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Data from mobile phone operators: A tool for smarter cities?

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Abstract
The use of mobile phone data provides new spatio-temporal tools for improving urban planning, and for reducing inefficiencies in present-day urban systems. Data from mobile phones, originally intended as a communication tool, are increasingly used as innovative tools in geography and social sciences research. Empirical studies on complex city systems from human-centred and urban dynamics perspectives provide new insights to develop promising applications for supporting smart city initiatives. This paper provides a comprehensive review and a typology of spatial studies on mobile phone data, and highlights the applicability of such digital data to develop innovative applications for enhanced urban management.

Keywords*: Smart cities, Mobile phone data, Urban management*

1. INTRODUCTION

1.1 Impact of ICT on cities

There is a vivid discussion in the literature concerning the impact of Information and Communication Technologies (ICTs) on cities. Important contributions can be found in the seminal work of Graham and Marvin (1996, 2001) on '*Splintering Urbanism*'; in Batty's (1997) ideas on '*Virtual Geography*'; and in Castells's (1996) '*Space of Flows*'. All these studies share one common idea: "The city itself is turning into a constellation of computers" (Batty, 1995, p. 155). But this observation is not yet the end: it can be argued that, nowadays, computers have become mobilized and personalized. Sheller (2004) argues that contemporary networked cities are made up by flows of people, vehicles, and information. Data about such massive flows are difficult to collect, but are becoming increasingly available for social science research, even on a real-time basis (Shoval, 2007). Such data could enable us to better 'tune' our cities, since most of their functions are being constantly monitored. Moreover, the use of such data in urban analytics of high spatio-temporal resolution has now actually become a trend in various scientific fields including geography (Miller, 2010; Arribas-Bel, 2014). The last two observations show the potential of such 'big data' in urban planning and urban management, encapsulated in the question: Can insights derived from research using such data help us to improve our cities? This is the main research question of this paper.

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1.2 The role of time-space information in geography

Several approaches can be employed to highlight or critically review the value of real-time geography in urban research (Tranos *et al.*, 2012). For example, the basis of a critical urban-political approach rests on the general argument that the pervasive character of ICTs across different economic sectors and urban environments supports the operation of the free market system at the global level (e.g. Sassen, 1991). Advocates of critical geography may even argue that space has become dehumanized and objectified (Graham, 1997). For instance, Soja (1989) highlights how, in the past, planning and geography have understood space as a dead, fixed, immobile, and undialectic entity, which is based on passive measurements instead of on actions and meanings. This creates the possibility of a new dimension for Newtonian influenced approaches towards space and time. Massey (1992) criticizes this research tradition by highlighting that space and time are conceptualized in classical physics as independent objects: "*Space is a passive arena, the setting for objects and their interaction*". Nonetheless, post-modern urban theory argues that there is little gain by separating space and time. On the contrary, there is only the joint effect of *space-time* (Thrift, 1996). Parallel to the non-linearity and multiplicity of time, places are non-contiguous, dissimilar, overlapping and dynamic entities (Graham and Healey, 1997). Geography based on digital data, e.g. mobile phone data, may address the above criticism of positivistic approaches to urban theory, as it enables the research community to analyse and model the *pulse of the city* (Batty, 2010). Such approaches do not focus exclusively on the physical form, but rather on human activity per se and its projection on cities. The underlying assumption here is that cities are not represented as a static canvas of urban zones. Instead, such research adopts a dynamic understanding of the urban environment, as manifested in numerous and diverse individual urban lifestyles. Space is not separated by time; the domain of such geography is the space-time continuum.

1.3 The role of mobile phone data to facilitate smart city objectives

In general, space-time data form a way to better understand the urban environment and its dynamics. Such data can serve to reveal how we as citizens relate to our urban contexts. In this sense, data analytics, usually enabled by data visualizations, can empower a city with knowledge and intelligence by helping us to identify patterns and relationships, enabling citizens and city managers with tools that support better decision making, discovery, exploration, and explanation of the city. The changes that digital technology – including the mobile telephone – have introduced in cities are, inter alia, reflected in a new faster pace of the urban lifestyle, and, in general, in a new and speedier urban systems metabolism. The latter refers to a *real-time city* which acts – and can be monitored – instantaneously (Graham, 1997; Townsend, 2000). This new characteristic of temporal and spatial responses from the standpoint of the urban user, which are then followed by reactions in terms of monitoring, creates a new exciting opportunity for urban planners and urban governance institutions.

For every 100 inhabitants of many cities, there were more than 85 mobile phone subscriptions[4] in 2011 (ITU, 2012). This remarkable increase (454 per cent in 2001-2011) indicates that mobile phones – including their broad communication options – have become an integral part of – and have undoubtedly transformed – the everyday life of a great part of the earth's population. Although this is easily visible to every observer, there is also another reading of this phenomenon: a great part of the earth's population can be now used as agents for data collection for (nearly) real-time, fine-grained spatial observations. In other words, what was initially introduced as an innovative mobile communication tool has now been transformed into a tool for socio-spatial research. And this is the particular focus of this paper, which provides a review and builds a typology of the various studies which utilize mobile phone data for spatial research in a smart city environment.

1.4 Aim and structure of the paper

The main objective of the present paper is to analyse, on the basis of an extensive literature review, whether and how the use of mobile phone data can facilitate urban management and planning. In other words, this paper aims to study whether and how research using fine-grained data from mobile phone operators can improve our cities. The starting point of this analysis is the 'smart city' framework, since the core of this concept is based on the interaction between ICT and urban space. Therefore, in Section 2, we discuss different smart city perspectives. Section 3 is devoted to a description of the nature of mobile phone data. Section 4 then focuses on the use of mobile phone data for analysing human activity patterns. Section 5 provides a review of earlier urban studies based on data from mobile phone operators. Section 6 follows with a concise but broad overview of the applicability of such data, in order to develop a range of smart city applications to highlight different urban management functions and their objectives. Finally, in Section 7, we discuss the contributions and limitations of these data, and how they can contribute to urban management and planning, while Section 8 concludes the paper.

2. A PANORAMA OF SMART CITY PERSPECTIVES

The increasing concentration of people in urban agglomerations calls for the design of new strategies to maintain and improve a liveable, sustainable, accessible, and economically-viable environment and settlement pattern for citizens. The digital revolution has enabled cities and policy makers to realise the link between ICTs and urban development. As a response, various marketing or

[4] This figure goes up to 122 for the developed world and down to 78 for the developing world.

theoretical conceptualisations have been introduced: *wired cities* (Dutton, 1987); *technocities* (Downey and McGuigan, 1999); *cyber cities* (Graham and Marvin, 1999); *creative cities* (Florida, 2005); *knowledge-based cities* (Carrillo, 2006); *real-time city* (Townsend, 2000); *WIKI cities* (Calabrese *et al.*, 2007; Ratti *et al.*, 2007b); *digital cities* (Komninos, 2008); *live City* (Resch *et al.*, 2012); *networked cities* (Castells, 1996); and *sentient cities* (Shepard, 2011). Despite this variance, the concept of *smart city* (Mitchell, 2006; Giffinger *et al.*, 2007) is the one which has gained the widest recognition among practitioners and urban researchers (see Nijkamp, 2010, and Caragliu *et al.*, 2011). Various different definitions of, and perspectives on, smart cities can be found in the relevant literature. For example, a technological innovation perspective (Komninos, 2006); an economic perspective (Nijkamp and Kourtit, 2011); a monitoring perspective based on sensors (Giffinger *et al.,* 2007); and a networked perspective (Nijkamp, 2008; Tranos and Gertner, 2012).

In general, the term 'smart city' is a fuzzy concept which is not used consistently in the literature. For the purpose of this paper, we use the definition of Giffinger *et al.* (2007) and Nijkamp and Kourtit (2011): a city is *smart* when investments in human and social capital (smart people), traditional transport (smart mobility), and modern digital infrastructure (ICTs) fuel sustainable economic growth (smart economy) and a high quality of life (smart living), with a wise management of natural resources (smart environment) through participatory governance (smart governance). In order for cities to perform well on the above dimensions, for improvement there is a need for evidence-based planning, which will enable a better identification of problematic sectors (e.g. transport) and areas (e.g. neighbourhoods) and a better allocation of resources. Such evidence-based planning is in desperate need of analytics and of relevant data to reveal caveats at a fine-grained scale, both in terms of space and time. A natural candidate, particularly in terms of its spatio-temperal characteristics, is the use of mobile phone data. In the next section, we describe the nature of such data in greater detail.

