MOBILE PHONE LOCATION DATA: NEW CHALLENGES FOR GEODEMOGRAPHIC RESEARCH

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ABSTRACT

Significant changes in spatiotemporal relationships have transformed the organisation of society in recent decades. Therefore, new approaches are required to understand the spatiotemporal aspects of human behaviour and the dynamics of society in the modern world. This paper introduces the possibilities and limitations of mobile phone location data in an attempt to initiate wider discussion among demographers about future research based on data obtained from new technologies.

Keywords: new technologies, mobile phone location data, Prague, mobility, population distribution, spatiotemporal behaviour

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INTRODUCTION

Significant changes in spatiotemporal relationships have occurred in recent decades. These have transformed both human behaviour and the organisation of society and space. Mobility has been increasing and continues to appear in new forms with various meanings, and at the same time there have been changes in the organisation of our space. These developments are reflected in the transformation of human spatiotemporal behaviour (*Vilhelmson*, 1999; *Cresswell*, 2006; *Sheller – Urry*, 2006; *Cresswell – Merriman*, 2011). Our daily lives and patterns of mobility and migration are becoming increasingly varied due to increasing opportunities in all realms of everyday life (*Novák et al.*, 2007; *Macešková – Ouředníček – Temelová*, 2009; *Šimon*, 2011; *Pospíšilová*, 2012a). Thus, the general patterns of human (spatiotemporal) behaviour have been 'disrupted' or at least significantly modified. Therefore, new approaches are required in the field of geodemographic research so that we can better understand the spatiotemporal aspects of human behaviour and the dynamics of society in the modern world (*Ratti et al.*, 2006).

However, to date, most of the studies on population distribution and mobility based on 'big data' employ traditional sources such as the population census or the population register, which are limited in terms of their ability to reflect the spatiotemporal aspects of human behaviour in today's more mobile society. For instance, people often do not always live at their recorded permanent residence; they may change their place of residence weekly or seasonally, and labour flexibility (both temporal and spatial) has also been increasing (*Svoboda – Ouředníček*, 2015). Similarly, there is a greater range of opportunities in terms of where one can spend one's leisure time. Indeed, people may move within a space during the day (and night-time) for many reasons. Consequently, the socio-spatial differentiation of a population is not stable, but rather is constantly changing.

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The most frequently used data source on human spatiotemporal behaviour – the population census – has a number of weaknesses in this respect (*Novák – Novobilský*, 2013). While a census can provide us with data on the resident or commuting population, other types of users of spaces are not considered. Other informal forms of living as well as places where people perform other activities besides working and studying are therefore not discernible in this type of data. A question added to the census regarding a person's place of 'usual residence', in other words, the place where a person stays on a daily basis regardless of their permanent residence (*CZSO*, 2015), led to an improvement in the accuracy of data (*Špačková – Ouředníček – Riška*, 2012; *Šanda*, 2015). Other informal forms of living as well as places of other activities besides working and studying remain unknown. However, due to the high cost of conducting a census and the growing unwillingness among the population at large to provide information about themselves, any other extension to the type of data collected via the census method is highly unlikely in the future. Moreover, the data from a census are often not up to date, even shortly after their release (*Novák – Novobilský*, 2013), and a large percentage of the questions relating to mobility are not answered. Therefore, to address issues of accuracy and the growing complexity of mobility patterns and spatiotemporal relations, traditional statistical data needs to be supplemented with data from new sources reflecting the dynamics of today's society (see also *Palmer et al.*, 2013).

In Czechia, most of the studies based on more detailed data reflecting temporality and changing patterns of behaviour during the day, week, or year, rely on their own surveys (i.e. the diary method) and cover a spatially limited population sample (*Doležalová – Ouředníček*, 2006; *Novák – Sýkora*, 2007; T*emelová et al.*, 2011; *Pospíšilová – Ouředníček*, 2011) or they rely on their own estimations (*Čermák et al.*, 1995; *Burcin et al.*, 2008). Unlike other countries (e.g. Germany, Poland, the USA, Macedonia), in Czechia there is no state-wide collection of data on the spatiotemporal behaviour of the population (what are known as 'time use surveys') except by private companies (e.g. data collected by the research agency MEDIAN). Therefore, identifying new data sources and innovative methods for geodemographic research should be a common interest for many.

New technologies such as GPS or mobile phones not only change human spatiotemporal behaviour, they also represent a great potential avenue through which to study this behaviour (*Ratti et al.*, 2006) because most of the time these devices move with their users (*Steenbrugen et al.*, 2013). In this paper, we focus on mobile phone location data (sometimes called mobile positioning data) that provide us with an exceptional opportunity to extend our research on human spatiotemporal behaviour and the temporal changes of the population in space. These data exist in the databases of mobile network operators, and in Czechia they cover the mobility of most of the population (in 2003, 66% of the population over the age of 16 used a mobile phone [*CZSO*, 2008], and this figure had risen to 97% by 2015 [*CZSO*, 2016]). This type of data is available for any given moment in time and, with some limitations, offers great spatial detail. The comprehensiveness of these data is the main reason for the rapid increase in the amount and scope of research based on mobile phone location data in the social sciences during the last 10 years (*Pae – Ahas – Mark*, 2006; *Ratti et al.*, 2006; *Ahas et al.*, 2008a; *Novák et al.*, 2013; *Silm – Ahas*, 2014a). However, the use of such has been relatively slow to penetrate the Czech academic environment (*Dufková et al.*, 2008; *Novák*, 2010; *Novák – Temelová*, 2012; *Novák – Novobilský*, 2013).

