16 Electronic Footprints in Transport Management

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16.1 Space-Time Geography: The Basis for Transport Management

Research on modern logistics and transportation systems has already a long history, but essentially their roots date back to the development of space-time geography in the 1960s (see Hägerstrand 1970). It should be noted that transport geography has increasingly lost the traces of a descriptive discipline on man-environment relationships. On the contrary, modern geography has increasingly turned into a data-handling scientific activity over the past decades. Transport geography offers a clear illustration of this trend. The methodology of data collection – and subsequent statistical analysis in spatial interaction modelling – has exhibited drastic changes over the years. Many flow models used in the transportation field (e.g. for commuting, shopping, recreation, freight transport) have traditionally used origin-destination (OD) data, either at an individual or at an aggregate level. Most of these models were based on gravity-type of approaches, which later on were often translated into spatial interaction models (SIMs). Well-known examples are entropy models and activity-based spatial models. All these approaches needed extensive data, obtained from either observed flows (e.g. manual counting, loop detection, cameras) or from (self-)reporting methods (e.g. mobility diaries, electronic devices, survey methods or telephone interviews). The increase in and research potential of large-scale data bases on the spatial behaviour of people laid the foundation for the operational nature of modern transport geography.

The history of quantitative data analysis in geography and regional science spans now already several decades. The need for a more appropriate behavioural underpinning of spatial interaction models led in the 1980s to the emergence and popularity of micro-based discrete utility (or choice) models, in particular multinomial logit and probit models, later on followed by conjoint analysis modelling. Such individually-based models were proven to be consistent with aggregate-oriented spatial interaction models and got widely accepted in the transport research community. They also turned out to be well suitable for actor-based policy simulation experiments, for instance, in the context of micro-simulation models and agent-based models. In this vein, modern geography exhibits increasingly the methodology of the natural sciences based on advanced statistical analysis and testable models (see, for a review, Pagliara and Timmermans 2009).

All such models were widely used for prediction purposes, evaluation experiments and policy analyses in the planning and transportation science field, for example, to trace the system-wide effects of road pricing on the behaviour of car drivers. With the advent and introduction of ICT, the computing capacity in quantitative research showed a dramatic increase, so that also spatial dynamics could be captured in a statistically more satisfactory way. Complexity theory has in recent years offered a remarkable contribution to a better understanding of the sensitivity of spatial systems' evolution to endogenous non-linear space-time behaviour. Space-time dynamics (e.g. in the cellular automata domain) became an important ingredient of advanced transportation research and spatial analysis, and prompted a new departure, viz. the use of data mining methods for large data sets. The current use of computational neural networks and genetic algorithms demonstrates convincingly the great potential of more sophisticated data collection techniques. The real essence of space as highlighted in Tobler's (1970) law ("*all things in space are related to each other, but nearby things are more related than distant things*") was taken up in a new strand of literature addressing spatial – and spatio-temporal – autocorrelation, either as testing devises or as design mechanisms for spatial (dynamic) models (see also Tobler 2004). Cellular automata, spatial filtering techniques and self-organized mapping procedures ('Kohonen maps') for spatial interaction analysis were a logical follow-up and complement to the above mentioned trends (see e.g. Arribas et al. 2010, Codd 1968, Couclelis 1997, Kohonen 2000, Kulkarni et al. 2002 and Patuelli et al. 2010).

In recent years, we have witnessed an increasing popularity of location-based services (LBS) and data using various kinds of electronic identification systems, so that at an individual level (a traveller, a container, a truck, or a taxi) the geographic position of a unit can be traced with great precision. Many applications are available for purchase and free-to-cell phone and other wireless device users. For example, Japanese parents are using location-based tracking devices to monitor the spatial movement of their kids. This new approach will certainly prompt many new applications in space-time geography.

An interesting source of individually-based information on the space-time position and behaviour of persons is in principle available from mobile (or cell) phone data, derived from the GSM network. The penetration rate of mobile phones is rapidly reaching a full saturation level in most OECD countries, so that a system-wide coverage does in principle exist, almost in continuous space-time format. Such data – as very accurate representations of the individual space-time location – are in principle available with telephone operators. If such data – in anonymous form – could be made available to the research community, an unprecedented source of information on the space-time geography of individuals could be used in applied research (see for an overview Steenbruggen et al. 2010).