3. MOBILE PHONE DATA

The use of mobile phone data is increasingly seen as a potential data source in order to develop new urban applications to support the smart city objectives. Such data are relatively cheap for mobile phone operators to collect because they are already produced for billing and network engineering purposes (Wang *et al.*, 2010). The most common format is the '*Call Data Record*' (CDR), according to which subscribers' mobile phone activities are recorded each time a user uses a service. These records provide a reasonably accurate method of sensing the activity and location of subscribers. The set of fields typically contained in an individual CDR include: originating and destination encrypted phone number; identifier of the sector that handled the mobile phones; the associated timestamp (date and time) of the call or text message; and the duration of the call. The individual level of information enables the aggregation of CDRs at different spatial and temporal scales. From a geographical point of view, several approaches exist in the literature in order to utilise the spatial information of CDRs (see Figure 1). Aggregated CDRs can be represented as: 1) *voronoi*[5] diagrams constructed around cell towers (Candia *et al.*, 2008; González *et al.*, 2008; Kuusik *et al.*, 2008; Song *et al.*, 2010a; Traag *et al.*, 2011); or 2) best-serving polygons using information from the mobile phone providers for the actual serving zone of each tower; or 3) the product of rasterization proccess[6] (Calabrese *et al.*, 2007; Reades *et al.*, 2009; Girardin *et al.*, 2009a).

The main limitations of CDRs lie in their sparse temporal frequency (data are generated only when a transaction occurs), and on their rather coarse spatial granularity, as locations are based on the granularity of a cell tower (Becker *et al.* 2011). Apart from that, cell towers vary in density (urban vs. rural), which affects estimates, and there are also some concerns regarding the privacy of the use of such data (e.g. Ahas *et al.*, 2007b). Despite these limitations, CDRs have become increasingly popular in urban analysis over the last 5-10 years, as will be illustrated in the next section, because of their ability to provide space-time information for individuals.

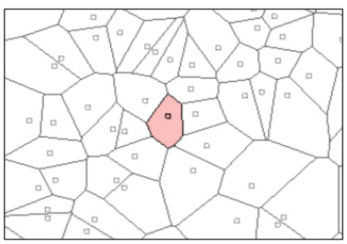
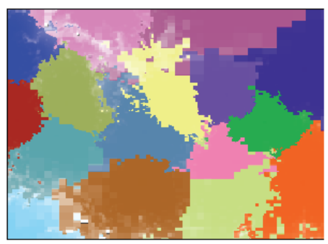
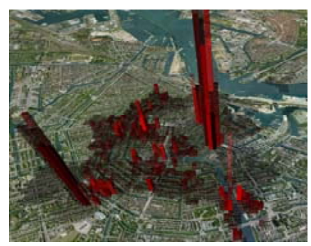

Figure 1a: Voronoi tessellation **Figure 1b: Best serving zones** **Figure 1c: Rasterization**

Source 1a and 1b: Calabrese (2011); 1c: Calabrese (2008).

4. ANALYSING HUMAN ACTIVITY PLACES AND MOBILITY PATTERNS

A sine qua non for understanding the dynamics of cities is to first understand and model human activities. Data from mobile phone operators have played a pivotal role in such research. For instance, Jiang *et al*. (2012) state that, in the literature, population is traditionally clustered into three groups (workers, students, and non-workers), and they provide temporal clusters based on different *activity types*[7]. In a more detailed study, Jiang *et al*. (2011, 2012) find that the population can be clustered into seven representative groups according to their activities during weekdays and weekends. Becker *et al.* (2011) has identified seven cell phone usage patterns via clustering techniques. However, in the literature, such findings are not compared or combined. Insightful

[5] A Voronoi diagram is a way of dividing space into a number of regions. A set of points (called seeds, sites, or generators) is specified beforehand and for each seed there will be a corresponding region consisting of all points closer to that seed than to any other. The regions are called voronoi cells. This method is often used when there is no best serving cell map available.
[6] Rasterization is a process where the original best-serving cell maps are converted to a finer grid structure (e.g. 40 x 40 m.). The mobile phone traffic intensity can be recalculated based on an approximated land-use specifications.
[7] e.g. home, work, school, transportation transitions, shopping, personal business, recreation, entertainment, civic, religion, other.

knowledge of these *population clusters* and *cell-phone usage patterns*, together with social demographic information, can provide a new perspective for urban management by addressing when, where, and how individuals interact with places in metropolitan areas (Jiang *et al*., 2011, 2012).

Moreover, the composition of social networks and human interactions is crucial not only for understanding social activities, but also for travel patterns (Carrasco *et al.*, 2006). To collect data on social interactions, different traditional approaches can be used, such as observations, interviews and diaries (Fu, 2007). Nevertheless, our knowledge of such complex relationships is limited. To gain new insights into such phenomena, various studies have been based on mobile phone data. The geographical analyses of social communities, based on network analysis, has been the subject matter of various studies (e.g. González *et al.*, 2006; Kwan, 2007; Schwanen and Kwan, 2008; Lambiotte *et al.*, 2008; Krings *et al.*, 2009; Blondel *et al.*, 2008, 2010; Eagle and Pentland, 2009; Eagle *et al.*, 2009a; Ratti *et al.*, 2010; Expert *et al.*, 2011; Onnela *et al.*, 2007, 2010, 2011; Calabrese *et al.*, 2011b). Such studies have highlighted the interdependence of social and spatial contexts, and have resulted in the identification of important activity places (e.g. home and workplaces), the capturing of individual mobility patterns among these places, and in total, and at an aggregated level, the reproduction of human densities in metropolitan areas.

Several scholars looked at mobile phone data to identify individual important activity places. These are significant places in the environment that are commonly recognized and used as key components of cognitive maps (Dijst, 1999) or are related to a person's activities (e.g., home or work place) (Golledge, 1990). The ultimate goal is to provide a clear picture of how groups of individuals interact with different places at different time of day. Traditional, this was the field of urban planners and social scientists. Recently it has attracted a more diverse body of researchers (Foth *et al.*, 2012).

The meaning of important activity places is analyzed from different statistical approaches and data sets: Paper based travel behaviour data (Flamm and Kaufmann, 2006); WiFi (Kang *et al.*, 2004); GPS (Zhou *et al.*, 2007); GSM in combination with GPS (Nurmi and Koolwaaij, 2006; Nurmi and Bhattacharya, 2008), and CDR's (Ahas, 2006b, 2008b, 2010; Gonzáles *et al.*, 2008; Bayir *et al.*, 2010; Isaacman *et al.*, 2011a; Csáji *et al.*, 2012; Ranjan *et al.*, 2012). Place learning algorithms can be divided into two classes: *geometry and fingerprint*. For an extensive review on different methodological perspectives, we refer to Nurmi and Bhattacharya (2008) and Ahas *et al.* (2010).

Csáji *et al.* (2012) concluded that most people spend most of their time at a few locations[8]. Huang *et al.* (2010) stated that these *anchor points*[9] and the routes between them are of significant value to

[8] This has been confirmed in several mobile phone studies (e.g. Gonzáles *et al.*, 2008; Bayir *et al.*, 2010; Song *et al.*, 2010a; Isaacman *et al.*, 2011; Ranjan *et al.*, 2012)

[9] e.g. regularly visited places, daily life centres, usual or important activity places, activity spaces of commuters (home or work place).

effective network management, public transportation planning and city management. For a better understanding of the effects of human movement, characterizing human mobility patterns is crucial (Phithakkitnukoon *et al.*, 2010, 2011). *Time geography*[10] has been suggested as a potential framework to analyze complex spatio-temporal patterns of individual activities and interactions (Shaw and Yu, 2009; Tian *et al.*, 2010). Since 2006, a number of studies has been initiated to analyze human mobility patterns (e.g. Eagle and Pentland, 2006; Mateos and Fisher, 2006; Shoval, 2007; Gonzalez *et al.*, 2008; Park *et al.*, 2010; Song *et al.*, 2010a, 2010b; Csáji *et al.*, 2012; Hoteit *et al.*, 2014). For example, Gonzalez *et al.* (2008) conclude that human trajectories show a high degree of temporal and spatial regularity, and follow simple reproducible patterns. This finding has been confirmed by a study of Song *et al.* (2010a; 2010b). By measuring the *entropy* of each individual's trajectory, they find a 93 per cent potential predictability in user mobility. Most remarkable, despite the significant differences in the travel patterns, they find a lack of variability in predictability, which is largely independent of the distance users cover on a regular basis. Despite our deep-rooted desire for change and spontaneity, our daily mobility is, in fact, characterized by a deep-rooted regularity. They also conclude that the development of accurate predictive models of human mobility is a scientifically grounded possibility.