Therefore, in this paper we aim to introduce the possibilities and limitations to using mobile phone location data and to suggest several directions for Czech geodemographic research in this area. First, we introduce the different types of mobile phone location data that exist and their advantages and disadvantages. Then we present an overview and evaluation of existing studies in this area that might be inspiring for Czech geodemographic research. Next we focus on Prague to demonstrate how mobile phone location data can be employed. We then conclude the paper with a discussion of the current situation regarding the availability of mobile phone location data in Czechia and make some suggestions for possible future directions that geodemographic research can take.

MOBILE PHONE LOCATION DATA

Mobile phone communication occurs through a network of towers and antennas (also known as base transceiver stations [BTSs]). The density of BTSs corresponds to that of the population. To communicate with the network, an individual mobile phone chooses a tower with an antennas – usually the closest one[3] – and a call detail record (CDR) is created in the database of the mobile network operator (*Soto – Frías-Martínez*, 2011). The territory of a country or smaller geographical units, such as districts or cities, can be divided into cells with a BTS, which are called location areas (LAs). The size of an LA depends on the population density and the intensity of calling activities. Generally, the size of an LA varies from 100–300 m in cities to several kilometres in rural areas (*Ratti et al.*, 2007). *Ahas et al.* (2008b) show that in Estonia, even data from less-populated areas can be useful because they are more accurate than some other types of data (e.g. tourism statistics). *Novák* (2010) calculated the accuracy of positioning (i.e. the ability to determine where the person using the mobile phone is situated) based on one of the main Czech mobile network operator's data on BTSs and their distribution and found that the average accuracy in Prague is 1,000 m (indeed, it is higher [200 m] in the city centre but decreases towards the outskirts [2,000 m]). The accuracy within Czechia can be described as quite high in regional centres (1,300 m), moderately high (3,500 m) in cities with over 10,000 inhabitants, and low in the countryside (6,000 m) (*Novák*, 2010). In addition to population density, geographical location is also important because the positioning is more accurate in suburban municipalities than in rural municipalities of the same size; methods for making positioning more accurate exist, but they need additional technical adjustments (*Novák*, 2010).

There are two basic types of mobile phone location or mobile positioning data (*Ahas et al.*, 2007a; *Novák*, 2010; *Lokanathan – Gunaratne*, 2015), namely 'passive' and 'active' mobile positioning data. Passive mobile positioning data are automatically saved in the databases of mobile network operators whenever phone users actively use their devices. This includes information on calls, SMSs (made/sent or received), and internet use. These data serve primarily as billing data (billing memory). Even though handovers are tied only to specific situations, it has been revealed that these data are able to describe population mobility with relatively sufficient accuracy (*Ahas et al.*, 2010b). Further, data originating from 'location updates' also fall under the passive data mobile positioning category. Information about the area of a mobile phone's location and each cross-border movement is regularly registered by the mobile network (*Novák*, 2010). It should be noted that an individual user of a mobile phone cannot be identified from these data (*Calabrese – Ratti*, 2006; *Soto – Frías-Martínez*, 2011). These data do not provide complete information about mobile phone users' daily movements; only some of the isolated localities of daily use are identifiable from passive mobile positioning data (*Novák*, 2010). However, it is possible to estimate a user's places of residence and work (*Ahas et al.*, 2008a; *Ahas et al.*, 2010b). In contrast, active mobile positioning data enable selected mobile phones (and thus the daily paths of the owners) to be traced using specialist software. These data are considered personal and in Czechia, like in many other countries, such data must be processed in accordance with the Personal Data Protection Act. Apart from exceptional situations (e.g. a court order), the written consent of the mobile phone user is required (*Novák*, 2010, *Novák – Temelová*, 2012). Currently, the most common studies are those based on passive data.

Use of mobile phone location data in research has both strengths and weaknesses. One of the undeniable advantages is that it is possible to obtain data regarding all (active) users of mobile phones. As the mobile phone is currently an ubiquitous location device in developed countries (*Ratti et al.*, 2006; *Novák*, 2010, *Novák – Temelová*, 2012), mobile phone data cover most of the population and can be considered representative (*Ratti et al.*, 2006). In the European Union, 91% of citizens have individual access to

3) There are also situations when a mobile phone chooses a more distant BTS, which means that the size of the areas covered by a BTS is not always fixed (*Ahas et al.*, 2008b).

Table 1 Usage of mobile phones by individuals in Czechia in 2008, 2012 and 2015

	2008		2012		2015	
	thousands	%	thousands	%	thousands	%
Total 16+	**8,053**	**90.6**	**8,251**	**96.0**	**8,511**	**97.0**
Gender						
Men	4,008	92.6	4,021	96.8	4,164	97.2
Women	4,045	88.7	4,231	95.2	4,347	96.9
Age group						
16–24	1,194	98.0	1,051	99.9	1,004	99.4
25–34	1,691	98.6	1,490	99.5	1,455	99.8
35–44	1,498	98.5	1,597	99.6	1,718	99.6
45–54	1,343	97.0	1,296	98.1	1,340	99.6
55–64	1,335	90.4	1,419	97.4	1,390	97.7
65–74	676	76.6	928	93.1	1,052	94.4
75+	317	46.0	470	70.0	551	78.9
Education (25+)						
Primary	681	67.5	790	83.5	648	87.3
Secondary without GCE	2,739	89.5	3,049	96.3	2,835	96.0
Secondary with GCE	2,424	95.3	2,320	97.7	2,684	98.9
Tertiary	1,013	96.9	1,195	98.8	1,34	99.0

