically (simulation) or real-time [4]. For example, the tracking data of a pedestrian in the city of Rouen is visualised as a tracking map and projected onto the city map (see **illustration 4.5**). This path of movement, among others, is tagged [5] with individual characteristics such as purpose, duration, direction, etc. and can be displayed by adding a legend (use of different colours of symbols) or opening the database. By performing non-spatial attribute database queries, we can explore the (spatial) statistics and measurements of specified groups or individuals and allow the investigation of their spatial patterns and relationships. By displaying the start and end point for each line, the direction of movement and the travel-mode (walking, cycling, driving a car, etc.), we increase our insight into way-finding, the nature of pedestrian movement and activity patterns of individuals or groups. Via the GIS, we can apply a predefined symbology or multi-level symbology with regard to large amounts of tracking data, increasing the efficiency of the process of data management.

Illustration 4.5
Tracking map of a tourist

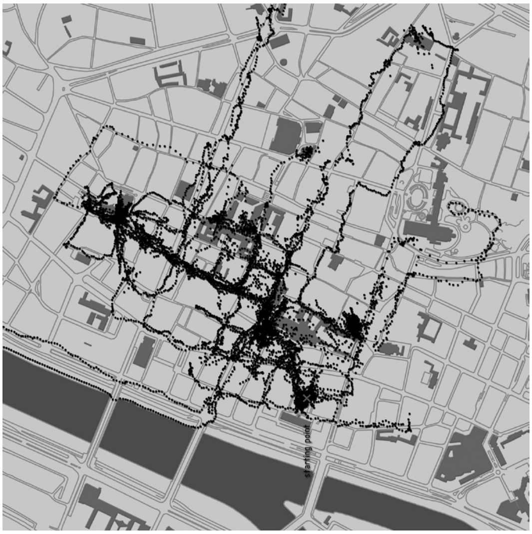


Illustration 4.6
Tracking map of a group of tourists

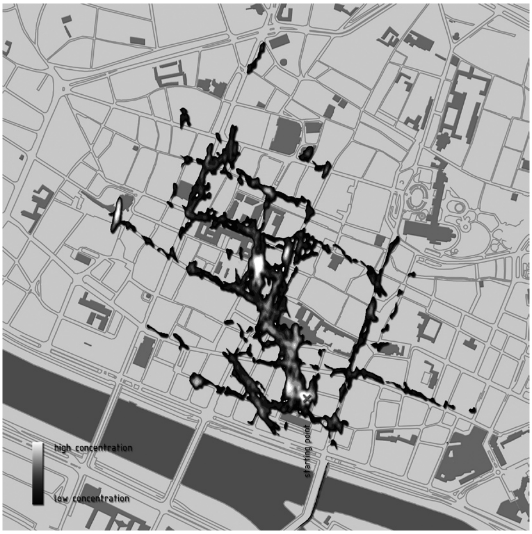


Illustration 4.7
Time-space pattern of commuters

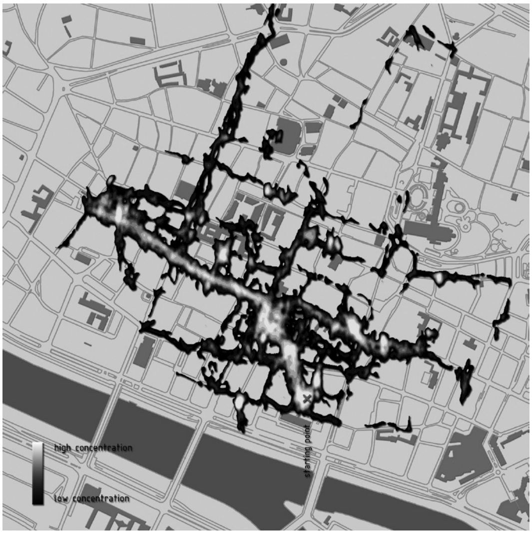


Illustration 4.8
Time-space pattern of tourists

To understand the processes of way-finding and the legibility of the city in relation to activity patterns, it is necessary to monitor patterns of movement of significant groups of pedestrians, not of individuals (e.g. Lynch, 1960; Hillier et al., 1993). With respect to this GPS data, two significant groups of pedestrians were merged (summarised), and generally categorised by familiarity, origin, purpose and duration (see chapter 7). This merged data is also represented as a tracking map, allowing patterns of movement to appear (see illustration 4.6).

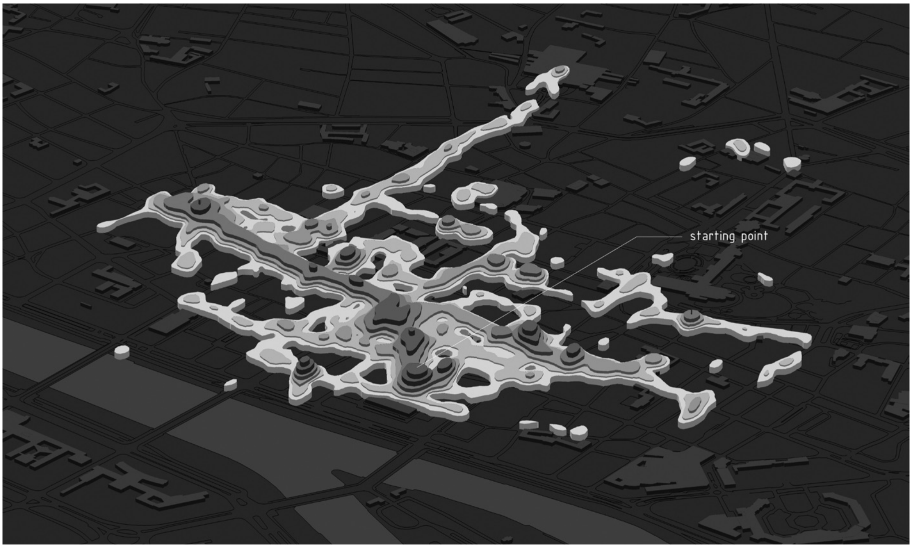
MAPPING DENSITY

By simply mapping the locations of features on areas with large amounts of tracking data, it is often difficult to see which areas have a higher concentration or intensity than others (see **illustration 4.6**). In other words, it is hard to derive patterns in this way at very fine levels of granularity, which is a key objective of the research. For this reason, density maps of the projected tracking data are created within GIS. Density shows the location of the highest concentration of features, and is particularly useful for looking at patterns rather than the location of individual features and for mapping areas of different sizes. It measures the number of features using a uniform real unit (such as a hectare or square mile), allowing distribution and magnitude to be easily distinguished.

In **illustrations 4.7** and **4.8**, tracking data is mapped using a density surface. A density surface is created in GIS as a raster layer. Each cell in the layer acquires a density value (such as number of pedestrians per hectares [6]) based on the total number of features within the specified radius of the cell divided by the area. This creates a running average of features per area, giving a smoothed, continuous surface (McCoy & Johnston, 2002; Mitchell, 1999). Several parameters will affect the way in which the GIS calculates the density surface, and thus what the patterns will look like. These include cell size, search radius, calculation method, and units. The cell size determines how coarse or fine the patterns will appear; the smaller the cell size, the smoother the surface. Generally, the larger the search radius, the more generalised the patterns in the density surface will be. The density surface is calculated by using a (weighted) kernel calculation, which gives more importance to features closer to the centre of the cell. The result is a more equal distribution of values.

In the density surface for commuters, we see a north-south oriented time-space pattern appearing (see **illustration 4.7**). Starting point is the parking area at Place de la Haute (Rue Saint-Denis), where handheld GPS devices were provided. From there, the commuters walked via the Rue de l'Epicerie along the Cathedral Notre-Dame to probable working destinations such as the Palais des Congres, or further northward via the Rue du Bec to the Palais de Justice or the Espaces Du Palais along the Rue St. Lô. High densities of commuters were also apparent at the Rue Jeanne d'Arc. In order to validate these conclusions, it is important to compare the results with the corresponding questionnaires commuters completed. A number of additional conclusions can be found in Spek (2008). However, for these commuters, the car park and their place of work were the most important sites. As seen on the map, commuters can be easily recognized by their patterns of movement, which are typically fast and short. A quite different pattern appeared for tourists with a more widespread distribution. For this group, a more or less northwest-southeast oriented movement pattern can be distinguished (see **illustration 4.8**). This pattern visualises the distribution and number of tourists and correlates with the most beautiful scenery and main attractions of the city. From the starting point at Place de la Haute, the tourists walked via the Place de la Calende to the Notre Dame. From there, most of them took the Rue du Gros-Horloge and Le Cros Horloge to Place du Vieux with the Jeanne d'Arc memorial as their end point. Moving back to the cathedral, slightly north toward the Rue du Gros, high concentrations of tourists are also evident near the Palais des Congres and the Galerie de l'Espace du Palais. From the cathedral to the east, the highest densities are to be found at the Rue Saint-Romain and Rue de Martainville, with the old cityscape and the Church of St. Maclou.

Illustration 4.9
Three-dimensional view of space-time patterns of tourists



To derive patterns from a calculation, the density-surface is usually displayed in a two-dimensional (2-D) view using graduated colours with a random or custom classification [7]. However, a three-dimensional (3-D) perspective can improve the readability of the map and increase the possibility of drawing conclusions from it. The height of the feature indicates the size of the location or area (see **illustration 4.9**). Patterns of density derived from GPS data can provide insight into the use of space and time. For line features, density shows patterns in space or the intensity of use. This addresses the question of the number of people using the path. For point-features, density represents patterns of time, or intensity of 'non-movement' (duration). This addresses the question of how long people stay.

CONCLUSION

The Spatial Metro project proves that the linking up of GPS and GIS is a powerful instrument for analysing pedestrian movement behaviour and exploring space-time activity patterns. Among other things, the concepts of mapping *movement* and *density* are addressed as fundamental GIS tools used for the delineation and analysis of spatial data in order to explore spatial patterns and relationships. By applying these concepts in the *pedestrian movement behaviour analysis,* we can show patterns of lines which represent patterns of *movement* in space. Density surfaces show patterns of *intensity* and *duration* in space and time. Beside these methods of analysis, overlay techniques and operations constitute one of the most useful functions of GIS. This overlay operation allows new information to be derived that does not exist in any 'single layer'. It can provide insights into spatial relationships, e.g. spatial correlations of large numbers of pedestrians and specific locations or attractions. Also, *non-spatial attribute database queries* are useful for (spatial) measurements and statistics, and allow quantifying specific patterns and relationships. Through this kind of analysis, we can comprehend and monitor pedestrian behaviour in city centres. In addition, design opportunities and solutions for spatial problems in the urban environment can be revealed by descriptive and comparative analyses of geographic locations, spatial patterns, and the distribution of features or events across an urban landscape.

Like other professional software, GIS software is very helpful, but not generally easy to use. Software developers are making great efforts to improve the user interface of GIS software, but still have a long way to go. There is a great deal of prejudice with regard to GIS. In order to convince (future) planners and designers that GIS is indeed a powerful tool for representation, analysis and modelling, it is necessary to persuade them by showing them examples of the broad range of possible applications, thereby pointing out the added value. GIS must also be an integral part of education in planning and design. Experience has shown that an intuitive, practical approach based on the philosophy of "learning by doing" is most effective in this sense, and has to be strongly interwoven with an assignment in planning or design.

Due to the introductory nature of this chapter, the emphasis has been placed on the just view applications of GIS in urban research, and various other methods and techniques still have to be explored and developed. It is clear however that GIS is a helpful instrument for urban planning and design and offers a platform on which these complex spatial environments can be dealt with and represented, analysed and modelled. Professional vocabulary can thereby be expanded and new approaches and instruments added to the toolbox to create sustainable and appreciated urban space. GIS moreover generates new insights through advanced spatial analysis and helps to increase efficiency and flexibility in the planning process.

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NOTES

1 Worlds leading off-the-shelf GIS-software developer.
2 The used GIS-software is ESRI ARC-INFO 9.2 with the Data Interoperability extension.
3 With or without a specific time-interval. In this research we use tracking data with a time-interval of 5 seconds, so it is possible to calculate on speed, etc (the farther apart the locations, the more rapid the movement).
4 For application in ArcGIS the Tracking analyst extension is needed.
5 Some information is added automatically by the GPS (e.g. time), other information derived from the questionnaires and is added manually in the database (e.g. purpose, mode of transportation).
6 For lines, the density is based on the length per unit area. For example, the total meters of logging lines of movement per hectare.
7 Common classification schemes are: Natural breaks, Quantile, Equal interval and Standard deviation.

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5

ALEXANDRA MILLONIG, KATJA SCHECHTNER
TU VIENNA, ARSENAL RESEARCH

MOBILE PEDESTRIAN NAVIGATION SYSTEMS

WAYFINDING BASED ON LOCALISATION TECHNOLOGIES

INTRODUCTION

Increasing traffic volumes have led to the development of traffic telematics services with the objective of improving transport safety and avoiding capacity overloads. A central component of telematics services is navigation systems based on localisation technologies. For example, the Global Positioning System (GPS) is used to determine the location of a car and to assign its position to road-related datasets. The Geographic Data Files (GDF), a European standard that is used to describe and transfer road networks and road-related data, serves as a basic dataset for car navigation technologies. It provides information on distances, directions, street names and specific "points of interest" (POI).

While navigation systems have been mainly developed for vehicles, technological progress has led to the construction of small and cheap components, allowing the design of mobile devices for pedestrian navigation services. These make it possible to provide navigational aid to users at any unfamiliar place. Especially in surroundings of public buildings such as airports or train stations, people subject to time pressure often find it difficult to find their way without delay. Pedestrians would hence benefit from a system offering navigational information via mobile devices. An overview of existing pedestrian navigation systems and some of their advantages and disadvantages can be found in Retscher (2004) and Miyazaki and T. Kamiya (2006).

Existing concepts aiming to provide car drivers with wayfinding instructions are not adoptable for the navigational needs of pedestrians for several reasons. Firstly, as pedestrians are not bound to the road network, they have a greater degree of freedom of movement compared to car drivers (Corona and Winter, 2001). Secondly, GPS localisation accuracy of 5-30 meters is often not sufficient for pedestrians, and locating GPS devices in buildings would be virtually impossible (cf. chapter 3). Hence, the accurate localisation of walking individuals demands additional technologies, especially if a person must be located on the correct floor of a multi-storey building (Gartner et al., 2004). Thirdly, car navigation services usually provide geometric information such as directions and metric distances, whereas human wayfinding strategies naturally rather include landmark information. Salient objects which are easily recognised and remembered should therefore be included in wayfinding instructions for pedestrians (Millonig and Schechtner, 2007).

The first part of this paper gives a survey of the state of the art of research on human spatio-temporal behaviour in connection with the development of pedestrian navigation systems. The second part of the paper deals with the problem of pedestrian route choice behaviour. It is in particular concerned with localisation technologies and their adaptation to location-based information systems. The third part of the paper outlines three projects performed at *arsenal research* and the Vienna University of Technology in these areas. Firstly, it describes a research project on the requirements with regard to the development of ubiquitous cartography for pedestrians in indoor and outdoor environments. Secondly, it describes a self-learning travel guide for city tourists based on mobile phones and GPS. Lastly, it describes an audio-guide system which provides landmark-based navigation instruction.

RESEARCH ON HUMAN SPATIO-TEMPORAL BEHAVIOUR

Mobile guiding systems provide information for travellers, both during and after their actual trip. The systems inform them of possible paths and ways to their designated destination with the help of small, handy devices like mobile phones or PDAs (Personal Digital Assistant). Such services give users the possibility of changing their location whenever they wish, while providing them with information and interesting facts about their current environment.

Pedestrian Route Choice Behaviour

Common concepts used in car navigation systems have proved to be inappropriate for the development of mobile navigation systems for pedestrians, especially as the complexity of human spatio-temporal behaviour makes it necessary to provide other route qualities than shortness. Several findings in the study of human route decision behaviour indicate that there are significant differences in the way in which pedestrians choose a specific path to a desired destination, e.g. the "most attractive", the "most convenient", the "safest" path, or the path with the "fewest turns" (the simplest path) (Blivice, 1974; Thomas, 2003; Golledge, 1995). Although it is often assumed that people will generally choose the optimal path to a specific destination, it is conceded that this may merely be true in standard situations. Helbing (1991) states that that non-optimal behaviour, and therefore differences in spatio-temporal behaviour, may also occur either due to an individual not yet having learned the optimal strategy, or in connection with certain emotional or other reasons leading to suboptimal behaviour. Deviations from optimal behaviour (i.e. choosing the fastest path) may also be caused by the fact that an alternative path is more attractive (e.g. less noisy, more friendly environment, less waiting time at traffic lights) (Helbing et al., 2001; Millonig and Schechtner, 2007).

Research on human spatio-temporal behaviour has shown that there are two main categories of behaviour-influencing factors, namely internal factors (personal characteristics of individuals) and external factors (characteristics of the environment). Internal factors refer for example to socio-demographic attributes (gender, age, health, etc.) (Daamen and Hoogendoorn, 2003) as well as culture, lifestyle, level of education, beliefs, and attitudes (Holden, 2000). External factors include characteristics of the trip (familiarity, trip length), properties of the infrastructure (type, attractiveness, shelter), and environmental characteristics (ambient, weather conditions) (Daamen and Hoogendoorn, 2003). External factors can also be classified according to different dimensions of route qualities: physical (distance, acclivity), emotional (attractiveness, safety), and cognitive qualities (complexity, landmarks) (see **illustration 5.1**).

All these results support the assumption that the choice of a specific route and actual walking behaviour depend on a variety of different influence factors. Hence, the decision to take a particular route is strongly influenced by an individual's knowledge of various interacting kinds of route qualities as well as his or her personal preferences and habits.

Application of Localisation Technologies for the Development of Mobile Pedestrian Navigation Services

The possibilities of improving navigation services for pedestrians by the application of localisation technologies are twofold. On the one hand localisation technologies offer the possibility of studying human spatio-temporal behaviour in order to obtain comprehensive insights into human wayfinding strategies and route decision processes. On the other hand ubiquitously available location-based information can serve a multitude of purposes for different

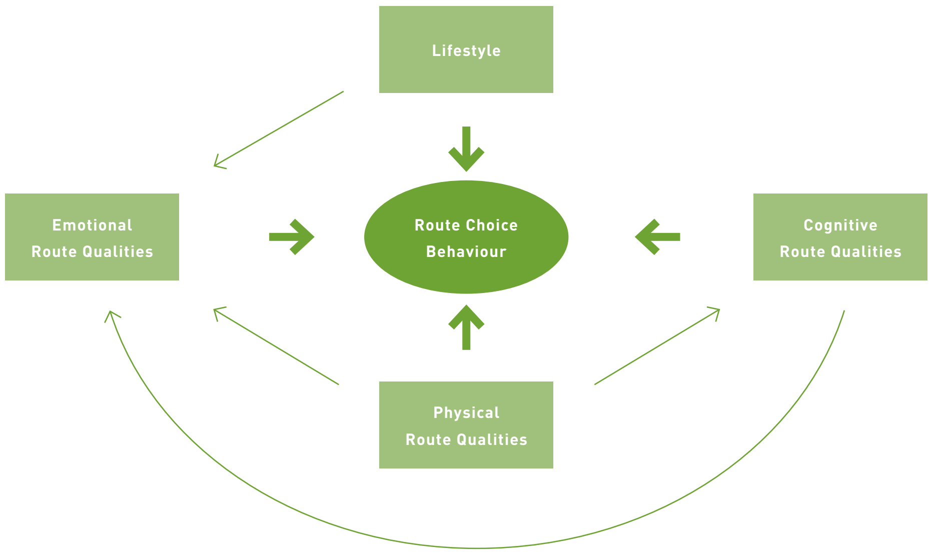

Illustration 5.1 Effects on route choice behaviour.

kinds of users. Route instructions and information concerning useful facilities in the vicinity can be tailored to individual needs and preferences.

As findings reveal that there is a great diversity of different navigation strategies and individual preferences concerning route qualities (see above), conventional navigation systems fail to respond to personal preferences and requirements with regard to spatial information. The development of future pedestrian navigation services and Location-Based Services will have to take individual preferences and wayfinding styles into consideration in order to provide efficient, personalised services to fulfil an individual's requirements. The investigation of human walking behaviour therefore calls for a combination of different empirical methods with a view to obtaining comprehensive information on pedestrian wayfinding and decision processes. While previous empirical studies on human walking behaviour usually had to rely on path following, inquiry techniques, and scene analysis, new technologies such as localisation systems and sensor networks offer innovative possibilities of collecting localisation data. The most commonly used methods are satellite-based technologies (Global Positioning System, GPS, cf. chapters 6 and 7), land-based technologies (cell identification, cf. chapter 8), sensor networks (e.g. RFID), or hybrid solutions (Bandini et al., 2007; Shoval and Issacson, 2007, cf. chapters 2, 9 and 10). The main advantages of using localisation technologies lie in the possibility of collecting data from a comparatively extensive environment. Furthermore, the employment of localisation systems does not require a great deal of effort on the part of the subjects under observation. Nevertheless, major limitations in the use of localisation technologies and sensor networks should be mentioned. At the present, localisation systems are still quite cost-intensive, as users have to be equipped with tracking devices. This also leads to the risk of observer effects, since participants are aware of the fact that they are being observed and might therefore change their behaviour. Still, the use of localisation technologies and sensor networks are expected to enhance the quality of human spatio-temporal behaviour research, especially when combined with complementary empirical methods (cf. chapter 10).

Current services offering navigational instructions for pedestrians still usually concentrate on physical route qualities, like shortness or accessibility for handicapped people (i.e. avoidance of stairs, use of elevators). However, the increasing amount of ubiquitously available information now offers the possibility to supply mobile users with efficient and practical location-based information. This enables the enhancement of wayfinding tasks with additional information on useful facilities in the vicinity.

PROJECTS AT VIENNA UNIVERSITY OF TECHNOLOGY AND 'ARSENAL RESEARCH'

This section outlines three projects related to pedestrian wayfinding based on localisation technologies performed at the Vienna University of Technology and *arsenal research*. The first section below describes a joint research effort with regard to requirements for developing ubiquitous cartography for pedestrians in indoor and outdoor environments. The subsequent section describes a self-learning travel guide for city tourists based on mobile phones and GPS. Finally, an audio-guide system providing landmark-based navigation instruction is described.

Ubiquitous Cartography for Pedestrian Navigation

This currently ongoing research project (UCPNavi) assumes that navigation in a ubiquitous environment with a combination of active and passive systems enables customised route guiding and therefore optimises the wayfinding process. Instead of passive systems that are installed on the user's device and frequently position the user as he moves along, new technologies originating in ubiquitous computing could enrich guiding systems by including information captured from an active environment. As recent developments in the field of mobile information and communication technologies have led to an increasing amount of ubiquitously available information, users can be offered a wide range of possibilities to be supplied with location-based information. Therefore, the wayfinding process could be enhanced with additional information and various presentation forms.

In addition to navigation support, it could be beneficial to supply the user with information adapted to the current task. This would mean that the user is perceived by a ubiquitous environment and receives location-based information that is suitable for the respective device or is supplied with helpful notes via a public display or similar presentation tools. Furthermore, these smart stations could substitute or complement traditional indoor positioning methods by sending coordinates of the station instead of locating the user. Based on the concept of Active Landmarks, which actively search for the user and build up a spontaneous "ad-hoc network" via an air-interface, a ubiquitous solution where an information exchange between different objects and devices is accomplished could be investigated for use in navigation.

As opposed to conventional navigation systems which are based on preinstalled software, ubiquitous cartography responds to an individual user at his present location in real-time. Interactivity is facilitated and wayfinding aid is more flexible, providing new opportunities and challenges in the field of cartography and offering new possibilities for research in positioning techniques with alternative sensors.

Due to the above mentioned reasons, the research topics in this project aim at the investigation of efficient positioning methods in a smart environment in combination with conventional positioning techniques, as well as the development of pedestrian typologies by observing the pedestrians' mobility behaviour at certain highly frequented environments using different tracking methods, and the determination of suitable route presentation forms, which could be provided either by the ubiquitous environment or by a passive system on the client of the user. **Illustration 5.2** depicts the project design. The empirical techniques used in the investigation of mobility behaviour include unobtrusive observations, tracking (using localisation technologies such as GPS and Bluetooth), and standardised interviews. The combination of multiple empirical techniques ("across-method triangulation") will allow a detailed investigation of the complexity of human route decision processes, individual habits and preferences, and discriminative features for different classes of spatio-temporal behaviour (Millonig and Gartner, 2007).

Preliminary experimental results concerning the investigation of human spatio-temporal behaviour prove that pedestrians show specific walking patterns which can be categorised. During a heuristic phase of unobtrusive observations in an outdoor and an indoor environment (a major shopping street and a shopping centre) a data set of over 100 trajectories of people observed by path-following methods has been collected.

First analyses using agglomerative hierarchical clustering algorithms provide three homogenous clusters for the indoor data. The outdoor dataset analysis produces eight clusters, with 86% of observations belonging to four classes, and only several observations related to the other four classes. This difference in behaviour could be the result of differing context influences; as the outside investigation area concerns an urban street, observed individuals may have other objectives than shopping. Persons who enter a shopping centre seldom pursue other goals than shopping, and their behaviour appears to be able to be categorised into several classes.

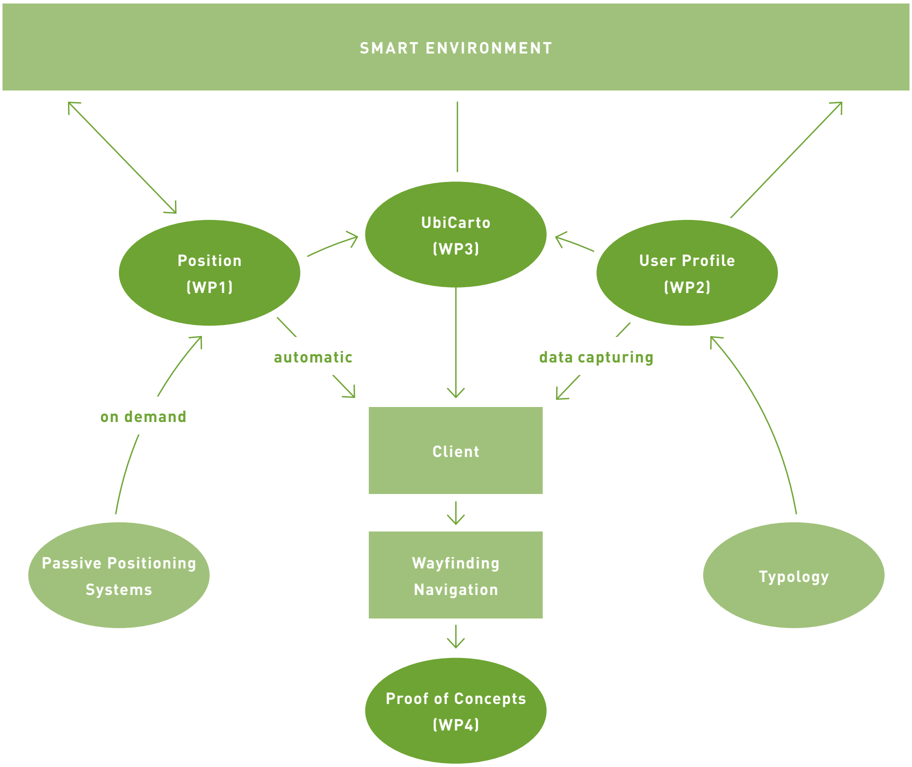

Illustration 5.2
The project work packages and their interaction.

55.6% of the observed individuals in the shopping centre can be related to a cluster showing a high percentage of time spent in front of or inside a shop (77.8%). Individuals falling in this category also walk at a lower speed than persons related to the other classes (mainly within a speed interval of between 1 and 1.1 m/s). Outside observations show a wider range of classes of behaviour. Although many individuals still spend some time inside a shop or standing in front of it, more time is spent walking around at a variety of different speed levels than in the indoor observation field. **Illustration 5.3** shows the main differences in the observable walking behaviour of pedestrians demonstrated by speed histograms of outdoor and indoor observations.

The results lead to the definition of an initial typology of pedestrian spatio-temporal behaviour in a specific consistent situation. The aim of the deductive phase of the study currently starting is to verify the provisional types defined in the first survey. The actual walking and route choice behaviour is observed using technological localisation methods (outdoor: GPS; indoor: Bluetooth) and will subsequently be compared with the formerly identified hypothetical typology. The analysis of the tracking results focuses on routes, velocities and breaks. After the tracking process, detailed standardised interviews are conducted with the participants who have been previously tracked to obtain information on their actual intentions, attitudes, lifestyle and socio-structural attributes. The obtained data is related to defined specific mobility types, allowing their validation with regard to internal homogeneity and external heterogeneity.

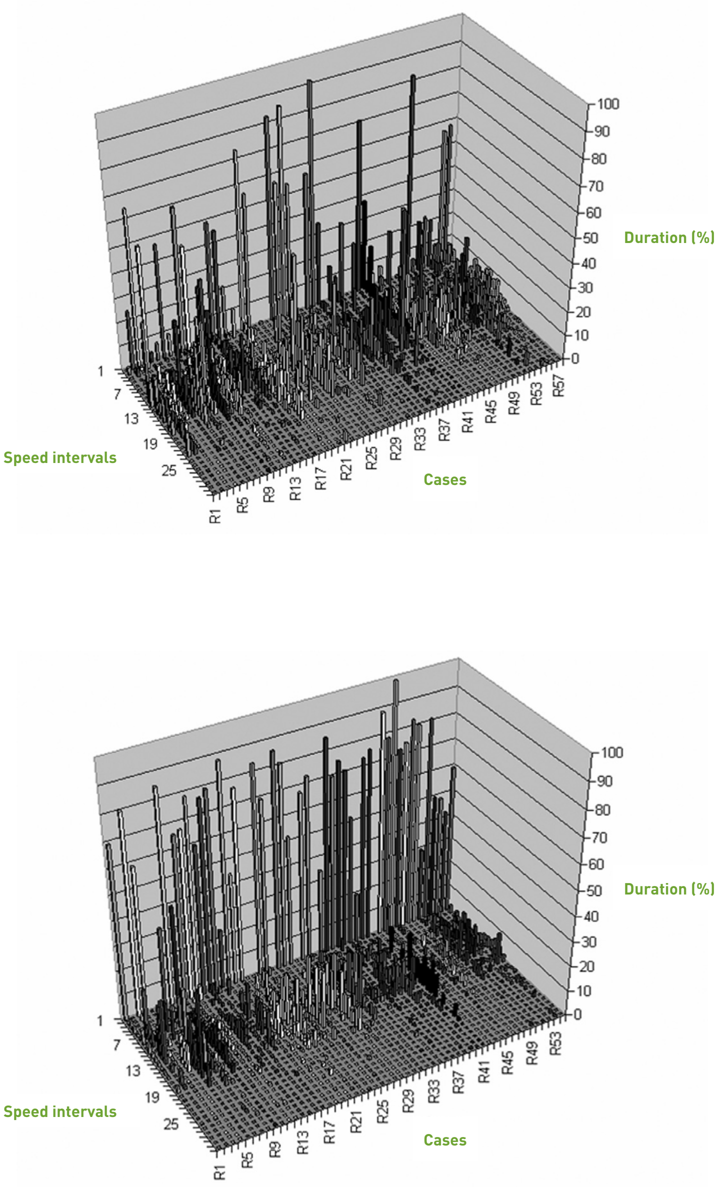

Illustration 5.3a and 5.3b
Histograms of all outdoor (above) and indoor (below) observations.

Based on the results of both empirical phases a model of pedestrian mobility styles is developed, including multiple aspects of each detected type (basic parameters of velocities, stops, and turns; behavioural characteristics; preferences; socio-demographic and lifestyle attributes). Discriminative features are determined and extracted, which can be used to provide customised information to specific types of pedestrians using an implemented wayfinding system.

Mobile City Explorer

The Mobile City Explorer (MCE) is a prototype for a location-aware travel assistant based on a combination of widespread conventional mobile phones with built-in cameras and GPS/GALILEO receivers (Wiesenhofer et al., 2006). Its aim was to provide city tourists with suggestions for a sightseeing tour based on their interest profiles which are adapted following their actual movement in the city on a client-server basis. Additionally, MCE provides tourists the possibility of capturing digital images, the contents of which are analysed by server-based object classification algorithms. Moreover, the route, the captured images, videos, text comments and acoustic impressions can be saved in an automated travel diary, which is accessible via WWW.

This concept allows the exploration of a city according to the individual interest profile, adapting real time according to the movement of the user. By combining the data of all tourists, it also allows the investigation of the movement of a specific group in the city, its main interests, etc.

The smart guide (mobile camera phone with GPS receiver and software for "High Level Routing") determines an initial sequence of Points of Interest (POIs). The suggested sequence of POIs takes into account user interests, current position and time constraints. This allows an individual trip to be provided best matching a tourist's interests. The service predicts interests and preferences for each individual user; deviations from the suggested route will result in updates in the High Level Routing model and lead to the reselection of POIs and tour recalculation.

Major research questions concern the accuracy of matching the position supplied by the GPS device with the actual city map (map-matching, and the problem of urban canyons (Ray, 2005, cf. chapter 12), the definition of deviation parameters (time and space) triggering an update of the initial route, and the visual information displayed on the camera display.