However, the above discussed studies (using mobile phone data to capture human dynamics) are not yet fully linked to the traditional methods related to social science of clustering daily patterns of human activities in cities. Therefore, the rich information regarding activity categories and social demographics of individuals should be incorporated in this work. Jiang *et al*. (2011, 2012) identified this gap and highlight the advantages of such interdisciplinary approach. Further, detecting and investigating locations and the mobility patterns between these locations, urban managers can identify specific measures for upgrading accessibility, vital utilities, or attractiveness, so that social cost is minimized (Um *et al.*, 2009). This leads to the discussion to the potential of using data from mobile operators in order to understand cities in a quantitative manner. As discussed earlier, this is a prerequisite for planning a smart city.

5. EARLY URBAN STUDIES BASED ON MOBILE PHONE DATA

In the literature, we may identify three main pioneering groups which made a significant contribution to the field of mobile phone data use in (early) urban studies: Barabási's 'Centre for complex network research'[11], Ratti's team of the 'MIT SENSEable City Lab'[12], and Ahas 'Mobility Lab'[13] of the University

[10] Time geography is a powerful conceptual framework for understanding human spatial behavior, in particular, constraints and trade-offs in the allocation of limited time among activities in space. Space-time path is one of the most important concepts in time geography. It traces the movement of an individual (Hägerstrand, 1967).
[11] Centre for complex network research: http://barabasilab.com/
[12] MIT SENSEable City Lab.: http://senseable.mit.edu
[13] Mobility Lab: http://mobilitylab.ut.ee/eng/

of Tartu. In 2005, Barabási (2005) and Vázquez *et al.* (2005) stated that: "The dynamics of many social, technological and economic phenomena are driven by individual human actions, turning the quantitative understanding of human behaviour into a central question of modern science". The team of Barabási initiated several pioneering studies on different research topics on network complexity including human dynamics (Candia *et al.*, 2008), human mobility patterns (Gonzáles *et al.*, 2008; Song *et al.*, 2010a, 2010b), social networks (Onnela *et al.*, 2007a, 2007b, 2010, 2011), public safety (Madey *et al.*, 2006, 2007; Bagrow *et al.*, 2011), and the spreading patterns of mobile phone viruses (Wang *et al.*, 2009). Barabási (2009) stated that "we are at the threshold of understanding complexity, based on the availability of large data sets" (Big Data). Knowledge gained from a social network perspective could significantly contribute to utilize CDR's for smart city objectives. However, a complete theory of complexity does not yet exist (Barabási, 2007).

One of the first attempts from the MIT SENSEable City Lab to study cities using data from mobile phone operators was applied in Graz and Milan (Ratti *et al.*, 2005, 2007a; Pulselli *et al.*, 2005, 2006). In this research, the authors adopted a new approach to better understand the increasing complexity of human settlements, not merely by observing their physical shapes, but also by sensing the citizens using data from mobile phone operators. The aim of this study was to investigate human dynamics by revealing the locations and intensities of urban activities, and to analyse mobility patterns. They used *Erlangs*[14] with a 1 hour time interval to illustrate the intensity of urban activities and its evolution in space and time. The analysis resulted in spatio-temperal signatures showing the intensity of mobile phone traffic at a given position in time and space. Based on these first promising results, they develop appropriate software as supporting tools for urban planning and urban management in a smart city framework in the city of Rome. These tools provided exploratory visualizations of various dimensions of cities from a dynamic perspective. Examples included the illustration of spatio-temporal patterns of mobile phone call intensity which, to a certain extent, reflect population presence, crowd gatherings, attractiveness of landmarks, concentration of (foreign) tourists, traffic flows, and the supply and the demand of public transportation in the space-time continuum (Ratti *et al.*, 2006; Calabrese and Ratti, 2006; Reades *et al.,* 2007, 2009; Calabrese *et al.*, 2011a). Several statistical methods were applied such as *K-means clustering* to extract spatial signatures with which to represent the city's heartbeat.

Since 2005, the team from 'Mobility Lab' of the University of Tartu also significantly contributed to this research field (e.g. Ahas and Mark, 2005; Pae *et al.*, 2006; Ahas *et al.*, 2007c). Examples of their work includes studies on tourism (Ahas *et al.*, 2006a, 2007a, 2007b, 2008a; Silm and Ahas, 2010;

[14] A measure of network bandwidth usage.

Kuusik *et al.* 2008, 2010), important activity places (Ahas *et al.*, 2008b, 2010; Järv *et al.*, 2014), commuting patterns (Novák *et al.*, 2013) and road traffic analysis (Järv *et al.*, 2012).

Mobile phone data studies based on these *space-time typologies* (Zandvliet and Dijst, 2006) can be utilized in an urban policy framework which enables urban authorities to capture current trends and to evaluate 'on the fly' whether existing conditions (e.g. mobile phone usage in a specific location) deviate from the average conditions at a given time and in space. In other words, such tools can facilitate the implementation of smart city objectives. The latter will explicitly be discussed in the next section.

6. MOBILE PHONE DATA AND URBAN MANAGEMENT APPLICATIONS

Since 2005, several empirical studies have utilized data from mobile phone operators to gain insight and knowledge into complex and rapidly changing spatial urban phenomena. In this section, we will critically analyse several case studies and focus on how the use of mobile phone data can support smart city objectives from the perspective of urban management. At the same time, this section provides a preliminary taxonomy of such applications, which is tied to the core of the smart city approach.

6.1. Smart mobility and transportation

Mobility and transportation are not only vital elements of cities, but also a key dimension in the smart city agenda, as discussed above. Research which utilizes the breadth of data produced by mobile phone operators can be a great opportunity to tackle specific issues (Steenbruggen *et al.*, 2013). Two such examples are discussed here.

Information regarding the demographics and origins of visitors in specific urban locations is usually scarce if not totally absent. Such information, especially at a fine grained temporal and spatial scale, can potentially play a pivotal role in managing resources and connectivity. Near real-time information from mobile phone data about population concentrations and, most importantly, about the origin of these populations can be usefully combined with GPS data about the location of buses and taxis (Calabrese *et al.*, 2011a; Veloso *et al.*, 2011; Kang *et al.*, 2013). The matching of such data can facilitate transport analysis, and enable operators to better tune – even on the fly – public transportation within cities. In a different example, data from mobile phone operators can be used to understand commuting patterns at a detailed temporal and spatial level. In particular, for a city with a commercial district, understanding where workers live and work can help manage vehicular traffic flows and plan public transportation services. For example, Becker *et al.* (2011, 2013) compared commuting patterns in Morristown (a suburban city in the greater New York City Metropolitan Area) using US Census data and data from CDRs. The results showed that data from mobile phone operators can lead to the same outcomes as official data. Interestingly however, mobile phone data are produced continuously and enable the constant monitoring of commuting patterns, the modelling of its fast and slow dynamics, and most importantly, the timely responses from the planning authorities. On the contrary, census data are usually released once every decade. Moreover, the costs of CDR data are minimal in comparison to the costs of organizing a census.

6.2. Smart economy

In a 24/7 culture, residents and visitors roam through metropolitan areas at all times and for different reasons. Knowing where people cluster for social activities, and at what times, allows business and cultural institutions to better target and price their outdoor advertising, as well as to maximize their opening times and schedule of events. It is reasonable to assume that call activity in commercial or business areas is an indicator for economic activity (de Jonge *et al.*, 2012). However, the call activity of a region during the week for residential, commercial, and business areas is different. Deriving a classification from the call activity profile of a region may aid strategic planning decisions related to land use, future investments, and business location strategies.

In addition, the tourism industry is, for most countries, another very important source of economic growth. In the age of low-cost flights, local authorities can never be certain about the quantity and nationalities of tourists in town. Knowing more about the behavior of tourists is the starting point in designing tourism and urban attractiveness policies (Kuusik *et al.*, 2010; de Jonge *et al.*, 2012). This is not a trivial task, as their trip routes are difficult to predict, and the same applies to the length of their stay, the actual places they visit, or the landmarks to which they are attracted. Data from mobile phone operators can provide support towards this direction, as is illustrated by the relevant literature. Calabrese *et al.* (2011a) have developed an illustrative application showing the density of people using mobile phones at different historic attractions. Girardin *et al.* (2009b) identified the spatial distributions of locals and foreign visitors to estimate their relative density in relation to some specific locations.

Important activity places, urban activity destinations, and human travel patterns, all have a strong relation with tourist mobility patterns. Human geographers have used such mobile positioning data as a spatial distribution tool for monitoring the concentration of tourists in a certain area of attraction (Ahas *et al.*, 2006a, 2007a, 2007b, 2008a). For example, Kuusik *et al.* (2008, 2010) studied repeated tourist visits at a country level (Estonia). Their study resulted in interesting estimations of the number of visitors and visits, the (average) visit duration, the distribution of (repeating) visitors at a country level, and the geographical distribution of repeat visits in the Estonian counties. Also seasonal variability plays an important role in the place of residence and seasonal migration of people and is strongly linked with tourism and holidays (Silm and Ahas, 2010). These types of information can prove to be vital for more efficient tourism planning at different spatial scales.