Zdroj: Sčítání lidu, domů a bytů 2001; VŠPS 2002.
Source: *Census 2001; LFS 2002.*

a mobile phone (*Special Eurobarometer 396*, 2013). According to the *Survey on ICT Usage in Households and by Individuals*, 97% of the Czech population aged 16 and over used a mobile phone in 2015 (Table 1) and, on average, there are 0.98 mobile phones per household member aged 6 and over (*CZSO*, 2016). Moreover, these figures are increasing every year and there are no large disparities in the use of mobile phones by gender, age, or education. The highest rate of use of a mobile phone has been recorded among people aged 25–34 years old and among those with a tertiary education, while the lowest usage occurs in the 75+ age group and among people with primary education. Thus, mobile phone location data have strong explanatory power for the population aged 16 and over, and this power is even stronger for the working-age population (16–64).

Given that mobile phone location data already exist in the databases of mobile phone operators, the financial cost of data collection is negligible. However, the data are owned by private companies and their use in research is dependent on close cooperation with them, which very often involves financial expenses for research institutions. Last but not least, use of mobile phone location data enables current research to be enriched with temporality (*Ratti et al.*, 2006), an issue that has long been often overlooked by many authors. The type of information that can be obtained makes it possible for researchers to evaluate the changes in population distribution during the day, week, month, or year, and any differences caused by the weather, season, the transition from day to night, working hours, specific events, etc.

The main weakness of mobile phone location data in terms of their use in geodemographic research is the absence of user details such as gender, age, income, etc. Basic information can be obtained from the contracts of mobile operators' clients; however, not all clients do have a personal contract and operators are often reluctant to provide such information.[4)]

4) See the paper by *Silm – Ahas* (2014a), where these details are used.

Some researchers have tried to solve this problem by trialling what is known as the 'social positioning method' (*Ahas – Mark*, 2005; *Ahas et al.*, 2007a; *Ahas et al.*, 2010a), where location data are collected with the informed consent of mobile phone users who are then asked to fill in a questionnaire aimed at obtaining their socio-demographic or other characteristics. Other researchers have developed their own software and provided it to selected mobile phone users for installation in order to obtain more detailed personal data on users and on their mobility patterns (*Eagle – Pentland*, 2006; *Liccope et al.*, 2008). In this method, the collected data are classified as active positioning data. The method is currently used to a limited extent and mostly in less extensive, selective studies with a relatively small number of respondents.

Other disadvantages relate mainly to the relatively few studies of this kind undertaken to date, and the associated lack of experience of data processing, which has meant only a limited examination of the procedures used for this purpose; there have been problems related to different and often unclear habits of mobile phone users, the incompatibility of BTS areas with administrative and statistical units, or issues of privacy, ethics, and legislation (*Novák*, 2010). However, it may be assumed that these weaknesses will gradually be overcome as these methods are used more widely.

MOBILE PHONE LOCATION DATA IN RESEARCH

The global system for mobile communications (GSM) was created in 1982 (*Steenbruggen et al.*, 2013), so it is a fairly new technology. The first projects and studies that dealt with mobile phone data are also quite recent, dating only to the 1990s (*Steenbruggen et al.*, 2013). These early studies were rather isolated and it was only post-2005 that interest in the application of mobile phone location data in research became more widespread. Over the last 10 years, research using these data has evolved from mainly methodologically and technically oriented pilot studies published by a few researchers (e.g. *Ahas – Mark*, 2005; *Pae – Ahas – Mark*, 2006; *Ahas et. al.*, 2007b; *Calabrese – Ratti*, 2006; *Ratti et al.*, 2006; 2007) to studies addressing a wide spectrum of issues in various scientific fields. As the spatial accuracy of mobile positioning is determined by the density of BTSs and population density, most current research focuses on urban areas. The members of two leading research teams of global significance are among those with the most extensive publishing record in this area (*Novák*, 2010), namely, Rein Ahas and colleagues in the Department of Geography at the University of Tartu in Estonia, who work in cooperation with a private company, Positium, and Carlo Ratti and colleagues based at the Sense*able* City Lab at the Massachusetts Institute of Technology in Cambridge, Massachussetts, USA.[5)]

Analyses based on mobile phone location data are diverse in their scope – from the impact of earthquakes on spatial mobility (*Bengtsson et al.*, 2011), criminology (*Schmitz – Cooper*, 2007), and transport studies (e.g., *Caceres – Wildeberg – Benitez*, 2008) to various aspects of people's everyday lives (e.g., *Ahas et al.*, 2010b). In the paper, we focus on two directions and groups of studies that are relevant to geodemographic research: (1) the temporal aspects of population distribution and (2) new aspects of migration and daily mobility. As *Palmer et al.* (2013) aptly note, research based on mobile phone location data fits well into the development of the mobilities paradigm in the social sciences.