Results from the pilot tests show that initially suggested routes were abandoned quite frequently and that interest profiles given at the beginning of the tour were altered considerably. **Illustration 5.5** provides an example of five different interest groups defined by a tourist at the

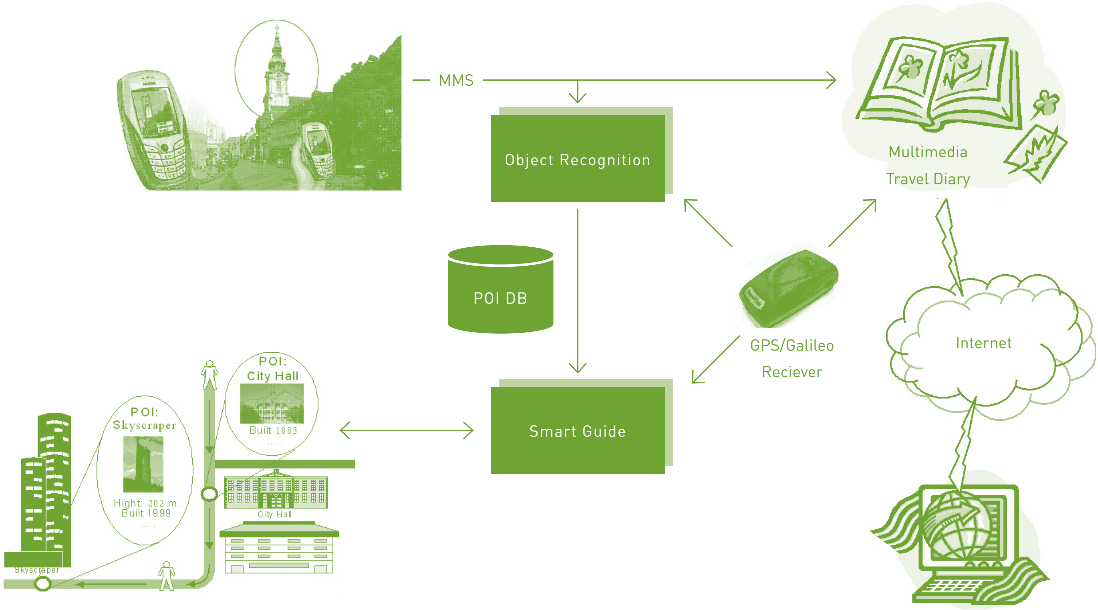

Illustration 5.4
Schematic View of the MCE Functionality.

beginning (front of the figure). In the course of the day, the change of route and the time spent at specific places indicates that his interests changed to subjects not listed at all at the beginning, while subjects listed at the beginning seem to be not at all interesting by the end (actual user interest probabilities at the back of the figure). More detailed information on learning interests based on motion behaviour can be found in Schrom-Feiertag and Ray (2007).

Similar results from other test users suggest that the motion behaviour of tourists in a city deviates considerably from suggested routes and that the actual interest profile of a tourist is less specific than the tourist might himself believe.

Aggregated data of the test users resulted in a clear picture of favourite locations for spending time in the test city. **Illustration 5.6** depicts as contour plots several spots where test users tended to have long dwell times, thus indicating sites of major tourist interest.

In order to learn tourist behaviour within a city on a large scale, a large set of real life data is required. Moreover, data interpretation has to take into account the current shortcomings of GPS technology in urban areas; registration times into the GPS service are long and position information is sometimes lost and/or may not be accurate enough for the pedestrian context.

Landmark and Speech-based Guiding System

The landmark and speech-based guiding system is based on a mobile phone-based audio system guiding users between landmarks. The landmarks have to be easily detectable and uniquely named and it must be certain that the object can be seen and clearly described (Sefelin et al., 2005).

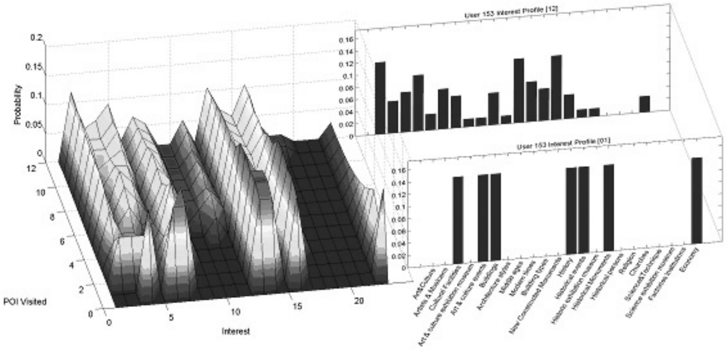

Illustration 5.5
Change of interest profile.

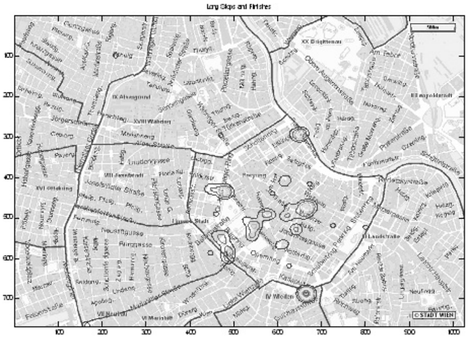

Illustration 5.6
Long time stops according to test data.

Illustration 5.7 sketches the general sequence of such mobile audio guidance. The person seeking help calls a specific number via his mobile phone and informs the system of the desired target. The system aims to determine a user's current position through a question-and-answer process and guides him to the desired destination using significant landmarks. The system

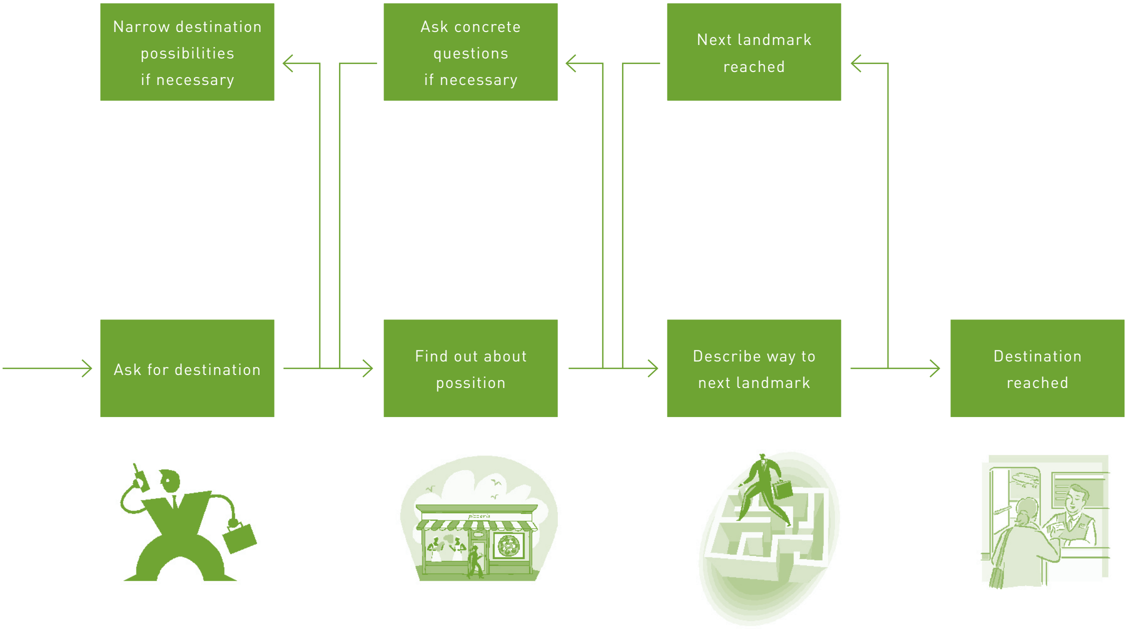

Illustration 5.7 Schematic Overview of a Guiding Dialogue.

therefore combines speech recognition, a text-to-speech module and efficient and clear routing via pre-defined paths between all landmarks.

The success of the guiding system depends on two key factors: 1) the identification of clear landmarks and the routes between them, and 2) the quality of the automatic speech recognition system. Landmark-based orientation is a natural wayfinding method for pedestrians (Millonig and Schechtner, 2007).

Two methods of identifying landmarks and routes were employed in the train station that we used as a test area, with cameras recording the daily movements of the people. By employing computer vision technologies, individual tracks were automatically collected. Based on the tracking data major routes and areas where many people stopped were identified. More detailed descriptions can be found in Bauer et al. (2006) and Brändle et al. (2006).

After having analysed major routes and main stopping areas, a study to identify the landmarks visible along these routes or from the stopping point led to the definition of reliable landmarks (e.g. particular shops, staircases, clocks).

Test users reported that the method of orienting themselves via landmarks was an efficient and successful method of wayfinding. Oral descriptions of the routes and landmarks also proved to be a mode people were used to. It has to be added, however, that one of the major challenges of automatic speech recognition is the presence of noise. This is moreover one of the key challenges in making speech recognition a reality for everyday and practical environments.

CONCLUSION

Illustration 5.8 Examples of landmarks: situated either along (e.g. statues, also signposts) or at a distance from the route (wall clock), or a unique part of the route itself (escalator).

Research on pedestrian spatial orientation behaviour and the subsequent development of navigation systems for pedestrians have to deal with the problem of obtaining sufficient reliable data to analyse real pedestrian movement and feeding these results back into efficient navigation systems. Without the widespread use of navigation systems, not enough data can be collected, and without enough data the navigation systems only offer poor services to the user, therefore preventing widespread use.

Localisation technologies currently offer the possibility of investigating human spatio-temporal behaviour and route decision processes in more detail, in order to develop navigation services which offer personalised route instructions and individually interesting location-based information. The employment of various localisation technologies is expected to increase the quality of human spatio-temporal behaviour research and to improve the possibilities of supporting pedestrian wayfinding by means of mobile navigation services. Localisation technologies and sensor networks are especially essential for the development of navigation systems for indoor environments. This contribution introduces several research projects employing different localisation and tracking methods either for the investigation of human walking behaviour or for the localisation of users in order to provide efficient localisation-based information and navigational instructions. The research projects refer to different kinds of specific target groups (e.g. tourists, passengers at railway stations, or pedestrians navigating through both indoor and outdoor environments) and employ several different localisation and tracking technologies for the assessment and analysis of human walking behaviour. Results indicate that there are multiple influence factors determining human route decision processes. The design of the physical environment (e.g. indoor or outdoor environment) leads to significant differences in wayfinding and route choice behaviour.

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6

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TRACKING VISITORS IN PUBLIC PARKS

EXPERIENCES WITH GPS IN DENMARK

INTRODUCTION

Very little scientific research based upon GPS tracking in a Danish context has been conducted and up until the present, no research at all has included comprehensive GPS tracking of human activity (cf. Jensen & Guldager, 2005; Jensen, 2003). There is therefore a need for explorative studies evaluating different tracking hardware and methodological set-ups and identifying various difficulties that may arise during data collection (Hovgesen etal, 2005). From 2003 up to the present, the Diverse Urban Space (DUS) research project has conducted various experiments with the use of GPS tracking as a survey instrument relevant to urban planning. This work has involved cases including the simple testing of equipment and both small and large scale surveys.

This chapter will first provide a concise overview of the different surveys and tests conducted within the DUS and briefly explain the main methodological experiences. Hereafter, a specific case in which GPS technology is applied to track the movements of park visitors will be dealt with in more detail with regards to the methodological set-up, results and applied hardware. In addition to the explanation of the general surveying technique and the results, one park in particular is used to illustrate a simple analysis of how Google Earth may be used in connection with real time visualisation undertaken on the basis of GPS tracking. Lastly, conclusions drawn from the park surveys and a number of more general conclusions on the basis of various other surveys are provided.

THE CASE STUDIES CONDUCTED WITHIN DUS

The following cases were conducted within DUS:

Case 1	Adults in Copenhagen; employees at Danish Centre for Forestry, Landscape and Planning, Denmark, 2005 (N = 10)
Case 2	School Children from a state schooln Glostrup, Denmark, 2005 (N = 14)
Case 3	School Children from state school in Hjerk-Harre, Denmark, 2006 (N =18)
Case 4	High school students from Aalborg, Denmark, 2006 (N = 49)
Case 5	School Children from a state school in Aalborg, Denmark, 2006-2007 (N = 30)
Case 6	The Aalborg GPS park survey of four public parks, Denmark, 2007 (N = 4.462)
Case 7	The DUS GPS surveys in Aalborg and Copenhagen, Denmark, 2007 - 2011, (N = 500+)

The 'school children' studies (case 2 and 3) were carried out in co-operation with 'The Research Unit for General Practice in Copenhagen' at the University of Copenhagen (Denmark) whereas the Aalborg studies (case 4 and 5) were carried out in co-operation with students from Aalborg University (see Kjærsgaard et al, 2006). The Aalborg GPS park survey was conducted in co-operation with the Municipality of Aalborg. The main aim of this research was to prepare the set-up for a new type of GPS-based survey of activity patterns in time and space that will give a new perspective on spatial interdependencies and spatial effects for the benefit of urban and traffic/mobility planning. The potentialities of using GPS-based surveys are illustrated by taking point of departure in data from the Aalborg GPS park survey of four public parks, Denmark 2007, namely 'Skanseparken', case 6.

The general approach in DUS has been incremental and seeking to continuously eliminate the most problematic parts of the survey set-up and replacing them with other solutions. Hence has the number of respondents grown steadily and so has the complexity of the conducted surveys. Furthermore, the cases involved a wide range of different respondent groups and types of hardware, giving a broad insight into the different technologies. The stepwise approach meant that the DUS took a non-interventional position in its contact with respondents. Respondents were consequently not required to answer questions when they were at certain places or at certain times as in case 2, in which the respondents were sent text messages, as the latter led to extremely low response percentages and poor data quality. The DUS therefore aimed at allowing respondents to schedule when to undertake the mandatory activities required from participating in the survey.

The work carried out with different technologies showed that the main challenge was to obtain an adequate battery lifetime. The problem led to the elimination of the most advanced tracking hardware, which often had additional capabilities such as the mobile phones used in case

2. Furthermore using relative 'low-tech' hardware minimizes the possibility of respondents mishandling the equipment. Lastly, it has appeared that not all population groups are equally easy to contact with a view to acquiring respondents. Young people and children are relatively easy to contact through institutions such as schools and nurseries, whereas the fact that there are fewer obvious organized forms for adults makes it more difficult to recruit them as respondents unless the basis of the respondent selection is related to the home location.

CASE 6 - THE AALBORG GPS PARK SURVEY

The GPS Park survey was the most recent and comprehensive of the completed surveys conducted by DUS and entailed contact with many respondents of different ages and social backgrounds. This led to the compilation of a great deal of information on the practical challenges of collecting data. The purpose of the survey was primarily to gain experiences with and develop a framework for large scale data collection using GPS technology and specific hardware. However, even though the aim was not to make advanced and elaborate analyses of the collected data, the results from the survey offered an opportunity to examine some of the possibilities for real time visualisation using Google Earth. The GPS Park case study thus worked through a wide range of challenges that many different GPS-based tracking research projects must address. The case study is therefore very well suited for others to learn from as well as serving as a source of inspiration for other researchers. The GPS Park survey was developed in cooperation with the Municipality of Aalborg which needed more information on the use of local public parks. The municipality aimed at using the information in the future redesign of specific areas in parks within its boundaries.

The survey was carried out in four parks in Aalborg in August 2007 and involved 4,462 park visitors. Each park survey consisted of two separate survey parts: a GPS tracking of respondents in the park and a questionnaire survey of respondents visiting the park. The GPS Park survey was carried out in Mølleparken on Wednesday 8 August and Saturday 11 August 2007 – both days from 06.00 and 22.00. In Søheltens Have the survey was carried out on Thursday 16 August and Saturday 18 August 2007 - both days from 07.00 to 19.00. In Skanseparken the survey was conducted on Wednesday 22 August and Saturday 25 August 2007 – both days from 07.00 to 19.00 and in Kildeparken on Wednesday 29 August 2007 from 07.00 to 19.00. All above mentioned dates and time intervals were prearranged with the Municipality of Aalborg.

In conformity with the prearrangements made with the municipality of Aalborg certain survey representatives were placed at a number of specific park entrances in each park. According to the agreed survey set-up the survey representatives at the chosen entrances approached all visitors entering the specific park inviting them to participate in a survey carried out by Aalborg

University in co-operation with the Municipality of Aalborg. If visitors declined to participate in the survey, the survey representative attempted to carry out a refusal survey consisting of only a limited number of questions.

If the visitor agreed to take part in the survey, he or she was given a GPS unit making them an official respondent. Respondents were asked to carry the GPS unit throughout their park visit up to the time that they were about to leave the park. At the exit of the park the respondents were furthermore asked to fill in a questionnaire. If survey representatives ran out of GPS units or encountered respondents who did not want to carry a GPS unit but were nevertheless willing to participate in the survey, this latter group was only subjected to the questionnaires carried out by the survey representatives at the park exit, and the GPS tracking was not carried out.

The questionnaire part of the survey therefore included all respondents who were open to being contacted at one of the chosen entrances/exits and who agreed to participate in the survey. The GPS tracking on the other hand only consisted of respondents who agreed to carry a GPS unit and to whom it was possible to hand one out. The refusal survey consisted of the visitors who did not wish to take part in the park survey but agreed to participate in the refusal survey. In addition, there were also visitors who declined to participate in any of the surveys or refused all contact. These visitors were counted separately by the survey representatives. Due to the limited numbers of available hardware units (in total 50 units), the units were distributed among the entrances of the park in question in proportion to the estimated number of respondents expected to enter the park. Periodic problems in connection with handing out hardware units to all respondents only occurred in a small number of parks.

It should be noted that owing to the explorative survey set-up, the survey concerned was not representative with regard to the everyday use of the parks over a year. A further factor that should be considered is that the actual survey set-up was not efficient in obtaining data from all respondents. The actual results presented in this article consequently fail to show representative activity patterns for each park or for each week, but only on the day on which the survey was carried out.

RESULTS FROM THE GPS PARK SURVEYS

As was noted earlier, the GPS Park surveys succeeded in making 4,462 visitors participate in the survey although there were substantial differences in response in the various parks. The differences were partly due to the sizes of the parks with Søheltens Have being the smallest, Skanseparken and Kildeparken of roughly the same size and Mølleparken the largest. However the high number of visitors in Kildeparken is due to its extremely central location in the city which connects the city centre and central business district with residential areas as well as being in close proximity to the central train station and several schools. Different from the other parks Kildeparken is not only a recreational park but also a thorough fare implying that many people did not have time to participate in the survey and not everyone could be approached due to a limited number of survey representatives.

Illustration 6.1 - The number of respondents within each survey category.
Note that respondents who carried a GPS also answered a questionnaire.

	GPS tracking	Questionnaire	Refusal survey	Non participants	Total number of people
Mølleparken	301	406	119	299	824
214,000 m2	37%	49%	14%	36%	100%
Søheltens Have	99	130	61	102	293
23,000 m2	34%	44%	21%	35%	100%
Skanseparken	132	153	41	104	298
67,000 m2	44%	51%	14%	35%	100%
Kildeparken	474	480	571	1996	3047
71,000 m2	16%	16%	19%	66%	100%
Total	1006	1169	792	2501	4462
	23%	26%	18%	56%	100%

The general impression from all four parks was that most respondents spent most of their time in the parks on the paths. This particularly applies to Kildeparken. However, some respondents spent a lot of time at certain locations outside the pathways. The majority of respondents who remained outside the ‘traffic areas’ are mainly found in some sort of ‘activity area’ such as a children’s playground, a tennis court or a fountain surrounded by benches while only a small number of respondents spent a prolonged period of time on the lawn (cf. Ostermann & Timpf, 2007).

The Aalborg GPS park survey and the hardware units used

In the light of a number of deliberations a GPRS-based hardware unit (Flextrack Lommy©, see **illustration 6.2**) with a built-in GPS was chosen to play a role in completing the Aalborg GPS park survey. Firstly, the design of the unit is simple, the unit is light and small (only weighing 99 gram and 74x61x23 mm), and it has a single small red on/off button. Secondly, the choice of this hardware unit gave the opportunity to follow the hardware unit online and in real time so that respondents leaving the park without having passed survey representatives at the chosen entrances could be tracked and caught up with.

Illustration 6.2
Flextrack Lommy©.

Although a number of hardware units were lost and some were accidentally left in the park, thanks to the above-mentioned tracking system it was possible to locate and collect them. A few other units were collected at the respondents' home address (in total five units from all four surveys), and a total of three hardware units were completely lost during all four surveys. One unit was destroyed by a young man participating in one of the surveys, and the parts were found in the park. Contact with another hardware unit was lost in the same park during the survey and the unit not found. The last hardware unit was tracked to an address, but the potential respondent refused to return it.

The accuracy of the GPS part of the hardware unit is based on a 16 Channel parallel Very High Sensitivity receiver with a sensitivity Tracking: -158 dBm / -188 dBW and a high efficiency Helix antenna.

The Aalborg GPS park survey and the results from Skanseparken

Skanseparken had the highest percentage of respondents that agreed to participate in the GPS tracking, and it is therefore reasonable to assume that the data quality is best for this park making Skanseparken most suited for further studies.

The results from the questionnaire survey conducted in Skanseparken were based on a total of 153 respondents while results from the GPS tracking were based on 132 respondents. Refusal surveys were carried out with 41 visitors while a further 101 visitors also declined to take part in the refusal survey. None of the persons in the last-mentioned groups therefore appear in the further analyses. The total number of visitors on the two days was 298 persons distributed over 106 visitors on Wednesday 22 August and 192 on Saturday 25 August 2007. Respondents who participated in the questionnaire survey had an average age of 39 with a maximum age of 85 and a minimum age of 7. 73 of the total number of respondents were women, and 81 were men, one of 'unknown' gender. On Wednesday 22 August, 68 respondents filled in the handed-out questionnaires and GPS tracking was carried out on 58 respondents. On Saturday 25 August 88 respondents filled in the handed-out questionnaire, and GPS tracking was carried out on 74 respondents.

SKANSEPARKEN AND THE MAPS

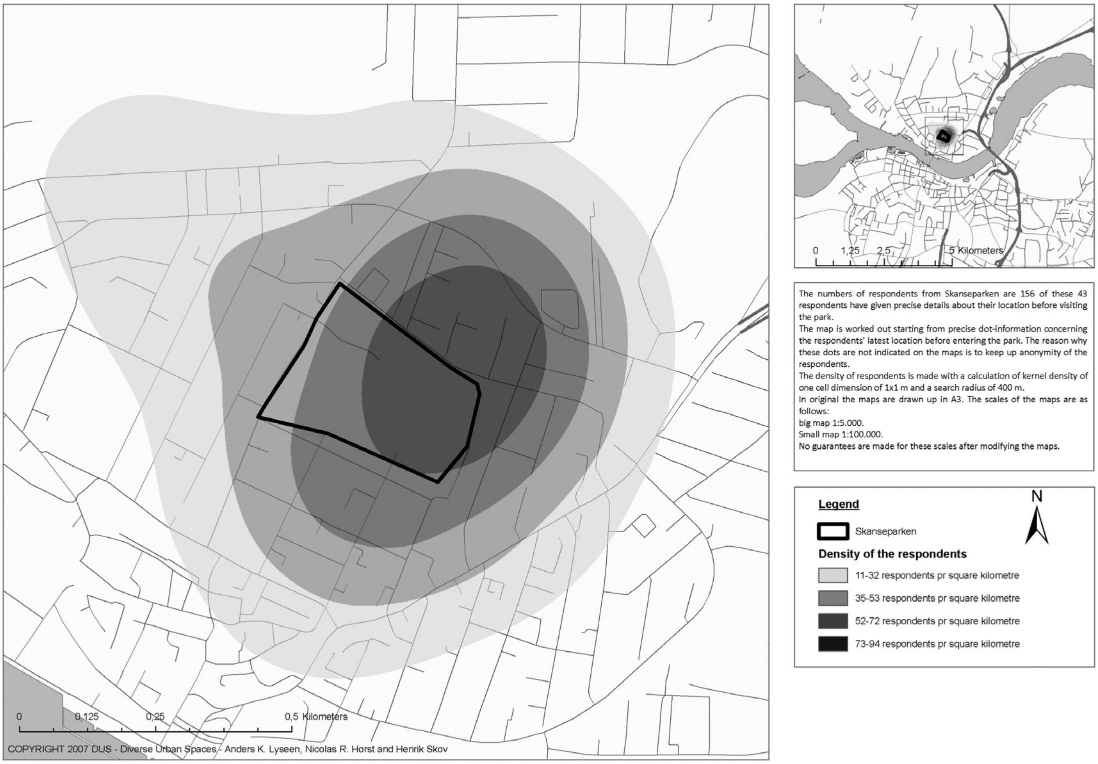
The map of surrounding urban areas

Starting from the GPS registrations of respondents' activity patterns in each park a number of GIS-based analyses were made while GIS was also used for drawing up analyses of where people came from in the surrounding urban areas.

The GIS map 'Respondents' latest location position'
The number of respondents from Skanseparken was 156. The map was based on dot information with regard to the respondents' latest location before entering the park. These dots are purposely not indicated on the maps with a view to maintaining the anonymity of the respondents. The buffers indicate the latest positions of the respondents. Each of the four buffers shows 25% of the respondents' latest positions, and in this way the map indicates the surrounding area respondents come from.

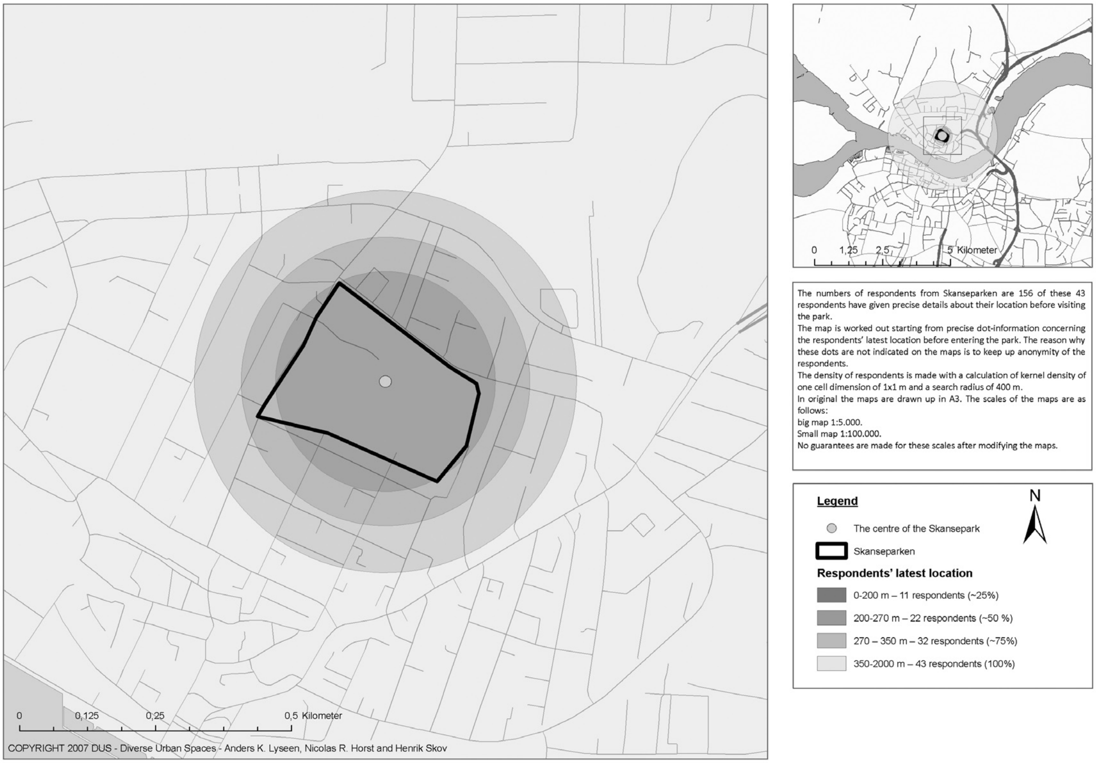
The GIS map Density of respondents' latest location
The map indicating the 'density' of the respondents' latest location is based on a calculation of kernel density of one cell dimension of 1x1 m and a search radius of 400 m.

Each of the above-mentioned maps was based on dot information with regard to the respondents' latest location before entering the park. The dots are purposely not indicated on the maps with a view to maintaining the anonymity of the respondents. The original maps were drawn up in A3 using the following scale: large map 1:5,000. Small map 1:100,000. No guarantees are given for these scales after modification of the maps.



The numbers of respondents from Skanseparken are 156 of these 43 respondents have given precise details about their location before visiting the park.
The map is worked out starting from precise dot-information concerning the respondents' latest location before entering the park. The reason why these dots are not indicated on the maps is to keep up anonymity of the respondents.
The density of respondents is made with a calculation of kernel density of one cell dimension of 1x1 m and a search radius of 400 m.
In original the maps are drawn up in A3. The scales of the maps are as follows:
big map 1:5.000.
Small map 1:100.000.
No guarantees are made for these scales after modifying the maps.

Illustration 6.3 – The GIS map; Respondents' last located position.



The numbers of respondents from Skanseparken are 156 of these 43 respondents have given precise details about their location before visiting the park.
The map is worked out starting from precise dot-information concerning the respondents' latest location before entering the park. The reason why these dots are not indicated on the maps is to keep up anonymity of the respondents.
The density of respondents is made with a calculation of kernel density of one cell dimension of 1x1 m and a search radius of 400 m.
In original the maps are drawn up in A3. The scales of the maps are as follows:
big map 1:5.000.
Small map 1:100.000.
No guarantees are made for these scales after modifying the maps.

Illustration 6.4 – The GIS map; density of respondents last location.

The park activity map

Parallel to the GIS-based analyses the visualising potentialities of Google Earth have been utilised including an indication of the respondents' accumulated time usage in the parks spread out over 5 x 5 metre grid cells. Google Earth was chosen as it was possible to utilise via free license, it contains information and 3D building layers, and due to its simple KML file structure. In addition it can be used to make results visible to respondents easily, simply, online and in real-time.

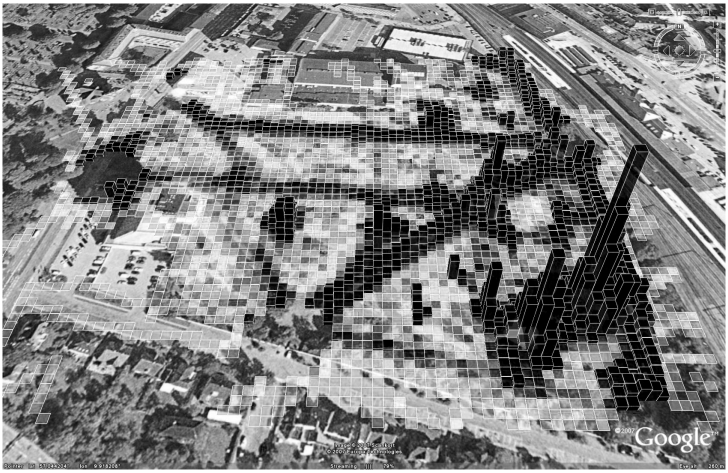
The Google Earth map – respondents' accumulated time usage
Time usage in the chosen parts of the park spread out over 5 x 5 grid cells. The height and the colour indicate the difference in use of time. The higher the column and the darker the red the more time was spent. A cell with no activity has neither height nor colour. Furthermore the cells within a 25-metre radius from the positions of the survey representatives are excluded with a view to excluding the registration of GPS units not carried by respondents when in the park. The cell with the highest accumulated time usage has a column with a height of 100 metres while all other cells have columns equal in height to the accumulated time usage in the individual cell in proportion to the accumulated time usage in the cell with the highest accumulated usage. This means that a cell with an accumulated time usage equal to 10% of the highest accumulated time usage will have a height of 10 metres. The colour scale is divided into ten steps so that the 10% of the cells with the lowest accumulated time usage are the lightest green and the 10% of the cells with the highest accumulated time usage are the darkest red.

CONCLUSIONS

In the light of the completed research projects, it can be concluded that the results from GPS-based surveys can be absolutely and successfully used to analyze activity patterns and communicate knowledge with regard to the use of specific urban areas to researchers/scientists, professional users and citizens. Depending on which survey set-up is chosen it is however important to consider the ethical set-up and to deliberate how many respondents will take part in the surveys against this background. This will also be the case even if the GPS-based survey only takes place in a park, and even if the respondents are informed that the survey set-up will provide complete and full anonymity.

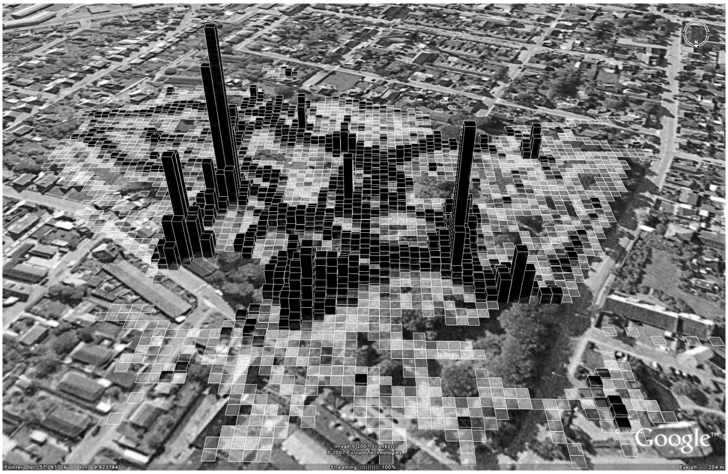
In relation to the hardware of the methodological set-up it is crucial to attain a satisfactory battery lifetime. In this regard, DUS has mainly found that it is beneficial to use relative simple GPS technology. The spin-off is that the equipment is more easily handled by the respondents. In relation to this challenge is it beneficial to the data quality to let the respondents themselves

Illustration 6.5
3D projections of respondent's accumulated time usage on the Google Earth map.



Kildeparken

Mølleparken



Skansenparken

schedule when to undertake mandatory activities within the project such as answering questionnaires or recharging the units.

Another problem is the representativeness of the results versus the collection cost. Conducting GPS surveys based on handing out GPS units is expensive and can only be carried out a few times and over limited time periods. This means that the results are not statistically representative of overall use as in this case overall use in the four parks. It is hereby important to consider the constitution and representativeness of the respondent group. Some population groups such as children and young people are easily contacted through institutions such as schools and kindergartens whereas recruiting adults as respondents may be less cost effective.

Lastly it is important to consider the trustworthiness of the patterns of activity and to ask whether respondents' activity patterns are influenced by the fact that they know their patterns of activity will be mapped even if registration is completely anonymous, as was the case in the reviewed GPS Park. In addition, a GPS-based survey set-up has a number of minor practical problems concerning the handing out and collecting of GPS hardware units, even if the hardware units do not represent any value to the respondents or are of no use to them afterwards.

In future research within the DUS, the main hypothesis will be that the increasing use of ICT and especially web-based communication is changing socialising, the search for information, shopping and thereby the overall activity patterns of people living in urban areas, and consequently also the use and role of urban space. There is thus a need to rethink the planning of urban space – in contrast to the functionalistic fulfilment of needs and the corresponding functional hierarchies that still dominate within the planning field. GPS-based tracking and surveys based on mobile technologies could be a tool to explore this new reality and thus inform and guide urban planning.

The research with GPS tracking and mobile technologies at Aalborg University was mainly conducted with the following areas of application in mind: firstly the effects of increasing 'virtuality' on the use and role of urban space, and secondly the effects urban areas create on spatial behaviour, transportation, environment and safety, as well as on use patterns, use contexts, and the promotion of use, especially in a health context. Current research efforts mainly point to the use of tracking and mobile technologies in connection with analysis and elaboration, presentation and dissemination in dialogue with the public. The use of GPS tracking and mobile questionnaires as survey technology will be particularly valuable to research into the use and significance of urban space due to the added value of geographical precision and the improved ability to 'record' itineraries through space. The new knowledge that is likely to be derived from this added value will naturally influence the planning process and will most likely strengthen the support provided in connection with decision-making. If it is possible to reduce costs and ethical concerns, mapping and revealing the behaviour of urban populations as an integral part of the planning process will become the norm in the future.