It is noteworthy that this idea of a continuous space-time map at an individual scale was already put forward by the late Swedish geographer Torsten Hägerstrand in 1967. He introduced the ‘space-time cylinder’ and its related time-space model (see also Figure 1) to offer a description of both individual space-time patterns and the resulting spatial interactions if many individuals were ‘en route’ at the same time and place, a situation caused by the universal limited supply of daily time resources. His work was regarded as a new perspective in social-behavioural geography, as it highlighted so clearly the essence of interaction and congestion phenomena in space (see Pred 1977). Three constraints appear to act as barriers on the daily mobility pattern of individuals, viz. capability constraints, coupling constraints and authority constraints. It also laid the foundation for activity-based transport geography, but, unfortunately, lack of data and the technology available to implement the framework precluded often a full operational application of his path-breaking ideas.

Now with the potential availability of large-scale continuous space-time information bases on spatial movements of individuals, a really interesting novel approach might be developed, which may have great implications for spatial modelling. Two such approaches can be found in the literature. The first proposed by Raubal et al (2004) incorporates elements of cognition by considering individuals’ preferences via Gibson’s (1979) theory of affordances. Cognitive constraints, e.g. choice behaviour, were not given explicit attention in the original time-geography framework. These constraints can help personalize LBS, allowing for the possibility to collect more detailed information about the choices individuals make, their likes and dislikes. The second adjusts the space-time prism concept to support interactions and activities between the physical and virtual spaces (Yu and Shaw 2008). This approach would help model and understand how in the age of mobile computing, where a variety of activities and services can be carried out on the go, individuals are allocating their space and time resources.

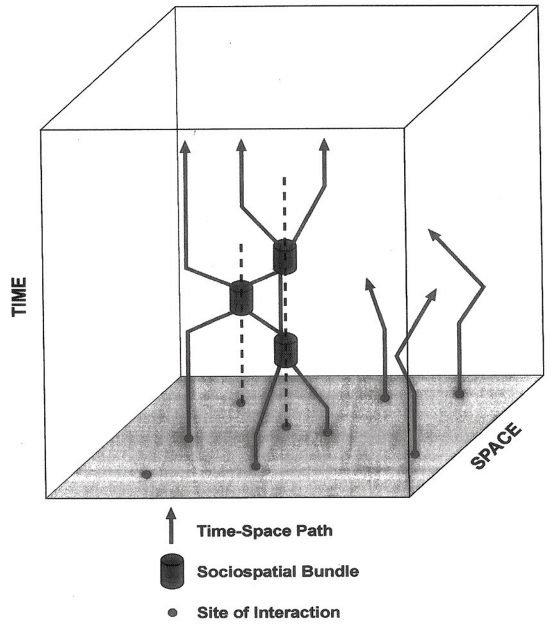

Figure 1. Hägerstrand's Time-Space Model (Source: Warf (2006))

In the recent literature, we see already the first interesting applications of GSM data, e.g. in the study of intensity of social networks (Eagle et al. 2009), the spatial distribution and concentration of tourists (Ahas et al. 2006), traffic speed and journey time (Bar-Gera 2007), individual mobility patterns in cities (Gonzales et al. 2008) or of urban structure patterns (Reades et al. 2009). Interesting applications can also be found in the use of private or public spaces by individuals (see, e.g., Calabrese et al. 2001), the concentration of people in a city (see, e.g., Reades et al. 2009), the activity spaces of commuters (see Ahas et al. 2006), non-recurrent mass events such as a popfestival (see, e.g., Reades et al. 2007), the entry of tourists in a certain area of attraction (see e.g., Ahas et al. 2007*,* Ahas et al. 2008), or the estimation of spatial friendship network structures (see Eagle et al. 2009). Especially in the transportation sector, the potential applications are vast, and consequently, the use of cell phone data has shown a rapid increase in urban transport applications. These data offer a rich source of information on continuous space-time geography in urban areas. They can be used for daily traffic management, but also for incidence management, for instance, in case of big fatalities, terrorist attacks, or mass social events such as festivals or demonstrations.