Patterns of population distribution change literally every second, and analyses based on traditional data sources that enable evaluation of a one-year period or even longer intervals are becoming insufficient. Thus, the interpretation of mobile phone location data represent a new challenge in this respect, and many authors have attempted to reveal different aspects of the temporalities of population distribution. *Carlo Ratti et al.* (2006) were among the first to present findings on the spatial differentiation of population changes during the day. Their study focuses on Milan, Italy, and is based on 16 days of data from BTSs (data that mobile operators have always stored) relating

5) For details, on Positium, Tartu, Estonia, see http://www.positium.com/ and for Sense*able* City Laboratory, Massachusetts Institute of Technology School of Architecture + Planning, see http://senseable.mit.edu/.

to users who make calls or send SMSs via each antenna in the city. Setting out with the hypothesis that 'the patterns of cell phone intensity correlate with the intensity of urban activity', they try to reveal important patterns of urban dynamics (*Ratti et al.*, 2006: 744). They concentrate mainly on identifying changes in areas with a concentration of mobile phone activity during the day (e.g. the shift in high-activity areas from the suburbs to the city centre during the morning hours) and daily population changes and related character (functional specialisation, social environment) in particular location areas.[6] Gradually, the same group of researchers developed a widely applicable real-time monitoring method for the urban environment that could be used for urban planning, transportation management, emergency system planning, and epidemic prevention, known as 'the real-time city' (*Calabrese – Ratti*, 2006; *Ratti et al.*, 2007; *Calabrese et al.*, 2011a). Not only mobile phone location data, where the movement of foreigners/tourists is distinguished from those of the local population, but also data provided by transport systems have been processed in this model.

Even though most studies tend to concentrate on the urban environment, the temporal aspects of population distribution can also be monitored on a national scale (*Deville et al.*, 2014). For geodemographic research, the compatibility of data with existing territorial units is important because it enables researchers to evaluate data in relation to the other characteristics of the localities under study, details of which are available from other types of statistical resources. Several studies have attempted to do this for the Prague metropolitan region (*Novák – Novobilský*, 2013; *Nemeškal – Pospíšilová – Ouředníček*, 2016; N*emeškal et al.*, 2016). One important finding from studies of changes in population distribution, especially in relation to predicting distribution, is the existence of a high degree of regularity in spatiotemporal patterns (*Sevtsuk – Ratti*, 2010; *Sun et al.*, 2011). The monitoring of population distribution during the day does not have to be merely descriptive; it can be used for more advanced or deeper analyses – for example, on seasonal or weather-induced spatial differentiation in the presence of tourists (*Ahas et al.*, 2007c; 2008b) or inhabitants (*Silm – Ahas*, 2010), on the automatic identification of types of land use (*Soto – Frías-Martínez*, 2011), and to assess the temporal aspects of segregation (*Silm – Ahas*, 2014a) or the typologies of daily rhythms (*Nemeškal et al.*, 2016).

Mobile phone location data have enriched mobility research in many ways. The main advantage of using this type of data for studying mobility patterns lies in the possibility of being able to monitor all daily movements (and not only those related to work or school) for any period of time regardless of the person's willingness to fill in a questionnaire/diary. Thus, studies based on mobile phone location data are able to reveal hitherto unknown patterns or aspects of human mobility and behaviour – for instance, similarities in the daily activity patterns of people who work in one area with the same characteristics[7] (*Phithakkitnukoon et al.*, 2010), the high degree of regularity in spatiotemporal movements and the probability of people returning to previously visited locations (*González – Hidalgo – Barabási*, 2008), ethnic differences in areas of activities (activity spaces) as a sign of segregation (*Järv et al.*, 2015; *Silm – Ahas*, 2014b), the relationship between changes in the use of mobile phones and travel behaviour (*Nobis – Lenz*, 2009), between people's daily mobility and their social ties, based on the frequency and length of calls made (*Phithakkitnukoon – Smoreda – Olivier*, 2012), or between people's spatial locations and their calls (*Calabrese et al.*, 2011b).

Moreover, studies need not be limited to assessing the mobility of the local population; they can also reveal patterns in the spatiotemporal behaviour of tourists (*Ahas et al.*, 2007c). By using the social positioning method and adding social characteristics to anonymous mobile phone location data, studies can be significantly enriched and can reveal significant social aspects of daily mobility. For instance,

6) Later studies have evaluated population distribution based on regularly collected mobile phone location data that are not dependent on the calling/SMS activity of the user (*Sun et al.*, 2011; *Nemeškal – Pospíšilová – Ouředníček*, 2016).

7) The authors divide the map of the coastal area of the State of Massachusetts into square cells (500 x 500 m) and to each of the cells they add the main activity that can be expected there (shopping, entertainment, eating, etc.).

Silm – Ahas – Nuga (2013) focus on gender differences in the movement in time and space of suburban populations in Estonia, while *Ahas et al.* (2010a) concentrate on differences in the daily rhythms of suburban commuters. A very detailed monitoring of daily mobility and activities can be obtained by combining analyses of mobile phone location data with in-depth interviews of a relatively small sample of respondents (*Licoppe et al.*, 2008; *Novák – Temelová*, 2012). An example of how mobile phone location data and a thorough knowledge of mobility behaviour can improve health studies is presented by *Madan et al.* (2010), who propose a model for predicting the health status of people from their daily movements and communication practices. Indeed, information derived from mobile phone location data can serve many organizations operating especially in developing countries in delivering healthcare (*Anokwa et al.*, 2009).

Even though mobile phone location data are primarily used to examine daily mobility, studies aimed at internal migration have also appeared over the last few years. Mobile phone location data can enrich migration statistics through the identification of unregistered movements, for instance with seasonal migration (*Silm – Ahas*, 2010). Some studies also reveal the effects of migration on people's behaviour. *Phithakkitnukoon – Calabrese* (2011) focus on the question of how migration influences social ties (their strength, distance, and perpetuation), while *Eagle – Montjoye – Bettencourt* (2009) investigate how patterns of communication change after people move from rural to urban areas and interact with their new social environment. Mobile phone location data can be especially beneficial for obtaining information about daily mobility and migration in developing countries where statistics tend to be of poor quality (*Blumenstock*, 2012).