The general experience within the Danish context and the GPS-based research projects has been that visually appealing, easily interpretable, and representative maps of e.g. commuters' behaviour seem to promote the interest of the news media and a wider public interest more strongly than is usual in the planning process. Furthermore, the response of the news media etc. gives the impression that information on what 'we' do, and how and why 'we' do it is popular reading. It is thus suggested that the newness of tracking and mobile technologies as survey devices combined with appealing forms of presentation are likely to succeed in fostering renewed interest in urban space and how it is used. This interest could be used to promote participation and general interest in urban planning. In a wider perspective, the tracking of citizens (GPS-based or GSM-based tracking of volunteers) could be built into future planning processes as an interesting and discussion-raising feature. The tracking and representation of spatial use patterns might also be combined with an interactive dialogue (voting by SMS, Web or Bluetooth, general or place specific) as well as the dissemination of information (SMS, Web, Bluetooth, phone numbers, place specific or general).

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7

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SPATIAL METRO
TRACKING PEDESTRIANS IN HISTORIC CITY CENTRES

This chapter describes the results of a series of pedestrian observation studies carried out in Norwich, Rouen and Koblenz as part of the Spatial Metro project. The goal of these studies was to observe pedestrian behaviour and to investigate pedestrian movement and experience in the city centres. The cities are engaged in improving the physical conditions and the experience of their city centres by investing in landscaping and engineering of public spaces, city beautification, wayfinding and in communication and information technology. (also see Spek, 2008)

The Spatial Metro project brings together a transnational group of partners, enabling them to co-operate with a view to improving city centres for pedestrians. The theme of Spatial Metro is 'Discovering the City on Foot'. The project aims to make city visits more enjoyable for pedestrians by making them easier to navigate, easier to walk around and easier to understand and appreciate (http://spatialmetro.org, accessed 11 July 2008).

The project has been allocated European Regional Development Funding through the INTERREG III/B Community Initiative. A group of ten organizations participate in Spatial Metro: The lead city of Norwich (UK) and the cities of Rouen (F), Koblenz (D), Bristol (UK), Biel/Bienne (CH), as well as academics from the University of East Anglia (UK), the Delft University of Technology (NL), the University of Koblenz (D) and the Swiss Pedestrian Association (http://spatialmetro.org, accessed 11 July 2008).

The main role of the chair of Urban Design was to develop instruments to evaluate visitor-experience and to observe the use of public space. The purpose of the observation studies was to evaluate the use of space in relation to investments, (rather than using the outcome as a design tool to pinpoint) opportunities and threads in the city; the outcome focuses on a comparison between the actual situation and real use.

For the observation of the public space, a specific method using Global Positioning System (GPS) devices capturing the movement of pedestrians was developed and put into practice. The recording of pedestrian behaviour was accompanied by a questionnaire adding background information on the participants. (Spek, 2006; Spek & Schaick, 2007)

This article will focus on the differences and similarities in pedestrian behaviour in three historic cities in three countries based on quantitative and qualitative research. Do people behave different in these three historic European cities? Can we distinguish different spatial patterns based on the origin and familiarity of the visitor and the purpose and duration of the visit?

After this introduction, the set-up and implementation of the fieldwork will be explained in 'Way of Working'. Here, the methods for processing the data and the criteria employed in connection with the analysis will be clarified. Following this, the results will be described and illustrations provided for each location. The chapter concludes with a synthesis comparing the findings of the different cities.

WAY OF WORKING

The method of collecting data on pedestrian behaviour is based on the Global Positioning System (GPS). GPS is primarily a system for navigation and orientation. The GPS system makes use of a network of satellites in orbit which send signals to earth (http://en.wikipedia.org/wiki/Global_positioning_system, accessed 21 Nov. 2007). A GPS device has the ability to receive these signals and compute its geographical position. At least three to four satellites are necessary in order to accurately determine a position (see chapter 3).

GPS devices are mainly known as navigation or orientation instruments such as car navigation systems or outdoor orientation equipment. The technique has been developed in the military in the United States. Since the year 2000, the technique has been more widely available to the public, although its accuracy is still limited (http://en.wikipedia.org/wiki/Global_positioning_system, accessed 21 Nov. 2007). Today, accuracy is around three to five metres in the open field. Europe is building its own global positioning system called Galileo. (see chapter 3; Spek, 2006; Spek & Schaick, 2007)

GPS tracking

The method of collecting data on pedestrian movement makes use of the ability that some GPS devices can store a sequence of positioning data at a determined time interval. This sequence results in a place-time log. The log file can be read out real-time or later and projected onto maps in a Geographical Information System (GIS). GIS has the ability to join different layers of information or different sources, but GIS also provides tools to process, model and visualize data. (http://en.wikipedia.org/wiki/Geographic_information_system, accessed 30 Nov. 2007; see chapter 4)

Why tracking pedestrians

With traditional methods it is possible to gain insight into pedestrian movement. However, this insight is limited to the scope of the method. Counting people at certain locations leads to insights into the density of the use of the public space only at these locations. Such methods do not collect information on journeys, patterns of use or route choices. Models could possibly estimate where people might walk. However, this would be based on a prediction, and not on an actual situation. Travel diaries might give insights in actual behaviour, but depend on the accuracy of people's minds. A case study in Delft (Spatial Metro workshop, Delft, February 2006: comparison between GPS output and mental maps) showed that the ability of people to reproduce a walked route in a map is inadequate. The actual walking pattern based on GPS tracks deviated repeatedly from the drawn map.

Using GPS technology it is possible to acquire accurate and detailed insights into actual behaviour. The technology will provide insights into the exact departure and return time, time spent at specific locations, destinations, the walked route or geographical route of the journey, the speed and the mode of transport (see chapter 3).

An important aspect of GPS tracking is to collect information on the whole journey from departure to return. In the event of activity-based research, people will probably have a GPS device for a certain period of time at their homes. In the event of studying pedestrian behaviour, this would make no sense, as it is not clear when and how often people will visit the city centre. Collecting data about pedestrian movement in cities requires other ways of distributing and collecting devices and gathering data. Other systems could involve tracking people living or working in a specific building, street or area or tracking people from a specific point at which they enter the city centre.

For the Spatial Metro project, the main target group is visitors of the city centre. The main points of interest are shopping (retail) or leisure (culture, heritage, drinking, dining). The most feasible way of collecting as much data as possible within a short period of time is to distribute and collect the tracking devices at an access point to the city. Access points are e.g. train terminals, bus stations and parking facilities. Parking facilities assure that people will return to their cars and thus return the device. Free parking was offered to people who decided to participate. This way of working meant that no GPS devices were lost. The drawback was that only visitors arriving by car were recorded.

To collect generically useable data without different weekdays affecting the data, data needs to be covered throughout the week. The time frame depends on both the target group and the opening hours of the activities in the city centre – the so called destinations or anchor points. In general, the distribution of the devices started around 10am and continued until around 5pm. People returning late were able to return the devices to the car park information desk (24/7). This practical time constraint excludes people who expect to arrive late.

Field work

From June 20th until June 26th 2007, a team from Delft University of Technology (DUT) in cooperation with Norwich City Council (NCC) carried out fieldwork in Norwich. After that, the field work in Rouen was carried out from October 1st until October 6th 2007 in cooperation with Rouen City Council (Marie de Rouen). Finally, from October 8th until October 14th, fieldwork was carried out in Koblenz in cooperation with Koblenz City Council (Stadtverwaltung Koblenz)

In each city, fieldwork was carried out from two different parking facilities at the same time. This made it possible to collect sufficient and comparable data within one week. The data will be generically useable and comparable as all data from the different locations is collected under the same conditions.

In principle, the chosen facilities were on either side of the city centre. In Norwich the first location was St. Andrews Car Park (1000 cars, opened June 2005), an important parking facility on the northern side of the centre core near The Lanes. The second location was Chapelfield Shopping Mall (1000 cars, opened in 2005 as well), located on the southern side of the centre core and developed at the location of an old chocolate factory. In Rouen the first location was Vieux Marché (400 cars), on the Westside of the city centre. The second location was Haute Vieille Tour (430 cars) on the Southwest side of the city centre. Finally, in Koblenz the location on the Westside was Löhr-Centre, a car park on top of the shopping mall (1400 cars). The second one on the Eastside was Görresplatz, an underground car park (350 cars). (also see Spek, 2008)

Procedure

The information and co-ordination point for the distribution and collection of GPS devices was located near the pedestrian entrance/exit of the parking garage. People leaving the parking garage were handed out flyers explaining the background and setup of the study and asked to contribute to the research. If they matched the 'shopping' or 'leisure' target group, a GPS was presented in return for their parking ticket. To understand the behaviour better, a questionnaire had to be filled in on return. Participation was extremely high. No personal information on any of the participants was kept. (Spek, 2008)

illustration 7.1
GPS-devices used
in the Spatial Metro
project

Processing data

Data was collected from two different sources: track logs resulting in temporo-spatial quantitative information and questionnaires resulting in social-geographical qualitative information. For data management reasons and to keep all data anonymous, a unique code was allocated to every entry.

Processing the data consisted of 5 steps: (1) validation, (2) cleaning, filtering and repairing, (3) individual analysis, (4) collective analysis based on the questionnaire and (5) findings and conclusions. The results of processing are layered analysis drawings in GIS, Photoshop and Illustrator. A selection of these drawing will be used to illustrate the results. (Spek, 2008)

Step 1 Validation

The assessment of temporo-spatial data was based on track data, matches between track data and questionnaire, the start point of the track, the end point of the track, and the readability and consistency of the track. If all questions received a positive response, the file was marked as valid. Otherwise, the file was rejected or had to be cleaned. In further steps of the analysis only valid tracks were taken into account. (Spek, 2008)

Step 2 Cleaning, filtering and repairing

The quality of the raw track log files varies depending on several factors. Cleaning, filtering and evaluating the tracks are necessary to determine validity. Within this study, tracks were only filtered and assessed, with no information which was lacking being added. (Spek, 2008)

Step 3 Analysis of individual data

After validation of the tracks the next step was the specific analysis of the route from the access point to the activities. For all distribution points a map with the alternative routes was generated. All tracks were checked with regard to the route used to walk into the city and the route used to return to the car park. Further, the type of journey was determined. A distinction was made between three types: (A) AREA, the destination is within the direct surroundings of the car park; (B) RETURN TRIP, same route to/from destination, probably a single destination and (C) ROUND TRIP, circular journey, different route, probably multiple destinations.

The following step in this type of analysis is the investigation of destinations and the time spent on these activities. Starting with a list of individual destinations, the result will conclude with a growing list of collective destinations ranking in time or frequency. This is very detailed research and as such has not yet been proposed within this study.

An important aspect for the analysis of tracks starting from Chapelfield and Löhr-Center is that people might start or end their journeys in the shopping mall. Time spent out on the streets can thereby be compared to time spent in a shopping mall and differences in behaviour can also be compared based on the type of starting point. (Spek, 2008)

Step 4 Analysis of collective data

The tracks themselves give an impression of use of the city when projected onto a map. Each individual track represents a person or group. Computations are required to create the collective image covering a selection of respondents. This can be established in GIS software where the temporo-spatial data was analysed using density calculations. With density calculations the number of lines or the number of points within a range of a certain locations are computed and visualised using a specific colour. The colour differs based on lower and higher values. This technique simplifies line or point drawings. Using a legend it is possible to limit the visible data and emphasize structures.

All data was collected with a frequency of 5 seconds. Each dot on the map can therefore be interpreted as representing 5 seconds. Point density represents the time spent at a location. Using the outcome of the questionnaire, density drawings were made for four space-related themes: (1) origin, (2) purpose, (3) familiarity and (4) duration. The demographic themes such as age, group and gender have not been used to prepare specific spatial maps.

Within the theme “Origin”, four subgroups can be distinguished: local, regional, national and international visitors. The theme “Purpose” can be divided into shopping (retail), leisure (i.e. drinking, dining, culture, heritage) and other purposes, including living, education, business or other formal appointments. Within “Familiarity” the subgroups are firstly visitors, occasional visitors and regular visitors. Lastly, the “duration” of the trip is based on the period of time between the distribution and the return of the GPS device. A representative subdivision is based on a two-hour time period, leading to the categories ‘less than two hours’, ‘two to four hours’ and ‘more than four hours’. Per theme two representative subgroups were chosen for the visualisation of the results and conclusions. (Spek, 2008)

Step 5 Findings and conclusions

The background data provided in the questionnaire was analyzed using statistical software, namely SPSS. Frequency tables show how many times an alternative was mentioned. Cross tabulations provide insight into the relationships between subjects or categories.

The analysis also includes the fabrication of conclusion maps. These maps summarize and elaborate the outcomes of the analysis drawings. The maps contain three elements (Spek, 2008):

(1) edge	hard borders in the city which are hardly crossed
(2) no-go area	neglected parts of the city within the range of the access point
(3) attractors	main destinations, buildings and spaces/places

RESULTS

In the following paragraphs the results will be amplified per location. In ‘Synthesis’ a comparison will be made between the cities and the locations. In the last paragraph ‘Reflection’, the method will be discussed in respect to the Spatial Metro project and the investments.

Norwich St. Andrews

The fieldwork in Norwich was carried out from Wednesday June 20th until Tuesday June 26th 2007. The first distribution location was located at St. Andrews car park on the northern side of the historic city centre. This relatively new car park has approximately one thousand parking spaces. Most of them are used by commuters, but specific spaces are reserved for shoppers. The car park is open 24 hours, 7 days a week. The full daily rate is 5.00 pounds. The fieldwork facilities were located near the southern exit on the route to the city centre. This car park is an ideal starting point for destinations around St. Andrews Plain and the Norwich Lanes shopping district. In total, 370 people responded resulting in 173 directly useable tracks. The graphical result of the collective use of space is illustrated in **illustration 7.2**. The origin of the respondents at this location was generally local (84%), although regional visitors were also represented (11%). As expected, the main purpose was shopping (80%), followed by leisure (12%). Most respondents were regular visitors (80%), followed by occasional visitors (18%). People generally stayed in the city centre 2-4 hours (48%), with 40% staying for a shorter period. The main route people took to walk to the centre was Exchange Street, directly in front of the exit and leading to the market and the main shopping street. Alternative routes were along St. Andrews Street and Charing Cross. The return route was generally the same. (Spek, 2008)

Illustration 7.2
Norwich St. Andrews – all valid tracks of seven days

Legend:
circles 400m/800m; dots with a 5-second interval

Norwich Chapelfield

The second distribution location in Norwich was located at Chapelfield mall, a car park and shopping mall on the southern side of the historic city centre. This is also a relatively new car park with approximately one thousand parking spaces. The main focus of the car park is shopping and leisure. The full daily rate is 20.00 pounds, but special flat rates are also available. Access to Chapelfield Car Park is limited from 8am to 10pm. This car park is an ideal starting point for destinations on the southern side of the city centre. The distribution facilities were located near the main exit to the car park in the central hall. In total, 270 people responded resulting in around 80 directly useable tracks. The graphical result of the collective use of space is illustrated in **illustration 7.3**. The origin of the respondents at this location was generally local (80%), although regional visitors were also represented (17%). There were scarcely any national or international visitors at the location. As expected, the main purpose was shopping (90%), followed by leisure (8%). Most respondents were regular visitors (72.5%), followed by occasional visitors (27.5%). People generally stayed in the city centre for 2-4 hours (45%), with 40% staying for somewhat shorter periods. The main routes taken leaving the car park and returning to it were the same, namely Malthouse Road in the direction of Gentleman's Walk. The main destinations were the shopping streets leading to Norwich Lanes and Tombland. In comparison to St. Andrews, the response was far lower, and there were more regional visitors, more shopping as the main purpose, more occasional visitors and people generally stayed for a slightly shorter period. (Spek, 2008)

Illustration 7.3
Norwich Chapelfield – all valid tracks of seven days

Legend:
circles 400m/800m; dots with a 5-second interval

Rouen Vieux Marché

The fieldwork in Rouen was carried out from Monday October 1st until Saturday October 6th 2007. The first distribution location was located at Vieux Marché car park on the western side of the historic city centre. The fieldwork facilities were located near the pedestrian exit of the garage. The car park is located in the main pedestrian area, which makes it an ideal starting point for the main cultural and commercial destinations. In total, 240 people responded resulting in 150 directly useable tracks. The graphical result of the collective use of space is illustrated in **illustration 7.4**. The origin of the respondents at this location was generally regional (46%), although local visitors were highly represented (37%). As expected, the main purpose was shopping (69%), followed by leisure (18%). Most respondents were regular visitors (64%), followed by occasional visitors (25%). People generally stayed in the city centre less than 2 hours (57%), with 35% staying for longer periods. The main route people took when walking to the centre was Rue du Gros-Horloge, directly leading to the Gros-Horloge ending at the Cathedral. Alternative routes were two parallel streets, namely Rue Saint-Lô and Rue Rollon. The route back was generally the same. The main destination was the shopping area between Vieux Marché and the Cathedral. (Spek, 2008)

Illustration 7.4
Rouen Vieux Marché – all valid tracks of seven days

Legend:
circles 400m/800m;
dots with a 5-second interval

Rouen Haut Vieille Tour

The second distribution location was located at Haut Vieille Tour car park on the south-eastern side of the historic city centre, directly south of the Cathedral. The fieldwork facilities were located near the main pedestrian exit of the garage. The car park is not located in the pedestrian area, but is relatively close to the main cultural and commercial destinations. In total, 180 people responded resulting in over 130 directly useable tracks. The graphical result of the collective use of space is illustrated in **illustration 7.5**. The origin of the respondents at this location was both regional (42%) and local (39%). The car park is also used by international visitors (11%). As expected, the main purpose was shopping (66%), followed by leisure (21%). Most respondents were regular visitors (58%), followed by both occasional visitors (22%) and people on a first-time visit (20%). People generally stayed in the city centre for less than 2 hours (50%), with 38% staying for longer periods of 2-4 hours. The main route people took to walk to the centre was Rue de L'Epicerie, directly leading to the Cathedral. Most other alternatives were also used. Remarkably, the route back varied significantly to the route taken in. The main destinations were the Cathedral and from there Vieux Marché via the Rue du Gros-Horloge. In comparison to Vieux Marché, the response was lower, but the origin of people was more or less identical; the same applies to the respondents' purposes. In Haute Vieille Tour, more respondents were new visitors and people tended to stay for longer periods. (Spek, 2008)

Illustration 7.5
Rouen Haut Vieille Tour – all valid tracks of seven days

Legend:
circles 400m/800m;
dots with a 5-second interval

Koblenz Löhr-Center

The fieldwork in Koblenz was carried out from Monday October 8th until Saturday October 13th 2007. The first distribution location was located at the Löhr-Center – a car park on the roof of the main shopping mall on the western side of the city centre. A new railway station for the city centre is planned at the rear of this mall, with its main entrance situated at the Löhr-Rondell. The fieldwork facilities were located near the main pedestrian exit of the garage. The mall is located on the edge of the pedestrian area and is relatively close to the historic city centre, but the main tourist destinations such as the riverfronts are beyond reach. The mall has three exits: one on the Southside to Löhr-Rondell, one in the middle on the western side and one on the northern side of the building which connects to a pedestrian tunnel. In total, 180 people responded resulting around 100 directly useable tracks. The graphical result of the collective use of space is illustrated in **illustration 7.6**. The origin of the respondents at this location was mainly regional (60%). National and international visitors also use this car park (20%). As expected, the main purpose was shopping (75%), followed by leisure (22%). Most respondents were occasional visitors (50%) but the location is also used by new visitors (20%). People generally stayed between 2-4 hours (58%) or less than 2 hours (26%). A large group only uses the car park to access the city (40%), but the car park is also used for the mall itself – 33% of all visitors stay in the mall for over one hour. The exit people mainly took when walking to the centre was the Western exit directly leading to the Löhrstrasse. However, the route back varied significantly to the outbound route. The main destinations were within a range of 400 metres, and were mainly on the Löhrstrasse – the shopping street. (Spek, 2008)

**Illustration 7.6
Koblenz Löhr-Center – all valid tracks of seven days**

**Legend:
circles 400m/800m;
dots with a 5-second interval**

Koblenz Görresplatz

The second distribution location was located at the Görresplatz car park on the eastern side of the city centre between the shopping district and the waterfront. The fieldwork facilities were located near the main pedestrian exit of the garage. The car park is located in the pedestrian area and is relatively close to the main cultural and commercial destinations. In total, 120 people responded resulting in around 100 directly useable tracks. The graphical result of the collective use of space is illustrated in **illustration 7.7**. The origin of the respondents at this location was mainly regional (54%). A fair number of national and international visitors also use this car park (38%). The main purpose was shopping (48%), directly followed by leisure (43%). Most respondents were new visitors (40%), followed by both occasional visitors (32%). People generally stayed in the city centre between 2-4 hours (51%), with 36% staying for shorter periods of less than 2 hours. The main route taken on leaving the location led to the shopping streets via the Firmunstrasse. However, remarkably enough, the route back varied significantly to the route in. People tended to browse their way back to the car park leaving a sprawled pattern of use. In comparison to the Löhr-Center the response was lower but more profitable. The origin of people in both locations was mainly regional, although Görresplatz had a greater number of national and international visitors. This factor affects the purpose statistics; in comparison to Löhr-Center, virtually twice the number of visitors to Görresplatz had leisure as their purpose, a number almost equal to that for shopping. In Görresplatz, far more respondents were new visitors, but people tended to stay for shorter periods. (Spek, 2008)

Illustration 7.7
Koblenz Görresplatz – all valid tracks of seven days

Legend:
circles 400m/800m;
dots with a 5-second interval

CONCLUSIONS

This paragraph will give an overview of the results and conclusions of the different cities and locations. The result of the themes will be compared with a view to understanding the differences and similarities in visitors' behaviour in different cities. The comparison will be based on the four main themes: purpose, origin, familiarity and duration. Two graphical themes have been added, namely distance and spatial pattern.

Origin

Origin is divided into three separate categories: local, regional, (inter)national (see **illustration 7.8**). In all cases, national and international were the smallest groups. Especially in Koblenz, national and global visitors were represented (Görresplatz 38% and Löhr-Center 21%). In Koblenz, the majority of visitors were regional (59 and 54% respectively). Rouen is more orientated toward regional (42-46%) and local visitors (37- 39%). Norwich therefore seems to

Illustration 7.8
Visitors to the three cities (6 locations) according to three scales of origin: local, regional and (inter)national

be operating on the lowest scale with mainly local visitors and a tendency toward attracting regional visitors (81-84% and 11-17% respectively).

Purpose

The primary purposes of the visitors were shopping and leisure (see **illustration 7.9**). Not surprisingly, the shopping purpose was much higher at the two mall locations (Norwich 89% and Koblenz 75%). The main purpose in Norwich was shopping (79-89%), followed by Koblenz (48-75%). Rouen was somewhere in the middle (66-69%). The leisure purpose was mainly represented in Koblenz Görresplatz (43%). In the other cities, leisure was only indicated for 8-22%. Within shopping, a distinction is made between daily, fashion and luxury and non-daily shopping. Koblenz represents the highest ranks for daily purposes (15-18%), followed by Rouen (1015%) and Norwich (5-10%). In Norwich on the other hand, Fashion & Luxury were more frequently indicated as shopping purposes (50-63%) compared to the other cities (26-43%).

Rouen Haut Vieille Tour **Koblenz Löhr-Center** **Koblenz Görresplatz**

Local Local Local

Regional Regional Regional

(Inter-) national (Inter-) national (Inter-) national

Illustration 7.9
Visitors to the three cities (6 locations) according to the purpose of their visit: shopping or leisure

Purpose

Norwich St. Andrews | **Norwich Chapelfield** | **Rouen Vieux Marché**

Shopping | Shopping | Shopping

Leisure | Leisure | Leisure

Illustration 7.10
Visitors to the three cities (6 locations) according to their familiarity with the city: first-time visitor, occasional visitor or regular visitor

Familiarity

Norwich St. Andrews | **Norwich Chapelfield** | **Rouen Vieux Marché**

First Visit | First Visit | First Visit

Occasional | Occasional | Occasional

Regular | Regular | Regular

Rouen Haut Vieille Tour

Shopping

Leisure

Koblenz Löhr-Center

Shopping

Leisure

Koblenz Görresplatz

Shopping

Leisure

Rouen Haut Vieille Tour

First Visit

Occasional

Regular

Koblenz Löhr-Center

First Visit

Occasional

Regular

Koblenz Görresplatz

First Visit

Occasional

Regular

Illustration 7.11 Visitors to the three cities (6 locations) according to the length of their visit: less than two hours, between two and four hours or more.

Duration

Norwich St. Andrews **Norwich Chapelfield** **Rouen Vieux Marché**

Less than 2 hours Less than 2 hours Less than 2 hours

2-4 hours 2-4 hours 2-4 hours

More than 4 hours More than 4 hours More than 4 hours

Familiarity

The assessment of familiarity with the city was based on the frequency of visits: first-time visitor, occasional visitor or regular visitor (see **illustration 7.10**). The respondents in Norwich clearly marked themselves as regular visitors (73-79%). The group hardly included any new visitors (0-3%). Rouen was visited by a mix of regular (58-64%) and occasional (22-25%) visitors. In Koblenz, the visitors were a mix of occasional (32-50%) and new visitors (18-40%). These figures correspond with the origin of the participants, assuming that locals visit the city centre more often and national and international visitors only incidentally.

Duration

For the duration, the time between distribution and collection of the GPS devices was calculated. Three workable divisions were made: less than two hours (< 2hrs), between two and four hours

Rouen Haut Vieille Tour

Less than 2 hours

2-4 hours

More than 4 hours

Koblenz Löhr-Center

Less than 2 hours

2-4 hours

More than 4 hours

Koblenz Görresplatz

Less than 2 hours

2-4 hours

More than 4 hours

(2-4hrs) and more than four hours (> 4hrs). The first conclusion is that the presence of a mall does not influence the total time spent. Both malls function as attractors and access points to the city. In this sense, a short time is spent in the mall and a longer period in the city. However, people also stay in the malls for longer periods and leave the malls for more limited periods. This influences the registered image of use outside the mall. A clear distinction can be made between the time spent in these three cities (see **illustration 7.11**). Participants stayed in Rouen for the shortest period of time: most of them under 2 hrs (50-57%) and some 2-4 hrs (35-38%). In Norwich, the respondents mainly stayed 2-4 hrs (45-48%), and some shorter (40%). Koblenz was the city where people generally stayed the longest: 2-4 hours (51-58%) and some shorter (26-36%).

Walking distance and form of covered area

For the spatial pattern, three types can be distinguished: line (or axis), area and main area with satellite destinations. Most locations fall within the area type. Exceptions are Koblenz Löhr-

Center with a strong axis as spatial character for all movement, and Norwich St. Andrews, undoubtedly an area with satellite destinations. To measure the maximum distance, circles of 400 and 800 metres were projected into the result drawings (5 and 10 minutes walking time respectively, depending on the spatial structure and local conditions). Evidently, Koblenz Löhr-Center has the smallest reach of approximately 400 metres. The other exception, also a mall location, was Norwich Chapelfield. Here the maximum walking radius was approximately 600 metres. All other examples had a maximum walking radius of approximately 800 metres.

REFLECTION

The tracking and questionnaire data give good insights into the behaviour and background of a large group of various types of visitors to the city centre. The technology makes it possible to collect and visualize data of movement. The background data provides the opportunity to select data and focus on specific themes and aspects. Using this method, it becomes clear that people behave in different ways in these historic European city centres. Different programmes (functions) are available, as well as different ways to access the city and different structures to use the city as a pedestrian. Up to the present, the method has only been used to monitor and visualise the dynamics in the participating historic cities. The method has not yet been used as a tool to evaluate or address urban design issues. However, this application of the tool can be foreseen.

Application of the results

In Norwich, various design issues can be mentioned. St. Andrews seems to be well-integrated its surroundings and contributing to the city. Especially Exchange Street has become a key access street into The Lanes. Chapelfield on the other hand seems to rely on connections to the north alone. The route between Chapelfield Mall and Gentleman's Walk is not consistent. The Chapelfield Gardens and the area around the bus station are scarcely used and scarcely directly accessible. More integration could be useful to activate these opportunities. Remarkably, King Street and Prince of Wales Street were both scarcely used by the respondents. It might be that the participating population is not attached to these areas, and that tracing visitors arriving at the railway station would show a different response. Still, in combination with Tombland as a turning point, the position in the network of the historically rich King Street could be improved. New access or arrival points on the eastern and western side would create new access streets. Finally, the investments in St. Andrews Plain should be part of a strategy to attract people to the area and connect smoothly to other areas such as Tombland and The Lanes. (Spek, 2008)

In Rouen a frame has been developed based on strategic routes (the lines), nodes (the stations) and access or arrival points (the gateways). The frame is strengthened by a light master plan, the illumination of key buildings and guiding people safely at night. The GPS tracking study indicates several issues. One of these is the neglect of the waterfront. A new route along the water has been suggested, but connections to the current urban tissue are required to improve the waterfront's attractiveness and accessibility. The Rue du General Leclerc offers High Quality Public Transport (TEOR), but is scarcely used by pedestrians. It is a border area between the pedestrian zone and waterfront. The Rue de la Republique is a barrier and due to the intensity of the traffic, not a pleasant route for pedestrians. Finally, the area around the Musee des Beaux-Arts is not well-integrated into the routes followed by the participants on their visits to the city centre. The area has an interesting public square. (Spek, 2008)

Finally, in Koblenz the Spatial Metro investments are part of a strategy for the Bundes Gartenschau in 2011. Up to the present, the research results have shown a limited use of the network and public spaces in the city centre; pedestrian activity is located in the main pedestrian streets. The Spatial Metro investments include essential upgrades of the current shopping streets for pedestrians. Other investments are crucial with a view to completing this work and providing a consistent system of public spaces and programmes. Essential projects are the Schlossstrasse and Zentralplatz. Further redevelopment is necessary to upgrade the waterfront and connect it better to the city centre and historic city. A first essential step has been set by redesigning the Löhrrondell, the key location connecting Schlosstrasse, Löhrstrasse, Löhr-Center and the new railway station. (Spek, 2008)

CONCLUDING REMARKS

The findings in this study are based on the explanation of the statistical information, the assessment of the drawings (density image of a theme), a comparison within the series of the theme and a comparison between locations. All outcomes should be considered as results derived from the behaviour of the participating population. The study does not provide insight into the background and behaviour of all visitors, but only the cooperating population.

The GPS method influences the potential population participating in the research and in this case, limits it to visitors arriving by car. Nevertheless, the results of the observation give a striking and useable image of the city.

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8

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MOBILE SURVEYS

In recent years, a new approach for estimating people's movement in cities has emerged through mobile phone positioning. As opposed to the more traditional methods of traffic surveys, automated counts, or individual counters on streets, the use of aggregated and anonymous cellular network log files has shown promise for large-scale surveys with notably smaller efforts and costs (Reades, Calabrese, Sevtsuk & Ratti, 2007). In addition, a frequent data feed from the cellular network has also been argued to demonstrate fine grain over-time variation in urban movements, which are lacking from the traditional prediction methods (Ratti, Pulselli, Williams & Frenchman, 2006). However, despite the positivist approach to the new methodology, additional evidence is needed to show how cellular network signals correlate with the actual presence of vehicles and pedestrians in the city. The purpose of this paper is to address this shortcoming by presenting the results of a survey effectuated in Rome, Italy in January 2007. Using the results of the two-day experiment, we will employ statistical models to investigate the relationship between empirical pedestrian and traffic counts on the streets of Rome with the simultaneous Telecom Italia Mobile (TIM) network signal and traffic prediction. Secondly, we will explore whether the mobile network data demonstrates the significant time-dependent variation that is missing from traditional fixed predictors like Space Syntax choice and integration analysis and could thus describe cities dynamically over time. Finally, we will also outline some general issues of accuracy in using aggregate mobile network data for estimating people's movement in cities.

INTRODUCTION

As more than half of the world's population now inhabits cities, and more cities are being designed and constructed than ever before, the need for analyzing and understanding how cities function in daily life increases. Most of the knowledge available to us on this topic is concerned with the social demographics and the constructed elements of cities – streets, buildings, public spaces, parks etc. Much less is known about how these elements are actually used and what the temporary patterns of people's movements between the fixed points look like. As people's movements and actions are hard to predict and difficult to track, it has been traditionally challenging to study the usage dynamics of large cities.

In recent decades, urban mobility modeling has witnessed a rise due to advances in computational capacity and the development of virtual simulation environments. Several theories have been developed to explain people's mobility. Hillier et al. have interestingly shown that people's movements in cities are remarkably tied to the geometric configuration of the street network (Hillier, Hanson & Peponis, 1987). Their quantitative technique of measuring topological graphs for predicting mobility flows, called Space Syntax, has gained particular popularity amongst architects and urban designers over the past decades. Others have argued that streets are more than topological networks and their usage is largely dependent on the morphology of the urban area (Anderson, 1986; Ellis, 1986; Mathema, 2000). Their approaches argue that streets are not only channels that allow people to flow between the nodes of an urban network, but also places of encounter and interaction; they are transit spaces as well as places. Both approaches suggest, however, that the usage of a street is strongly dependent on urban form: on the one hand on the arrangement of connections, on the other, its content and shape. Transportation researchers have studied the impact of amenities, land use and transit connections on transportation flows (Cervero, 1989; Handy, 1996; Rodriguez & Woo, 2002; Zegras, 2005) and developed quantitative models to predict pedestrian volumes of an area (Chung, 2003). Yet other scholars have claimed that physical neighborhood characteristics only have a minor impact on travel behaviour (Crane, 1996). More recent developments in discrete choice modeling (DCM) have started simulating pedestrian and vehicular movement dynamically in time (Antonini, Bierlaire, Webber, 2006; Ben-Akiva et al., 1997). Even though most researchers argue that urban form does affect pedestrian activity, and accept that mobility patterns can be at least partially predicted, there does not seem to exist an agreement on how and to what extent. Overall, the scientific explanations of mobility flows present multiple views and a lack of consensus and an empirical methodology for confirming the theories is much awaited.