6.3. Public safety

City authorities regularly have to face the challenge of predicting population presence and the movement of crowds for public safety reasons. Examples include big events such as sports events and concerts, but also demonstrations and emergency situations. Data from mobile phone operators can be employed for this purpose, and enable urban planners to conduct crowd modelling. In more detail, crowd modelling is the basis for useful applications such as predicting the use of space, preventing dangerous situations, or planning an emergency evacuation. The combination of crowd management and modelling with data indicating mobile phone activity is a promising application for the smart city framework. Calabrese *et al.* (2010) have analysed the relationship between individual mobility traces extracted by data provided by mobile phone operators and social events. Anonymized traces from the Boston Metropolitan Area were employed and juxtaposed with a number of selected events that had happened in the city and which had attracted considerably sized crowds. The outcome of this analysis showed a strong correlation between the origins of people attending an event and the type of event. Apparently, such information is valuable in city management in order to take decisions about crowd management before and after social events. In the same spirit, Traag *et al.* (2011) focused on detecting unusually large social events based on a *Bayesian location inference framework*[15]. The outcome of this study was a methodological framework for deciding who is attending such events. Nevertheless, as they only used limited positional data from GSM antennas, the validation of the results was rather difficult without additional information.

Although the estimation of population density in real-time has always been a challenge in urban management, it is remarkable that such studies are very rare. Csáji *et al.* (2012) has shown that there is a strong relation between census data and estimates based on mobile phone data at a county level (a correlation of 0.92). This indicates that it is possible to accurately estimate population size based on mobile phone data at an aggregated level. However, as stated by Isaacman *et al.* (2012), urban areas are characterized by a different population density during the course of a day. For instance, residential areas are likely to be more populated at night-time, though, in fact most inhabitants are asleep, while commercial districts are more likely to be more populated during the daytime. Therefore, temporal information needs to be included in such a modelling exercise. Girardin *et al.* (2009b) estimated the relative density of locals and foreign visitors, but real-time estimates of actual numbers are missing. Frias-Martinez *et al.* (2010, 2012) proposed a tool for using mobile phone data for computing cost-effective census maps from a socio-economic perspective. Such a modelling exercise could be extended to estimate real-time population density.

[15] In statistics, Bayesian inference is a method of inference in which Bayes' rule is used to update the probability estimate for a hypothesis as additional evidence is learned.

Also in the field of crisis management, there is a growing interest in using telecom data for crowd management and anomaly detection. For instance, responses to a crisis require a high level of preparedness, and the precise knowledge of how many people could be exposed in the incident area. Currently-used risk maps only provide a static picture of the exposure, since they are based on information from the Census or other regular surveys. Different examples have been found in the relevant literature regarding proactive crowd-sourcing and the provision of timely information on the status of a city or a region (Schoenharl *et al.*, 2006; Madey *et al.*, 2006, 2007; Pawling *et al.*, 2007, 2008a, 2008b; Vaidyanathan *et al.*, 2008; Vaidyanathan 2010; Vaidyanathan and Johnston, 2011). In total, CDRs and data from mobile phone operators can be used as a valuable information source for issuing early warning signals. Nevertheless, an inherent limitation of such data is the lack of qualitative information regarding the nature and the cause of existing anomalies.

Moreover, the temporal breadth of such data enables the modelling of human behaviour when exposed to rapidly changing or unfamiliar conditions (e.g. natural, technological, or societal disasters) (Vespignani, 2009). Bagrow *et al.* (2011) explored the societal response to external perturbations to identified real-time changes in communication and mobility patterns due to different types of emergency. They find that communication spikes accompanying emergencies are both spatially and temporally localized.

6.4. Land-use and sustainability

Information on land use and the dynamic nature of the way citizens use urban space is crucial for urban planning and the sustainable development of cities (Pei *et al.*, 2013). Land-use types in urban landscapes are not necessarily well-defined in the sense that one specific area may have multiple functions. In a case study on Madrid, Soto and Frias-Martínez (2011) identified five clusters of actual land use based on human behavior from CDRs using *fuzzy-c means*. In another study in Boston, Toole *et al.* (2012) used a random forest algorithm, which showed that mobile phone data are capable of delivering useful information on actual land use that supplements zoning regulations.

One of the main objectives of smart cities is to create a sustainable environment with a wise management of natural resources. Becker *et al.* (2013) analysed the combination of commuter distance with the amount of carbon dioxide emitted in order to create carbon footprints. This allowed the computation of the rough amount of carbon dioxide emitted per commuter and a new tool to evaluate environmental impact and to improve transportation management. Mobile phone data can, for example, also be used to estimate the relationship between population density and energy consumption. This will provide new spatial tools to develop a more sustainable environment.

7. DISCUSSION

Call detail records can serve a variety of functions. For instance, CDRs are essential for mobile phone billing purposes, but also for legal and surveillance purposes. From an urban perspective, such data are extremely useful, mainly because their high spatio-temporal resolution and are gaining ground as a tool to support smart city objectives. On basis of the above review, it can be concluded that data from mobile phone operators are increasingly used as information carriers in urban analysis. We are now, after 10 years of research, in a position to evaluate whether this strand of analysis has helped us better understand and manage cities. The smart city framework has been used as a reference point, because it provides the necessary theoretical justification for such an exercise.

The present review has highlighted the contribution of such data sources in achieving smart city objectives. In a nutshell, it enables the identification, the analysis, the visualisation, and the simulation of the heartbeat of the city in a way that no other secondary data source can do. Such exercises, as highlighted previously, can result in prolific outcomes in the context of urban planning and management. More specifically, such outcomes are related to: (a) mobility and transportation, as CDRs enable a precise modelling of both elements at a very detailed temporal dimension, not just as a snapshot, but instead, in a continuous manner; (b) the urban economy, as such data and related analyses can support economic activity related to sectors such as tourism, retail and marketing; (c) public safety, as modelling based on such data can radically enhance issues related to crowd and risk management; and (d) land-use planning, revealing the actual use of places, again in a temporally continuous manner, and feeding back this knowledge in to urban planning.

On the basis of the extensive literature, we can make the following general observations:

- Mobile phone data are a promising source to develop a wide range of smart city applications. However, there are as yet only a few solid examples of using such data in real-life urban management.
- CDRs are generated only when a transaction occurs, which makes it hard to define suitable models for crowd control and to estimate the real-time presence and movements of such crowds. Nevertheless, such data offer an excellent addition to existing data sources.
- The results show that anomalies in real-world data can be detected, although, because of the nature of CDRs, no conclusive causal inferences can be made.
- Urban management applications need not only real-time mobile phone data, but a full spectrum of information sources – digital and analogue – that are needed for the effective governance of urban systems.

In addition to clear obvious advantages of CDR, there are also some limitations. Firstly, CDRs are not open source data. They are the property of telecom operators, and thus there is limited access for researchers. The availability of such data is usually regulated due to specific contracts with telecom operators. Because there are only a limited number of telecom operators per country, it is not easy for businesses to develop applications. City managers might be encouraged to be more active to stimulate telecom providers to open their data for urban analysis and applications for cities. In addition, telecom operators are very cautious in sharing CDRs due to privacy issues. Since such records have the potential to reveal private, personal information, they are generally protected by strict regulations. Legislators have addressed the use of personal information with various laws, a situation which has implications for location and sensor services. For example, the EU Directive 95/46/EC provides the legal framework for the protection of individuals with regard to the processing of personal data, while Directive 2002/58/EC addresses location privacy specifically, stating that location data can be processed only after being anonymized or after having gained the consent of the user, who should be perfectly informed of the use that will be made of their personal data. Moreover, researchers have also identified conceptual limitations when using CDR data in urban models. Isaacman *et al.* (2012), for example, has highlighted some issues which lack a realistic approach to model human mobility, such as spatio-temporal realism about population densities, studying too small geographic areas, or models which aim to be universal, and thus do not adapt to different geographic areas. Studies that investigate the characteristic spatio-temporal pattern of the collective human mobility from a more dynamic perspective, and make a comparison between different urban environments, are very rare. For example, previous work has shown a significant differences between cities (areas) along metrics such as: commute distances (Isaacman *et al.*, 2010, 2011a, 2011b; Becker *et al.*, 2013); commuting patterns (Amini *et al.*, 2014) mobility patterns (Liu *et al.*, 2009; Isaacman *et al.* 2011b; Calabrese *et al.*, 2011a; Kang *et al.*, 2012; Tanahashi *et al.*, 2012; Amini *et al.*, 2014); community structures (Eagle *et al.*, 2009b; Amini *et al.*, 2014), hotspots (Louail *et al.*, 2014), and population density (Martino *et al.*, 2010; Becker *et al.*, 2013; Csáji *et al.*, 2012; Isaacman *et al.*, 2012; Sagle *et al.*, 2012; Yuan and Raubal, 2012). The findings of such studies can be helpful for policy makers in understanding the characteristics and dynamic nature of different urban areas, as well as updating environmental and (public) transportation policies. Ranjan *et al.* (2012) concluded that the nature of CDRs, which are sparse in time and space, may in some cases cause biases in capturing the overall spatial-temporal characteristics of demographic groups, when studying population level inferences, which may exhibit variable mobility. Finally, Wesolowski *et al.* (2013) have shown that, despite the bias introduced by differential phone ownership, mobility patterns within particular regions are surprisingly robust across populations.