Knowledge about the temporal aspects of population distribution as well as the mobility patterns of individuals can serve as a suitable tool for regionalisation. *Carlo Ratti et al.* (2010) present a regionalisation of Great Britain based on the interactions between people and compare them with the administrative regions. *Jakub Novák et al.* (2013) introduce the potential of mobile phone location data for mapping commuting flows and functional regionalisation in Estonia. They conclude that mobile phone location data can be an alternative source to traditional data sources. The authors of a research report titled *Delimitation of the Functional Area of Prague Metropolitan Region for Integrated Territorial Investments* come to a similar conclusion, which can also be seen in an opposite sense; the data on commuting flows from the census are still sufficient for functional regionalisation despite the high proportion of uncompleted returns, which was the case for the most recent census (*Ouředníček et al.*, 2014).

POPULATION DISTRIBUTION AND DAILY RHYTHMS BASED ON MOBILE PHONE LOCATION DATA: THE EXAMPLE OF PRAGUE

Until recently, studies on the distribution of the population and their daily rhythms in the Prague metropolitan region were based solely on data from censuses, estimations (*Čermák et al.*, 1995; *Burcin et al.*, 2008, *Pospíšilová – Ouředníček – Křivka*, 2012; *Pospíšilová et al.*, 2012), and surveys (participants' diaries and researchers' observations) (*Doležalová – Ouředníček*, 2006; *Novák – Sýkora*, 2007; *Pospíšilová*, 2012b; *Pospíšilová – Ouředníček*, 2011). Access to mobile phone location data has opened up new avenues for Czech research in this field. They combine the main advantages of the sources of data mentioned here; they can reveal the temporal dimension of population distribution (changes in any frequency), all kinds of mobility (related to all activities), and for almost the entire population. In this chapter, we focus on a comparison of socio-spatial differentiation in Prague based on data from the last census and mobile phone location data. We aim to show and discuss the benefits of mobile phone location data compared to the census data (the benefits of which are already known) to highlight the different potential of both to reveal a pattern of population distribution and its changes, and to emphasise the advantage of working with both of them. Then we present short-term changes in socio-spatial differentiation and examples of daily rhythms in selected localities based on mobile phone location data. The aim of this part is to demonstrate the unstable pattern of population distribution in Prague that can be revealed from mobile phone location data.

Jakub Novák can be considered a pioneer in the use of mobile phone location data in the Prague metropolitan region and Czechia, in both basic (*Novák*, 2010; *Novák – Temelová*, 2012) and applied research (*Ouředníček et al.*, 2014; *Novák – Novobilský*, 2014; *Pospíšilová et al.*, 2012) in the social sciences. The following example of using mobile phone location data builds on his work and also recently published specialist maps on daily rhythms in the Prague metropolitan region (*Nemeškal – Pospíšilová – Ouředníček*, 2016; *Nemeškal et al.*, 2016). Data were provided by the CE-Traffic company and cover one of the main Czech mobile network operators' users on an average weekday and weekend day in spring 2013.[8)] Data cover the users who were present in an urbanistic district (basic settlement unit which is called urbanistic district in Prague and other urban areas) during a one-hour interval. If they moved during this time across more than one urbanistic district, they are considered to be present in the urbanistic district in which they spent the most time.

The real population distribution within Prague differs from the distribution of the residential popu-

Figure 1 Difference between the usually resident population and the number of mobile phone users during the night in cadastral territories

Source: CZSO (2011); CE-Traffic (2013).

8) The days were chosen from a bimonthly period as typical days representative of most other days. Data were calculated to be representative of the entire population by CE-Traffic (http://www.ce-traffic.com/cs/).

lation (with permanent or usual residence) and from that of daily users of spaces based only on commuting to work and school. Traditional data sources have limited power to collect all migratory movements (and thus the real spatial pattern of the residential population) and all daily movements (and thus the real pattern of population distribution). In this regard, mobile phone location data can help to obtain better knowledge of the real pattern of population distribution. Figure 1 shows the difference between the spatial pattern of the usually resident population based on the 2011 census and the spatial pattern of mobile phone users between 3 a.m. and 4 a.m.[9] In Prague, the number of inhabitants with their usual residence there is lower than the number of mobile phone users at any given time, which shows that more people spend the night in Prague than live there. The larger number of users might be due to the presence of foreigners, daily users, people who are not registered as residents, or people who have changed their residence since the last census (*Nemeškal – Pospíšilová – Ouředníček*, 2016). There is no clear pattern to these differences in spatial distribution. It can be seen from the figure that the largest differences appear across the entire city: in the city centre and some of the inner city localities, in several parts of the outer city, and in some quarters in the outskirts (mainly in the western part of the city). In these areas, there are 1.5 times more mobile phone users than the usually resident population. There may be several reasons for this, such as the presence of tourists, services, new residential developments, the Prague ring road as an important traffic hub, or warehouses. Mobile phone users also outnumber residents in most of other cadastral territories that are mostly adjacent to the quarters described here; however, the differences are not that great. More or less the same number of both types of population or even a higher number of residents than mobile phone users is evident in residential quarters away from the main and most frequented traffic routes. Despite the limits of this comparison (data refer to different kind of population), it is useful for demonstrating that the spatial distribution of the registered resident population does not correspond to the real situation at any time.