It should be noted that the use of LBS data (in particular, GPS or GSM information) has also met scepticism and even criticism, as in this case it may be possible to track humans in all their space-time movements. Some authors talk even about *'geoslavery'*[1] as a new form of big-brother control on location behaviour (see, e.g., Dobson and Fisher, 2003; Reades 2010) and highlight important privacy issues (Sui 2004, Jiang and Yao 2006). Notwithstanding such socio-ethical issues, GIS technology offers an important vehicle for the use of such geo-based devices for mobility planning and management. The Open GIS Consortium (OGC) (http://www.opengis.org) through the OpenGIS Location Service (OPENLS) initiative has defined standards to facilitate the interaction with LBS. ESRI, the largest GIS company world-wide (Shiode et al. 2002), as part of its efforts to stay in the forefront of GIS technology, has offered its services as part of the Amazon Cloud (ESRI 2010) (for a

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[1] Geoslavery is in the 'Encyclopedia of Human Geography' (p. 186) defined as follows: "*Geoslavery is a radically new form of human bondage characterized by location control via electronic tracking devices. Formally, it is defined as a practice in which one entity (the master) coercively or surreptitiously monitors and exerts control over the physical location of another individual (the slave). Inherent in this concept is the potential for a master to routinely control time, location, speed, and direction for each and every movement of the slave or, indeed, of many slaves simultaneously. Enhanced surveillance and control may be attained through complementary monitoring of functional indicators such as body temperature, heart rate, and perspiration*". For an interesting historical overview of the general issue of dataveillance we refer to Clarke (1988).

discussion on cloud computing for mobile users see Kumar and Lu 2010). This will provide organizations the ability to run GIS services in the cloud without having to purchase the software. This in turn will offer LBS additional functionalities previously unavailable that can manipulate and analyze the spatial data giving even more importance to the development of new approaches in the field of time-geography.

The previous observations offer a clear demonstration of the radical changes in modern geographical research, where large micro data bases offer an unprecedented scope for detailed spatial analysis of human behaviour. This new opportunity calls also for a more critical reflection on the research methodology of transport geography and logistics. The latter issues will be touched upon in the next section, which is more explicitly devoted to the spatial footprint of GSM networks.

16.2 GSM Network Data and Digital Footprints

Modern geo-science has a great potential for transportation and logistics. The spatial positioning of a given unit (person, object) does not only refer to its exact geographical location, but also to the precise time (or period) of that unit at this particular location, its movement and direction, as well as its speed. Modern electronic information systems – in particular through the use of GPS or GSM systems - are able to identify the position of any mobile or fixed unit and offer thus a unique research opportunity in contemporaneous space-time geography. We will illustrate the scope of this type of research by referring to the potential of GSM technology.

The information from GSM applications emerges from space-time communication counts (call volumes), often based on the Erlang as a standard unit of measurement of telephone traffic. In principle, any telecom operator has real-time information on the space-time communication pattern – and hence the spatial positioning – of any client. In the area of transportation and traffic management such cell phone data are a potentially rich source of reliable information on locational positions of individuals or vehicles.

Information on location is historically recognized as a strategic and valuable asset of cellular network providers (see, e.g., Teckinay 1998). Indeed, one of the most powerful ways to personalize mobile services is based on geographic location. The use of this information enables users to experience and exploit value-added services and the cellular network provider to offer differentiation and incremental profitability by increasing its subscribers base (Clarke 1998). Spatial information offers thus great economic opportunities.

Over the past decade, a number of research studies and operational tests have attempted to develop wireless location services in fields like tourism, energy distribution, public transportation, urban planning, disaster management, traffic management, etc. It is conceivable that, given the increasing need to manage road traffic, congestion and transport impacts on the environment, most applied research work and projects have been undertaken in the area of traffic management and incident management (see Steenbruggen et al. 2010).

It is noteworthy that new data research methods and tools are being developed to explore new types of user-related spatio-temporal data in fields that are strongly related to traffic management, such as urban dynamics and urban planning. The Real Time Rome project (see Calabrese and Ratti 2006) is one of the first examples of an urban-wide real-time monitoring system that collects and processes data provided by telecommunications networks and transportation systems in order to understand patterns of daily life in the city of Rome. Observing the real-time city becomes a means to understand the present and to anticipate the future urban environment. The authors address a broad range of research issues, like: how do people move through certain areas of the city during special events (gatherings); which landmarks in Rome attract most people (icons); where do we find the highest concentrations of foreigners in Rome (visitors); and is public transportation offered at places where the people are (connectivity)? Such questions offer a great challenge to modern geo-science.