8. CONCLUSIONS

As shown in this paper, a better understanding of how, where, and when people move on a daily basis, especially in densely populated areas, could lead to improvements in urban planning, transportation infrastructure design, and assessments of environmental impacts. A few years back, Ahas and Mark (2005) predicted that geo-located data from mobile phone operators would be utilized in three areas in urban planning: namely, transportation, dynamics of urban space, and marketing. This paper has indeed demonstrated the wide applicability of mobile phone data in achieving smart city objectives. Nevertheless, such data cannot be approached as a panacea. The complexity of urban environments calls for a combination of various and diverse data sources. In such a framework, the wealth of data which remains hidden in the hard drives of various mobile phone operators could be a useful addition to permanent efforts to make our cities smarter.

References

Ahas, R. and Mark, Ü. (2005). Location based services - new challenges for planning and public administration? *Futures* 37, pp. 547-561.

Ahas, R., Aasa, A., Mark, Ü., Pae, T. and Kull, T. (2006a). Seasonal tourism spaces in Estonia: Case study with mobile positioning data, *Tourism Management* (28)3, pp. 898-910.

Ahas, R., Mark, Ü ., Järv, O. and Nuga, M. (2006b). Mobile positioning in sustainability studies: Social positioning method in studying commuter's activity spaces in Tallinn, in: Mander, U., Brebbia, C. A. & Tiezzi, E. (eds.) The sustainable city IV. Urban regeneration and sustainability. Southampton, Boston: WIT Press.

Ahas, R., Aasa, A., Silm, S. and Tiru, M. (2007a). Mobile positioning data in tourism studies and monitoring: Case study in Tartu, Estonia, in: M. Sigala, L. Mich and J. Murphy (eds.), *Springer Computer Science: Information and Communication Technologies in Tourism*, Springer, Vienna, 2007, pp. 119-128.

Ahas, R., Aasa, A., Roosea, A., Mark, Ü., Silm, S. (2007b). Evaluating passive mobile positioning data for tourism surveys: An Estonian case study. *Tourism Management* 29(3), pp. 469-486.

Ahas, R., Aasa, A., Silm, S., Aunap, R., Kalle, H. and Mark, Ü. (2007c). Mobile Positioning in space-time behavior studies: Social positioning method experiments in Estonia. *Cartography and Geographic Information Science* 34(4), pp. 259-273.

Ahas, R., Saluveer, E., Tiru, M. and Silm, S. (2008a). Mobile positioning based tourism monitoring system: Positium barometer *Computer Science: Information and Communication Technologies in Tourism*, in: P. O'Connor, W. Höpken and U. Gretzel (eds.), Springer, Berlin, 2008, pp. 475-485.

Ahas, R., Silm, S., Saluveer, E., Järv, O. (2008b): Modelling home and work locations of populations using passive mobile positioning data, in: Gartner, G., Rehrl, K. (eds): Location Based Services and TeleCartography II: From sensor fusion to context models, pp. 301-315.

Ahas, R., Silm, S., Järv, O., Saluveer E., Tiru, M. (2010). Using mobile positioning data to model locations meaningful to users of mobile phones, *Journal of Urban Technology* 17(1), pp. 3-27.

Amini, A., Kung, K., Kang, C., Sobolevsky, S. and Ratti, C. (2014). The impact of social segregation on human mobility in developing and urbanized regions. *arXiv preprint arXiv:1401.5743*.

Arribas-Bel, D. (2014). Accidental, open and everywhere: Emerging data sources for the understanding of cities. *Applied Geography* 49, pp. 45-53.

Bagrow, J.P., Wang, D. and Barabási, A-L. (2011). Collective response of human populations to large-scale emergencies. *PLoS ONE* 6(3): e17680. doi:10.1371/ journal.pone.0017680.

Barabási, A.-L. (2005). The origin of bursts and heavy tails in human dynamics. *Nature* 435, pp. 207-211.

Barabási, A.-L. (2007). The architecture of complexity: From network structure to human dynamics. IEEE Control Systems Magazine 27, pp. 33-42.

Barabási, A.-L. (2009). We are at the threshold of understanding complexity, *12 Scientists on the 21st Century*, World Science Forum, Budapest, 2009, pp. 19-26.

Batty, M. (1995). The computable city. *International Planning Studies* 2, pp. 155-173.

Batty, M. (1997). Virtual geography. *Futures* 29, pp. 337-352.

Batty, M. (2010). The pulse of the city. *Environment and Planning B: Planning and Design* 37, pp. 575-577.

Bayir, M.A., Demirbasa, M. and Eagle, N. (2010). Mobility profiler: A framework for discovering mobility profiles of cell phone users. *Pervasive and Mobile Computing* 6, pp. 435-454.

Becker, R.A., Caceres, R., Hanson, K., Loh, J.M., Urbanek, S., Varshavsky, A., and Volinsky, C. (2011). A tale of one city: Using cellular network data for urban planning. *Pervasive Computing,* 10(4), pp. 18-26.

Becker, R.A., Cáceres, R., Hanson, K., Isaacman, S., Loh, J.M., Martonosi, M., ... and Volinsky, C. (2013). Human mobility characterization from cellular network data. *Communications of the ACM* 56(1), pp. 74-82.

Blondel, V.D., Guillaume, J. L., Lambiotte, R., and Lefebvre, E. (2008). Fast unfolding of communities in large networks. *Journal of Statistical Mechanics: Theory and Experiment* 10, P10008.

Blondel, V.D., Krings, G. and Thomas, I. (2010). Regions and borders of mobile telephony in Belgium and in the Brussels metropolitan zone. *e-journal for academic research on Brussels* 42, 4 October 2010. ISSN 2031-0293.

Calabrese, F. (2008). Using cell-phone data to understand urban dynamics in the city of Amsterdam. MIT SENSEable City Laboratory publication.

Calabrese, F. (2011). Urban sensing using mobile phone network data. Ubicomp 2011 Tutorial. Smarter cities technology centre, IBM Research.

Calabrese, F. and Ratti, C. (2006). Note on real-time Rome. *Networks and Communication Studies NETCOM* (20)3-4.

Calabrese, F., Kloeckl, K. and Ratti, C. (2007). WIKICITY: Real-time urban environments. MIT publication.

Calabrese, F., Pereira, F., Di Lorenzo, G., Liu, L. and Ratti, C. (2010). The geography of taste: analyzing cell-phone mobility and social events, in *International Conference on Pervasive Computing*, 2010.

Calabrese, F., Colonna, M., Lovisolo, P., Parata, D. and Ratti, C. (2011a). Real-time urban monitoring using cell phones : A case study in Rome. *IEEE Transactions on Intelligent Transportation Systems* (12)1, pp. 141-151.

Calabrese, F., Smoreda, Z., Blondel, V. and Ratti, C. (2011b). Interplay between telecommunications and face-to-face interactions – a study using mobile phone data, PLoS ONE 6(7): e208814.

Candia, J., Gonzalez, M.C., Wang, P., Schoenharl, T., Madey, G., Barabási. A.L. (2008). Uncovering individual and collective human dynamics from mobile phone records. *Journal of Physics A: Mathematical and Theoretical* 41(22), pp. 1-16.

Caragliu, A., Del Bo, C., and Nijkamp, P. (2011). Smart cities in Europe. *Journal of Urban Technology* 18(2), 65-82.

Carrasco, J., Hogan, B., Wellman, B. and Miller, E.J. (2006). Collecting social network data to study social activity-travel behaviour: An egocentric approach, Toronto: University of Toronto. http://www.chass.utoronto.ca/~wellman/publications/Collecting/Collecting.pdf

Carrillo, F.J. (2006). Knowledge cities, Oxford, Elsevier Inc.