The distribution of the population in Prague changes over the course of the day (24 hours) in accordance with the pattern and temporal aspects of functional use (here functions serve as what are called 'pace makers') (*Parkes – Thrift*, 1975; *Goodchild – Janelle*, 1983; *Mulíček – Osman – Seidenglanz*, 2011). Figure 2 illustrates how the daily pattern of population distribution differs significantly from that at night (based on mobile phone location data). In Prague in the morning (between 10 a.m. and 11 a.m.) several important concentrations of people are apparent. First, in the city centre, which covers not only the historical core, but also adjacent quarters, some of which serve as secondary centres (Smíchov, Karlín, Libeň, Pankrác and Budějovická), and second, in the area that continues south from these quarters almost to the border of Prague, where there is a hospital of importance to the city and beyond, as well as several centres of shopping and services (SAPA, Centrum Chodov and other areas). Third, in the eastern part of the city there are two areas with a higher daytime than night-time population: one of them is in the northeast part of Prague, which has an industrial history and where subway stations (in Vysočany, Hloubětín, Prosek a Letňany) are located in the vicinity of shopping and office areas, and two small airports, a multifunctional exhibition centre, and several production and storage areas are situated (Vysočany, Kbely, Satalice); and the second is not completely separate and is located to the southeast, where there is a large industrial zone and shopping centres. In the western part of Prague, the belt along the edge of the city creates a distinct pattern that is clearly related to the presence of the Prague ring road, which together with other functions, including being the location of several production and storage areas (Třebonice, Řeporyje, Radotín, Modřany), a shopping centre (in Třebonice), and an international airport (Ruzyně), are probably the reason for the predominance of a daytime over a night-time population.

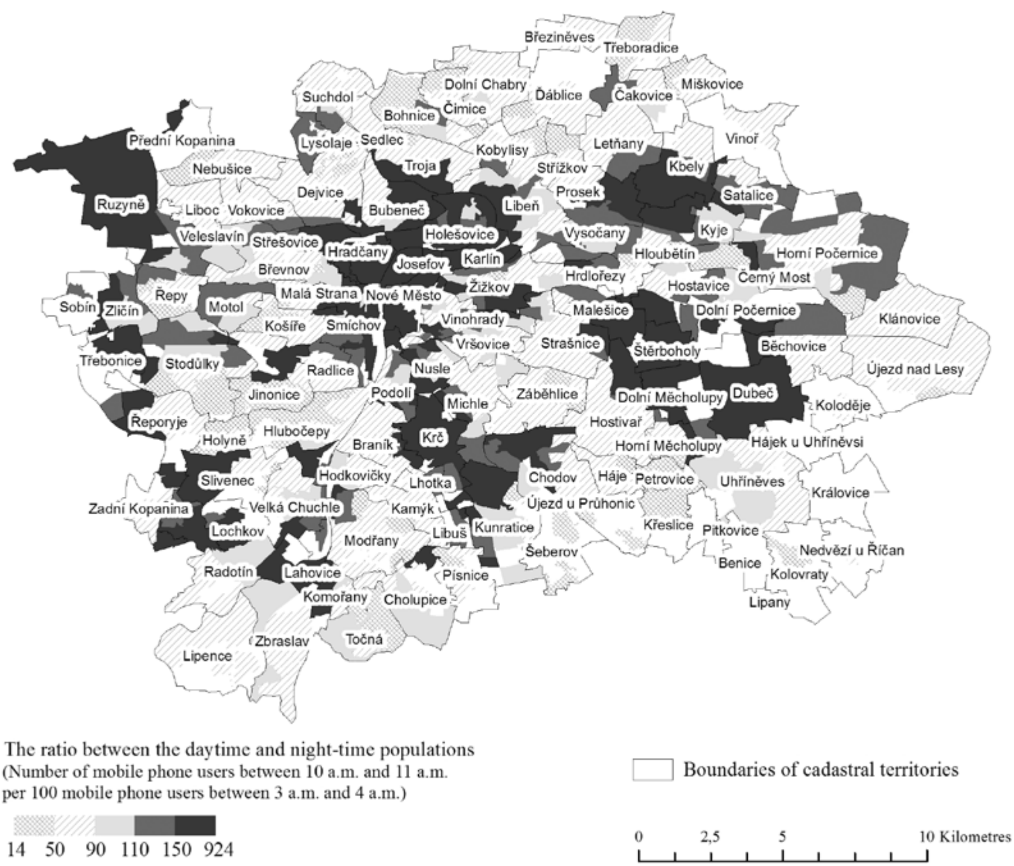
To summarise, in Prague the daytime population is (not surprisingly) over-represented in those

9) This pattern does not refer to the real resident population; it refers to the night-time population, i.e. people present in a given locality during the night.

quarters with a smaller number of inhabitants and a concentration of functions related to production and consumption. Transportation infrastructure, such as subway stations and main roads,[10] is also revealed to be important in this respect. Thanks to the high level of detail on the generated map, many other smaller concentrations of daily population can be identified, such as at shopping centres in the vicinity of housing estates (e.g., Černý Most, Čakovice). The rest of Prague, mainly residential areas situated all over the city, lose their populations during the day, and thus the daytime population is under-represented in these parts.