Recent developments in portable communication have rendered mobile phones increasingly affordable and popular, which makes mobile network logs appealing for aggregate analysis of urban population flows. The work on the geographic analysis of mobile phone log files effectuated thus far has mainly centered on two aspects: the positioning of individual users for a variety of location based services (LBS), social networking and individual tracking purposes (Ohmori, Harata, Nakazato, 2005; Laineste, 2003) and probing the mobile data for vehicular traffic analysis (Kummala, 2002; Rose, 2006; cf. chapter 11). Relatively little work has been done to analyze the aggregate movements of people in the city through mobile phone data. This has been attempted in a few projects at MIT's SENSEable City Laboratory (Ratti, Pulselli, Williams & Frenchman, 2006; Ratti, Sevtsuk, Huang & Pailer, 2005; Calabreses, Reades & Ratti, 2007), and Tartu University in Estonia (Ahas, Aasa, Mark, Pae & Kull 2007) . This lack is probably caused by the difficulty to obtain the data and the uncertainty about how well mobile traffic data represents the actual mobility of people in cities. Yet, for urban planners, this is the most awaited kind of analysis, which could possible yield empirical evidence for explaining large scale dynamics of an urban population.

The mobile network data also has its reservations. Compared to the more detailed information available in origin and destination surveys, and DCM models, aggregated analysis of mobile network logs does not yet inform us where people's journeys start and end. Instead, the data only describes how many callers are where at any given time. However, this qualitative shortcoming is counterbalanced by a quantitative advantage: the network logs can be obtained from a city-wide telecom system that is already in place with relatively minor effort. Furthermore, the data can theoretically be sampled in real-time for a period of any length. These are the promising advantages of mobile network data. The purpose of this paper is to analyze how accurately and reliably the data describes the actual presence of people on city streets. Using Rome as a case study, we will be addressing two main questions. First, do the vehicle estimates (BSC data) and overall network activity measures (Erlang data) on Telecom Italia's network correlate with empirical observations of vehicles and pedestrians on specific streets in Rome? And secondly, does mobile phone data predict additional over time variation in mobility patterns that is missing from traditional fixed predictors?

MEASURES

Predictors

In Italy, there are now more registered mobile phones than people [1]. The data used in this paper comes from Telecom Italia (TIM), the largest service provider in the country. Besides TIM, there are three other large service providers in Rome: Omnitel Vodafone, Wind and Blue. TIM is currently market leader in the city, supplying about 40.3% of the share. This constitutes approximately one million users in Rome, less than half of the city's population. However, TIM's data used in this study does not describe the activity of all the registered users in Rome, but only those who were actively engaged in phone calls during the measurement periods. In particular, we will be using two distinct sources of TIM's network data: 1) traffic information from Erlang measurements of individual antennae and 2) aggregate vehicular traffic predictions from Base Station Controllers (BSC). We use Erlang in the models as a question predictor for pedestrian counts, and BSC_veh as a question predictor for vehicle counts.

Erlang measurements are commonly used for assessing aggregate mobile network traffic in particular cells. An Erlang measure is essentially a use multiplier per unit time. The use of one mobile phone for one hour in a particular cell constitutes one Erlang, whereas the use of two phones for half an hour each also constitutes one Erlang. Each network cell has a unique Erlang value at any given time, depending on the amount and length of calls processed by that cell. In this study, Erlang data from selected cells in Rome was measured at 15 minute intervals during two days as shown in the sample in **Illustration 8.1**.

Illustration 8.1 - Example of Erlang values

	Erlang Values				
Cell ID	**RM25**	**RY36**	**RK38**	**RJ98**	**RM01**
12/01 08:00..08:15	16277	1219	16277	7056	3730
12/01 08:15..08:30	22543	1170	22543	9393	6350
12/01 08:30..08:45	29100	1302	29100	12571	8722
12/01 08:45..09:00	38321	1636	38321	12338	8320
12/01 09:00..09:15	53393	2224	53393	16715	8689
12/01 09:15..09:30	62582	3124	62582	23185	11347
12/01 09:30..09:45	64678	2843	64678	21049	10999
12/01 09:45..10:00	72001	3316	72001	25904	13380
12/01 10:00..10:15	69800	2905	69800	24433	12184
12/01 10:15..10:30	76793	4313	76793	30870	12107

For the purpose of this analysis, we transformed the Erlang values in TIM's dataset by dividing the raw measures by the area of the given cell and the amount of antennae in that cell. This resulted in an Erlang measure that shows how much call volume is processed in each cell per equal unit area and a single antenna.

In addition, estimates for the number of calls originating from vehicles were obtained from two base-station controllers (BSC) in the north-eastern part of the city center. Each BSC monitored the activity in a set of individual cells and aggregated the information into a continuous rectangular grid of 250x250 meters, covering the area of multiple cells. Thus each BSC measurement estimated how many calls within each 250x250 meter "pixel" in a 15 minute time period had occurred, and filtered out those that had a mean speed above 8km/h during the call, categorizing the latter as the number of vehicles. Unlike Erlang, which was generated by all calls that were processed by a given cell, BSC measures were obtained by anonymously triangulating all clients who engaged in calls, determining which pixel they were located in. The callers' position was obtained by using a combination of methods including cell Id, angle of arrival, timing advance, and signal strength triangulation. The raw information was presented in matrix form, where each value corresponded to the estimated number of calls from vehicles in a certain pixel, as shown in **Illustration 8.2**.

Illustration 8.2 - BSC estimates for calls originating from vehicles

```
HOUR 8; MINUTES 15
YEAR 2007; MONTH 1; DAY 12
CITY Roma
NROWS 48; NCOLS 56
ULXMAP 785566.000000; ULYMAP 4650585.000000
XDIM 250.0; YDIM 250.0

0  0  0  0  0  0  0  0  1  0  0  0  0  0  0  0  0  0  1  0  0  0  0  0  0  0  0  1  0  0  0  0

0  0  0  0  0  0  0  0  0  0  0  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0

1  1  0  0  0  0  0  0  0  0  1  0  1  1  2  1  0  0  0  0  0  0  3  0  0  0  0  0  1  1  1  2

0  0  0  0  0  0  0  0  1  1  2  2  3  3  4  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0

0  0  2  0  0  0  0  0  0  0  1  0  1  2  2  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
```

In addition to the two question predictors from the mobile network, a few additional control predictors were used. *Major_arterial* was a dichotomous predictor indicating whether a street was classified as a major arterial road in the Navteq street database or not. Two commonly used space syntax measures were also included: integration with a radius of 400m (int_r400) and choice with a radius of 3200 m (choice _r3200) (a more detailed explanation of these variables can be found in Hillier (1984 (1989)). The value for the integration analysis with the radius of 400 meters (int_r400) is commonly used in space syntax as a predictor of average pedestrian flow on a particular street. The choice analysis with a radius of 3200 meters is commonly used for vehicular traffic predictions. Since the choice values are computed with an exponential distribution, we followed a common practice of transforming the choice_r3200 values by a log2. Finally, *Weekend* was a dichotomous predictor indicating if the count was measured on a Friday or Saturday. **Illustration 8.3** presents the descriptive statistics of the predictors and outcomes used in the models.

Illustration 8.3 Descriptive statistics of the outcomes and predictors

	Mean	Std. Deviation	Range	Min.	Max.	N
Pedestrians	198.28	216.63	1046.00	10.00	1056.00	396
Vehicles	141.97	128.26	634.00	2.00	636.00	374
BSC_veh	0.78	0.83	3.50	0.00	3.50	396
Major_arterial	0.33	0.47	1.00	0.00	1.00	396
Raw cell_Erlang	35017.26	29893.93	92737.00	116.00	92853.00	396
Cell_Erlang_norm (question)	0.05	0.04	0.12	0.00	0.13	396
Int_400	33.42	19.37	74.61	-1.00	73.61	374
Log2_ch_r3200	15.51	3.72	14.05	4.17	18.22	374
Weekend	**0.50**	**0.50**	**1.00**	**0**	**1**	**374**

Outcomes

Based on the availability and geographic distribution of Erlang and BSC data, 9 locations in the neighborhood around the Termini train station in Rome were selected for comparative pedestrian and traffic counts. This area was attractive for the study because it was well covered in TIM's dataset and it contained a uniformly dense urban fabric with ostensibly many pedestrians and cars. The counts were effectuated on January 12th and 13th, a Friday and a Saturday. On both days, six counters counted vehicles and pedestrians from 8am to 8pm on 18 street segments using tally-sheets. Pairs of two counters circulated between three particular street intersections in a continuous loop, counting the two intersecting streets at each intersection for 15 minutes at a time, returning to the same place once every hour. The intersections and street segments were chosen after a personal site visit, so that the seemingly largest intersection in each cell of interest gave a representative estimate for the pedestrian and vehicular traffic in that cell. The counting period was chosen to match the 15-minute Erlang and BSC measurement periods. **Illustrations 8.4 and 8.5** below illustrate the chosen streets that were counted and the corresponding Erlang cells and BSC pixels.

ANALYSIS

Naturally the 9 intersections that were chosen varied in exact size. As the mobile phone data estimates referred to the whole coverage area of network cells or BSC pixels, and not individual streets, then the representational "weight" of each counted street was different. Furthermore, all streets where counts occurred had a slightly different importance relative to the total set of

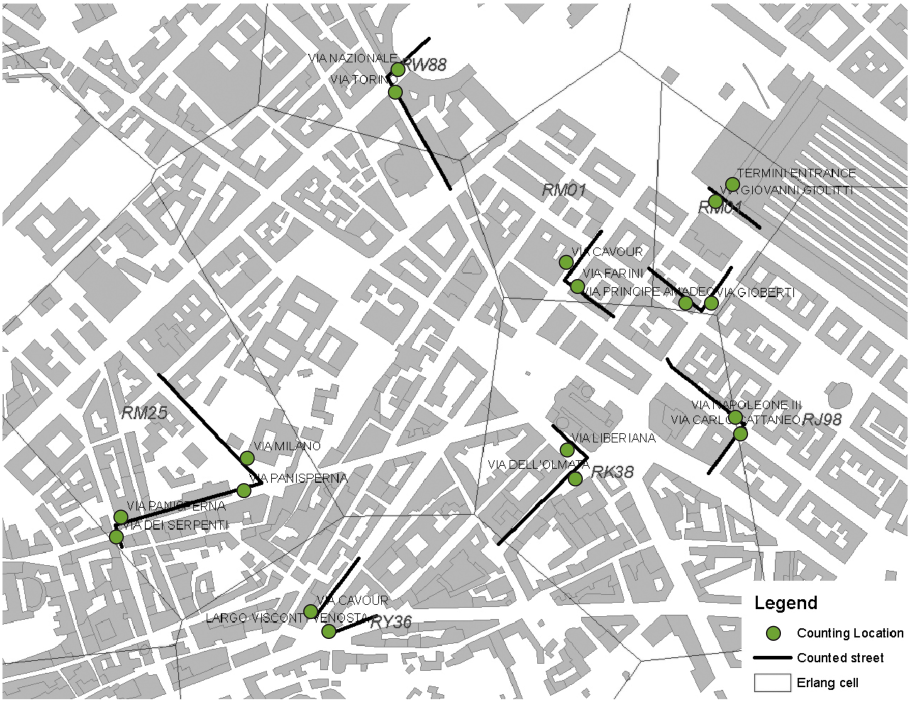


Illustration 8.4
Map of counted streets and Erlang cells.

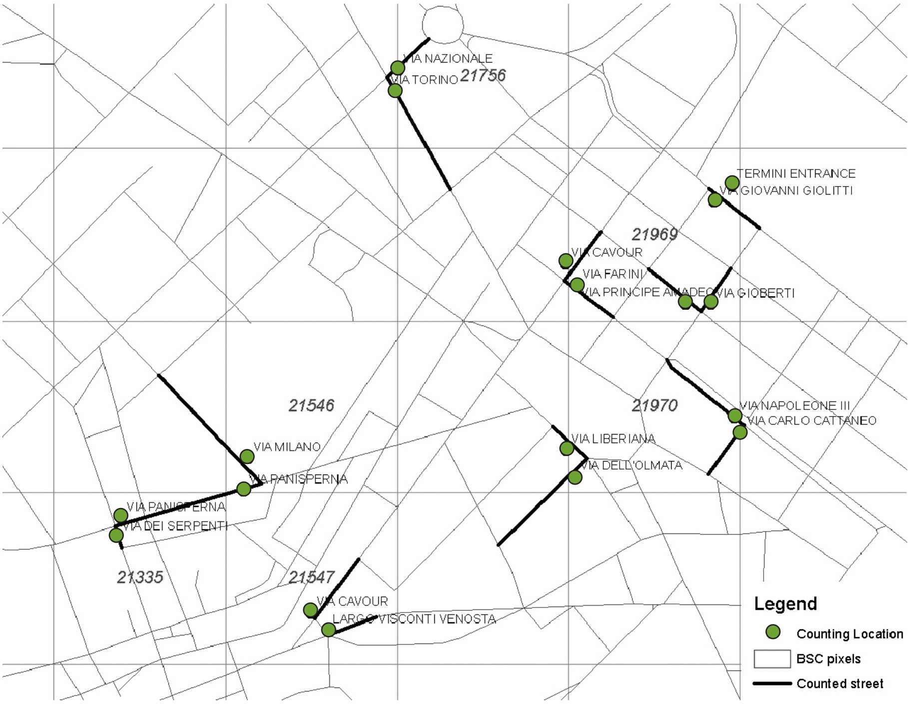


Illustration 8.5
Map of counted streets and BSC pixels.

streets within each cell or pixel. Some streets were clearly the busiest ones out of all the streets within a given cell, whereas others were less hierarchal compared to the rest of the streets in the pixel. Therefore some count locations naturally captured a larger proportion of traffic in their area than others. These location differences and the repeated nature of the counted data (every location was counted 11 times a day, and 22 times during both days) demanded that the similarity of variance at the same locations during different counting times be taken into account. For specifying a statistical model this suggested that a multilevel structure of repeated measurements be used. A multilevel structure was therefore specified in the SAS software MIXED procedure using a random effects model. Using this model, we will first proceed with the analysis of the vehicle prediction and subsequently turn to pedestrian counts.

TIM's Vehicle Traffic Prediction

First, the unconditional model M1 was specified as a base line against which we could compare the gains of adding predictors from the mobile network. The unconditional model allowed the intercepts to have random effects at different counting locations. The estimated parameters of this model are shown in **Illustration 8.6**. The fixed effect of the intercept across all locations showed that the average count during the first observation period (8.00-8.15am) was 141.97 vehicles. The random effects part of the models show how the intercepts and residuals vary across the counting locations. We see that intercepts did vary significantly between locations ($p < 0.01$), which indicates that a large portion of the variation (81%) can systematically be attributed to differences amongst counting locations. The remaining 19% of all variation was attributable to the residuals of individual streets, which suggests that the differences between streets were a much greater cause of variation than the hourly fluctuations of vehicles on particular streets.

After specifying the unconditional model, we added only BSC_veh as a predictor to model M2 in order to test if BSC_veh alone could explain variations in the counted traffic data and thus be singularly used as a reliable estimate for vehicle traffic on particular streets. The results showed that BSC_veh did have a significant fixed linear effect on the vehicle counts: a one point change in the BSC_veh estimate was associated with a 20.01 point change in vehicle counts ($p < 0.001$).

Looking at the random effects, we see that the improvement in prediction between different locations attributable to TIM's vehicle prediction in M2 can be summarized by the proportional decline in the between-street residual variance. This shows that Telecom Italia's vehicle prediction could alone explain 31% of the variation in our traffic counts. This correlation was quite good, considering that most (81%) of the variation in the counts came from differences

Taxonomy of fitted multilevel models describing the relationship between the empirical vehicle counts and TIM's vehicle traffic estimates, cntrolling for road-classes and Space Syntax choice estimates (n streets= 18, n counts= 342)

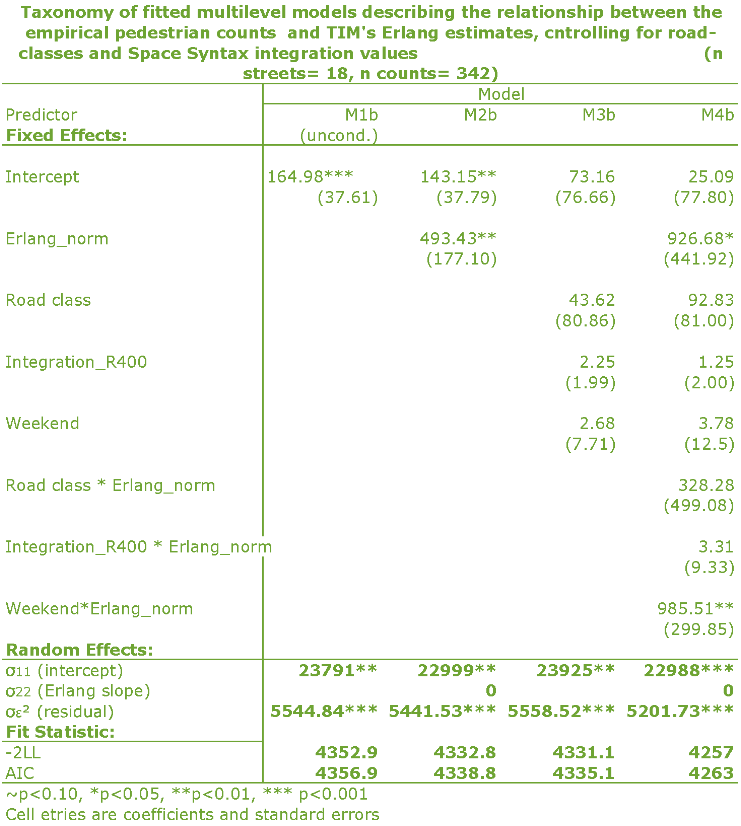
	Model			
Predictor	M1 (uncond.)	M2	M3	M4
Fixed Effects:				
Intercept	141.97***	127.22***	7.84	56.35
	(28.80)	(24.16)	(92.48)	(75.84)
BSC_veh		20.01*		-36.74
		(8.06)		(29.63)
Road class			150.78**	136.58**
			(46.90)	(38.26)
Log2_ch_r3200			6.64	3.71
			(6.03)	(4.93)
Weekend			-43.96***	-48.52***
			(5.46)	(7.75)
BSC_veh * Road class				18.89
				(17.47)
BSC_veh * Log2_ch_r3200				2.02
				(1.98)
BSC_veh*Weekend				12.39
				(9.72)
Random Effects:				
σ_{11} (intercept)	**13950****	**9649.54****	**7661.08****	**4948.68****
σ_{22} (BSC_veh slope)		**746.90***		**682.04***
σ_{ε}^2 (residual)	**3286.03*****	**2764.02*****	**2787.65*****	**2415.83*****
Fit Statistics:				
-2LL	**4157.6**	**4098**	**4066.2**	**4000**
AIC	**4161.6**	**4106**	**4070.2**	**4008**

Significance level ~p<0.10, *p<0.05, **p<0.01, *** p<0.001
Cell etries are coefficients and standard errors

Illustration 8.6
Taxonomy of fitted multilevel models predicting vehicle counts.

between streets. The within-street residual variance declined by 16% with the addition of BSC_veh, which means that Telecom's traffic estimate also explained 16% of the traffic over time variation on the same streets. In addition we see that the random effect of BSC data (σ22 BSC_veh slope) was also significant at a 95% confidence level, suggesting that the relationship between TIM's traffic estimate and the actual counts varied from street to street. We thus conclude that a significant relationship of BSC_veh and empirical counts is found, and 31% of the between-street variations as well as 16% of the within-street variation in vehicular traffic are explained by TIM's vehicle prediction. These findings are encouraging given the very small mean and range of BSC_veh values. Furthermore, we know that BSC_veh is an estimate for an urban area of 250x250 meters, which includes many different streets, whereas the counting data was collected from only specific streets within each square. Based on these results we can hypothesize that using the BSC_veh values for estimating traffic at a larger scale than singular streets (for instance, block level, neighborhood level or even district level) might result in even better predictions.

Illustration 8.7
Taxonomy of fitted pedestrian count models.



Taxonomy of fitted multilevel models describing the relationship between the empirical pedestrian counts and TIM's Erlang estimates, cntrolling for road-classes and Space Syntax integration values (n streets= 18, n counts= 342)

	Model			
Predictor	M1b	M2b	M3b	M4b
Fixed Effects:	(uncond.)			
Intercept	164.98***	143.15**	73.16	25.09
	(37.61)	(37.79)	(76.66)	(77.80)
Erlang_norm		493.43**		926.68*
		(177.10)		(441.92)
Road class			43.62	92.83
			(80.86)	(81.00)
Integration_R400			2.25	1.25
			(1.99)	(2.00)
Weekend			2.68	3.78
			(7.71)	(12.5)
Road class * Erlang_norm				328.28
				(499.08)
Integration_R400 * Erlang_norm				3.31
				(9.33)
Weekend*Erlang_norm				985.51**
				(299.85)
Random Effects:				
σ_{11} (intercept)	**23791****	**22999****	**23925****	**22988*****
σ_{22} (Erlang slope)		**0**		**0**
σ_{ε}^2 (residual)	**5544.84*****	**5441.53*****	**5558.52*****	**5201.73*****
Fit Statistic:				
-2LL	**4352.9**	**4332.8**	**4331.1**	**4257**
AIC	**4356.9**	**4338.8**	**4335.1**	**4263**

~p<0.10, *p<0.05, **p<0.01, *** p<0.001
Cell etries are coefficients and standard errors

We next explored whether the addition of TIM's traffic estimate to a different conditional model, which already contained three static predictors: road-class, radius 3200m choice estimate from Space Syntax analysis, and a dummy variable for weekend, could explain any dynamic variation in the outcome. Since both road classifications and space syntax estimates provide a fixed average value for each street, regardless of the fluctuations in traffic that occur on the street in an hourly, daily or weekly scale, we expected the BSC_veh estimates, collected at 15min intervals, to improve the model significantly

The results showed that the addition of the BSC data to the conditioned model that already included road_classes, space syntax choice values and *weekend*, decreased the within-street residuals by 13%. Thus we find that there was indeed a component of over time variations in the traffic counts explained by TIM's traffic predictions, which was not be predicted through the fixed predictors. Again, the results are encouraging even though the majority of over time residual variations on individual streets still remained unexplained with TIM's predictor in the model and we conclude that the BSC_veh estimates do show promise for illustrating how vehicular traffic flux oscillate at particular streets during different hours of the day.

ERLANG AND EMPIRICAL PEDESTRIAN COUNTS.

We will now turn to the analysis of how the antenna level Erlang measures predicted the pedestrian flux on particular streets. Since the analysis is very similar to the vehicular traffic analysis above, we can directly turn to the findings.

The unconditional model for predicting pedestrian flux through TIM's Erlang measurements was specified similarly to the unconditional vehicle model. The results of the pedestrian models are shown in **Illustration 8.7**.

The intercept of the unconditional model, used as a baseline, showed that during the first counting period (8.00 – 8.15am) there were on average 164.98 pedestrians on a street. The random effect of the intercept shows that the counts at different locations did vary significantly ($p < 0.01$).

We next added the Erlang predictor to the model and tested whether Erlang alone would reveal a significant relationship with the pedestrian counts. The resulting estimated Erlang fixed effect captured the initial relationship between the normalized Erlang and pedestrian counts across all locations. This effect was significant and showed that between 8.00 and 8.15AM, locations that differed in one point with respect to normalized Erlang, differed by 493.43 pedestrians ($p < 0.001$). However, the random effect of Erlang (σ22) was zero, which implies that there is no evidence to suggest in our sample that the relationship between Erlang values and empirical pedestrian counts varied between locations. Rather, we only see the fixed effect of Erlang suggesting that this relationship is uniform across all counted streets.

Looking at the residual changes, we find that the between-street residual variance decreased by only 4% with the introduction of Erlang to the model and the within-street variation decreased by 2%. This led us to conclude that Erlang did not improve the between-streets or within-street predictions of pedestrians much. Given that Erlang measures were distributed across all streets in the whole cell to explore the activity on specific single streets, it was not surprising to find very little correlation between the two. Furthermore, Erlang measures were generated by all calls from within the cell, not only from pedestrians on the streets, but also calls from parks, buildings, vehicles and so on. We concluded that in the given sample, the Erlang measure alone predicted little pedestrian activity on specific streets.

Lastly, we also explored whether the addition of Erlang data could explain the dynamic variations of pedestrians at specific streets, which a model with fixed predictors could not account for. The fixed predictors that were added to the unconditional model were Road Class and the radius 400m integration value from space syntax. A dummy variable for the weekend was also included. The estimated coefficients of this model (M3b) are shown in **Illustration 8.7**.

While the fixed effects of the above mentioned control predictors remained insignificant, Erlang in M4b did have a significant relationship to the outcome. The Erlang coefficient suggested that a one point change in Erlang values was on average associated with a 926.68 ($p < 0.05$) point change in pedestrian counts, controlling for weekends, road classes and choice values. The decrease in residual variance suggested that the addition of Erlang to a controlled model did improve the pedestrian prediction, but not much: Erlang accounted for 4% of the between-street residual variance and 6% for the within-street residual variance. The relationship between Erlang values and empirical pedestrian counts thus led to the conclusion that Erlang measurements were only marginally successful in predicting pedestrian flux on the chosen streets.

This makes intuitive sense. An important complication in relating Erlang values to actual population distribution is the changing nature of callers' behaviour. When the total call volume increases, for instance, then the sample size that generates an Erlang value also increases and we should expect a more accurate prediction from Erlang during the hours of large call volume. The same concern applies to the changes in average call length. If average calls are systematically longer during certain hours of a day, then Erlang values would increase, but the actual population distribution could remain the same. In addition, the average call length could also vary by area- people in residential areas might make longer calls than people in a noisy shopping area during the same hour. Unfortunately the data on call lengths and user behaviour was not available to us in this study and remains to be tested in future research.
As a preliminary test for these variations, the students in Rome also counted the number of passing pedestrians who were using cell phones. The analysis of these data showed that there was a significant positive correlation between Erlang and the number of pedestrians observed talking on the phone during the counts ($R2 = 6\%$, $t=5.01$; $p < 0.0001$) and that the proportion of pedestrians using mobile phones did significantly vary during different hours of the day as well as across different locations ($p < 0.05$). This suggests that when a larger proportion of pedestrians use their phones on the street, Erlang values are significantly larger, whereas the amount of pedestrians can remain similar. In future work using Erlang values for estimating callers' distribution, it would thus be important to account for how the total number of calls and the average call length vary throughout a typical day and to consider these variations when interpreting the relationship between Erlang and the caller's distribution.

CONCLUSION

Does the usage of a mobile phone network at a particular time reflect the distribution of people in a city? And could the data from the network dynamically predict the amount of vehicles and pedestrians on particular streets?

Indeed, to at least some extent, suggest the findings of our study, which compared two types of mobile network indicators with empirical counts of vehicles and pedestrians on the streets of Rome. First, we used the BSC measures which positioned each phone call geographically and measured the caller's speed of movement during the call, as a predictor for vehicular traffic. Secondly, we used the Erlang measures, which indicate the total usage intensity of each network antenna, as a predictor for pedestrian traffic.

Our analysis showed that Telecom Italia's estimate for mobile phone calls from vehicles was successful in predicting approximately a third of the traffic patterns at specific streets. This finding corroborates the idea of using vehicle estimates from a mobile-phone network in future transportation analysis. Telecom Italia has in fact already started using these measures to estimate the traffic conditions on the highways around Rome. For urban planners, this data now opens up an opportunity to investigate the driving dynamics in different neighborhoods with much less effort than offered by the traditional origin destination surveys and traffic counts. The data could also be used for assessing the role of urban design, land use and public amenities in travel mode choice in different neighborhoods (cf. chapters 7, 10, 11 and 13).

Erlang values were marginally, though significantly, successful in predicting pedestrian flux at particular streets. Only 2-4% of the pedestrian flow was forecast by the data. This finding was discouraging, but intuitively reasonable. Erlang measures at antennae provide an overall indication of call volumes processed by the particular cells and give no information on whether the callers were still or moving, indoors or outdoors, and are therefore less likely to correlate with a specific subset of callers, such as pedestrians used in this study. Since the measures are taken at the antenna level, the data also provides less accuracy and certainty for predicting the true location of callers. However, the relative ease of access and ubiquity of the Erlang in any mobile phone network still make the data very attractive for further study. Using a larger study area and accounting for the typical calling behaviour could potentially yield more accurate predictions of the actual population distribution at a particular time. Another interesting alley of research already emerging, is to cluster Erlang patterns at cells that are used similarly over time into sensible groups, in order to functionally describe urban areas that behave similarly over time.

Mobile networks thus remain interesting and valuable resources of information for urban analysis. Cell phones, though only as proxies, can be used to describe other human activities than calling, and their continuously expanding adoption worldwide provides an unprecedented sample in studying the daily activities of urban dwellers. Unlike other electronic devices that register usage patters (i.e. cashier counters, ATMs, subway gates etc.) in fixed positions, mobile phones travel along with people as they inhabit the city in daily life, thus describing not only how places are used, but also the personal experience of people in cities. The availability of mobile network data offers an entirely new type of evidence and scale for the dynamic study of cities.

NOTES

1 1.24 mobile phones per person, CIA World Factbook 2005.

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9

JOANNE HEYINK LEESTEMAKER, CITY WORKS
LEON VAN BERLO, TNO

OUR DAILY DANCE IN TIME AND SPACE

BACKGROUND

It is possible to visualise the impact of the spatial design on people's time-use patterns. In the Netherlands, both Statistics Netherlands (CBS) and the Netherlands Institute for Spatial Research (RPB) research these effects and impacts. One conclusion is that more than half of the working population commute between 50 and 60 kilometres daily, totalling up to three hours per day. Our growing mobility in connection with work and leisure consumes an even greater part of our daily time budget. The need to make spatial planning more time-efficient is therefore an important item on the political agenda. In densely populated areas, accessibility and multi-functionality are vital factors thereby.

We consider user-oriented planning the right way to conduct spatial planning. It requires us to consider more than just the classic land-use patterns. Human time-space should also play a significant role in our deliberations on how to plan for the future. We can foresee that in the long run, demand-driven urban development will lead to time-conscious urban design. Tools to observe, map and analyse these changing patterns in human time-use are therefore in the process of being developed.

The patterns of human time-space use have been changing rapidly since the introduction of new modes of transportation. The accessibility of a location has become an important selling point. This has led to the multiple use of locations near highway crossings, train stations or airports. Here groups of people gather to shop, play sports, savour culture, meet other people, work or relax in public spaces such as squares, cafes, restaurants and hotels. New urban centres referred to as edge cities consolidate these optimal meetings in time and space. Changing patterns in the distribution of human activities in time and space moreover create a need for new types of information.

Various applications of geo-referenced information currently being developed are or will be both commercially and publicly available. These applications combine functions such as mobile communication, GPS, digital photography, e-mail, cartography, satellite imaging and internet access. One of the first applications of so-called 'location based services (LBS)' has been the tracking & tracing of convicts on parole and animal species in the wild. In the United States, web-based products are available that enable parents to trace the whereabouts of their children, so-called Child Monitoring Services. Locative media are also a powerful tool in the hands of urban investigators wishing to learn directly from users the specific routes they take and the locations or events they attend. Locative media can help to unveil the specific mental maps that an individual user has in his or her head. The experience and perception of a place or route can be reported by residents by means of short texts and photos. We decided to further develop geographical research techniques such as Hägerstrand's space-time path and diary analysis. In doing so we developed *Sense of the City* as a method of providing insight into the simultaneous but diverse patterns and experiences of people in regard to time and space.

DYNAMIC 3-D MAPS WITH LOCATIVE MEDIA

The online tool *Sense of the City* was developed and tested between 2005 and 2007. *Sense of the City* combines tracks of participants as a day-path in time and space, diaries, texts, images, maps, aerial and satellite photos on a real-time website. Through the use of GPS, *Sense of the City* is able to position the location of the participants in the project and to track their routes, velocity and distance as soon as they move. The participant can add significance to his or her route by uploading images and text messages. Uploading recorded sound and digital video to the website is also possible. All of these contributions add up to make dynamic maps. *Sense of the City* has published these maps online. They show how participants experience their individual time-space continuum. More in detail, they show the spatial choices participants make, as well as where they live, work, practice sports, meet up and recreate and relax. Even more interesting is the possibility of analysing the spatial behaviour of many people simultaneously. This will be possible as soon as common mobile phones include inbuilt geo-reference functions.

A promising research topic that can benefit from these new instruments is identifying those locations where the multi-functional use of time and space is the most desirable and the most promising. Other locations could be left open and designed as silent places in order to maintain or create nature areas. While designing new neighbourhoods, infrastructure, parks

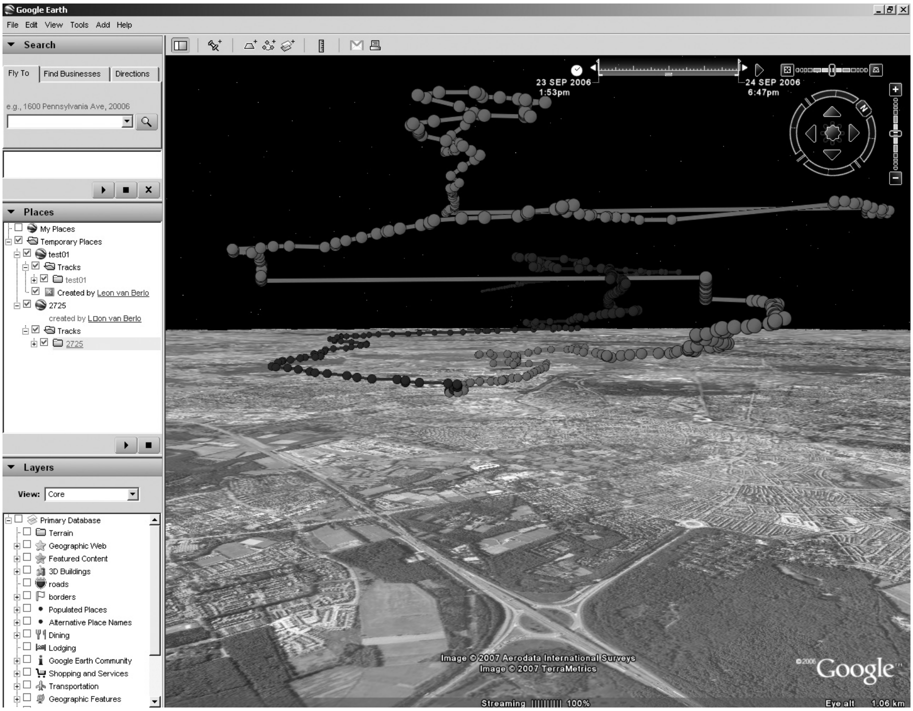


Illustration 9.1
Tracking routes in three dimensions

or city centres, it is possible to take the actual patterns in time and space use into account. Web 2.0 techniques can offer a bird eye's view of the human dance in time and space on aerial maps. A *Sense of the City*-project provides such an interactive website. It integrates real-time tracking of routes in three dimensions and user information, uploaded on to an aerial map (see **Illustration 9.1**). *Sense of the City* is a first example of the integrated use of technology that traces the complex unity of time, place, action and individual emotions with precision. This opens perspectives for quantitative space-time research and the qualitative investigation of perceptions of places and cities.