Castells, M. (1996). The rise of the network society. Oxford: Blackwell.

Csáji, B.C., Browet, A., Traag, V.A., Delvenne, J.C., Huens, E., Van Dooren, P., Smoreda, Z. and Blondel, V.D. (2012). Exploring the mobility of mobile phone users. *Physica A: Statistical Mechanics and its Applications* 392(6), pp. 1459-1473.

Dijst, M. (1999). Two-earner families and their action spaces: A case study of two Dutch communities, *GeoJournal* 4:3, pp. 195-206.
Downey, J. and McGuigan, J. (1999). *Technocities,* London, SAGE Publications Ltd.
Dutton, W.H. (1987). *Wired cities: Shaping the future of communications,* London, Macmillan.
Eagle, N. and Pentland, A. (2006). Reality mining: sensing complex social systems. *Personal and Ubiquitius Computing* 10(4), pp. 255-268.
Eagle, N. and Pentland, A. (2009). Eigenbehaviors: identifying structure in routine. *Behavioral Ecology and Sociobiology* 63(7), pp. 1057-1066.
Eagle, N., Pentland, A. and Lazer, D. (2009a). Inferring friendship network structure by using mobile phone data, *PNAS* (9)36, pp. 15274-15278.
Eagle, N., de Montjoye, Y. and Bettencourt, L.M. (2009b). Community computing: Comparisons between rural and urban societies using mobile phone data. In *Computational Science and Engineering, 2009. CSE'09. International Conference on* 4, pp. 144-150, IEEE.
Expert, P., Evans, T.S., Blondel, V.D. and Lambiotte, R. (2011). Uncovering space-independent communities, in spatial networks. *PNAS* 108(19) pp. 7663-7668. May 10, 2011.
Flamm, M. and Kaufmann, V. (2006). The concept of personal network of usual places as a tool for analyzing human activity spaces: A quantitative exploration, paper presented at 6th Swiss Transport Research Conference, Ascona 2006.
Florida, R. (2005). *Cities and the creative class,* New York, Harper Business.
Foth, M, Forlano L, Satchell C, Gibbs M (eds.) (2012). From social butterfly to engaged citizen: urban informatics, social media, ubiquitous computing, and mobile technology to support citizen engagement. MIT Press, Cambridge, Mass.
Frias-Martinez, V., Virseda, J., Rubio, A. and Frias-Martinez, E. (2010, December). Towards large scale technology impact analyses: Automatic residential localization from mobile phone-call data, in: *Proceedings of the 4th ACM/IEEE International Conference on Information and Communication Technologies and Development* (p. 11).
Frias-Martinez, V., Soto, V., Virseda, J. and Frias-Martinez, E. (2012). Computing cost-effective census maps from cell phone traces, in *Workshop on Pervasive Urban Applications*.
Fu, Y-C. (2007). Contact diaries: building archives of actual and comprehensive personal networks, Field methods, 19 (2), pp. 194-217.
Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler-Milanovic, N., Meijers, E. (2007). Smart cities – Ranking of European medium-sized cities, Centre of Regional Science, Vienna UT, October 2007. Retrieved December 18, 2012, from http://www.smart-cities.eu
Girardin, F., Vaccari, A., Gerber, A., Biderman, A., and Ratti, C. (2009a). Quantifying urban attractiveness from the distribution and density of digital footprints. *International Journal of Spatial Data Infrastructure Research* 4.
Girardin, F., Vaccari, A., Gerber, A., Biderman, A. and Ratti, C. (2009b). Towards estimating the presence of visitors from the aggregate mobile phone network activity they generate, in: International Conference on Computers in Urban Planning and Urban Management, 2009.
Golledge, R.G. (1990). Cognition of physical and built environments, in: T. Garling and G. Evans (eds.), Environment, cognition and action: A multidisciplinary integrative approach (New York: Oxford University Press, 1990).
González, M.C., Lind, P.G. and Herrmann, H.J. (2006). A system of mobile agents to model social networks. *Phys. Rev. Lett.*96, 088702.
González, M.C., Hidalgo, C.A. and Barabási, A.L. (2008). Understanding individual human mobility patterns. *Nature*, 453(5), pp.779-782, June 2008.
Graham, S. (1997). Cities in the real-time age: the paradigm challenge of telecommunications to the conception and planning of urban space. *Environment and Planning A* 29, pp. 105-127.
Graham, S. and Healey, P. (1997). Relational concepts of space and place: Issues for planning theory and practice. *European Planning Studies* 7, pp. 623-646.
Graham, S. and Marvin, S. (1996). *Telecommunications and the city*. London and New York: Routledge.

Graham, S. and Marvin, S. (1999). Planning cybercities? *Town Planning Review*, n. 1, pp. 89-114.
Graham, S. and Marvin, S. (2001). *Splintering urbanism*. London, New York: Routledge.
Hägerstrand, T. (1967). Innovation diffusion as a spatial process, University of Chicago Press, Chicago, Illinois, USA.
Hoteit, S., Secci, S., Sobolevsky, S., Ratti, C. and Pujolle, G. (2014). Estimating human trajectories and hotspots through mobile phone data. *Computer Networks* 4, pp. 296-307.
Huang, W., Dong, Z., Zhao, N., Tian, H., Song, G., Chen, G., Jiang, Y. and Xie, K. (2010). Anchor points seeking of large urban crowd based on the mobile billing data. Advanced data mining and applications, Lecture notes in *Computer Science* 6440/2010, pp. 346-357.
Isaacman, S., Becker, R., Cáaceres, R., Kobourov, S., Rowland, J. and Varshavsky, A. (2010). A tale of two cities, in: Proc. 11th ACM Workshop on Mobile Computing Systems and Applications (HotMobile), pp. 19-24.
Isaacman, S., Becker, R., Cáceres, R., Kobourov, S., Martonosi, M., Rowland, J. and Vasharsvky, A. (2011a). Identifying important places in peoples lives from cellular network data, in: *9th Intl. Conference on Pervasive Computing*, pp. 133-151. Springer Berlin Heidelberg.
Isaacman, S., Becker, R., Cáceres, R., Kobourov, S., Martonosi, M., Rowland, J., and Varshavsky, A. (2011b). Ranges of human mobility in los angeles and new york. In *Pervasive Computing and Communications Workshops (PERCOM Workshops),* IEEE International Conference on managing ubiquitous communications and services, pp. 88-93.
Isaacman, S., Becker, R., Cáceres, R., Martonosi, M., Rowland, J., Varshavsky, A. and Willinger, W. (2012). Human mobility modeling at metropolitan scales, in: *Proceedings of the 10th international conference on Mobile systems, applications, and services*, pp. 239-252. ACM.
ITU (2012). The World in 2011: ICT Facts and Figures. in: http://www.itu.int/ITU-D/ict/facts/2011/index.html
Järv, O., Ahas, R. and Witlox, F. (2014). Understanding monthly variability in human activity spaces: A twelve-month study using mobile phone call detail records. *Transportation Research Part C: Emerging Technologies*, Vol. 38, pp. 122-135.
Järv, O., Ahas, R. Saluveer, E., Derudder, B. and Witlox, F. (2012). Mobile phones in a traffic flow: A geographical perspective to evening rush hour traffic analysis using call detail records, PLoS ONE 7(11)
Jiang, S., Ferreira, J. and González, M. (2011). Understanding the link between urban activity destinations and human travel patterns. Paper presented at the Computers in urban planning and urban management 2011 Conference, Lake Louise, Canada.
Jiang, S., Ferreira, J. and González, M.C. (2012). Clustering daily patterns of human activities in the city. *Data Mining and Knowledge Discovery* 25(3), pp. 478-510.
Jonge, E. de, Pelt, M. van, and Roos, M. (2012). Time patterns, geospatial clustering and mobility statistics based on mobile phone network data, in: *Paper for the Federal Committee on Statistical Methodology research conference, Washington, USA*.
Kang, C., Ma, X., Tong, D. and Liu, Y. (2012). Intra-urban human mobility patterns: An urban morphology perspective. *Physica A: Statistical Mechanics and its Applications* 391, pp. 1702-1717.
Kang, C., Sobolevsky, S., Liu, Y. and Ratti, C. (2013). Exploring human movements in Singapore: A comparative analysis based on mobile phone and taxicab usages, in: *Proceedings of the 2nd ACM SIGKDD International Workshop on Urban Computing* (p. 1). ACM.
Kang, J.W., Welbourne, W., Stewart, B. and Borriello, G. (2004). Extracting places from traces of locations, in: Proceedings of the 2nd ACM International workshop on wireless mobile applications and services on WLAN hotspots (Philadelphia, PA, USA: ACM Press, 2004).
Komninos, N. (2006). The architecture of intelligent cities; Integrating human, collective, and artificial intelligence to enhance knowledge and innovation. *2nd International Conference on Intelligent Environments.* Athens: Institution of Engineering and Technology.
Komninos, N. (2008). *Intelligent cities and globalisation of innovation networks,* Abingdon, Routledge.