The pattern of socio-spatial differentiation in Prague remains unchanged almost all day. The concentrations of the daily population are not affected by changes in daily activities; however, they do gradually shrink over time (see Figure 3). Only a few smaller areas such as the city centre and the international airport, where the daytime population significantly outnumbers the night-time population, remain stable until the evening (8–9 p.m.), whereas the population

Figure 2 Areas (urbanistic districts) with a high concentration of daily users, spring 2013

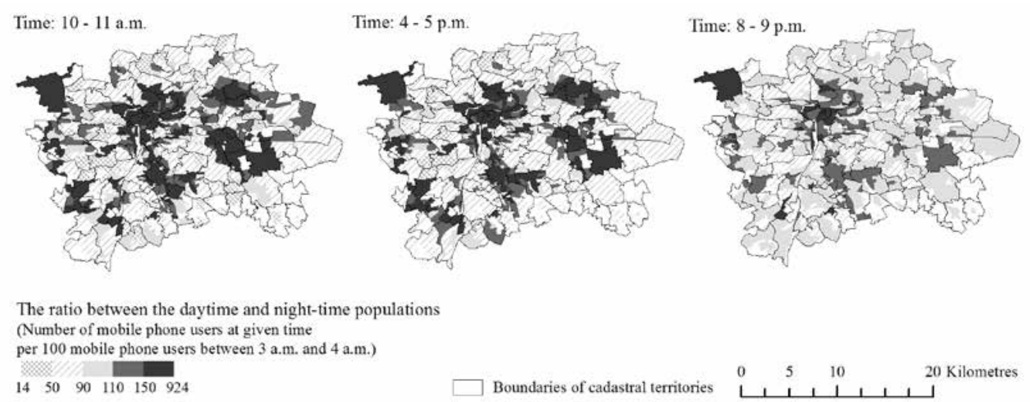


Source: CE-Traffic (2013).
Note: Urbanistic districts with no mobile phone users are shown in white.

10) The effect of the Prague ring road is also apparent in the eastern part of Prague.

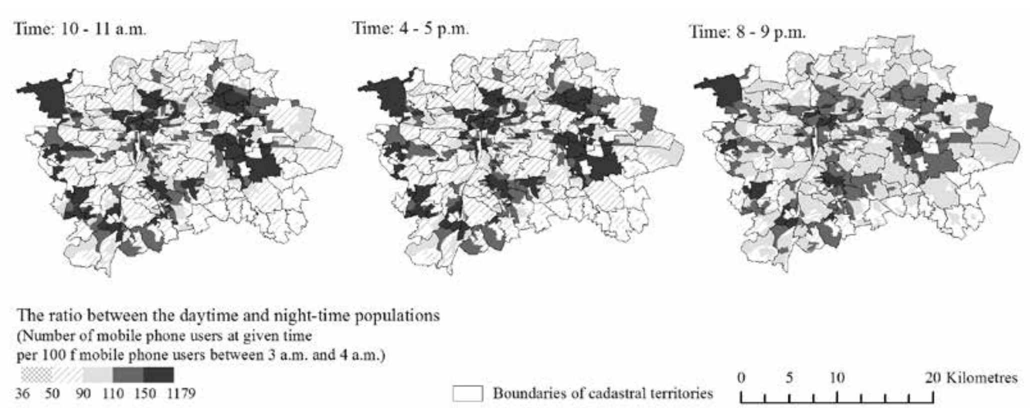
in the other localities decreases more quickly. Even in the evening, however, all the localities with high concentrations of daily population are still visible on the map. A very similar pattern of population distribution can be observed during the weekend (see Figure 4). The areas of concentration of the daytime population in Prague at the weekend are smaller than on weekdays mainly because of the reduced presence of people in industrial and office areas; some of these areas even disappear from the map. However, there are also fewer people present in parts of the city centre that are not attractive to tourists, primarily where residential buildings and government institutions prevail. These areas also shrink over time, yet overall the presence of people is significant in more localities than during weekdays.

Figure 3 Pattern of population distribution based on mobile phone location data during the weekday, spring 2013



Source: CE-Traffic (2013).
Note: Urbanistic districts are depicted in the maps. Urbanistic districts with no mobile phone users are shown in white.

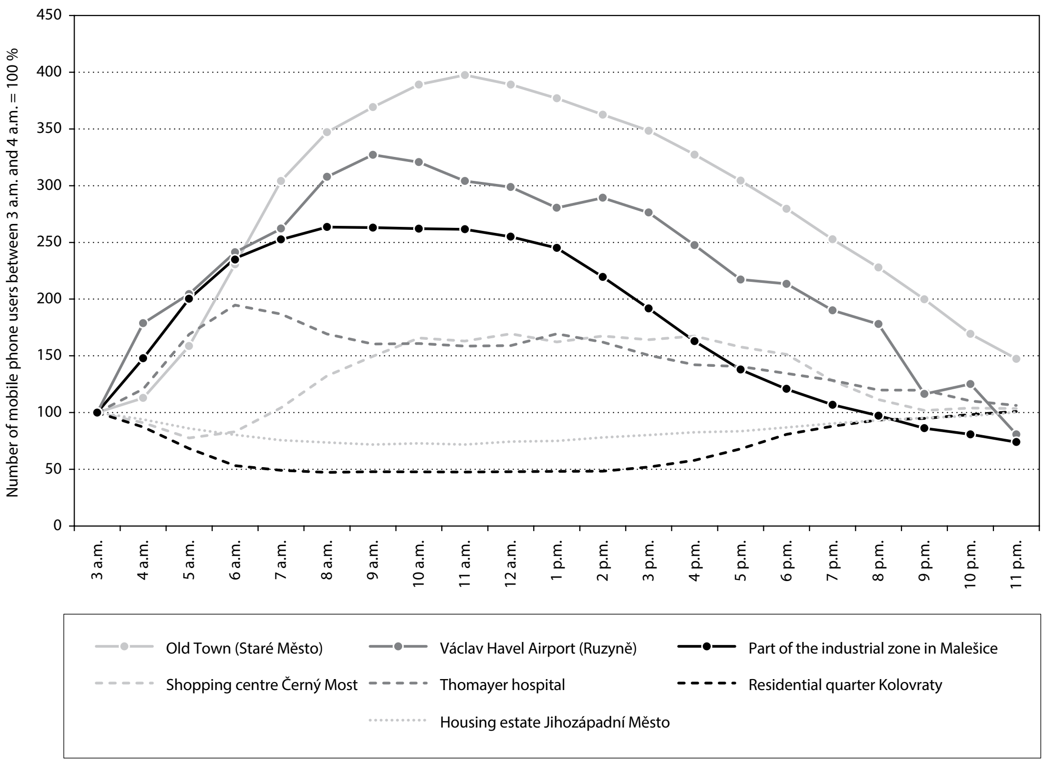
Figure 4 Pattern of population distribution based on mobile phone location data during the weekend, spring 2013