THE EINDHOVEN CASE

With new paradigms in Dutch spatial planning, municipalities will be increasingly just one example of many actors, and their role will shift from allowing towards enabling. As a result, municipal services will have to be well informed with regard to how residents and users perceive their surroundings. For seven days, the participants of the *Sense of the City* project in Eindhoven were asked to collect images and comments in connection with their daily routines in public space, coupled to certain social themes. In addition to housing and work, a link was made with the main themes of the Service for Social Development of the city of Eindhoven: Meeting, Developing, Recreation and Safety Nets. Participants were selected on the basis of their expected unique spatial patterns, forming a broad spectrum of possibilities of the spatial use of the city. *Sense of the City* aims to draw up an inventory of this use and analyse it for the benefit of municipal services. Qualitative data are consequently collected on prototypical use and the perception of public space and urban facilities.

Geo-tracing: from market vendor to policeman

In the case of Eindhoven, the *Sense of the City* website included the routes of all participants simultaneously, in real time, and the images they generated and sent by e-mail (see **Illustration 9.2**). *Sense of the City* displayed that information on three kinds of maps: satellite images of Google Earth, aerial photos of the city and maps of various scales. These maps were provided by the municipality, unlocking her intranet databank in *Geogids* software and projecting data onto this mapping material. Participants later wrote down their comments on their routes and the photographs taken. The images could be followed on three large led-screens displayed on strategic locations in the city. The scope of the project was somewhat limited. The sponsor PHC-Telecom supplied ten Nokia 6680 mobile phones. The participants were a real estate

SENSE OF THE CITY

Sense of the City is een spel waarmee we Eindhoven opnieuw ontdekken. Kies een deelnemer uit het menu.

TE LAAT

Rennend de roltrap op, de trein van negen over half zes moet gehaald worden, geen tijd voor de avondzon, drukte op het perron. Een stroom van duizenden jonge forensen, die Eindhoven verlaat, eb en vloed van de stad. Even rust, de trein is al weg en ik ziet een oude vriend, samen zoeken we een plek in de zon bij het station.

© 2006 Sense of the City

Illustration 9.2
Tracing Eindhoven on www. senseofthecity.nl

agent, a pizza deliverer, a policeman, a first aid nurse, a marathon runner, a working mother, a secondary school pupil, a design academy student, a market vendor and a city cleaner. Their individual experiences were subsequently stored, replayed and analysed. The marathon runner, for instance, recounted how he didn't do his daily rounds on the city's training courses but on the bypass around the city, in the exhaust fumes, on the asphalt. This stretch is exactly 12 kilometres long, thus "forcing myself to run my daily distance without taking any shortcuts". The action radius of one participant differed greatly from the next. The school pupil uses only a limited amount of public space; she is either at home or at school or somewhere in-between. The working mother on the other hand has a large range; she cycles from the sports ground to shopping centre, to work, to school and home. It is no surprise that her weekend starts with "a relaxed Saturday morning at home".

Analysing data on 3-D maps

While analysing the data, we realised that we had to develop a possibility of visualising the 3-D component of the times of the data on the maps. Mei-Po Kwan's 3-D mapping of behaviour in Franklin County inspired us to look for a way to map the third dimension in a similar way (**Illustration 9.3**). In this illustration, the vertical axis represents the temporal progression

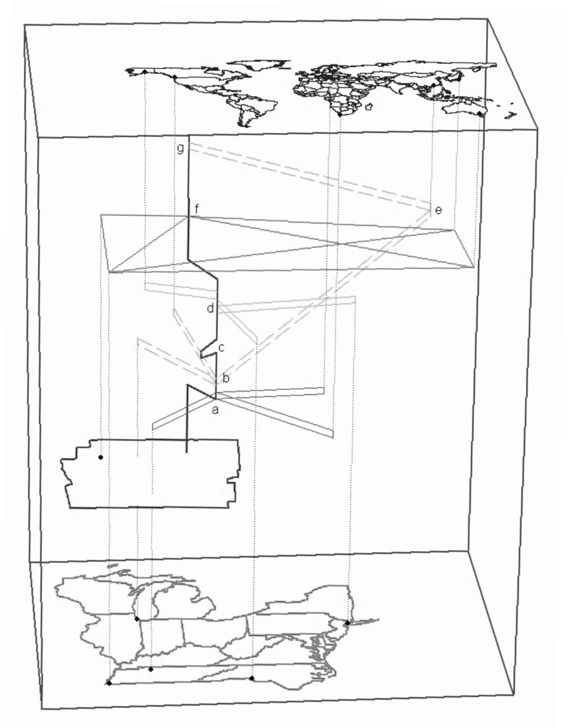


Illustration 9.3
The 3-D aquarium of Franklin County, Ohio by Mei-Po Kwan. Source: http://geog-www.sbs.ohio-state.edu/faculty/mkwan/Gallery/STPaths.htm, accessed 11 May 2008

RABOBANK

Rabo Vastgoed

060416 [3493]

start: 16-04-06 08:05:13
end: 16-04-06 23:18:11
distance: 43.42 km

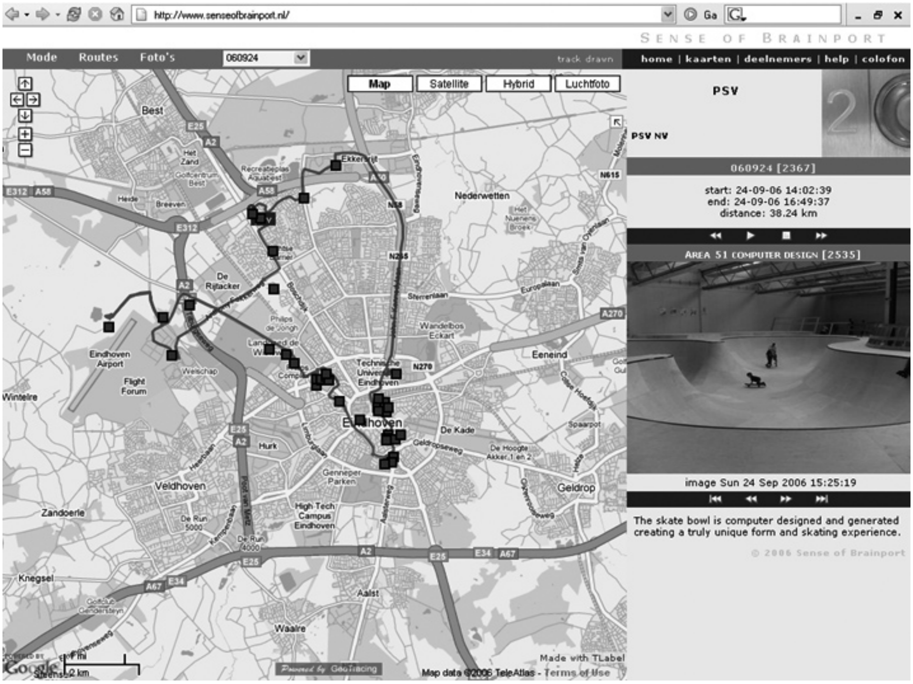
NONAME [4038]

image Sun 16 Apr 2006 19:20:54

Kwaliteit van historische bebouwing blijft.

© 2006 Sense of Brainport

Illustration 9.4
The website shows the daily pattern of a captain of industry on the satellite map of the Eindhoven region



PSV

PSV NV

060924 [2367]

start: 24-09-06 14:02:39
end: 24-09-06 16:49:37
distance: 38.24 km

AREA 51 COMPUTER DESIGN [2535]

image Sun 24 Sep 2006 15:25:19

The skate bowl is computer designed and generated creating a truly unique form and skating experience.

© 2006 Sense of Brainport

Illustration 9.5
The website shows the daily pattern of a captain of industry on the street map of the Eindhoven region

of movement in space. Multiple individuals can be analysed simultaneously for an easier comparison of their activity patterns. We developed a tool to automatically visualise GPS data in mobile phones on Google Earth (see box 1). Using this technique, we can fill a 3-D aquarium at a specific place and use it as a chrono-geographic model to analyse a group of participants and their use and perception of time and space in order to design a place for future needs.

EVALUATION AND FURTHER TESTING: TOWARDS A WIKI-ATLAS OF CITIES

Most research meets with less than 40 percent response and intensive follow-ups are required to persuade people to participate in qualitative research. However, *Sense of the City* met with an enthusiastic and intensive response on the part of all participants. Data collection was a playful affair and was carried out by the participants exclusively. They were curious and enthusiastic about using new technologies, and fascinated to see their own routes and perceptions charted. *Sense of the City* produced the tracks of ten people in a period of one week. This collection of individual day-paths shows the beginning of a pattern of prototypical users moving through their city. It will be even more interesting to see how individual patterns coincide. Who will meet who, where and when? This will help us identify the collective nodal points of the city, and could indicate where the municipality should plan facilities in connection with its four main themes (Meeting, Development, Recreation and Safety Nets). It does however require larger data sets, and we will therefore have to wait until everybody owns 'smart phones' with high resolution cameras, GPS navigation and fast internet access. Mobile phone service providers can already locate the exact whereabouts of their subscribers. This data is currently used by the police to trace missing or wanted persons. In the future, we hope to use these data as quantitative input for qualitative research on perceptions of the city.

A second test within the framework of *Sense of the City* was conducted in the wider region of Eindhoven, a region which is planned to be developed as a high-tech cluster referred to as Brainport. The time-space continuum of the Brainport region is built up by means of data on the daily patterns and perception of fifty captains of industry. Their dreams and wishes for the future moreover shape the framework of the Brainport Region 2020. Their factual traces and perceptions are documented on www.senseofbrainport.nl (see **illustrations 9.4 and 9.5**).

A more general application of the *Sense of the City* principle enables participants to make their own contributions, as is in the process of taking place with collective web 2.0 projects such as Wikipedia. Cities or regions could provide information on the web through residents who allow themselves to be traced. In this way, a Wiki-atlas of the city is produced. Large companies such as building societies or networks of industry could also manifest themselves on a Wiki-

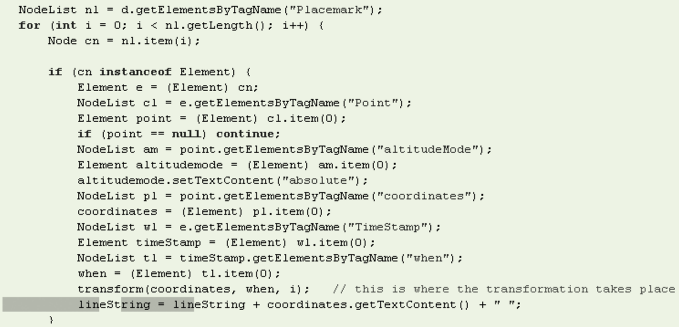
Box 1 Visualisation of the temporal dimension of tracing data on aerial photos

How should the temporal dimension of tracing data on aerial photographs such as Google maps be plotted? Data collected through the mobile phones, used in Sense of the City project is exported to a database that is placed online. The structure of the data is the well-known GPS Exchange Format or GPX. GPX is a light-weight XML data format for the interchange of GPS data (waypoints, routes, and tracks). This GPX data can easily be imported in Google Earth. This project did not follow that procedure. We first transformed the GPX data to Keyhole Markup Language or KML. KML is a file format used to display geographic data on Google Earth, Google Maps, and Google Maps for mobile. KML uses a tag-based structure with nested elements and attributes and is based on the XML standard. The translation of data from GPX to KML takes place using a XSLT stylesheet. XSLT is a language for transforming XML documents into other XML documents. XSLT is designed for use as part of XSL, which is a stylesheet language for XML. In addition to XSLT, XSL includes an XML vocabulary for specifying formatting. XSL specifies the styling of an XML document by using XSLT to describe how the document is transformed into another XML document that uses the formatting vocabulary. XSLT is also designed to be used independently of XSL. However, XSLT is not intended as a completely general-purpose XML transformation language. Rather, it is designed primarily for the kinds of transformations that are needed when XSLT is used as part of XSL. The KML file that was given by the translation is a 'flat' file. The polygons do not rise from the ground as we want in a time-space aquarium. This is because the original GPS data also naturally lack raising data that is useful for this application. All the previous steps are taken merely to transform the GPS data from mobile phones to KML files that Google Earth uses natively. This is mainly done due to the fact that Google Earth has not fully implemented support for GPX data.

The next part is the part in which an algorithm changes the height of the waypoints in the KML files. This is the fun part of this project as the changes are clearly visible. The changing of the waypoints in the KML files is a tricky business. It does not 'just' entail the changing of the height variable of the waypoints. First, the oldest timestamp has to be found in all the KML files. This oldest timestamp is the 'start-point'. Then the latest timestamp has to be found, also in all of the KML files. The waypoint that contains the latest time is set to the 'end-point'. Now the z-value of the 'start-point' is set to 13. This is the height of Eindhoven, so the start-point is set to the ground. Now the z-value of the 'end-point' is set to 3500. This is the top of the time-space aquarium. 3500 is a nice number for the aquarium because it is not too high, nor to low (so the lines are much too compact to see them differentiate). The next step is to calculate the seconds between the end-point and the start-point. Now the number of 3487 (derived from 3500-13) is divided by the number of seconds between the start-point and the end-point. Next, the time is connected to the height (z-value) of a waypoint. The final step is to adjust the z-value of the waypoints, corresponding to the time. Of course this is done for all the KML files. A piece of the code to do this is given in Illustration 9.6.

A complete time-space-aquarium is given in a bunch of KML files. The final step is to read the KML files in Google Earth (see Illustration 9.7). While constructing time-space-aquariums with this tool, one has to consider the following: when the GPS data has too many 'leaks' (open places), the rendered aquarium has open spots. This does not help in representing the use of the space. Also, the different users (lines) should use about the same space in about the same time. If this is not the case, the time-space paths can also be represented separately. The advantages of using Google Earth for the representation of time-space-aquariums are obvious. A model is given instead of a static picture. Each user can walk around and through the model, which is a great experience. The use of Google Earth is wide-spread, so it is a very generic tool. For the time being, it is therefore an open source tool. The KML files can be put online. In this case they will be open to the public. The next step in the development of this tool is to make it fully automatic. The data from mobile phones will be sent directly to a web-server where the data is stored. This web-server will analyse the data and render the time-space-aquariums on the fly (this means it will render on command of the user). The server has the native data which means that it can also render other types of models which represent time-space use.

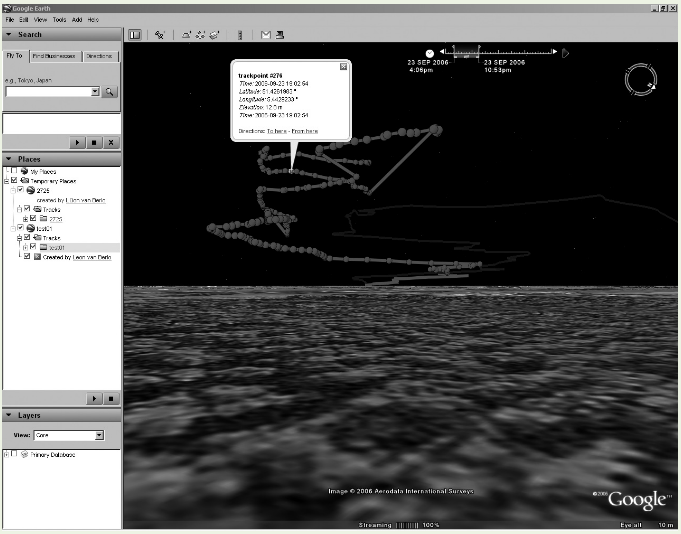
Illustration 9.6 - Piece of the code to create 3-D aquariums of time-space paths



```
NodeList nl = d.getElementsByTagName("Placemark");
for (int i = 0; i < nl.getLength(); i++) {
    Node cn = nl.item(i);

    if (cn instanceof Element) {
        Element e = (Element) cn;
        NodeList cl = e.getElementsByTagName("Point");
        Element point = (Element) cl.item(0);
        if (point == null) continue;
        NodeList am = point.getElementsByTagName("altitudeMode");
        Element altitudemode = (Element) am.item(0);
        altitudemode.setTextContent("absolute");
        NodeList pl = point.getElementsByTagName("coordinates");
        coordinates = (Element) pl.item(0);
        NodeList wl = e.getElementsByTagName("TimeStamp");
        Element timeStamp = (Element) wl.item(0);
        NodeList tl = timeStamp.getElementsByTagName("when");
        when = (Element) tl.item(0);
        transform(coordinates, when, i);   // this is where the transformation takes place
        lineString = lineString + coordinates.getTextContent() + " ";
    }
```

Illustration 9.7 - Reading the 3-D kml files in Google Earth



trackpoint #276
Time: 2006-09-23 19:02:54
Latitude: 51.4261983 °
Longitude: 5.4429233 °
Elevation: 12.8 m
Time: 2006-09-23 19:02:54

Directions: To here - From here

atlas. The region Brainport is an example in this respect; this network of high-tech industry in the region of Eindhoven aims to present itself on, and investigate by using the internet. It will position itself through *Sense of Brainport*. Brainport is thus the first candidate for the Wiki-atlas.

Amersfoort is the second candidate. The city plans to present itself on the occasion of its 750th birthday by means of a new interactive map of the city, a 3-D-atlas containing the lives and experiences of its inhabitants, using various means of modern information and communication technology.

CONCLUSION

The need for time-specific and place-specific information on the human daily dance has been clearly articulated. The technologies to be used to gather this data and store it in such way that it can be analysed within a reasonable timeframe have recently become available. By testing these techniques (web 2.0, aerial photos, mobile phones with GPS, GIS and spatial databases), it has became obvious that they should be integrated into one tool. Analysing the data gathered and stored by means of such a tool requires a 3-D visualisation in a chrono-geographic model, a description of which has been given (see box). The next step is to present a full analysis of the chrono-geographic datasets on people's daily dance in time and space. This is foreseeable in 2008.

Sense of the City is a product of CityWorks, an office for spatial planning and of Just van den Broecke, De Waag Society. Sense of the City was developed using a subsidy granted by Ruimte voor GeoInformatie and an 'InnovatieVoucher' granted by SenterNovum. The 3-D time-space aquariums were developed by Léon van Berlo from the Netherlands Organisation for Applied Scientific Research (TNO).

10

WENDY BOHTE, KEES MAAT, WILKO QUAK, TU DELFT

A METHOD FOR DERIVING TRIP DESTINATIONS AND MODES FOR GPS-BASED TRAVEL SURVEYS

INTRODUCTION

Travel patterns of individuals are becoming more and more varied in time and space. To understand complex travel patterns, current travel behaviour research increasingly focuses on trip chaining, complete daily and weekly activity patterns and relationships with spatial structure on a detailed level (e.g. Krizek, 2003; Golob, 2000; Boarnet & Sarmiento, 1998; Maat & Timmermans, 2006).

Due to this shift to a more integral approach, it has become essential to use data collection methods that are able to obtain detailed travel behaviour characteristics of all trips an individual makes throughout a day and preferably for several consecutive days. Current travel behaviour research combines in its analyses data on the location of origins and destinations, destination type, trip length, trip duration, departure and arrival times and mode choices. In addition, even more specific data such as exact routes, activities and the people who accompany respondents during their trips are being used. Moreover, the availability of detailed spatial data enables researchers to perform analyses on the effect of spatial structure on travel behaviour at a very detailed level. Paper travel diaries, as frequently used in the past decade, provide much better data than traditional recall surveys (e.g. Stopher & Wilmot, 2000; Arentze et al., 2001). However, the burden of taking these detailed notes all day increases the risks of non-response and reduced accuracy. Moreover, a major drawback of the paper diary method is the difficulties respondents have in determining the exact locations of their visits.

A recent solution for these drawbacks is a collection method on the basis of the Global Positioning System (GPS), which is potentially more accurate and less of a burden on respondents than paper diary methods. Not only can exact locations of trip destinations and travel times be recorded, but also additional characteristics such as exact routes (Wolf, et al., 2003; Forest and Pearson, 2005; Steer Davies Gleave & Geostats, 2003; Ohmori et al., 2005). GPS is a satellite-based navigation system which makes it possible to determine locations with an accuracy of approximately 10 metres. Especially when GPS data are placed in a GIS application for further interpretation, the possibilities of the use of GPS are promising (cf. chapter 4). Moreover, the lower burden on the respondent allows a longer collection period than just a few days. Furthermore, data collection by means of GPS yields an advantage in terms of data processing. The data is immediately available in digital format, thereby avoiding the need for time-consuming data entry and data entry errors.

To date, data collection by means of handheld GPS receivers has only been applied in a few, largely experimental studies. The majority of GPS-based studies have been conducted in the USA, with GPS receivers being placed in cars. However, as the focus in many travel behaviour studies is not only on the car, and as in many countries modes other than the car have a considerable modal share, travel behaviour data should be collected for all different modes. With the introduction of light-weight handheld GPS receivers with an increasingly better reception, a sharp increase has recently been observed in the use of GPS receivers for measuring trips by other travel modes (Steer Davies Gleave & Geostats, 2003; Kochan et al., 2006; cf. chapters 5, 6, 7 and 9). Nevertheless, few studies include the registration of modal choice and destination types due to the fact that in contrast to travel times and distances, these travel characteristics cannot be derived directly from GPS logs and require a more complex derivation method.

This chapter contributes to the improvement of GPS-based travel surveying by introducing a combined method of GPS, GIS and web-based user interaction, which has been applied in large-scale fieldwork in the Netherlands. With over 1000 participants, as far as we know, this is the first time that a GPS-based method that measures travel mode choice as well as the location and type of destinations that are visited has been used on such a large scale. The chapter focuses in particular on the identification of travel modes and destinations, which is still an under-researched issue (see also chapter 8). For the greater context of this study, we refer to Bohte et al (2007).

Our approach concentrates on the issue of deriving and validating the purpose of trip destinations and travel modes, while also allowing reliable multi-day data collection. The method consists of an interpretation process and a validation process. The interpretation process uses spatial data (e.g. railways, shops) and characteristics of the respondents (e.g.

home address, possession of cars) to interpret data from the logs. The travel behaviour data that result from this interpretation round can be adjusted and added to by the respondents in a validation application. The link between both processes is interactive; when new individual characteristics (e.g. the address of a friend's house) are entered by the respondents, these characteristics will be used for further interpretation of the data.

The remainder of this chapter is structured as follows. The following section gives an overview of the advantages and drawbacks of current GPS-based data collection methods that are suitable for measuring choice of travel mode and/or trip destinations. The subsequent section describes the GPS-based method that we developed and in section four the value of our method is evaluated by presenting the results of the fieldwork we recently undertook. The results are compared with results from an internet survey that was carried out at an earlier date and also with the Dutch Travel Survey (DTS) that uses paper diaries. The chapter ends with conclusions on the use of GPS-based methods for the collection of travel behaviour data and a discussion of future possibilities.

LITERATURE REVIEW

Travel researchers are currently experimenting with different GPS-based data collection methods. This review focuses on methods that can be used to derive modal choice and destination types visited. Travel behaviour characteristics such as travel times and distances can be derived almost directly from GPS logs, as a GPS receiver records exact positions and exact times.

A simple, straightforward method for collecting the data that cannot be derived from the GPS logs alone is to ask the respondents directly. Some studies asked respondents to use a paper diary in combination with a GPS receiver, while others asked respondents to enter the data in a GPS-enabled mobile phone (Ohmori et al., 2005) or PDA (Kochan et al., 2006). However, these methods do not solve all the accuracy and burden drawbacks of paper diary methods. Therefore, for deriving modal choice and destination types, GPS data have to be combined with spatial data and respondent characteristics using smart algorithms.

Tsui and Shalaby (2006) deduced the travel mode from the logs by taking the average and maximum speed and the rate of acceleration observed during the trip. In a second method, they also used spatial data, such as public transport routes. Underground trips were identified by examining whether the previous trip ended in the vicinity of a metro station and the beginning of the following trip started near another metro station. Both methods were tested on the GPS logs of nine volunteers in Toronto and both achieved good results, although the method using GIS performed the best. See also Chung and Shalaby (2005).

For deriving destination types from GPS logs, the use of GIS is indispensable. GPS logs provide no information on the kind of location concerned. A few studies describe possibilities for deriving destinations by combining GPS logs with GIS maps, although current literature is limited to studies focusing on car travel (e.g. Wolf et al., 2001). Schönfelder et al. (2002) found on the basis of experience that an important precondition was the availability of detailed maps. Doherty et al. (2006) theoretically described a method that both combines GPS and GIS and enables us to determine travel modes and destination types. In their method, GPS logs are first split into trips, then activities and missing sections are determined via algorithms and subsequently start and end times, travel modes used, and activity locations and the use of space in the vicinity of the activity locations determined. The details derived from this process are then presented to the respondents in tables in an internet questionnaire. The respondents are asked to check the details and among other things, add information relating to the number of travelling companions. It is possible to view the trips on a map in the application should respondents wish to do so. Any adaptations to the data by the respondents are made in the tables.

In addition, we argue that a GPS-based method requires the validation of the data by its respondents by showing them the results derived and asking for validation, as well as corrections and the addition of trips and trip characteristics. Stopher and Collins (2005) have shown the value of an internet recall survey. The development of an interactive web-based system is complicated and as far as we know, no system has yet been designed that works almost perfectly. However, when a working system is developed, the processing of GPS data into trip characteristics should be relatively fast and inexpensive, as no manual data entry is needed. The Internet is a medium that enables the presentation of derived data as interactive maps and tables.

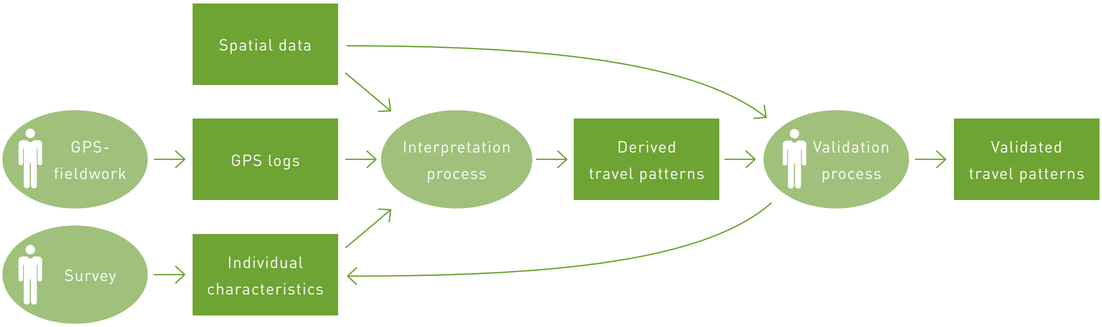
An option that does not seem to be discussed in literature is the use of individual characteristics (household composition, possession of travel modes, home and work addresses, etc.) as input for the algorithms that derive trip characteristics from the GPS logs. A small survey held in advance can yield valuable information and decrease the amount of information that has to be acquired at a later date (cf. chapter 13).

ARCHITECTURE OF THE GPS-BASED SYSTEM

This section describes the architecture of the GPS-based system that identifies modes, location of destinations, destination type and trip distances, times and duration as accurately as possible and with as little a burden on the respondents as possible. Attention is also focussed on validation of the results by the respondents.

The GPS-based system consists of two main processes: an interpretation and a validation process (see **Illustration 10.1**). Three different sources are placed in a spatial database (PostgreSQL/PostGIS): GPS logs created by providing respondents with GPS receivers for one or more days, individual characteristics of the respondents collected by a survey and spatial structure data. The spatial data consists of various sources, such as road networks, railways, public transport stops, shops and other services. Moreover, all addresses of the home and work locations are geocoded. Individual characteristics include gender, availability of a driving licence and a car, an annual season ticket for public transport, work status, and so on. During the interpretation process, a collection of scripts that include various algorithms runs on top of the database to combine and interpret the different data sources. When trip characteristics are reconstructed, as far as possible, they are forwarded to the validation process. The main part of the validation process consists of a web application (using Flash) that obtains its data from the spatial database. In the user interface of the web application, the derived data are presented to the respondents in maps and tables. The respondents are asked to use this validation application to correct and add to the derived trip characteristics. The link with the interpretation process is interactive. When the input of the respondents provides new individual information such as the addresses of friends and family or in the event that new trips are added, this information will be reused for further interpretations.

Illustration 10.1 - Architecture of the GPS-Based System



The interpretation process

In the interpretation process, characteristics of the trips made by the respondents are derived from the raw data in the GPS logs. In addition to the GPS logs, two other sources are used as input, namely spatial structure data and individual characteristics of the respondents. To derive trip information from the GPS logs, the following steps are used (cf. chapter 7): (1) filtering track points from the GPS log; (2) splitting the GPS log into trips; (3) deriving modal choice and destination types for the trips; and (4) post-processing. The parameters used in the algorithms are partly derived from other travel behaviour data, partly from validated data in this data set, and partly from logic thinking.

Filtering track points

Before the GPS log is analyzed, a number of cleaning operations are performed. Some of the filtering is carried out to reduce the amount of data and some to remove measurement errors from the GPS log. A GPS log consists of a series of points, so-called 'track points'. Each track point is described in the log on the basis of x and y coordinates and a time stamp. Data is also recorded on the quality of the measurement and the speed of the GPS. These data are used to remove track points with low quality measurements or an unrealistically high speed.

Special care needs to be taken to detect whether the GPS is in rest. Due to measurement errors, a GPS that is in rest does not return to the same position each time, but acts as moving slowly. In most cases, filtering out these points is straightforward, based on the typical movement behaviour and the known accuracy of the GPS device. However, when the receiver is indoors, it only sees a small fragment of sky and incorrectly produces tracks even when the receiver it is not moving.

Splitting tracks into trips

After the most unreliable track points have been removed, the log is divided into actual trips made. The parts of the log that must be considered for separate trips is deduced from the respondent's rest periods by means of the loss of satellite reception in buildings. Although dividing up a trip based on changes in the respondent's speed seems to be a good method, in practice, a single trip appears to include many speed changes. When the GPS logs indicate that someone remained at a certain location for at least three minutes, the location in question is classed as the destination of the previous trip. Wolf et al. (2001) compared the use of different thresholds and found that a three minute threshold resulted in the best prediction. As activity-based research increasingly analyses the complexity of multi-modal travel, multi-modal trips are divided into stages (a stage is a part of a trip, between mode changes), meaning that railway stations and bus stops are included as separate destinations. If a respondent rides his bicycle to the train station, takes the train and then walks to work from the station, this is classified as three trips.

When the log is split up in trips, this automatically shows the times and locations at which trips were started and completed. This is because if it is known which track point was the first to be placed at a location where someone remained for an extended period of time, it is also known what time the person arrived there and the x and y coordinates of the point in question. It is possible to deduce the departure time from the first track point placed at some distance from the location where the person remained for an extended period of time.

One of the shortcomings of the current generation of GPS receivers is the fact that after the receiver has been turned off or in the event of lost reception, it often takes a while (usually no more than 30 seconds) before a GPS receiver has found enough satellites and receives enough signals to be able to determine its location (this is also referred to as getting a 'fix'). This often means that the departure from a location is not logged. When the final track point of one trip and the start point of the next trip (these should always be the same) are far apart, the end point of the previous trip is chosen as the most reliable.

Determining travel modes

To determine the travel mode, different data are used. By deriving the average and nearly-maximum speed, in most cases, it can firstly be estimated whether the person walked, cycled or drove a car. Nearly-maximum speed is used to avoid using track points that were registered when satellite reception was not optimal, causing misplaced registration and the wrong estimation of speeds. When the average speed is below 10 km/h and the nearly-maximum speed is below 14 km/h, it is estimated that a person walked. An average speed between 10 and 25 km/h and a nearly-maximum speed between 14 and 45 km/h leads will lead to the estimate being made that a person cycled. When the average trip speed is between 25 and 200 km/h, it is estimated that a person travelled by car.

To determine whether a trip was completed by train instead of by car, a link to GIS data is required, as the speeds of these travel modes may be very similar. By checking whether at least one third of all track points of a trip lie within 50 meters of a railway and by comparing the coordinates of the starting and ending point of a trip with the locations of train stations via underlying GIS maps, it is determined whether a trip is likely to have been made by rail and that the respondent therefore probably took the train.

These algorithms will not always make the correct distinction between different travel modes. For example, when people are running, the estimated travel mode will probably be 'bicycle'. Furthermore, no algorithms have been developed to detect the use of scooters or other less common modes. When in future applications acceleration and speed changes within a trip are also analysed, it will be possible to increase the number of correctly predicted travel modes.

Determining category of the destination

GIS data are also used to estimate the category that the visited destinations fall within. All the potential destinations are classified in 13 categories, such as 'home', 'work', 'friends/family' and 'cultural'. Destinations of facilities are derived from GIS maps listing Points of Interest (POIs) such as the x and y coordinates of schools and other facilities. If a trip ends within a radius of approximately 50 metres from a known location, it is assumed that this is the location being visited. Because shopping centres and railway stations can be spread out over a large area, they are not represented by points, but their whole outline is drawn in GIS maps.

Due to the fact that the home addresses of respondents are already known (as this is where the GPS receivers were delivered to and collected from), these can be entered into the database. The postal codes of the work locations of the respondents are also translated into x and y coordinates. Because the work location will be frequently visited, the work address is asked for in the survey carried out in advance. If a respondent's trip ends within 100 meters from his home or work address, it will be assumed that he went home or to work.

If it is not possible to filter out a possible destination category on the basis of the underlying GIS maps and the known data on the respondent, the destination category will be listed as 'unknown' until the respondent has indicated in the internet application what category the visited destination is in.

The algorithms that are used to determine the destination types of the trips are relatively straightforward. In the near future, more complex algorithms will be constructed to enable us to derive increasingly accurate trip data from GPS logs. For example, when there are several known locations within a 50-metre radius of the end of a trip, it should be possible to not automatically select the nearest location, but to select the destination based on (individual) values allocated to the possible locations. This means that if a supermarket is located a little further away from the end of a log than a police station, it will, in the first instance, still be assumed that the respondent visited the supermarket. It is also possible to allocate individual values to the respondents for each type of destination included in the probability calculation. This means, for instance, that people with school-age children are more likely to be assumed to be visiting a school than people without children.