Krings, G. Calabrese, F., Ratti, C. and Blondel, V.D. (2009). Urban gravity: A model for inter-city telephone communication networks. *Journal of Statistical Mechanics: Theory and Experiment* Vol. L07003.

Kuusik, A., Ahas, R. and Tiru, M. (2008). Analysing repeat visitation on country level with passive mobile positioning method: An Estonia case study, University of Tartu, Positium LBS.

Kuusik, A., Ahas, R., and Tiru, M. (2010). The ability of tourism events to generate destination loyalty towards the country: an Estonian case study. *Discussions on Estonian Economic Policy* 18.

Kwan, M.-P. (2007). Mobile communications, social networks, and urban travel: Hypertext as a new metaphor for conceptualizing spatial interaction. *The Professional Geographer* 59(4), pp. 434-446.

Lambiotte, R., Blondel, V.D., de Kerchove, C., Huens, E., Prieur, C., Smoreda, Z. and van Dooren, P. (2008). Geographical dispersal of mobile communication networks. *Physica A* 387, pp. 5317-5325.

Liu, L., Biderman, A. and Ratti, C. (2009). Urban mobility landscape: Real-time monitoring of urban mobility patterns . MIT publication.

Louail, T., Lenormand, M., Cantú, O. G., Picornell, M., Herranz, R., Frias-Martinez, E., ... and Barthelemy, M. (2014). From mobile phone data to the spatial structure of cities. *arXiv preprint arXiv:1401.4540*.

Madey, G.R., Szabo, G. and Barabási A.L. (2006). Wiper: Integrated wireless phone based emergency response system, in: V.N. Alexandrov et al. (eds.), ICCS 2006, Part III, LNCS 3993, pp. 417-424. Springer-Verlag Berlin Heidelberg 2006.

Madey, G., Barabási, A.-L., Chawla, N.V., Gonzalez, M., Hachen, D., Lantz, B., Pawling, A., Schoenharl, T., Szabó, G., Wang, P. and Yan, P. (2007). Enhanced situational awareness: Application of DDDAS concepts to emergency and disaster management, in: *International conference on computational science, serial lecture notes in computer science (LNCS 4487)*, Y. Shi, G. D. van Albada, J. Dongarra, and Sloot, P. M. A. (eds), May 2007, pp. 1090-1097.

Martino, M. Calabrese, F., Di Lorenzo, G., Andris, C., Liu, L. and Ratti, C. (2010). Ocean of Information: Fusing aggregate and individual dynamics for metropolitan analysis. IUI'10, February 7–10, 2010, Hong Kong, China.

Massey, D. (1992). Politics and space/time. *New Left Review* 196, pp. 65-84.

Mateos, P. and Fischer, P.F. (2006). Spatiotemporal accuracy in mobile phone location: assessing the new cellular geography, in Dynamic and Mobile GIS: Investigating change in space and time, pp. 189-212.

Miller, H.J. (2010). The data avalanche is here. Shouldn't we be digging? *Journal of Regional Science*, 50 (1) (2010), pp. 181–201.

Mitchell, W. (2006). Smart City 2020 – Emerging technologies are poised to reshape our urban environments. Web. Accessed on 09/10/2011 http://www.metropolismag.com/story/20060320/smart-city-2020

Nijkamp, P. (2008). XXQ Factors for sustainable development: A systems economics view. *Romanian Journal of Regional Science* 2(1), pp. 1-34.

Nijkamp, P. (2010). Lands of hope and glory, Megacities: *Exploring a sustainable future* (S. Buys, W. Tan and D. Tunes, eds.), 010 Rotterdam 2010, pp 100-111.

Nijkamp, P. and Kourtit, K. (2011). *Global challenges and local responses in the urban century: A scoping document*. Amsterdam: Vrije Universiteit.

Novák, J., Ahas, R., Aasa, A. and Silm, S. (2013). Application of mobile phone location data in mapping of commuting patterns and functional regionalization: a pilot study of Estonia. *Journal of Maps* 9(1), pp. 10-15.

Nurmi, P. and Koolwaaij, J. (2006). Identifying meaningful locations, paper presented at 3rd annual international conference on mobile and ubiquitous systems: Networks and Services (MobiQuitous), San Jose, CA, 2006.

Nurmi, P. and Bhattacharya, S. (2008). Identifying meaningful places: The non-parametric way, J. Indulska *et al.* (eds.): Pervasive 2008, LNCS 5013, pp. 111-127, Springer-Verlag Berlin Heidelberg 2008.

Onnela, J-P., Saramaki, J., Hyvonen, J., Szabo, G., de Menezes, M.A., Kaski, K., Barabási, A.L. and Kertesz, J. (2007a). *Analysis of a large-scale weighted network of one-to-one human communication*, 2007 *New J. Phys.* 9, 179.

Onnela, J.-P., Saramaki, J., Hyvonen, J., Szabo, G., Lazer, D., Kaski, K., Kertesz, K. and Barabási, A.L. (2007b). Structure and tie strengths in mobile communication networks, in: *Proceedings of the National Academy of Sciences of the United States of America* 104, pp. 7332-7336.

Onnela, J-P., Arbesman, S., Barabási, A-L. and Christakis, N.A. (2010). Geographic constraints on social network groups, *PNAS*, pp. 1-5, Nov 2010

Onnela, J-P., Arbesman, S., Gozales, M.C., Barabási, A-L. and Christakis, N.A. (2011). Geographic constraints on social network groups, *PLoS one* 6, e16939.

Pae, K., Ahas, R. and Mark, Ü. (eds.) 2006. Joint space. Open source on mobile positioning and urban studies. X Venice Biennaale of Architecture. Positium, Tallinn, 174 p.

Park, J., Lee, D.S. and González, M.C. (2010). The eigenmode analysis of human motion. *Journal of Statistical Mechanics: Theory and Experiment*, 2010:P11021.

Pawling, A., Chawla, N.V. and Madey, G. (2007). Anomaly detection in a mobile communication network. Department of computer science and engineering, University of Notre Dame. Notre Dame, IN 46556.

Pawling, A., Yan, P., Candia, J., Schoenharl, T. and Madey, G. (2008a). Anomaly detection in streaming sensor data. University of Notre Dame, USA.

Pawling, A., Yan, P., Schoenharl, T. and Madey, G. (2008b). WIPER: An emergency response system, in: Proceedings of the 5th International ISCRAM Conference – Washington, DC, USA, May 2008. F. Fiedrich and B. Van de Walle (eds.).

Pei, T., Sobolevsky, S., Ratti, C., Shaw, S. L. and Zhou, C. (2013). A new insight into land use classification based on aggregated mobile phone data. *arXiv preprint arXiv:1310.6129*.

Phithakkitnukoon, S., Horanont, T., Di Lorenzo, G., Shibasaki, R. and Ratti, C. (2010). Activity-aware map: identifying human daily activity pattern using mobile phone data, in: *Human Behavior Understanding*, pp. 14-25, 22 August 2010, Istanbul, Turkey. Springer Berlin Heidelberg.

Phithakkitnukoon, S., Calabrese, F., Smoreda, Z. and Ratti, C. (2011, October). Out of sight out of mind -- How our mobile social network changes during migration, in: *Privacy, security, risk and trust (passat)*, 2011 ieee third international conference on and 2011 ieee third international conference on social computing (socialcom), pp. 515-520. IEEE.

Pulselli R.M., Pulselli F.M., Ratti, C. and Tiezzi , E. (2005). Dissipative structures for understanding cities: resource flows and mobility patterns. Becon 2005, in: Proceedings of the 1st International conference on built environment complexity.

Pulselli, R.M., Ratti, C. and Tiezzi, E. (2006). City out of Chaos: Social patterns and organization in urban systems. *International Journal of Ecodynamics* (1)2, pp. 125-134.

Ranjan, G., Zang, H., Zhang, Z.L. and Bolot, J. (2012). Are call detail records biased for sampling human mobility? *ACM SIGMOBILE Mobile Computing and Communications Review* 16(3), pp. 33-44.

Ratti, C., Sevtsuk, A., Huang, S. and Pailer, R. (2005). Mobile landscapes: Graz in Real Time. MIT publication.