In this context, Reades et al. (2007) have analysed how cell phone data in Rome can provide a new way of looking at cities as a holistic dynamic system. This approach can provide detailed information about space-time urban behaviour. They use Erlang data normalized over space and time and derive spatial ‘signatures’, which are specific time patterns of the use of the mobile network that are typical of a certain area. The authors found a mix of clusters that suggest a complex set of spatial relationships between ‘signatures’. The GIS visualizations of this approach generated an overall structure for the city that displayed a correspondence between the levels of telecommunication and the types of human activities. Ratti et al. (2006) also look at urban dynamics using cell phone data for the city of Milan as part of the Mobile Landscape project. They focus in defining the character of a neighborhood, commuting patterns, levels of activity, and other types of urban movements. In a similar vein, Girardin et al. (2008) explored the use of cell phone network data and geo-referenced photos for the presence and movements of tourists with user-originated digital footprints. Their approach provides an improved understanding of different aspects of urban mobility and travel. Geo-science in the form of electronic real-time data appear to offer a new perspective for transport and mobility management.

Road traffic analysis and prediction are apparently one the most attractive areas of use for mobile network data. Steady growing traffic volumes have led to unsurmountable congestion and mobility problems, especially during the rush hours, in both urban areas and on highway networks. While traditional measuring methods, such as road loops or camera detection, are certainly effective and rather precise, there are practical and financial limitations to their use. Detection loops installed under the road pavement are regularly installed on highways, but their application in urban environments appears rather unfeasible, given the number of roads that need to be monitored and the complexity of installation. Similar concerns can be raised for detection cameras, which are a feasible option for a limited number of measurement points. There is an increasing need for less expensive monitoring systems and more effective and reliable information systems. GSM systems may become then a promising option.

It is not surprising that there is a growing interest in using anonymous tracking of wireless devices as a way to generate information to support traffic management without requiring expensive and complex installations of ad-hoc measurement systems. As transportation agencies seek to better manage and operate the transportation system, there is an increasing need for traffic condition data across the road network. While this idea is conceptually appealing, its adoption is still limited and the research in this field is still largely dominated by pilots and experiments (see Fontaine and Smith 2004). But increasingly, we see applications in various fields, such as:

- estimation of origin-destination flows;
- assessment of traffic speed;
- assessment of travel time;
- assessment of traffic volumes;
- anticipation of congestion;
- identification of people’s presence and activity.

It is thus clear that the use of wireless location and cell phone data appears to offer a broad range of new opportunities to create sophisticated and less expensive applications for traffic management. There are indeed many advantages compared to other technologies, but there are still some important issues that need to be resolved, in particular factors that influence accuracy, reliability and data quality as well as techniques used for validation. From a broader socio-economic perspective, attention has to be focused on performance requirements of transportation agencies, privacy issues, road safety implications of mobile phone use, data ownership, business models and public-private partnership to deploy, test, improve and implement new technologies. In this way, GIS prompts many new developments and challenges for the transport sector.

Modern GIS technology in combination with location based services (LBS) – in the context of either GPS or GSM systems – is indeed able to design real-time tracking and tracing systems for goods and people. Especially the integration of spatial integration and individual information from various sources has raised public concern on personal surveillance and information privacy. As mentioned above, in principle an integrated space-time information system may pave the road towards permanent location control, coined geoslavery (see Dobson and Fisher 2003, Goss 1995). Clearly, the advantages of remote-control tracking and tracing systems are numerous, for instance, in route navigation systems, LBS in the trucking sector, wristbands for tracking the movements of schoolchildren, incident identification among mountaineers, spatial positioning of temporarily released prisoners, etc. However, there are evidently also shadow sides to be faced by public authorities and commercial vendors or marketers aiming at exploiting the potential of such electronic information systems, in particular as an 'information master' may structurally control time, location, speed and direction for every movement of any individual. It is clear that specific regulations on the use of and access to such electronic tracking and controlling systems are needed to prevent any abuse and violation of privacy protection.

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