Post processing the data

After analysing individual trips, the generated trip diaries are post-processed and analyses are performed that consider more trips together. One example is merging small and short shopping trips within one shopping area, while another example is that if a trip ends near one railway station and reappears later near another, it is assumed that a train trip was made.

The validation process

After the data have been interpreted, they are presented to the respondents in the web-based user interface of the web application. The respondents are asked to check their travel behaviour data and to make corrections and/or additions where necessary.

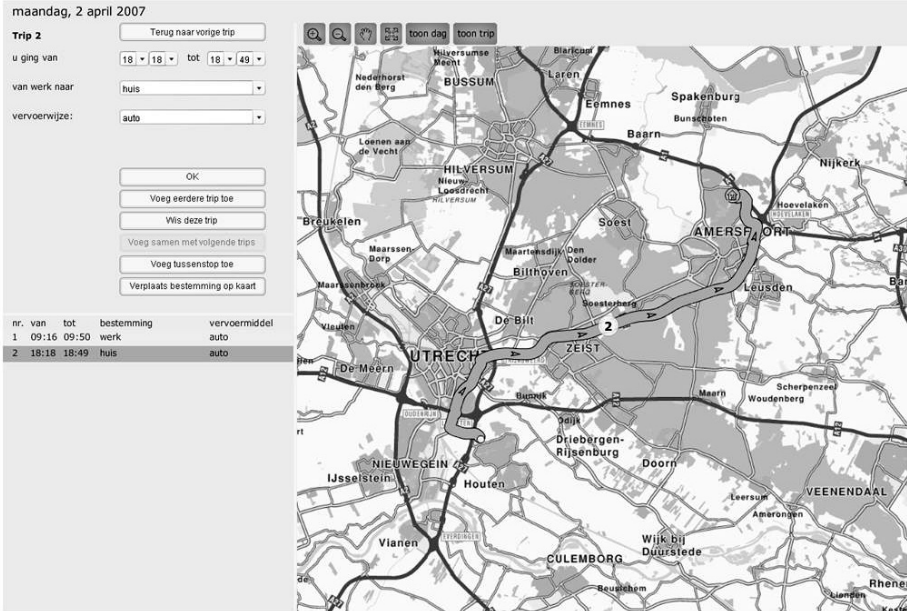
The decision to use the internet was taken for several reasons. Firstly, an important advantage of using the internet for a recall survey is that when entering information, the user interacts directly with the database and information provided can then immediately be used to better approximate the respondents' trips at a later date. In contrast to telephone surveys, respondents can answer the survey whenever they wish. Another important advantage is the possibility of easily showing respondents their travel behaviour depicted on a zoomable map and allowing them to move locations in their trips on the map. An experiment carried out by Stopher and Collins (2005) showed that respondents where able to indicate missed trips and destinations on maps depicting the routes they had taken. Finally, exchanging the data via the internet also eliminates the associated costs of delivery and data entry.

An important disadvantage could be the risk of generating a selective response. To be able to use the application, respondents have to have at least some experience with computer programmes and the computer and internet connection they use must not be too slow. These preconditions may lead to an under-representation of older and lower-educated people. However, in recent years, computer and internet accessibility have grown enormously and it can be expected that selectivity caused by lack of computer skills and respondents without access to a computer or with no or slow internet connections will decrease rapidly. Moreover, as surveys are generally over-represented by older people, this may be balanced by using computer-based surveys.

Interface

The interface of the validation application consists of a map and a table depicting all trips a respondent visited in a day as derived from the spatial database as well as a form that respondents can use to adjust the depicted trip characteristics (**see Illustration 10.2**). The map can be panned dynamically and zoomed in and out, with a changing level of detail while zooming. This is realized by using a map database with maps on six successive spatial scales. The maps, provided by Falk, include street names and points of interest on the lowest spatial level. The trips on the map are linked dynamically with a table that lists each trip with the originating location, the departure time, the travel mode used, the arrival time and the location of the destination.

Illustration 10.2
A screenshot of the user interface of the web application



maandag, 2 april 2007

Trip 2

u ging van 18 18 tot 18 49

van werk naar huis

vervoerwijze: auto

nr.	van	tot	bestemming	vervoermiddel
1	09:16	09:50	werk	auto
2	18:18	18:49	huis	auto

Adjusting trips and trip characteristics

When the algorithms used in the interpretation process were not able to determine or wrongly determined the starting or ending times of a trip, or when the travel mode used or the category of the destination visited could not be derived correctly, respondents can adjust these trip characteristics by choosing an (other) option from the dropdown menus. When the respondent amends any data, the amendments concerned are passed on to the spatial database and are used for further interpretation, after which the new data are used to better estimate the trips of the respondent in the days after the adjustment was made (self-learning).

When the GPS log is not correctly divided into trips, respondents can merge or split trips. Respondents can also change the location of the destination of a trip if the GPS receiver stopped logging before the end of a trip or even add a whole trip if the receiver was forgotten, the battery was not charged or the receiver failed to acquire reception of satellites.

A CASE STUDY

The GPS-based data collection method we developed was applied for the collection of over one thousand one-week travel behaviour patterns. This data collection was part of a larger research project (Bohte & Maat, 2007), but the data can be used for a broad range of travel behaviour research (cf. chapter 11).

In this section, the results and evaluation of this case study are used to evaluate the method. The section starts with a description of the study area, the respondent sample and the fieldwork organisation. The interpretation process is then evaluated by discussing the percentages of modes and destination types that had to be changed or added by the respondents because they were not able to be correctly derived from the interpretation model. Certain results (trip frequencies and trip chains) are subsequently compared to data from the Dutch Travel Survey (AVV-MON, 2006; the government's national survey, a one-day paper recall survey). Finally, some of the results from the evaluation survey held among the respondents are presented.

Description of the case study

The fieldwork took place in the first half of 2007 among a sample of residents of Amersfoort (137,000 inhabitants), Veenendaal (61,000 inhabitants) and Zeewolde (19,000 inhabitants) – three municipalities in the centre of the Netherlands. Due to the facts that our research focuses on residential choice, most people in the Netherlands choosing to rent a house have limited options and availability is low and distribution (partly) regulated, we restricted our study to home owners.

The respondents were recruited from the respondents of an internet survey held at the end of 2005. In total, 1200 respondents participated in the GPS fieldwork, 1104 of whom completed the entire project. The respondents carried a hand-held receiver for one week. The receiver we used was an adjusted Amaryllo Trip Tracker (http://www.amaryllo.com, acc. April 7, 2007; see illustration 10.3) that was programmed to log a track point every 6 seconds. The battery lasts approximately 16 hours which was accomplished by disabling all unnecessary functions. One day after the receivers had been collected again, the GPS logs from the receivers were entered into the interpretation process to be combined with spatial structure data (location of shops,

Illustration 10.3
The Amaryllo tracker

railway stations, railways, schools and cultural services) and data on individual characteristics (car ownership, home and work addresses) that were collected beforehand. The same day, the respondents received an e-mail with a link to the user interface of the validation application, enabling them to validate and add to the registered and derived data.

Corrections by the Respondents

By determining what percentage of all travel modes and destination types had to be provided or changed by the respondents in the validation application, we can estimate the success of the interpretation process. In almost three-quarters of all cases, the travel mode proves to have been estimated correctly in the interpretation process. Car use was deduced correctly most often (75% of all trips), followed by cycling (72%) and walking (68%) respectively. Trips that ended at home were placed in the correct destination category most frequently due to the fact that the home location was already known (74% of all trips that ended at home). Visits to shops were estimated correctly in 35% of cases. Although the home addresses of friends and family were not known in advance, 11% of these visits were nonetheless recognised as such in the database. These latter estimates may contribute towards the 'learning' function, which remembers the category of the destinations that were visited earlier in the week.

Trip Characteristics

By comparing travel characteristics from the GPS dataset with data from the Travel Survey (AVV-MON, 2006; DTS) it can be estimated whether the GPS-based method produced reasonable results. Illustration 10.4 shows that the destination and mode shares in both data sets are quite similar, with the absolute numbers being higher in the GPS dataset. Nonetheless, the number of tours per day is almost equal in both datasets (GPS: 1.56 and DTS: 1.61). The main difference lies in the number of trips per tour. The respondents in the GPS sample have an average of 2.9 trips per tour while the respondents from the DTS survey demonstrate an average of 2.3 trips per tour. On one hand, it may be the case that the GPS method measures more trips than the traditional method. It can be expected that in a paper recall survey such as the DTS, small stops on a tour such as picking up a child or a short visit to a shop on the way back from work may be forgotten. On the other hand, we realize that the higher number of trips may be partly caused by trips that are incorrectly divided into more than one trip due to the fact that the reception of satellite signals failed for a while and respondents failed to merge these trip parts in the validation application later on. Further analyses of the GPS dataset are necessary to be able to determine more accurately the cause of this relatively high number of trips per tour.

Illustration 10.4
Average Number of Trips per Mode per Day and per Destination per Day

	GPS-based method (1,104 respondents, 7,395 days)		DTS recall survey (40,208 respondents/days)	
Destination	**Mean**	**Share**	**Mean***	**Share***
Work	0.84	18%	0.60	16%
Study	0.03	1%	0.02	1%
Shop	0.60	13%	0.42	11%
Social Visit	0.29	6%	0.26	7%
Recreation	0.47	10%	0.43	11%
Home	1.56	34%	1.61	42%
Other	0.77	17%	0.47	12%
Travel Mode	**Mean**	**Share**	**Mean***	**Share***
Car	2.44	54%	2.01	53%
Train	0.10	2%	0.09	2%
Bus/tram/metro	0.04	1%	0.09	2%
Bicycle	1.17	26%	0.81	21%
Foot	0.74	16%	0.75	20%
Other	0.06	1%	0.06	2%
Total Number Of Trips	**4.55**	**100%**	**3.80**	**100%**

* weighted to match age and education level of the GPS dataset

Results from the evaluation survey

After the respondents finished the validation of the week they participated in the fieldwork, they were asked to fill in an evaluation survey. Questions focused on their experience of the week they carried the GPS receiver and their evaluation of the user interface of the validation application.

The results of the evaluation survey showed that only 1% of the respondents found it a considerable nuisance to continuously carry the receiver, 11% found it somewhat a nuisance and 88% didn't mind at all. However, remembering to carry the receiver was found to be a problem by a large proportion of people (over 40%). A quarter of all respondents did in fact forget their receiver on one or more occasions. The vast majority of respondents (91%) did not consider the fact that the receiver had to be charged in a power point to be a problem.

Many respondents found checking and updating their trips fairly difficult. Nearly 25% said that they found following the programme quite difficult and 40% somewhat difficult. One of the reasons given was that there are still a great deal of gaps in the GPS logs. This was especially the case for respondents with a car with heat-resistant windscreens and respondents who frequently travel by train. People with little computer experience or an older computer experienced a relatively high degree of difficulty with the application. Some respondents found it difficult to remember the trips they had made in the initial days of the fieldwork more than a week later. Nonetheless, a third of all respondents were able to go through the entire validation process in fifteen minutes or less, while two-thirds needed half an hour. Although Doherty et al. (2006) assume that respondents will have difficulty interpreting the maps, this is not supported by the evaluation. Due to the frequent use of route planners on the internet and in-car navigation systems, it is not unreasonable to expect that many people already have some experience using digital maps.

CONCLUSION AND DISCUSSION

This chapter describes a GPS-based data collection method which we have developed for the collection of travel behaviour of individuals. We evaluated the system by applying it in large-scale data collection. The main aim of the development of this method was to build a system that can be used to collect travel times and distances, modal choice and destination types as accurately as possible, and which will also place a low burden on the respondents. The experience and evaluation of the use of other GPS-based methods was used as a starting point for the development of our method. Compared to other methods, this system has a stronger focus on validation by the respondents.

The GPS-based system consists of an interpretation process and a validation process. Three data sources are combined in the interpretation process: GPS logs, individual characteristics of the respondents and spatial structure data. When in the interpretation process trip characteristics are reconstructed, as far as possible they are passed on to the validation process. In the user interface of the validation application, the derived data are presented to the respondents in maps and tables. Here, the respondents can adjust the derived trip characteristics. The link with the interpretation process is interactive and new information delivered by the respondents is used for further interpretations.

The evaluation of the case study was satisfying. Due to the fact that GPS receivers can register exact location coordinates, the location of destinations can be determined with an accuracy that cannot be approached by traditional methods. Furthermore, because the method is able to derive substantial trip data before the respondents go through the validation application and also adds extra information while they are validating the data, the burden on the respondents is reasonably low. The data collected by means of the survey conducted beforehand proved to be very useful as input for the algorithms in the interpretation process. The participants did not experience carrying and charging the GPS receiver as being a nuisance and were enthusiastic about viewing their trips in the maps of the validation application. The majority of respondents were able to go through the validation application in a reasonably short period of time. This meant that the 7-day travel behaviour was able to be collected from more than a 1000 respondents. The comparison with data from the national travel survey showed that the GPS-based method was able to record a larger number of trips. This indicates that fewer trips were missed.

However, the evaluation also showed that the method has room for improvement. Firstly, the method is dependent on the quality of the GPS receivers used. The receiver that was used in the case study presented worked poorly inside trains, which meant that many train trips were missing. People had to remember to recharge their receivers every night. As a substantial part of the technical drawbacks such as the battery life and the size and weight of receivers may be largely solved or at least improved within the next few years, it is important that if possible, new research projects use state-of the-art GPS receivers.

Secondly, although the majority of the respondents required 30 minutes or less to go through the validation application, some did struggle a lot with it, especially people with very few computer skills, old computers and complicated travel behaviour. In addition, because of the poor reception of satellites inside trains, frequent train travellers had to add many trips, potentially meaning a lot of extra work. An extension of the algorithms used in the interpretation to derive more data automatically would mean a further decrease of the complexity of validating the results for the respondents. Progress can be expected to be made in a survey by asking the right questions. Moreover, algorithms could be constructed that compare trips of the same respondents on different days. Since a large part of people's travel behaviour is based on routines, gaps in one day can perhaps be repaired with information from other days, even in real-time when the respondents are using the validation application.

In summary, we can conclude that, at present, both GPS and GIS are starting to make a significant contribution to collecting data on travel behaviour of individuals. The system we proposed solves some of the previous shortcomings and has proved to perform well. However, if the current (technological) developments continue, and methods for collecting the necessary additional information such as the method described in this chapter are developed further, it is likely that data collection by means of paper diaries will disappear entirely in the near future, and will be replaced by methods that collect data with the aid of GPS and related technologies.

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11

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TRACKING DOWN THE EFFECTS OF TRAVEL DEMAND POLICIES

INTRODUCTION

This chapter addresses two issues related to tracking people through mobile technologies and spatial planning decisions. The first major part deals with the question of how knowledge developed through the use of new tracking technologies can impact the *spatial planning process*. We argue that global positioning system (GPS) data are valuable – if not vital – for the improvement of travel demand forecasts by means of an activity-based transportation model when assessing travel demand management (TDM) policies such as spatial planning strategies. Based on a brief historical outline with regard to planning policies and an overview of various travel demand models, the need for advanced data and their use in modelling practice is shown. In the next section, the other topic of this chapter discusses what kind of *spatial interventions* can be expected due to the use of new tracking technologies. Here, four application areas related to travel demand modelling are identified and subsequently explained: the use of route knowledge and the concepts of accessibility, activity spaces and mental maps.

THE USE OF GPS DATA IN THE PLANNING PROCESS

Brief historical outline: rise of the sustainable development paradigm and its implications for transportation policy making

To fully understand the use and usefulness of GPS data in research related to the transportation and *spatial planning process* in general and travel demand modelling efforts specifically, a rough outline of the historical context is required. Since the 1950s most industrialised Western countries have faced a baby boom, a massive growth in individual motorization and the rise and expansion of urban sprawl. Originally, planning policies focussed on mastering the increasing travel demand by adjusting – i.e. expanding – the supply of transportation infrastructure. These policies were adopted in an immediate response to the predicted growth in car ownership and use. But growth continued steadily and additional infrastructural capacity even induced new traffic flows (Kitamura & Fujii, 1998).

In the course of time, the negative effects of the vast amounts of motorized traffic – congestion, traffic accidents, emissions, the monopolization of urban space and excessive land consumption – became a growing concern. There was a rising general environmental awareness, stimulated by the Club of Rome and its most famous report of 1972: *Limits to Growth* (Meadows et al, 1972), and growing concern as to how to manage the environment in the pursuit of economic wealth, which was expressed in the Brundtland report: *Our Common Future* published in 1987 (World Commission on Environment and Development, 1987). This document pushed sustainable development into the mainstream political agenda.

In this context of increasing environmental awareness and the generally accepted policy paradigm of sustainable development, transportation policies shifted from facilitation to reduction and control (Dijst, 1997). Moreover, an integrated approach with other policy areas such as spatial planning and environmental policies is still being further developed. Although there is still some way to go, promising examples of integrated policy-making are arising. For instance in the region of Flanders (Belgium), mobility and transportation analysis, views and goals constitute a vital part of all recent 'spatial structure plans' at different policy levels, while in recent 'mobility plans' an integration of spatial context, traffic and transportation networks and flanking policies in three defined scopes is mandatory (Zuallaert, 1998).

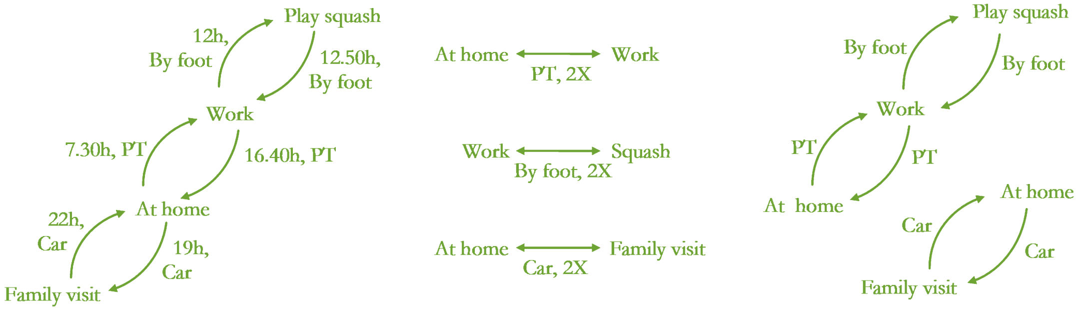
A general term for policy strategies that result in more efficient use of transportation resources is travel demand management (TDM). Objectives of such measures are to: (1) alter travel behaviour without necessarily embarking on large-scale infrastructure expansion projects, (2) encourage better use of available transport resources, and 3) avoid the negative consequences of continued unrestrained growth in private mobility (Krygsman, 2004).

Besides supply-oriented measures for all travel modes, TDM measures typically touch various factors of influence in travel scheduling and execution. Examples are the spreading of peak-period travel through relaxing working, school and shopping hours, congestion charging, ridesharing schemes, and suchlike. Besides, TDM measures can adopt spatial planning schemes serving similar policy goals of reducing energy consumption and the need to travel, e.g. Transit Oriented Development (USA), Carfree Cities (worldwide), the Dutch ABC approach (Townshend, 2006) and Transport Development Areas (TDAs), a UK practice (Hines et al., 2002). Scenarios of spatial concentration, which can be implemented by moving facilities from smaller concentrations and merging them with larger clusters of facilities in the neighbourhood, as well as spatial separation scenarios occur in reality. Victoria Travel Policy Institute (2007) offers an overview of successful TDM, including land use management schemes.

Shift in scientific support to transportation policies: from ‘four step’ to ‘activity-based’ modelling of travel demand

Parallel to this shift in political programmes and planning content, methodological changes could be witnessed in the scientific support of planning policies in the second half of the 20th century. Since the early sixties, a rational process view of planning was widespread and faith in the application of science in policy-making was rapidly increasing (Taylor, 1998). Definitions of planning problems or goals, or even plans and policies themselves, could thus be equated with scientific hypotheses that needed to be subjected to severe empirical testing before being implemented.

Transportation policy issues were treated in this way. Originally, the estimation and forecasting of travel demand and behaviour were handled by a standard methodological approach, commonly referred to as the four-step modelling approach (Ruiter & Ben-Akiva, 1978). Obviously, these initial estimations mainly focused on policies with regard to infrastructure expansion. In these models, trip generation, trip distribution, mode choice and route assignment are handled likewise. Earliest trip-based models of travel demand overly simplify complex patterns of daily activities and travel. This is illustrated in **Illustration 11.1**. Trips are modelled independently, and the time component is lacking, as is the direction and further sequential information, thus resulting in an isolated modelling of travel. Moreover, most of these models are macroscopic, using aggregate data and generating aggregate outcomes.



Complex reality Trip-based model Tour-based model

Illustration 11.1 Simplification of complex activity travel patterns in trip-based and tour-based models

Next generation tour-based models sought to overcome some of the shortcomings of the earliest trip-based models in that they model home or work-based travel tours, taking the sequential information partially into account. Still, spatial limitations are numerous, the time component is lacking and some tours remain independent of each other.

As policy approach is shifting from rather simple supply-oriented measures to more complex TDM measures, the need to effectively analyse, evaluate and implement a range of scenarios is giving rise to the awareness that an improved understanding of individual travel choices and behaviour is essential to accomplish reliable and policy responsive forecasts. Traditional four-step methodologies have proved to be inadequate in achieving this. The advanced travel demand models need to embody a realistic representation and understanding of the travel context and the decision-making process of individuals in order to mimic their sensitivity to a wider range of transport policy measures.

The major insight that enabled researchers to gain such a better understanding of travel behaviour is the idea that travel demand is generated by the activities that individuals and households need or wish to perform. Travel is merely seen as a means to pursue goals in life, rather than a goal in itself. Therefore, modelling efforts should primarily concentrate on modelling activities or on a collection of activities that form an entire agenda which triggers travel participation, also commonly referred to as the activity-based modelling approach. These approaches enable transportation forecasting through the evaluation of TDM measures and aim at predicting which *activities* are conducted *where*, *when*, for *how long*, *with whom*, as well as the *transport mode* involved. In addition to this shift from trip-based to activity-based models of travel demand, modelling techniques have evolved rapidly from aggregate approaches to the microsimulation of individual behaviour, favoured by the dramatic increase in computational capacity during the last decades.

An example of an operational activity-based microsimulation model for travel demand is Albatross (Arentze & Timmermans, 2000). This model is sensitive to changes in various groups of variables that can be affected by TDM measures, including population, schedule skeletons, opening hours, land-use, travel costs and travel times. The number of possible scenarios to calculate in terms of these groups of variables is almost infinitely large.

Growing need for accurate data: tracking people can make the difference

Obviously, in order to model and predict all these different facets of individual daily activity-travel by means of an activity-based transportation model, accurate data is needed to start with. A hand-held logging system based on a Geographic Information System (GIS) can be used to collect data for all these facets of travel behaviour and its context. Compared to other common methods of data gathering, there are numerous advantages.

The travel diary shaped as a paper-and-pencil questionnaire, asking people for their travel behaviour during a certain time period, has long been and in fact still is the dominant form of data collection in transportation research. Its technological simplicity and the fact that it can be completed anywhere are undeniably advantages. However, due to the required detail, this method is tedious, complex, prone to errors and answers may lack consistency.

Alternatively, desktop computer-assisted data collection tools may be used for filling out activity scheduling surveys in order to provide activity-travel diary data. Such methods can provide user guidance and enhance data quality, but these systems are not able to trace the actual activity-travel execution in real time due to their limited portability.

In order to solve this portability problem, a Personal Digital Assistant (PDA) equipped with GPS technology can be used to enhance the data collection tool's mobility (Kochan et al., 2005) (see **Illustration 11.2**) (cf. chapter 10). The portability of a PDA data collection tool enables in-situation data input while preserving the ability to perform consistency checks on the data provided by the respondent.

Illustration 11.2
Personal Digital Assistant (PDA) equipped with GPS technology

There are five clear potential advantages of equipping a PDA with GPS technology to supplement activity-travel data: (1) when using a desktop computer-assisted data collection tool, the respondents have to remember the exact locations of their start and end positions - a tricky job and a well-known source of error - whereas with a PDA equipped with GPS, trip origin, destination, and route data are automatically collected without burdening the respondent with the data; (2) as the respondent may forget to report an activity trip, there is another advantage in the recovery of unreported trips, as all routes are recorded automatically; (3) accurate trip start and end times are also automatically determined, as well as trip lengths; (4) the GPS data can be used to verify self-reported data; (5) both the data entry cost and the cost of pre and post-processing the data constitute a significant share of the total data collection cost (Zhou, 2004). Fortunately, both can be reduced to a minimum with computer-assisted forms of data collection (cf. chapter 10).

In addition, more can be expected from GPS data in the near future. Recent research outcome shows promising results in modelling attempts to predict activity types based on the combination of GPS tracks, GIS data and demographic information (Mc Gowen, 2006). In this way, GPS tracks could replace the daily travel diary and thus decrease both response burden and data gathering costs of surveys to a large extent.

All arguments mentioned above in favour of the use of GPS tracks are particularly applicable to the (spatial) planning process as all other things being equal, they should result in higher quality spatio-temporal data. Higher quality data is obviously a precondition for a more reliable travel demand modelling. The latter may even be more applicable for spatial scenarios as these are highly dependent on accurate spatial information, which can only be provided by means of a PDA with accurate GPS technology.

Use of GPS tracks: some examples and future expectations

Unfortunately, the evaluation of a PDA with GPS technology has only rarely taken place within the context of transportation research. However, in recent years, the topic has been receiving increased attention. Two well-known examples are the semiautomatic data collection device used in the Lexington Travel Survey (Batelle, 1997) and the computer-based intelligent travel survey system used by Resource Systems Group Inc. (1999), which used interactive geo-coding and other intelligent functions that can be provided by GIS to reduce the reporting burden on the survey respondents.

Currently, a comprehensive and extensive research program that has been funded by the IWT, an Institute for the Encouragement of Innovation through Science and Technology in Flanders

(Belgium), is contributing to this line of research (see Janssens & Wets, 2005). Among other things, the data to be collected by this program will be on 2401 households. Approximately one half of the sample will receive a PDA module, equipped with GPS. The other section of the sample will be questioned by means of a traditional paper-and-pencil method. This choice enables the researchers to carry out comparative studies with respect to the reporting behaviour of both target groups in terms of response rates, experience, etc. Households have been selected using a stratified cluster technique, which ensures a geographical and spatial distribution in the sample representative for the study area of Flanders.

The survey asks the members of the selected household to fill out an activity schedule, an activity-travel diary and to report rescheduling decisions (the reasons for rescheduling are reported as well) during a one-week period. In comparison with other activity-based studies, this survey period is particularly long, especially in combination with the high number of households that will participate in the survey. Finally, detailed cost estimates have already been made and a description of logistics and required computer assisted telephone interview (CATI) support are currently being investigated and will also be reported in the study. The data will be used as input for a state-of-the-art activity-based transportation model, which will enable the researchers to calculate the impact of a range of TDM measures and spatial planning scenarios.

With regard to the forecast of future developments, there are high hopes for a simplification of the collection of individual route tracks. A serious alternative for GPS location positioning is based on mobile phones (cf. chapter 8). Firstly, mobile phones are widely spread across the population. As a result, no additional hardware is needed on the user side (in contrast to a GPS receiver), enabling larger samples to be included in a survey at virtually no additional cost. Secondly, although the location positioning accuracy strongly depends on the density of the mobile phone network, new algorithms are being more widely adopted to reduce the measurement error on the location positioning.

SPATIAL INTERVENTIONS BASED ON GPS DATA

The second topic of this chapter discusses the kind of spatial interventions to be expected due to the use of new tracking technologies. Four application areas related to travel demand modelling are identified in this respect: the use of route knowledge and the concepts of accessibility, activity spaces and mental maps.

Route knowledge

The use of route knowledge is first explained. As briefly mentioned above, the use of a PDA with GPS technology will enable researchers to track the route followed to reach a particular destination (see Illustration 11.3). The use of this information has a number of important advantages.

Firstly, it will be possible to achieve a more realistic behavioural modelling of route choice in transportation models. While this latter component is mainly lacking in activity-based models to date, it is often over-simplified in current four-step transportation models. In these, route assignment is usually based on the use of straightforward shortest-path algorithms, whether it be distance or time sensitive. When GPS information is coupled with activity diary data, it will be possible to link the actual route choice and the activities conducted. This will enable the implementation of more robust traffic assignment approaches in transportation modelling.

In addition, a second opportunity offered by this detailed route knowledge consists of the fact that it will also be possible to specifically determine the spatial factors that influence route choice when GPS tracks are combined with other spatial databases in a GIS environment. Indeed, when this can be achieved, it will be possible to evaluate and model the effects of future spatial interventions in cities in order to influence route choice behaviour (e.g. at city traffic network level, what are the effects of a cut in certain links in the network).

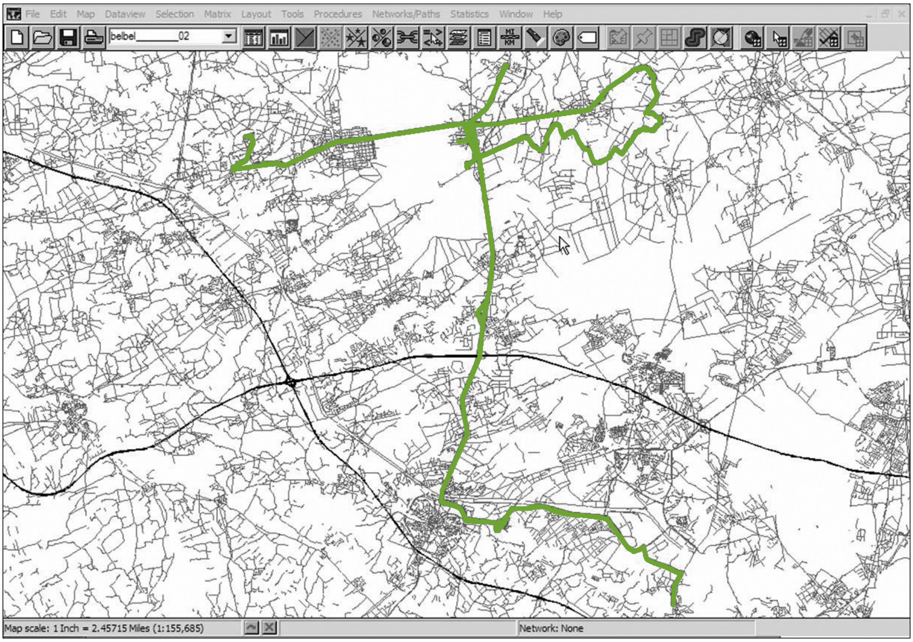


Illustration 11.3 GPS route data visualized in TRANSCAD

A third advantage of GPS track recording is the fact that both static (infrastructure) and dynamic factors (night or day, seasons, events, traffic conditions) of the environment can be taken into account in view of the fact that (in certain environmental circumstances) the route choice is observed at a given point in time.

Accessibility

Second is the concept of accessibility. This is an important construct which can be better evaluated thanks to the use of a PDA tracking device. The accessibility measure represents the ease of access to certain destinations. Measured for different modes of transport, accessibility can be an important benchmark in assessing how 'smart' the growth of an area is in terms of the potential to use sustainable modes of transport.

In econometric models of travel demand, accessibility is expressed as a certain cost which can be a compound of travel distance, travel time, travel costs, etc. causing some form of disutility for the individual. In activity-based models, accessibility is also a measure of testing the feasibility of generated activity travel schedules.

Sometimes the accessibility measure is computed in a simple way, for example by multiplying the distance as the crow flies or from the core of the origin zone to the core of the destination zone with an average measure of car speed. More advanced methods like calculating logsums are also used taking detailed specifications of the accessibility into account, such as mode choice, time of day (peak and off-peak), travelled route over the network, level of service (LOS), travel purpose, route choice options, individual differences, etc.

An important improvement in the measurement and computation of accessibility can be established through the integration of GIS in the travel demand model (Kim & Kwan, 2003), and the exploitation of the knowledge of actual route choices. There is a strong tendency to disaggregate individual-based accessibility measurement, using space-time constraints to generate potential path areas (PPA) – the accessibility between two consecutive fixed activities (Chen & Li, 2006) – and to identify feasible opportunity sets (FOS).

Activity spaces

Related to the previous concept of accessibility is the next concept of activity spaces or the physical mapping or enumeration of places visited in the past. Although reasonably new, this concept constitutes an important application field related to travel demand modelling. The analysis of individual activity spaces (using longitudinal travel data) can be motivated by an interest in spatial behaviour from a planning point of view.

Indeed, the enumeration of daily-life activity locations and the analysis of the distribution of such places reveal both the supply structure of activity opportunities in space and the destination choice behaviour of travellers given their perceived supply. This invites transport planning and research even more to evaluate and present future urban structures from the perspective of sustainable transport policy. This evaluation includes for example measures to increase the amount of opportunities (i.e. potential destinations) to satisfy the activity demand in the household's neighbourhood which eventually reduces travel expenses, further congestion and emissions.

There is evidence that local accessibility oriented land-use planning matters (Banister, 2000). However, the complexity and non-linearities in the interaction between locational supply and the actual choice of destinations (Schönfelder & Axhausen, 2003) should not be neglected. Nevertheless, precise quantification of these activity spaces for various population groups requires a significant amount of data on activity behaviour (Morency & Kestens, 2006). It is exactly these data that can be generated by an activity travel survey designed for a PDA equipped with GPS technology.

Mental map

Finally, the development of the mental map concept can benefit from the knowledge provided by individual tracking technologies. At an individual level it is important to realise that the relationship between travel decisions and the spatial characteristics of the environment is established through the individual's perception and cognition of space. As an individual observes space, for instance through travel, the information is added to the individual's mental map (spatial learning). Among other things, the mental map subsequently shapes the individual's travel decisions, since it reflects what an individual knows and thinks about the environment and its transportation systems (spatial planning).

Although this concept is often referred to in theoretical frameworks of travel demand models, actual model applications are scarce, mainly due to problems in measuring the construct and putting it into the model's operation (Hannes et al, in press).

A clear example of the opportunity for the development of this concept offered by GPS tracks is the following; when stated travelled routes and stated distance estimates can be compared to actual travelled routes and actual distance information as recorded, there will be an idea of how the mental map is formed and how it affects individual future decision-making when operating in a spatial environment. This insight will enable both spatial planners and transportation modellers to take this information into account in their planning decisions and modelling attempts.