Ratti, C., Pulselli, R.M., Williams, S. and Frenchman, D. (2006). Mobile landscapes: using location data from cell phones for urban analysis, *Environment and Planning B: Planning and Design* 33, pp. 727-748.

Ratti, C., Sevtsuk, A., Huang, S. and Pailer, R. (2007a). Mobile landscapes: Graz in real-time, in: G. Gartner, W. Cartwright and M.P. Peterson (eds.). Location Based Services and TeleCartography. Springer Berlin, pp. 443-444.

Ratti, C., Calabrese, F. and Kloeckl, K. (2007b). WikiCity: Connecting the tangible and the virtual realm of the city. *GEO Informatics* 10(8), pp. 42-45.

Ratti, C., Sobolevsky, S., Calabrese, F., Andris, C., and Reades, J. (2010). Redrawing the map of Great Britain from a network of human interactions. *PloS ONE* 5(12): e14248. doi:10.1371 / journal.pone.0014248.

Reades, J., Calabrese, F., Sevtsuk, A. and Ratti, C. (2007). Cellular Census: Explorations in urban data collection, Analysis of cell phone use can provide an important new way of looking at the city as a holistic, dynamic system. *IEEE Pervasive Computing* 6(3), pp. 30-38.

Reades, J., Calabrese, F. and Ratti, C. (2009). Eigenplaces: analysing cities using the space-time structure of the mobile phone network. *Environment and Planning B: Planning and Design* 36, pp. 824-836.

Resch, B., Zipf, A., Breuss-Schneeweis, P., Beinat, E. and Boher, M. (2012). Live cities and urban services - A multi-dimensional stress field between technology, innovation and society**,** in: Proceedings of the 4th international conference on advanced geographic information systems, applications, and services - GEOProcessing 2012, Valencia, Spain, January 30 - February 4, 2012, pp. 28-34.

Sagl, G., Loidl, M. and Beinat. E. (2012). A visual analytics approach for extracting spatio-temporal urban mobility information from mobile network traffic. *ISPRS Int. J. Geo-Inf.* 2012, 1, pp. 256-271; doi:10.3390/ijgi1030256

Sassen, S. (1991). The global city. New York, London, Tokyo. Princeton, New Jersey: Princeton University Press.

Schwanen, T. and Kwan, M.-P. (2008). The Internet, mobile phone and space–time constraints. *GeoForum* 39(3), pp. 1362-1377.

Schoenharl, T., Bravo, R. and Madey, G. (2006). WIPER: Leveraging the cell phone network for emergency response, *International Journal of Intelligent Control and Systems* 11(4), pp. 209-216.

Shaw, S.L. and Yu, H. (2009). A GIS-based time-geographic approach of studying individual activities and interactions in a hybrid physical–virtual space. *Journal of Transport Geography* 17, pp. 141-149.

Sheller, M. (2004). Mobile publics: beyond the network perspective. *Environment and Planning D: Society and Space* 22, pp. 39-52.

Shepard, M. (2011). *Sentient city: ubiquitous computing, architecture, and the future of urban space*. MIT Press, Cambridge, Mass.

Shoval, N. (2007). Sensing human society. *Environment and Planning B* 34, pp. 191-195.

Silm, S. and Ahas, R. (2010). The seasonal variability of population in Estonian municipalities. *Environment and Planning* A 42(10), pp. 2527-2546.

Soja, E. (1989). *Postmodern geographies*. London: Verso.

Song, C, Qu Z., Blumm, N. and Barabási A.-L (2010a). Limits of predictability in human mobility. *Science* 327, pp. 1018-1021.

Song, C., Koren, T., Wang, P. and Barabási, A.-L. (2010b). Modelling the scaling properties of human mobility. *Nature Physics* 6, pp. 818-823.

Soto, V. and Frıas-Martınez, E. (2011). Robust land use characterization of urban landscapes using cell phone data. Workshop on pervasive urban applications in conjunction with 9th Int. Conf. on Pervasive Computing**,** San Francisco, CA.

Steenbruggen, J., Borzacchiello, M.T., Nijkamp, P. and Scholten, H. (2013). Mobile phone data from GSM networks for traffic parameter and urban spatial pattern assessment: a review of applications and opportunities. *GeoJournal* 78(2), pp. 223-243.

Tanahashi, Y., Rowland, J. R., North, S. and Ma, K. L. (2012). Inferring human mobility patterns from anonymized mobile communication usage, in: *Proceedings of the 10th International Conference on Advances in Mobile Computing & Multimedia*, pp. 151-160. ACM.

Thrift, N. (1996). Inhuman geographies: landscapes of speed, light and power, in: N. Thrift (ed), *Spatial Formation* London: Sage. pp. 256-311.

Tian, H., Ma, X., Wang, H., Song, G. and Xie, K. (2010). A novel approach to estimate human space-time path based on mobile phone call records, in *Geoinformatics, 2010 18th International conference on* June (pp. 1-6). IEEE.

Toole, J.L., Ulm, M., González, M.C. and Bauer, D. (2012). Inferring land use from mobile phone activity, in: *Proceedings of the ACM SIGKDD international workshop on urban computing*, pp. 1-8. ACM.

Townsend, A.M. (2000). Life in the real-time city: Mobile telephones and urban metabolism. *Journal of Urban Technology* 7, pp. 85-104.

Tranos, E. and Gertner, D. (2012). Smart networked cities? *Innovation: The European Journal of Social Science Research* 25(2), pp. 175-190.

Tranos, E., Steenbruggen, J. and Nijkamp, P. (2012). Mobile Phone Data and Urban Analysis: An Exploratory Space – Time. *Tinbergen Institute Discussion Paper*, No. 13-139/VIII, pp. 1-14.

Traag, V.A., Browet, A., Calabrese, F., and Morlot, F. (2011, October). Social event detection in massive mobile phone data using probabilistic location inference. In Privacy, security, risk and trust (passat), 2011 ieee third international conference on social computing (socialcom), pp. 625-628. IEEE.

Um J, Son S, Lee S, Jeong H and Kim, B. (2009). Proc. Natl. Acad. Sci. 106 14236.

Vaidyanathan, A., Billinghurst, M. and Sirisena, H. (2008). Characterizing and visualizing mobile networks, in: *Proceedings of the New Zealand Computer Science Research Student Conference* (*NZCSRSC)*, April 2008, Christchurch, New Zealand.

Vaidyanathan, A.(2010). A test-bed for emergency management simulations A case-study including live call data in New Zealand, *(IJACSA) International Journal of Advanced Computer Science and Applications* (1)3, September 2010.

Vaidyanathan, A. and Johnston, D. (2011). The use of cell-phone technology for improved disaster response: A case-study from New Zealand. The Australasian Journal of Disaster and Trauma Studies.

Vázquez, A., Oliveira, J.G., Dezsö, Z., Goh, K.-I., Kondor, I. and Barabási, A.-L. (2005). Modeling bursts and heavy-tails in human dynamics, http://arXiv.org/abs/physics/0510117.

Veloso, M., Phithakkitnukoon, S., Bento, C., Fonseca, N. and Olivier, P. (2011). Exploratory study of urban flow using taxi traces, in: *First Workshop on Pervasive Urban Applications (PURBA) in conjunction with Pervasive Computing, San Francisco, California, USA*.

Vespignani, A. (2009). Predicting the behavior of techno-social systems. *Science* 325, pp. 425-428.

Wang, H., Calabrese, F., Di Lorenzo, G. and Ratti. C. (2010). Transportation mode inference from anonymized and aggregated mobile phone Call Detail Records, paper presented at 13th IEEE on Intelligent Transportation Systems (ITSC).

Wang, P., Gonzalez, M., Hidalgo, C. and Barabasi, A.L. (2009) Understanding the spreading patterns of mobile phone viruses. *Science* 324, pp. 1071-1076.

Wesolowski, A., Eagle, N., Noor, A.M., Snow, R.W. and Buckee, C.O. (2013). The impact of biases in mobile phone ownership on estimates of human mobility. *Journal of The Royal Society Interface* 10(81).

Yuan, Y. and Raubal, M. (2012). Extracting dynamic urban mobility patterns from mobile phone data, in *Proceedings ,of the 7th International Conference, GIScience 2012, Columbus, OH, USA, September 18-21*, *Geographic Information Science* pp. 354-367. Springer Berlin Heidelberg.

Zandvliet, R. and Dijst, M. (2006). Short-term dynamics in the use of places: A space-time typology of visitor populations in the Netherlands, *Urban Studies* (43)7.

Zhou, C., Frankowski, D., Ludford, P., Shekhar, S. and Terveen, L. (2007). Discovering personally meaningful places: An interactive clustering approach, *ACM Transactions on Information Systems* (TOIS) 25(3), pp. 1-31.

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