SUMMARY

In this chapter we have indicated a major benefit derived from the use of GPS data in the activity-based modelling of travel demand aimed at the evaluation of transportation and spatial planning policies, namely the refinement and improved predictive accuracy of the forecasts of the effects of TDM. As such, an increased efficiency of such policy measures can be achieved. Over and above this, we have specified four spatial application areas related to travel demand modelling that could benefit from the use of new tracking technologies. The exploitation of route knowledge, accessibility, activity spaces and mental maps largely depends on knowledge acquisition from individual activity travel tracks. The accumulation of such knowledge will lead to a better understanding of individual choices and their spatial determinants, a prerequisite for any policy that aims to alter individual behaviour in order to attain sustainability objectives.

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12

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COLLABORATIVE MAP GENERATION — *SURVEY AND ARCHITECTURE PROPOSAL*

INTRODUCTION

The current widespread use and higher quality of GPS devices is drastically increasing the need for up-to-date digital maps to feed better and more reliable intelligent travelling assistance services.

While on one hand the main industrial players can be seen to make large investments in order to satisfy this demand, on the other, a new trend is slowly emerging from the Internet social networking trend (sometimes referred to as 'Web 2.0') which should not be neglected. As in many other cases, the commercial approaches are superior in terms of quality and in coverage at the beginning, but the effect of a community working together is unexpectedly powerful. See, for example, the case of Wikipedia (as opposed to encyclopaedias such as Encarta or Britannica).

We more specifically refer to Collaborative Map Generation, which consists of jointly building a geographical map of a region or a city out of shared geo-referenced traces (normally GPS). Up until the present, a few efforts have been made, the OpenStreetMap project (http://www.openstreetmap.org, accessed 23 July 2008) probably being the best known. There are, however, two major hurdles to the success of this approach: the aggregation of new traces has to be done manually and, even worse, individual traces are rarely devoid of errors, in spite of the high quality of current devices.

In this collaborative approach, the input data (GPS traces) is inherently rich in terms of information about individual and social mobility. Its aggregation can provide more than a roadmap – it represents real urban mobility. In this sense, since this framework necessarily needs a set of methodologies to automate common processes such as filtering and smoothing, mode detection or statistical analysis, a very useful outcome is the deployment of such information for transport and urban planners. One could, for example, deduce mobility trends and predict possible improvements in transport networks (cf. chapter 11). Until the present, this has mainly taken place manually, sometimes also using simulators calibrated with sampled data (sometimes even from lengthy personal interviews). A GPS sharing framework in the form described here would give dramatic improvements in time efficiency.

It is thus clear that an automated Collaborative Map Generation platform also provides a wealth of information regarding individual and collective mobility patterns, provided that a contract of privacy, security and trust is provided to all contributors (as is the case in any Web2.0 platform). At an individual level, for example, the 'personal network' can be determined or better routes and transport means suggested. At an urban level, for example, congestion points, places where people stay for periods of time and transport means usage can be detected, to name a few indicators.

The first breakthrough in this context will take place happen when efficient trace aggregation is achieved. In this chapter, we intend to present the Map Making State-of-the-Art and discuss current and future prospects for the development of an automated methodology for map aggregation that takes into account the need for integration of mobility data and the social networking trend, which we believe will eventually become the main source of geographical maps. This will allow us to abstract a general architecture for a Collaborative Map Generation system and discuss in some detail the technical challenges for each module (and its current solutions). In doing so, we hope to show that as a very relevant and desirable 'side effect', a set of algorithms must be developed that will help with regard to those Transport and Urban management tasks referred to above. We address filtering, map matching, update and aggregation, steps for the construction of the maps, and some efficient algorithms and data structures that are used to compress, process and query the map once generated. The chapter closes with a number of conclusions.

STATE-OF-THE-ART

Making maps

Map making (or cartography) is a discipline that has been subject to many technical revolutions in the course of time. From angle measurement to the North star aided by sextants and telescopes to more sophisticated settings, such as aerial photography and laser range finders, cartographers have given their best to achieve maps of the highest quality. The still recent age of artificial satellites in the orbit of the Earth (which started in 1957 with Russia's Sputnik) produced far-reaching improvements. This revolution generated two important new tools for map-making: satellite imagery and the Global Positioning System (GPS). The former enabled cartographers to start making high-precision global maps and, aided by the higher definition of airplane photography and localized measurements (e.g. altitude, pressure, temperature), to quickly acquire large quantities of geographical data. With the advent of micro-computers, this high quantity and quality of databases eventually led to the emergence of Geographic Information Systems (GIS), which are nowadays fundamental for a range of applications (also see chapter 4).

Differently to satellite imagery, GPS technology reduces the referential to a single point (as opposed to entire maps given by pictures). This enables the individualised use of geo-reference and opens up a myriad of new applications, ranging from navigation to location-based services, or LBS (e.g. "where is the nearest Restaurant?", "What is the weather forecast for today?"). It is now common to find vehicles and mobile phones or PDAs with GPS receivers, and there is a dramatic increase in the number of these applications, both commercial and freeware-based (cf. chapter 5).

Again, for the cartographer, GPS has also meant serious improvements. Particularly with Differential GPS (DGPS) [1] and Real Time Kinematics (RTK) [2], which allow for sub-meter accuracy, these technicians can now guarantee a more than satisfactory accuracy in a large number of features (e.g. roads, buildings). Moreover, the popularity of GPS and handheld devices has contributed to the low prices and lightweight solutions that can now be found on the market, and which are currently highly favoured by cartography experts (Wadhwani, 2001).

At an industrial level (e.g. Tele Atlas, http://www.teleatlas.com, accessed 23 July 2008), the mappings have to be made at a systematic and intense basis, and it is therefore common to use special purpose vans with GPS (DGPS when available), odometer and cameras (Desmet, 2005). These techniques have been applied for several years (e.g. by Grejner-Brzezinska (1995)). The major problem with this solution is the need for constant updates. Whenever a change in the area is made (e.g. new roads, change in traffic direction, speed limit, etc.), an update has to be made of the map. Furthermore, these approaches tend to neglect pedestrian and alternative transport means (e.g. bike, cf. chapter 13), which would imply even more unstable maps.

The common process for updating geographical maps uses GPS as well as satellite imagery. Some systems and algorithms exist (Yun et al, 2004; Gerke et al., 2004) that directly or indirectly help identify visible road geometry and associate it with geographic positions. However, such approaches still require close human attention and, above all, cannot identify several important route features (e.g. traffic direction and speed limits) or non-standard roads (e.g. off-road). They thereore still have to be complemented by careful high precision GPS data collection on ground. It is, consequently still a very slow and resource-consuming process.

Autonomous systems

Given the need and costs of constant map updating, the search for autonomous systems was the logical next step. The two main map provider companies (TeleAtlas and NavteQ) and four major car manufacturers (BMW, FIAT, Daimler and Volvo), have been involved in two projects under the coordination of the ERTICO European consortium on Intelligent Transport Systems (ITS) (ERTICO, 2007): ActMAP and FeedMAP. ActMAP (Flament, 2005) lasted for 3 years (2002-2005) and its aim was to investigate and develop "mechanisms for online incremental updates of digital map databases into vehicles. Up-to-date map components containing dynamic or static location-based content should be integrated and/or attached to the in-vehicle digital map". The final results include reference architecture for the on-line update of digital maps. In the design specification developed, the authors proposed methodologies, procedures and data formats to enable an efficient process of updating maps, from map providers to users.

The FeedMAP project expects to complete the loop by transmitting data from the client to the provider, integrating it semi-automatically into the map. This project commenced in 2006 and is expected to be finished by the end of 2008. In FeedMAP, the main aim is to "assess the technical and economic feasibility of map data correction by providing a map data feedback loop applied to a map data updating framework using the ActMAP standardized exchange formats and mechanisms". As can be seen from **Illustration 12.1**, the authors propose a complete cooperative process that takes as actors the map providers, the clients and public authorities.

Commercially, the results of these and related projects are already visible. The most salient example is TomTom Map Share technology (http://www.tomtom.com/page.php?Page=Mapshare, accessed 23 July 2008), in which the user can record traces and send them to the map server. The whole process is still essentially manual (the symbolic information, the error correction, the aggregation), and it therefore strongly resembles OpenStreetMap philosophy, mentioned in the next section.

On the academic side, Schroedl et al. (2004) fully specify a system for generating geographical maps from DGPS traces. Their approach consists of successive processing steps: individual vehicle trajectories are divided into road segments and intersections, a road centerline is derived for each segment, lane positions are determined by clustering the perpendicular offsets from it, and the transitions of traces between segments are utilized in the generation

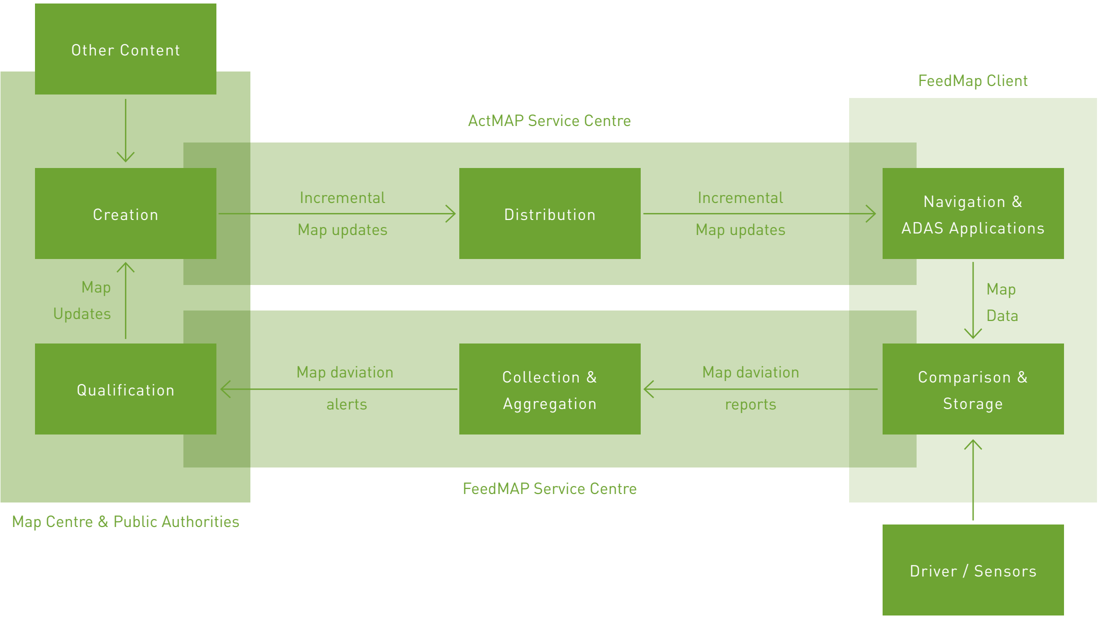


Illustration 12.1 Architecture of FeedMAP

of intersection models (Schroedl et al., 2004). Although as far as we know the most extensive as yet within academia, no further results have been published, possibly due to an industrial strategy (an associated patent was registered – US Patent nr. 6385539).

Partly a follow-up, the work of Brüntrup et al. (2005), 'Map Generation', may be the first that explicitly considers the collaborative side. In this project, the authors developed a system that incrementally generates a map of the world, starting from an 'empty' map and gradually adding new data collected from GPS traces. The system applies Artificial Intelligence search techniques to perform what is commonly known as Map Matching, the task of identifying which parts of an already existing map a given set of coordinates should correspond to. When no map segment is found, the set of coordinates should correspond to a new road (and thus aggregate it as a new segment of the map). 'Map Generation' performs reasonably well as long as the first traces for each segment are of a high quality, but has difficulties in improving an initial map with GPS errors (which is rather common in a realistic setting). In other words, it lacks a more precise feedback correction mechanism, perhaps with a 'forgetting factor'.

The observable investment in ActMAP and FeedMAP allows us to predict an improvement in the quality of maps in car navigation commercial systems in the coming years. However, the essence of these approaches (particularly the FeedMAP side) relies on having users participate and contributing. Such an approach is mainly common in Web 2.0 applications (e.g. Wikipedia, del.icio.us, MySpace, Blogspot, WikiMapia), and is rarely successful when based on a commercial relationship.

On the other hand, although they have fewer resources, the academic approaches are improving in quality and their constituents (namely the Map Matching modules) are currently extremely efficient. It has become difficult to make a technical comparison between the two, due to lack of information. From what is publicly known, industrial players are focused on improving maps for car navigation and integrating the system with other ADAS (Advanced Driver Assistance Systems), while academia is focused on general-purpose solutions (e.g. bike or pedestrian navigation).

Mapmaking and Web2.0

Collaborative projects currently exist for manually creating maps from GPS traces. The most popular and complete one is OpenStreetMap (OpenStreetMap, 2007). OpenStreetMap is a project "aimed squarely at creating and providing free geographic data such as street maps to anyone who wants them." In this project, each user can upload his/her GPS trace logs and use an editor (jOSM) to complete/correct the data (e.g. define directions, connections to other segments, add names, etc.). The resulting joint 'map of the world' can then be seen and the data can be processed for other uses (such as car navigation). In general, the major drawback of such a system is the manual effort demanded of ordinary users.

Map making and mobility analysis

The space in terms of the relationship between these systems and urban mobility analysis is still rather unfilled. Other than average speed, hot spots, points-of-interest and typical map features (e.g. gas station, parking lot, hospital, etc.), there is not much more information in the process added to the inferred route maps. OpenStreetMap representation is still open to added features and some related projects are actually adding external statistics (e.g. Stockholm GIS info, with dangerous and goods roads, nature reserves, built up areas, etc.; http://www.gisdata.se, accessed 2007), but a great deal more has to be done to achieve valuable content.

AN ARCHITECTURE FOR COLLABORATIVE MAP GENERATION

From a detailed analysis of previous work, we abstracted an architecture for Collaborative Map Generation (**Illustration 12.2**) that covers those works and that will direct our own next research steps, described in this section. We assume that the system is fully automatic, and that a base map may be initially absent (an initial empty map of the world).

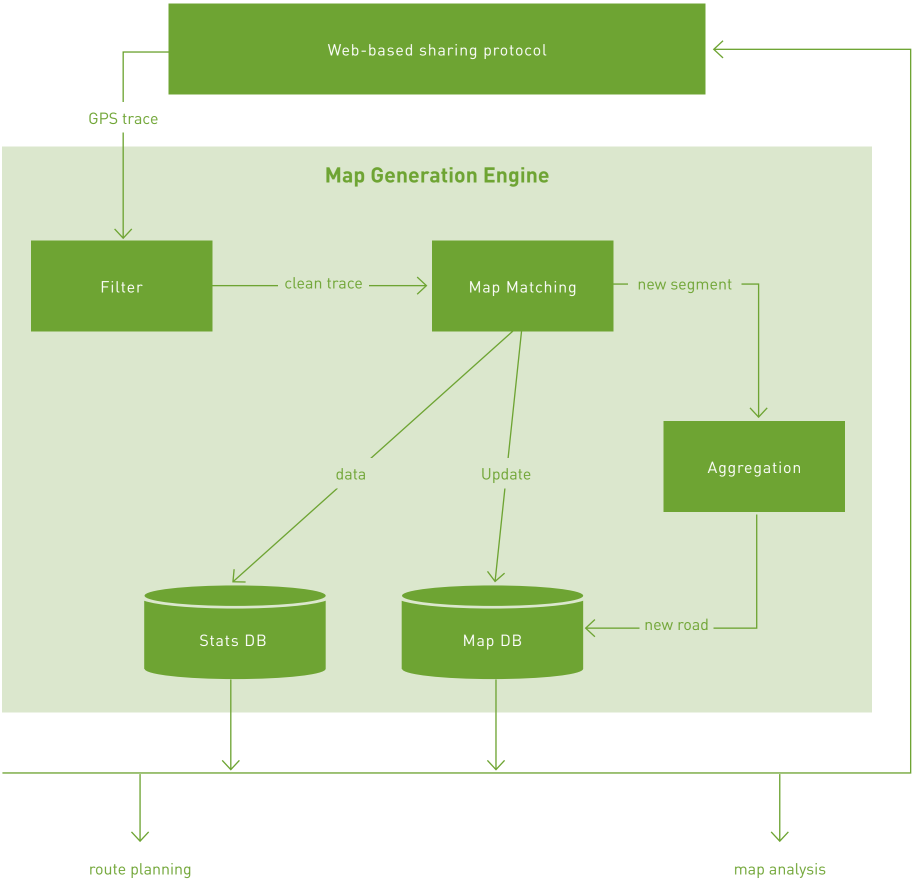


Illustration 12.2
General
Architecture

As with many other Web2.0 applications, we include a *front-end interface* accessible via a Web browser. This will be responsible for feeding the Map Generation engine with GPS traces. Notice that we expect each trace to be analysed separately (as opposed to what happens in the above-mentioned work of Schroedl et al. (2004), where traces are processed in batches). Each incoming GPS trace will then be *filtered* for consistency (as in the Map Generation project by Brüntrup et al. (2005)).

The filtered trace will then be matched to the existing map in the *Map Matching* module. The parts of each trace that achieve a correct match to the map (i.e. points that placed on the already existing roads of the map) will serve to *update* the *Map*. The procedure to be used in this correction mechanism consists of averaging the centerline according to the number of previous estimates and the confidence – according to DOP [3] – of the current one. The traces that reflect a 'new road' shall be *aggregated* taking into account the intersection treatment suggested by Schroedl et al. (2004). Regardless of being updated or aggregated, the *Map Matching* module will allow inference of mobility data that will feed the statistics (*Stats*) database (e.g. average speed, time spent in locations, most probable transport means used).

External services can be connected to this platform, for example for route planning or for map analysis (e.g. visualising cycling routes, transport usage, places where people stay for long times).

Filters

GPS traces always produce a considerable number of errors. There are many reasons for this: receiver clock errors, satellite clock errors, satellite orbit error, atmospheric effects (particularly Ionosphere and Troposphere) and multipath effect (e.g. when a signal is reflected in a building). Such error essentially affects the positioning estimation in each new calculation. This means, for example, that from one second to the next, the difference in estimation may vary in the order of meters. A study conducted by Refan and Mohammadi (2001) focused on averaging positioning estimates in a fixed point giving approximately 7 meters of standard deviation (with an amplitude of approximately 30 meters) for each axis, with a 5 minute sample of GPS points. These error values increase considerably when the receiver starts moving.

Many improvements to GPS accuracy are under research and some are already in production. In the case of DGPS and RTK, specific hardware conditions are necessary to effectively acquire accuracy improvements that are not available for low cost devices. A different technique, referred to as Dead Reckoning, consists of using other information (e.g. accelerometers, inertial sensors, assumption of correct route) to infer the precise location. These information sources

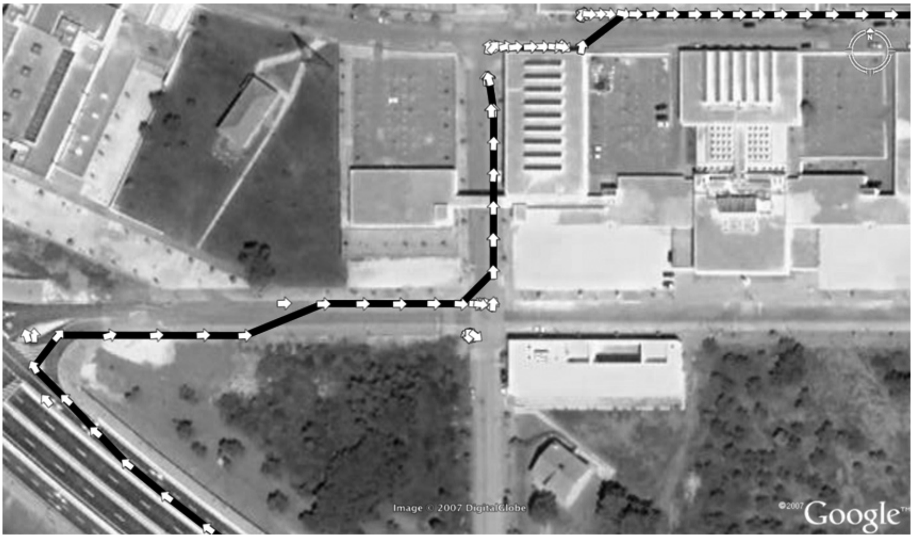


Illustration 12.3 Filter application to a GPS trace. The arrows indicate trace points, while the thick line corresponds to the filtered path proposed

are particularly useful in 'urban canyons' or even when no access to satellites is possible (e.g. indoors, tunnels). Although no special GPS hardware is necessary, Dead Reckoning normally uses other sensors or assumes uncertain facts, thus making the solution complex. In our case, we intend to use common off-the-shelf and low cost GPS receivers, and neither of these solutions is therefore applicable. The accuracy improvement has to be made exclusively with software post-processing of the traces. In other words, using filters.

Kalman filters, Recursive Least Squares and Linear Regression are currently being studied, with attention to car, bike and pedestrian traces. **Illustration 12.3**, for example, illustrates the result of the application of Cumulative Displacement Filter (inspired in Kalman filter). Particularly in slow movements (e.g. curves), the error can be seen to possibly strongly affect the road geometry. In terms of pedestrian traces, it has thus far been shown that Kalman related filters produce extremely bad results, while linear regression demonstrates fewer weaknesses. It is, however, noticeable that using a rule-based approach (e.g. people cannot move faster than 2m/s) allows for a reasonable first pass (without smoothing). **Illustration 12.4** shows an original pedestrian trace and a filtered one (indicating sub-traces, their beginning and ending, and places where the person stayed).

Notice that the problem we face goes beyond the common approaches: processing is made off-line (we have the entire time series, not only the 'past') and no auxiliary hardware resources are available.

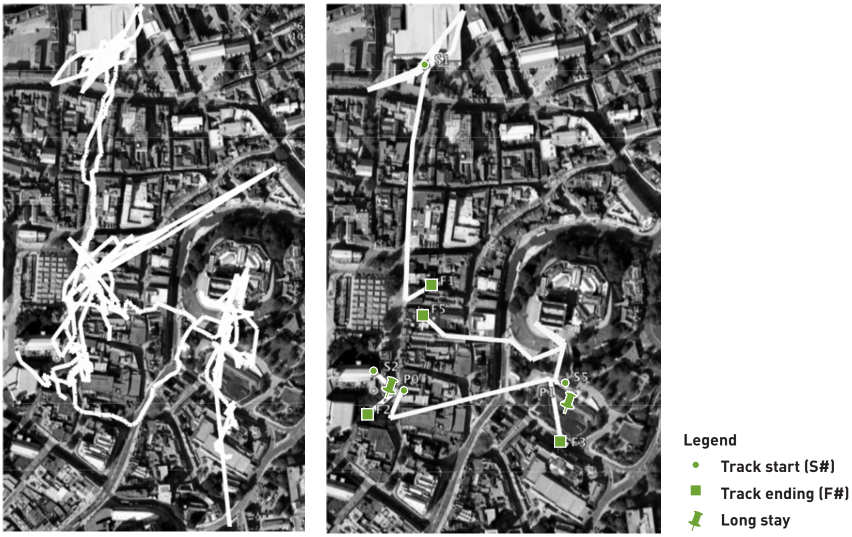


Illustration 12.4
Pedestrian trace (from Norwich, Spatial Metro project).
On the left side, the original trace data; on the right side, the filtered results

Illustration 12.5

Upper left:
Initial map (white line)
Upper right:
Recorded trace

Below:
Matching obtained with the GA
(Triangles mean unmatched)

Map Matching

For the task of map matching, we need a method that takes advantage of the topology of both the new trace and of the map constructed so far. Furthermore, the offline nature of the system allows for preference on precision over performance (of course, within reasonable limits). A genetic algorithm is being designed that evolves each potential match according to minimization of distance, penalization of gaps and incorrect topology. For readers unfamiliar with genetic algorithms (GAs), we will hereby summarize the concept: in a GA, several solutions to a problem are generated randomly at the beginning (the initial population); according to a fitness evaluation, a portion of them can be selected to generate the following generation. These solutions can be crossed with each other, providing their 'genetic material' to new individuals, and can be subject to 'genetic mutation'. This process is thus repeated iteratively, generation after generation. After a number of generations a satisfactory solution is found, and the algorithm stops having found the best solution ('individual') so far [4]. In our case, a solution, or 'individual', is composed of a sequence of 'point-to-curve' matches (the 'genes'). Thus, in theory, each individual could have as many genes as points in the trace. To limit this complexity involved, we use a segmentation of the trace according to the idea of Chawathe (2007), in which a trace is divided into shorter parts bound by points with high confidence matches. Our fitness function consists of the weighted sum of average, maximum and minimum distances, the sum of the gap size (subsequences of unmatched points) and the sum of the jump size (when two consecutive points in a trace match to different roads). **Illustration 12.5** gives an example of the initial map obtained from previous traces (a), the trace as evaluated (b), and the GA result (c).

This algorithm will then be compared to others: Depth First Search (Brüntrup et al., 2005), Frechet curves (Brakatsoulas et al., 2005), Least Squares Estimation (Blewitt and Taylor, 2002), and Multiple Hypothesis (Marchal et al., 2005). Again, the experiments will be directed towards bike, car and pedestrian traces.

Aggregation

Whenever a trace is found that does not match the existing map, we have to consider a possible new road in the map. There are essentially two approaches to aggregation: incremental and batch-based. In the incremental approach, we determine the points of intersection of the new set of segments with the existing map. In the batch-based approach, we recalculate the entire sub-network that fits the area of traversal of the new trace (by recovering all the original traces).

Incremental Aggregation

An incremental approach for map generation has the advantage of time-efficiency, as compared to the batch-based approaches. For this reason, it can also be used on-line. However, due to errors in normal GPS receivers, particular care has to be taken not to propagate them.

The algorithm we currently have from the Map Generation project (Brüntrup et al., 2005) subdivides the world into tiles and for each new trace, the *trace processor* interpolates new trace nodes. In the main processing loop, three modules *walk* along the trace. The *scan module* is the first module and scans the environment of the trace for nodes that are candidates for merging. After each scan the *AI module* decides which of the nodes should actually be used. Finally the *apply module* uses these results to merge the nodes with the trace (which would actually correspond to an *update*, not to an *aggregation*) or create new nodes on the map. In **Illustration 12.6**, an example can be seen of the original traces provided (a) and the resulting portion of the map (b). An improvement for the inference results for off-roads and roundabouts applies genetic algorithms to tune parameters (Scholz 2006). The dynamically generated map can serve a series of applications, particularly for navigation and providing up-to-date statistical information about the roads (e.g. average speed/congestion). In **Illustration 12.7**, we can see a sequence of map 'snapshots' in time; the map grows as new traces arrive.
The map matching algorithm can already provide us with a *triage* that separates two different

Illustration 12.6
Left:
Set of traces around a roundabout
Right:
Aggregated map, obtained from the traces

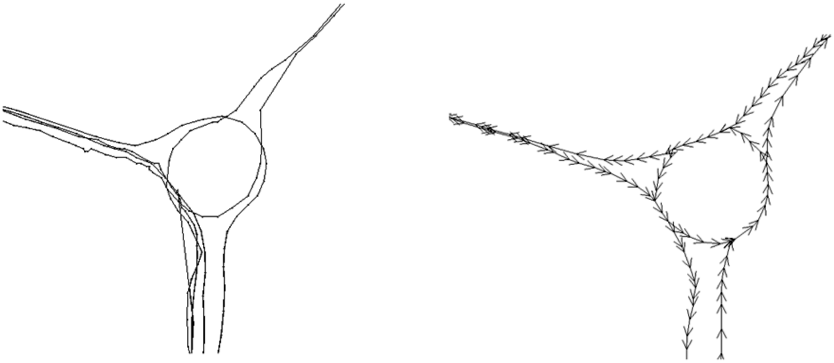
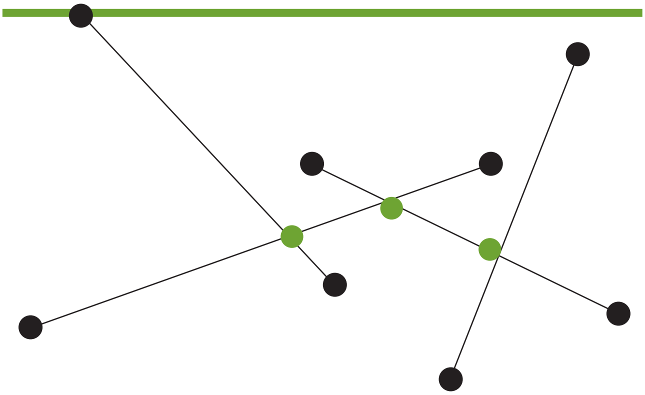


Illustration 12.7
Incremental Map Construction

Illustration 12.8
Segment Intersection of Batched-based Map Construction



tasks: updating the tiles with corrections to existing maps (Update phase), and adding entirely new segments to the map, which represent new roads (Aggregation phase).

The quality of the map will be sensitive to the successive updates and aggregations of traces. Although each new pass will provide correction, a bias towards the most recent ones will be inevitable. Such a problem can be attenuated if we apply batch-based construction periodically, by using all received traces so far (kept in the database) and applying them at once. This is set out in the next section.

Batch-based Aggregation

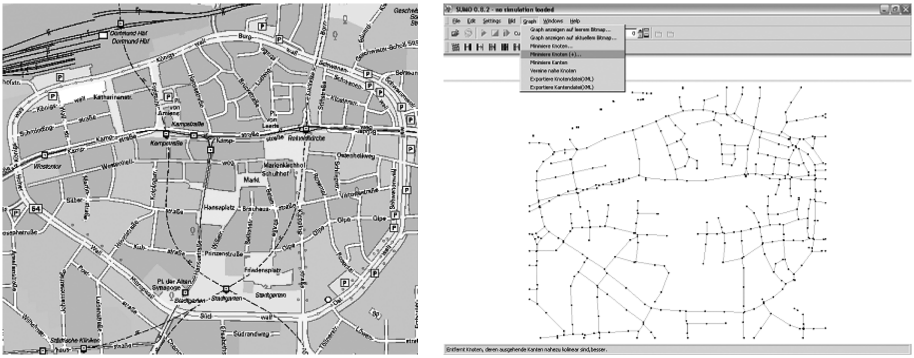
In a batch-based map construction algorithm, the traces are taken at once and organised in clusters (and sub-clusters) in order to make a *travel graph,* which is the embedded overlaid set of GPS traces together with the according intersections. To compute the superimposed graph, the sweep-line segment intersection algorithm (Bentley and Ottmann, 1979) is adapted (see **Illustration 12.8**). As opposed to the original algorithm, the generated graph is weighted and directed. At the intersections, the newly generated edges inherit direction, distance and time from the original data points. In typical travel networks, the number of edges is proportional to the number of nodes, as the node degree is bounded by a small constant. If it can be said that the graph is *planar* – as is often the case – the number of edges is linear in the number of nodes. Once the travel graph is built, many nodes of degree 2 remain. For computing the shortest paths these nodes can be merged by adding the distances of adjacent edges. Actually, only start, end and segment intersections remain, reducing the space complexity of the graph.

Batch-based map construction thus proposes to build the map 'all at once' from a batch of traces. This is only possible in an off-line basis. As said above, we propose the use of this method periodically (applied to a tile at a time) in order to 're-scan' the graph with all traces obtained over a period of time. Other methods can be applied, such as constructing a Base Map from (satellite or raster map) images.

Base Map Construction

In addition to satellite images, as referred to above, we may also use a method to extract calibrated road topology from raster maps to provide a *base map* for the collaborative map generation process. In many areas of interest, detailed vector maps are scarcely available and in some regions of the world, vector maps are not available at all. On the other hand, low-cost raster maps are frequently accessible. The images are often calibrated with respect to some form of global coordinate system to be translated to GPS. A bitmap is taken and different graphics filters used to infer the road geometry. We propose an aggregation algorithm that extracts road fragments and constructs a graph of the road network. To evaluate the proposed

Illustration 12.9
Base Map Generation (a) and inclusion in a Traffic Simulation Tool (b)



Entfernt Knoten, deren ausgehende Kanten nahezu kolinear sind,besser.

Illustration 12.10
Point Localisation Structures Quadtree

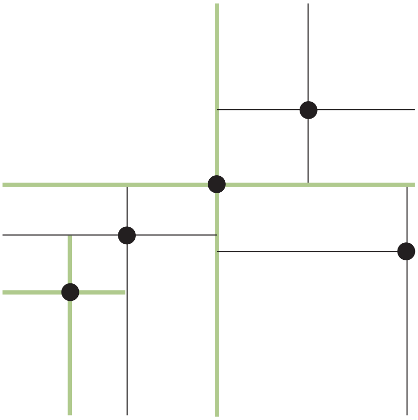
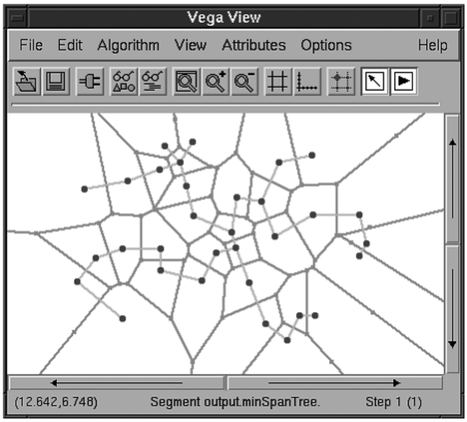


Illustration 12.11
Point Localisation via Voronoi Diagram.



(12.642,6.748) Segment output.minSpanTree. Step 1 (1) algorithms, the approach was integrated into SUMO (**Illustration 12.9**), a state-of-the-art traffic simulation tool for urban mobility (Drodzynski et al. 2007).

Efficient Map Representations

A map is beneficial to a user only if it can rapidly answer location queries. Before a query on the map based on given start and goal locations can be processed, their nearest corresponding entry nodes have to be found, i.e. efficient map matching in real time has to be carried out. For a set of queries, this is best accomplished by an assisting point localisation structure that supports nearest neighbour information.

Tile Regions

If the map is organized in form of tiles, we first have to find the set of tiles that a trace is located in, e.g. by looking at its bounding box of coordinates and retrieving this set for further processing. This has the advantage of allowing the integration of data to be distributed as far as the affected tiles do not overlap. The drawback is that a uniform distribution of fine-grained tiles is memory inefficient. One of the most interesting dynamic data structures for rapidly storing and retrieving tile information is *Quadtrees* (Finkel and Bentley, 1974), a balanced tree with children NW, NE, SW, and SE at each node (**see Illustration 12.10**).

Voronoi Regions

Another apparently suited data structure for nearest neighbour localization is the *Voronoi diagram* (Voronoi 1907). The structure consists of Voronoi regions $V(p)$ such that all points in the interior of $V(p)$ are nearer to p than to any other point in the point set (see **Illustration 12.11**). A search structure can be associated on top of the diagram or by its geometric dual, the Delaunay triangulation. A randomised construction for the triangulation and the associated search structure is presented by Berg et al. (1997).

Routing

Even though routing first seems to be unrelated to the map construction process, many search enhancements can be pre-processed and included in the map. Searching for the shortest route in the inferred graph can be sufficiently accomplished by a single run of the single-source shortest paths *algorithm of Dijkstra*.

Many modern navigation systems either provide their services through Internet portals, so that portable devices access large databases through communication with a server, or rely on portable devices with limited capacities. In the following, we address efficient algorithms and data structures to reply to frequent queries. Most of the algorithms exhibit the fact that the graph is embedded in the plane, so that refined geometric information on the set of all possible shortest paths can be associated to nodes or edges.

A* Search

Heuristic search is a well-known technique for reducing the number of expansions for a shortest path. This technique of *goal direction* includes an additional node evaluation function h into the search. The estimate that is applied to accelerate route planning measures the straight-line distance to the set of goal nodes. In this case, A* mimics Dijkstra's algorithm by changing the edge weights from $w(u,v)$ to $w(u,v)+h(v)-h(u)$ together with offset $h(s)$ given at the start node s (see Illustration 12.12). If one is interested in the shortest path in more terms than those of mere distance, the heuristic has to be adapted.

Illustration 12.12 Effect of Straight-line Distance Heuristics on the Search Space.

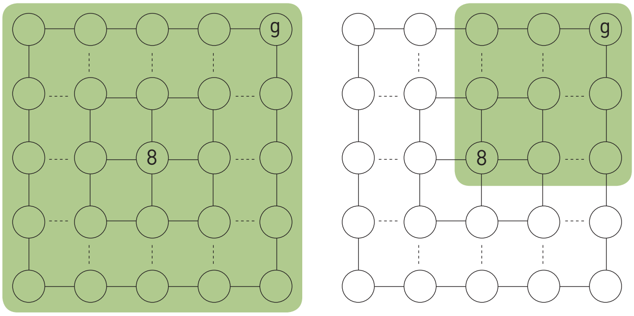
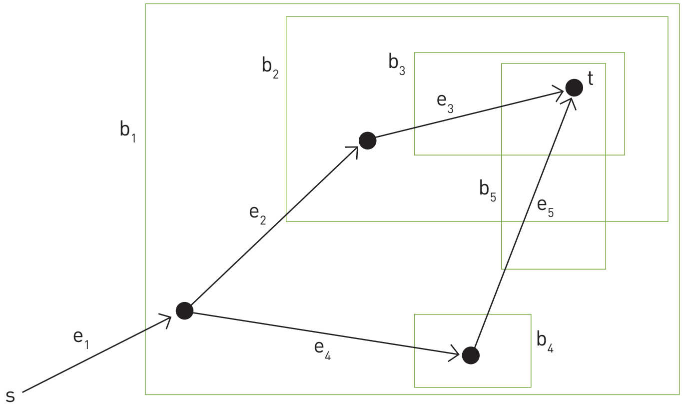


Illustration 12.13 Enhancing the Search with Geometric Containers.



Geometric Containers

Another possibility for decreasing the size of the search space is to ignore some of the neighbour points. The neighbours (or more precisely the incident edges to these neighbours) that can be safely ignored are those that are not on a shortest path to the target. In a pre-processing step, for each edge, we store the set of nodes that can be reached on a shortest path that starts with this particular edge. While running Dijkstra's algorithm or A*, we then refrain from inserting edges into the search queue that are not part of a shortest path to the target. The problem is the quadratic amount of space required to store this information, which is not available even for contracted graphs. Hence, we do not remember the set of nodes that can be reached on a shortest path for an edge, but approximations of it, so-called *containers*. Incorporating such geometric pruning preserves the completeness and optimality of a route planning algorithm, since at least one shortest path from the start to the goal is preserved.

Graph Rewriting

It can be advantageous to modify the routing graph simply to accelerate shortest path queries. One option is to apply abstraction to the graph structure by contracting nodes, to obtain a hierarchy of graph layers. More refined techniques have been established that reach out up to recent developments. A very influential approach is to insert *transit nodes* into the map to separate the base graph from the *highway graph* (Bast et al., 2007). Speed-ups of factors 100 and more have been obtained.

CONCLUSIONS

In this chapter, we have seen a smooth introduction to rising requests for collaborative and automated map construction on a set of GPS traces recorded by a host of individual devices. Besides the emergent roadmap, such methodology allows the elicitation of important information regarding individual and collective mobility. Examples include the inference of individual and crowd pedestrian networks or urban space use, correlated with time. By themselves, the statistics obtained from such a voluntarily built database can be substantial, for example for better calibration for simulations and to obtain detailed Origin-Destination matrices.

In terms of motifying individuals, collective map making is an answer to many important challenges for generating highly accurate, multi-modal and up-to-date maps. Automatically pre-processed and adapted positioning data can be used to accelerate the usability cycle on top of low cost devices. Maps in current use e.g. for navigation on the device are extended and refined on-the-fly by recording and integrating new traces.

Our working prototype (see **Illustration 12.14**) illustrates the advantage of the collaborative approach by comparing the aggregated map (a) on top of Google Earth (b), Google Street Map (c – notice the big error) and OpenStreetMap (d).

Besides surveying projects and existing solutions, this chapter reflected many algorithmic details as a portfolio to build a working architecture. We start with filtering of data, turn to incremental map aggregation via segment intersection, then to batch-based map construction, and the construction of a quick base map from raster map images. Moreover, for enhanced use of the map in a route planning system we show how to organize it for location queries and annotate it for accelerated shortest path search.

Illustration 12.14a-d Collaborative Map as an Overlay on top of Google and OpenStreetMap.

ACKNOWLEDGEMENTS

The authors would like to thank DFG for its support in connection with the project ED74/3. Moreover, the work was also supported by the running of the map generation software by Björn Scholz and the use of the filters and aggregator by Nuno Pereira.

NOTES

1 In Differential GPS (DGPS), each earth-fixed station, which extremely accurately knows its position, detects the error of the incoming GPS signal and propagates a correction to the surrounding receivers through radio communication

2 In Real Time Kinematics (RTK), the philosophy is similar to DGPS, but corrections are made to the *carrier phase* measurements (as opposed to the messages contained in it).

3 Dilution Of Precision – An estimate of GPS quality based on satellite alignment with respect to the receiver

4 For more information on this subject we suggest, for example, Goldberg (1989)

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13

JEROEN VAN SCHAICK, TU DELFT

TRACKING RESEARCH
AN AGENDA FOR URBAN DESIGN AND PLANNING

INTRODUCTION

Is there a future for tracking research in the context of urban design and planning? What about urban design and planning in the context of a world in which ubiquitous tracking might become an everyday phenomenon?

Tracking technologies seem to offer a door into the candy-store-of-their-dreams for researchers in urban studies. Potentially, everything can be tracked and traced, from people to goods and from vehicles to animals; specific places, routes or behaviour can be monitored, and individual people, their social networks or whole masses of people examined.

Tracking technologies are particularly interesting for urban design and planning in comparison to older techniques used to conduct research on human behaviour, such as travel and activity diaries. Tracking technologies make it possible to collect large datasets on human behaviour with a high level of accuracy, combining directly temporal and spatial data. Tracking technologies make it relatively easy to link additional information in databases to data on time-space paths. Moreover, tracking data is potentially highly communicative, since it is possible to make the data visually available and (real-time) accumulated, both individually and/or collectively. With trackable (even GPS-equipped) mobile phones entering the arena, it is possible that researchers will no longer need to worry about selecting a representative sample, as they can simply track 'everybody'. Moreover, location-based services are rapidly developing and are thus an economic drive for the spreading of tracking devices. This means that the devices might be ultimately ubiquitous, thus rendering concerns about the deployment of tracking devices for research purposes obsolete.

In light of this technological advancement, the possibilities opened up by using tracking technologies in academic research would seem to be immense. But is this actually the case? This book has shown that the initial phase of technological development offers promising vistas from a multitude of disciplines. However, it also shows that the application of tracking technologies can be quite complicated. After the openings given in the previous chapters, the goal of this last chapter of the book is to synthesise a future agenda for the application of tracking technologies in urban design and planning. This future agenda will be developed below on the basis of four lines of inquiry. These reflect the set up of the roundtable workshops at the expert meeting *Urbanism on Track*:

- The possibilities for integrating navigation issues that are part of daily life and urban design matters
- The possibilities for using tracking research as an evaluative, analytical or explorative tool in urban design
- The possibilities for support in decision-making in planning processes by tracking
- The possibilities for raising the value and validity of data and data collection relevant to urban design and planning

Firstly, the following section sketches the suppositions held by researchers on the relevance of tracking technologies, in particular amongst experts dealing with tracking technologies in relation to urban design and planning. Against this background, the subsequent sections examine the above-mentioned four lines of inquiry. The paper concludes by formulating a future agenda for the application of tracking technologies in urban design and planning in a number of pragmatic ways.

BACKGROUND: SUPPOSITIONS ON TRACKING TECHNOLOGIES

The expert meeting *Urbanism on Track* provided some interesting insights into the underlying suppositions and viewpoints on the role of new technologies, in particular tracking technologies, in the context of urban design and planning (see illustration 13.1). Firstly, 5 major levels can be set apart with regard to attitudes towards the relation between tracking technologies and urban design and planning, ranging from scepticism (level 1) to utopianism (level 5) (see also Schaick, 2008). The table of illustration 13.1 differentiates between two sub-levels for pragmatic attitudes (3a and 3b) and two sub-levels for the utopian attitudes (5a and 5b).

Distinctions can also be made between different types of arguments that support attitudes to technologies. These arguments express the often implicit, though sometimes explicit, value judgements on the role of new technologies in the field of urban design and planning in particular and society in general. Moreover, these value judgements are linked to the suppositions held by researchers on the relationship between technology, the city and people's behaviour. Several authors describe the way in which the introduction of ICTs into daily life since the 1990s has caused several shifts to occur in the relationship set out above, as did the introduction of 'old' new technologies such as rail transport and telephone in the past (Graham and Marvin, 1996).

There are three main challenges to these suppositions:
- The introduction of advanced tracking technologies forces researchers to question suppositions on human spatial behaviour, as qualitatively, if not quantitively, it changes people's activity behaviour.
- The socio-technical context of urban research is continuously and rapidly changing. The continual development of new technologies for use in daily life means that people's behaviour in a certain environment is not a given. The confusion about how cities are actually affected by developments in telecommunications has remained since it was first pointed out by Graham and Marvin (1996). This means that with the introduction of new technologies, the choice of subjects for urban research is under pressure to shift.
- The introduction of tracking technologies might change the nature of urban research. It gives researchers the possibility of developing new research questions in light of the accuracy and amounts of data, of adopting new research techniques due to new data collection / generation / computation / combination possibilities, and of communicating the outcomes of research in new ways, due to the possibilities of visualisation. Moreover, the interaction of users with these technologies, while tracking technologies are used by researchers to observe behaviour, needs special attention.

In light of the different basic attitudes towards tracking technologies, these challenges can be crystallised into a range of possible applications and directions for developing tracking technologies in urban design and planning. **Illustration 13.1** shows that the basic attitudes differentiate ideas about the development of applications of tracking technologies along three lines:
- the degree to which assumptions can be made on the influence on people's behaviour by ICTs, in particular tracking technologies (undermining suppositions on people's behaviour held by urban designers and planners)
- the degree to which assumptions can be made on changes in the spatial-physical conditions of people's behaviour, either by the introduction of ICTs or other factors (changing the subject of urban design and planning)

Illustration 13.1

The introduction of tracking technologies in the urban design and planning domain: suppositions, challenges and reactions.

	Basic attitude	Changing suppositions on activity behaviour in urban design and planning	Changing subject of urban design and planning	Changing nature of research in urban design and planning
1	"The results of studies using advanced tracking technologies are useless to urban design and planning"	Urban design and planning should not concern itself at all with suppositions on human behaviour, as it is changing too fast to be accounted for in designs	Focus on urban ground plan and physical-technical transformation of cities	Urban design and planning focuses on relationships with technical fields of study (e.g. civil engineering) instead of social (spatial) sciences.
2	"It is not going to be that dramatic a change, but – as designers - we need to become aware of activity behaviour in general and advanced tracking technology is a good tool for that purpose"	No major changes - basic biological functions are determining for activity behaviour; some qualitative changes are acknowledged	Durée of the physical environment will remain the stable factor in making urban designs and plans. Accommodating faster changing processes such as changes in mobility behaviour through spatial flexibility and gradual adaptation	Visualisation is used as an additional layer in urban analysis
3a	"The more data – the better our models – the better we can plan"	Based on contemporary body of knowledge in time geography	Spatial transformation modelling combined with activity-based traffic modelling. Focus on operationality of models.	Advanced tracking technologies provide large amounts of data as input in models; tendency towards linking databases and data mining; testing existing hypotheses and models.
3b	"Advanced tracking technologies provide a great instrument to get experts from different disciplines on one table"	During a planning process, expert opinions clash in organised environments and produce a new shared expert opinion	Decision support systems	Playful use of advanced tracking technologies; raising awareness about activity behaviour; visualisation is used as a communication instrument between experts
4	"Behaviour is changing, so we need new physical conditions"	Activity and mobility behaviour changes both qualitatively and quantitively due to the introduction of advanced tracking technologies	Exploring new spatial-physical conditions for activity and mobility behaviour; new concepts for urban design and planning, for example with regard to accessibility	Project-based ex-ante and ex-post research using advance tracking technologies; new conceptualisations of city-ICT relationships.
5a	"In time, physical interventions will become second to real-time urban management"	Real-time interaction of mobile and immobile information devices leads to new and controlled activity and mobility patterns	Urban planning is concerned with the (real-time) management of urban flows and rhythms rather than with making physical changes to cities. Planners as Big Brother.	Research focuses on finding new mappings and conceptualisations of the city; going beyond the same type of research conducted, for example, using diaries.
5b	"The availability of advanced tracking technologies will lead to empowerment of civil society groups in urban development and management"	Pervasive computing leads to new types of social networks with power to act because they have information about the urban system they live in.	Urban planning has become a bottom-up process emerging from civil society groups organising their space using ICTs. No place for urban designers and planners.	Research focuses on mapping social networks

- the degree to which assumptions can be made with regard to ongoing changes in scientific urban research and its basic hypotheses under the influence of ICTs (changing the nature of scientific research in urban design and planning)

Against this background, we can start working towards a realistic future for tracking in relation to urban design and planning. The subsequent sections provide the building blocks for a research agenda on the basis of the roundtable workshops held at *Urbanism on Track*.

LOOKING AT TRACKING AS PART OF DAILY LIFE

An initial perspective for a future research agenda can be developed if we look for answers to questions arising from tracking as part of daily life. The most obvious fact is that the development of tracking technologies has been linked to the development of location-based services – of which navigation is the most mature – since GPS technology was freed from the military straightjacket in which it was launched several decades ago. For a few years now, the combination of several different tracking technologies has offered us a wide range of possibilities for application (see chapter 3). Researchers acknowledge that the commercial application of tracking technologies cannot be ignored. Moreover, this should be taken as an opportunity for the development of academic applications of tracking technologies.

From this perspective, two approaches prevail in discussions between researchers. Firstly, examples are emerging of the side-by-side development of (a) services based on tracking technologies and (b) spatial interventions that anticipate the (omni)presence of tracking technologies in daily life. From this perspective, tracking technologies are primarily seen as a technique to observe behaviour. Examples can be found on three spatial scales at least, distinguished by different modes of transport and communication, namely pedestrian mobility, vehicle-based mobility and mobile communication.

Pedestrian mobility is a major theme for developers of location-based and location-aware services (see chapters 5 and 7). However, at this stage, it cannot be stated that tracking and walking are intensely linked all the time and everywhere. Pedestrian behaviour linked to tourism and leisure activities seems to be of particular interest for developers of commercial applications. With regard to academic research, tracking technologies offer a particular advantage over paper diaries for registering exact routes taken and the kind of trips that research subjects easily forget, typically ‘quick’ trips by foot from the home or the office such as posting a letter. However, raising the accuracy of tracking data on leaving indoor environments still needs to be a major point of improvement. In addition, pedestrian mobility should be seen as part of a greater mobility chain. This is why, in general, research on pedestrian mobility benefits greatly from a combination of research techniques.

The integration of tracking devices in vehicles is growing. Since a few years ago, car-based mobility has become intensely connected to the technological development of tracking technologies. The increasingly widespread use of navigation devices strongly depends on tracking technologies. The latest developments point to the further integration of mobile phone tracking with navigation devices for the purpose of detecting traffic jams. Other vehicles are being tracked as well. The tracking of taxis, buses and lorries is becoming increasingly common, especially from the point of fleet management, logistics or theft prevention. In particular, road pricing is an example of an application that has a direct relevance to urban design and planning. The advantage of tracking data collected in this way is that datasets often include a very clearly defined group of users, making the interpretation of data relatively easy. However, it also limits future possibilities for research, as ownership of these datasets is not quickly transferred or shared with researchers.

Over the last decade, mobile communication has become the most ubiquitous technology available for providing possibilities for tracking people. Mobile phones have a high level of penetration on a global level. Theoretically, this development can supply an endless source of data for researchers. In particular, the combination of mobility data with communication data could be interesting with a view to investigating social or business networks.

Another approach to tracking as part of daily life is to focus more on the way in which tracking technologies change people's behaviour when they actively use or passively carry a tracking device. In this case tracking can be, but is not primarily, used as a technique for observation. Two examples of research subjects in this light are research on how the use of tracking technologies changes people's mental maps (see also chapter 11), and research on how the use of tracking technologies changes people's time and space use. Although these are relevant research subjects, this chapter focuses on tracking technologies as research instruments.

What conclusions can we draw from looking at tracking technologies as part of daily life? In his essay *Sensing Human Society*, Shoval (2007; cf. chapter 2) states: "The fact that an ever-increasing proportion of human society constantly carries a tracking device at all times and in all places creates new possibilities for spatial research." Researchers are expected to increasingly exploit and depend – or at least count - on familiarity with and the future ubiquity of tracking devices. This dependency makes it crucial to develop ways to work across the borders between university and commercial operators and interactively with the users of these technologies. In this light, understanding user-technology interaction is central to the future development of research.

This perspective shows that it is crucial to be aware of biases related to the dominant mode of transport in research projects. Dominant categories are pedestrian tracking, automobile tracking by in-vehicle GPS devices and the tracking of public transport vehicles such as buses or other service transport such as taxis or cargo vehicles. One bias in such research is the neglect of multimodality in travel chains or activity chains. This can be dealt with by deploying tracking devices over longer periods of time and having devices carried 'on the body'. The introduction of the mobile phone as a tracking device that can be used for tracking research might solve some of these problems. However, several researchers have warned that mobile-phone tracking is not the ultimate answer to all research questions to tackle using tracking devices. Moreover, each of these technologies fails to solve the omission of people that are not using these technologies. It would seem that a strategy of tailor-made technologies is best for academic purposes, while for general purposes, the integration and compatibility of technologies is necessary with a view to get coverage by tracking technologies in as many different environments as possible. This, in turn, could lead to new applications in academic research.

EVALUATION, ANALYSIS AND EXPLORATION WITH THE HELP OF TRACKING

A second perspective on a future research agenda can be developed when moving from a focus on user-technology interaction towards the interaction between the urban designer and tracking technology. This section examines the possibilities of using tracking research as an evaluative, analytical or explorative tool in urban design. Exploration, analysis and evaluation are essential elements of any urban design and planning process. For exploration, analysis and evaluation by using tracking technologies to be of value, it is important that results can be directly linked to the development of spatial strategies and the physical design of space.

The use of tracking technologies as an evaluative tool links up to the desire of urban designers to test the effects of spatial interventions. Although tracking people for this purpose seems to be a logical step, it is not simple. Hardly any longitudinal studies have been conducted (notable exceptions are the MOBIDRIVE dataset (Axhausen, Zimmermann, Schönfelder, Rindsfüser & Haupt, 2002), see Schönfelder, Axhausen, Antille & Bierliare (2002) on matching longitudinal data from different sources, and the work of Ahas, Aasa, Silm, Aunap, Kalle & Mark (2007) on aggregated mobile phone data over the course of a year). Moreover, no studies using tracking technologies are known to have purposefully tested a situation before and after spatial interventions. This may be due to the fact that the technique is relatively new and still in development – most studies so far can be regarded as pilot studies, and research has only structurally focussed on tracking techniques in the last couple of years. Another or further explanation could be the fact that there are structural problems in applying tracking technologies this way, such as a lack of willingness to commission longitudinal research from within spatial planning practice. However, examples are available of actors in planning practice having commissioned research on activity patterns for spatial planning purposes using diaries (see Boelens, Sanders, Schwanen, Dijst & Verburg, 2005).

Data from GPS devices offer simple possibilities to visualise individual tracks. This makes tracking data available for the visual analysis of spatial structures. For other tracking devices, there are a host of experiments using visualisation for the purpose of visualising rhythms, flows or places where people stop and look around (see chapter 8). Two types of visualisations have been greatly stimulated by the introduction of tracking technologies, namely dynamic visualisations (movies) and interactive visualisations. Tracking is associated with different ways of developing interactive imagery, e.g. updating and correcting, adding photographic material to tracks and the interactions embedded in location-based services (see also chapter 12).

By tracking specific target groups such as the inhabitants of a city or visitors to a city, children, women or ethnic groups, the use of tracking technology can help analyse specific patterns of use and analyse the problems that particular groups encounter when moving around a city. Specific household configurations have not been used much as a starting point in tracking research, but have been in diary-based activity research.

Deploying tracking devices as an explorative tool might help in developing more user-oriented spatial scenarios. The awareness of the importance of use aspects is prevalent in the field of spatial planning and design, although to a limited degree (e.g. see from different angles Klaasen (2005) and Gehl & Soholt (2002)). The application of tracking technologies in the education of planning professionals and in concrete design and planning projects can be an important step forwards in the development of awareness of people's activity patterns. In particular, the deployment of tracking devices in a workshop environment amongst different stakeholders in a planning process might help to build understanding in a playful way by using tracking-based visualisations as a medium. The combination of other media such as photograph, digital notes or recordings could enrich this approach (cf. chapter 9).

What can we conclude from looking at tracking technologies from the perspective of urban design? The main added value of tracking technologies in this regard literally lies in getting the user in the picture. Further, the evaluation of spatial interventions has been firmly placed on the agenda by participants of *Urbanism on Track*. Finally, the perspective of urban designers can draw special attention to the importance of visualising tracking data.

DESIGN AND DECISION SUPPORT BY TRACKING

Moving away from more or less hands-on approaches to tracking devices, this section examines how tracking technologies might become part of a wider array of instruments used by urban designers and planners. The focus in this section is on the possibilities of a role for tracking technologies in computer-aided decision-making in planning processes.

The introduction of tracking technologies in daily life necessitates the rethinking of the theoretical frameworks for research on activity patterns, such as those developed in the field of time geography. A major application of tracking technologies is the use of tracking data for modelling activity behaviour (see chapters 10 and 11). Such models are used as decision support systems in spatial planning processes. With regard to modelling activity behaviour, tracking plays a double role in influencing people's behaviour and at the same time provides a tool to investigate that behaviour, as set out earlier in this chapter. Researchers generally expect higher accuracy from their models when they use tracking data instead of data from travel diaries. Another expectation is that tracking research can be carried out in less time and at less cost, and can collect greater amounts of data than when using traditional research techniques.

A number of initial experiments indicate the possibility of real-time input in the management of urban spaces (see chapter 8). Particular areas of application could be traffic management or the management of events. This could have major implications for the way in which public space and roads are designed, although the technology is too new to anticipate the precise effects. Although it may risk becoming futuristic, the real-time management of urban spaces is an interesting avenue of future research.

Another angle from which design and decision support can be regarded is the use of geographic information systems and in a broader sense the use of layer approaches (see chapter 4; for a critical review of layer approaches see e.g. Schaick & Klaasen, 2007). Tracking data can be superimposed on geographical and functional maps, either in a database or with visual map overlays. The confrontation between different datasets or different types of visual information can support the making of design choices.

What can we conclude from looking at tracking technologies from the perspective of computer-aided decision support? As addressed in the preceding section, visualisation as a mediating instrument is highly important in supporting decision-making in design and planning processes. The pursuance of a higher level of accuracy is the main driver for the large scale use of tracking technologies. The limits of what is possible when using tracking technologies for design and decision support have not yet been reached.

VALUE, VALIDITY AND ACCESS TO DATA: PRAGMATICS AND IMPLICATIONS

The last perspective for a future research agenda on tracking technologies in urban design and planning goes back to basics – tracking data. In this section, we focus on raising the value and validity of data and data collection relevant to urban design and planning. What kind of datasets are referred to here? What level of accuracy is needed, desired and feasible? This last section, in which building blocks are developed for a future research agenda for tracking technologies in urban design and planning, looks at enriching tracking data, data collection methods and the relevance of scale and concludes by addressing privacy.

Firstly, the information directly derived from the raw data is generally not sufficient to draw significant conclusions about behaviour or activity patterns. Additional information is required to answer most research questions relevant to spatial planning, e.g. on the type of activity, who the activity was carried out with or the question of whether the tracking device was carried all the time and by the right person (cf. Lee-Gosselin, 2002). Additional data can be collected simultaneously or indirectly from other sources (see Verbree, Maat, Bohte, Nieuwburg, Oosterom & Quak, 2005; Janssen, Wets, De Beuckeleer & Vanhoof, 2004). It can also be derived from the raw data or from previously obtained information through the use of algorithms or other computational techniques (see e.g. Wolf, Guensler & Bachman 2001). To decide on relevant research questions and methods of collecting additional data and to interpret results, research teams are currently developing multidisciplinary teams, including several technology specialists, database specialists, geographers and planners. The last group is generally limited to transportation specialists, although spatial planners or urban designers are occasionally included in research teams (see e.g. Institute for Mobility Research IMOB at University Hasselt, Belgium).

Secondly, researchers have pointed out a trend whereby data-mining is slowly gaining ground over data-gathering. It is becoming easier to collect large amounts of data, both in terms of time and number of people. The big question remains 'who are these people?' and even more interesting 'who are they not?' A shift is occurring from selecting a sample of the population in which researchers deploy devices to the development of data-mining procedures and to procedures that depend on voluntary uploading of data by individuals. However, data-mining cannot solve all data problems. The ownership and accessibility of large datasets for example, such as mobile phone location data, is still often limited to the companies collecting the data.

Thirdly, the scale and scope of tracking research projects will always determine the desired level of accuracy and vice versa. Scale and scope are determined by the spatial activity pattern in which research is interested, the time grain of research samples, and the number of people tracked. Both the method and the outcome differ substantially when the research is spatially limited to a small area, e.g. a train terminal or to a large area, e.g. regional activity patterns, or to the relation between areas and trips of different scales, e.g. in research on tourist travel patterns. The differences between tracking studies focussing on a single activity, on activity chains or on complete activity patterns each need different levels of accuracy and other additional data. Most researchers seem to agree on 7-day periods as the most relevant and feasible time unit for tracking an individual's activity pattern, but research not focusing on activity patterns on an individual level does show different temporal grains (e.g. research on the use of a public space in one day and night). Choices with regard to the temporal scale of a study can be, but are not *necessarily* related to the spatial scale or to the number of participants and vice versa. Important factors in how choices are made regarding the scale and scope of research projects are the accessibility of data (e.g. related to the research budget) and the logistics of the distribution of devices. The size of the group of respondents is also important as this can lead to differences in the logistics of research and other requirements for data management, but also to other types of research claims, for example on the aggregate effects of behaviour.

Fourthly, when looking at the expert opinions during *Urbanism on Track*, the different ethic implications of using tracking technologies were not guiding in considering the future of urban design and planning in light of advanced tracking technologies. Future research should put privacy back on the agenda.

What can we conclude from looking at tracking technologies from the perspective of data? From a technology-driven approach, we need to turn towards an approach that prioritises the reason for conducting the research in the first place. This means that technology-driven research has to connect up to concrete policies in urban design and planning. It also means that the characteristics of a research project should logically connect to what it is necessary to know. This sounds logical, but as we are still in the early stages of this research field, research experiments are often driven by what is possible rather than what we need to know. To make the right choice between GPS, mobile phones or other technologies, a decision has to be taken as to both the level of accuracy and the additional data required.

LOOKING BACK AT *URBANISM ON TRACK*: AN AGENDA AND SOME CONCLUDING REMARKS

The goal of this last chapter of the book was to formulate a future agenda for the application of tracking technologies in urban design and planning. The chapter has followed four lines of inquiry, looking at tracking technologies from different perspectives: tracking technologies as part of daily life, the possibilities of using tracking research as an evaluative, analytical or explorative tool in urban design, the possibilities for support in decision-making in planning processes by tracking and lastly the value and validity of data and data collection. However, during the expert meeting *Urbanism on Track*, the themes discussed in this chapter failed to provide ready-made agendas for future research in urban design and planning. The immediate results of the expert meeting were fragmentary, overlapping, of different orders and unfairly biased towards a positive approach to new technologies. This chapter has reconstructed a number of basic underlying principles through a critical review of the results of the expert meeting. The reading of the results in this chapter is coloured by an emphasis on their relevance for urban design and planning, stronger than the immediate input of the participants would have indicated. This is an indication that tracking technology has yet to gain firm ground in urban design and planning. The question can therefore be asked as to whether there is a future for tracking research in urban design and planning.

Although the enthusiasm expressed in this book suggests that there is indeed a future for tracking technologies in urban design and planning, it cannot be taken for granted that urban designers and planners will embrace tracking technologies immediately and completely. Neither can it be assumed that researchers and designers will now take the step from collecting and processing data in the context of travel behaviour studies or activity behaviour studies to actually applying the knowledge acquired when making an urban design or drawing up a plan. It is a fallacy to think that tracking technologies can miraculously solve all problems in urban design and planning related to applying knowledge to researching human behaviour (cf. Ter Heide & Wijnbelt, 1994). With regard to using tracking technologies in the context of urbanism, it is important for technology-oriented researchers to be aware that the main language of urban design and planning is visual. In addition, the possibilities of using tracking technologies – e.g. the integration of temporal and spatial data and the integration of individually collected data and aggregated data – should be fully exploited with a view to rendering them relevant to urban design and planning. However, there is no magic recipe for optimising the relevance of tracking research.

In this light, against the backdrop of basic attitudes with regard to tracking technologies in the context of urban design and planning (see illustration 13.1), a number of preferences for approaches can be stated for various specialised fields of knowledge. These have been simplified and are based on the findings of the expert meeting *Urbanism on Track*. Transportation-oriented scientists prefer a modelling and simulation approach. Urban designers seem to prefer an approach focussing on the increasing awareness of human behaviour. Spatial planners and to a certain extent geographic information specialists seem to prefer multi-tier and/or multi-method approaches. Geographic information specialists and transportation specialists both trust that in the long run, answers will be provided by the development of extensive databases or data warehousing. More generally supported by different specialisations are (1) the application of longitudinal measurements using tracking technologies before and after spatial interventions and (2) multi-actor, multidisciplinary approaches to planning. However, both these approaches are said to encounter significant problems in research and planning practice. Several ways forward can be conceived of.

In the short term, possibilities are (a) the raising of funds for multidisciplinary work, (b) developing a discourse on privacy and ethical considerations with regard to using tracking technologies in the context of urban planning and design, (c) developing a road map for implementation in urban design and planning, (d) starting using tracking technologies in participatory planning processes as a *serious gaming* tool, (e) developing sophisticated visualistion tools and principles, building from geovisualisation, but focussing more on meaningful representations for planning and design processes.

Other goals can be pursued within relatively longer terms. Research can be strengthened both in terms of effort and multidisciplinarity; (a) creating conditions for comparative research using data from studies using tracking technology. Different lines of research could focus on standards and/or the compatibility of tracking data, data warehousing and supportive comparative research on transportation systems and urban systems alike; (b) operationalising behavioural and decision models based on tracking data; (c) developing new ways of collecting data using innovative tracking technologies or innovative applications of tracking technologies for specific design and planning-oriented research, for example the development of longitudinal studies.

Attempts to formulate longer-term research goals may run the risk of becoming futuristic. Both technological advancements and societal trends become highly insecure and unpredictable on this time horizon. Two tiers of thinking seem to dominate discussions on this long-term research future: (a) real-time planning and (b) sustainability. However, within the context of this chapter, these subjects are too extensive to be further developed. We can conclude however that tracking technologies are here to stay. It can be regarded as the task of multiple disciplines to develop – in cooperation – applications of tracking technologies in urban design and planning that, metaphorically speaking, go beyond "building iron bridges as if they were made of wood", as a participant at the expert meeting stated. In the end, the message of this chapter, and perhaps of this entire book, is that it is not simple to apply or even integrate tracking technologies in urban design and planning. It is however definitely worthwhile.

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URBANISM ON TRACK

Tracking technologies such as GPS, mobile phone tracing, video and RFID monitoring are rapidly becoming part of daily life. Technological progress offers huge possibilities for studying human activity patterns in time and space in new ways. Delft University of Technology (TU Delft) held an international expert meeting in early 2007 to investigate the current and future possibilities and limitations of the application of tracking technologies in urban design and spatial planning. Urbanism on Track combines the edited papers of those involved, giving a state of the art of a highly dynamic field of research.

Urbanism on Track introduces the reader to the basics of tracking research by means of a number of examples. What is tracking? How is data influenced by the context in which it is collected? How can we process and visualise tracking data? And what about the role of tracking technologies in navigation? Urbanism on Track showcases tracking experiments in urban studies, planning and design – from pedestrian navigation in Austria to Danish field tests, from TU Delft's Spatial Metro project to MIT's Real Time Rome and last but not least the Sense of the City project realised in Eindhoven.

Urbanism on Track provides insight into the advantages of using tracking technologies above other research techniques. But it also shows the bottlenecks in gathering and processing data and applying research results to real-life problems. The book discusses the replacement of paper travel diaries, relevance for transportation policies, the possibilities of a new cartography and attitudes towards implementing tracking technologies in urbanism.

The emphasis on the application of tracking technologies in urban design and planning makes Urbanism on Track a unique book, setting the agenda for the structural embedment of research using tracking technologies in urbanism.

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