Source: CE-Traffic (2013).
Note: Urbanistic districts are depicted in the maps. Urbanistic districts with no mobile phone users are shown in white.

Variable socio-spatial differentiation is reflected in the distinctive daily rhythms of particular localities.[11)] Usually, localities with similar functional patterns share the same daily rhythm (for instance, *Jiří Nemeškal et al.* [2016] identify nine types of daily rhythms in the cadastral territories of the Prague metropolitan region) and the same kind of function can be identified in the daily rhythms of all localities where it is present (*Pospíšilová*, 2012b). Figure 5 provides examples of the daily rhythms in selected localities that have different functions within the city of Prague.[12)] As the functional specialisation is the most important factor influencing daily rhythms (*Goodchild – Janelle*, 1983; *Pospíšilová*, 2012b), each curve in the graph has a different shape; both the ratio between the daytime and night-time populations and temporal variations of population differ. Three localities exhibit a large difference between daytime and night-time populations, namely the Old Town in the city centre, the industrial zone, and the airport. The difference is greatest in the Old Town. Compared to the other two localities, the increased influx of people takes place later in the day here. On the other hand, the population starts to decrease much earlier in the industrial

Figure 5 Daily rhythm of selected localities in Prague, spring 2013



Source: CE-Traffic (2013).

11) The daily rhythm of a locality is a temporal pattern of daily use that arises from a combination of functional specialisation, the other characteristics of the locality, and the everyday lives of a diverse range of people (*Goodchild – Janelle*, 1983; *Pospíšilová*, 2012a).

12) The localities (one or more urbanistic districts) were selected to represent typical urban functions and their temporal patterns.

zone than in these other two localities. This is because these localities are frequented by different types of daily users. The daily rhythms in the other two non-residential localities are much more balanced. In the hospital area, the effect of the early morning rush hour is apparent and this is followed by a relatively constant number of people being present during the morning time and a gradual decrease in the afternoon. In the shopping centre, the population increase is determined by shop opening hours (only during daylight hours) and is therefore not apparent until 7 a.m. The two residential quarters have inverse daily rhythms; they lose population during the day. The decrease is larger in Kolovraty, a residential quarter on the outskirts, because there are no other important functions there. In contrast, the housing estates in Prague are well equipped with service facilities, so the presence of other functions (mainly shopping and services) results in a lower population decrease during the day.

THE USE OF MOBILE PHONE LOCATION DATA: A DISCUSSION OF THE CURRENT SITUATION AND FUTURE DIRECTIONS OF GEODEMOGRAPHIC RESEARCH IN CZECHIA

The use of mobile phone location data represents a big challenge for geodemographic research. There is no doubt that this new technology has changed both mobility behaviour and the functioning of society as a whole (*Ratti et al.*, 2006). However, it can also help us to study it by exploring our constantly changing reality in order to help us to gain a deeper understanding of the spatial aspects of human behaviour. Because demographic behaviour is influenced by local as well as national or even global socio-spatial contexts, acquiring knowledge of the temporal characteristics of spaces on different scales is of great importance for demographers (*Entwisle*, 2007). Although the use of mobile phone location data in various research fields has evolved rapidly in recent years, there are still relatively few demographers[13] who are taking advantage of the detail that these data can provide. Therefore, there is great potential for demographers to formulate new questions on, and seek answers to existing questions in, both (geo)demographic and mobile phone data research topics (see also *Palmer et al.*, 2013). As in many other European countries, research based on mobile phone location data is still at a nascent stage in Czechia (c.f. Estonia). Only a few teams in the country are developing this kind of research (e.g. Research and Development Centre for Mobile Communication, Czech Technical University in Prague; the Urban and Regional Laboratory, Faculty of Science, Charles University in Prague; and the Faculty of Informatics and Statistics, University of Economics, Prague),[14] although the Prague Institute of Planning and Development has also recently started to use mobile phone data for its analyses.

The main obstacle to the wider use of these data in (geodemographic) research is, in our opinion, their availability. Developing a cooperative relationship with mobile operator(s) is a relatively problematic process because they tend to regard their data as classified and are concerned about losing the trust of their customers (*Novák*, 2010). However, these concerns are gradually being overcome and we have witnessed a spread in the use of mobile phone location data in both the private and public sectors, as well as in basic and applied research in Czechia. Strictly speaking, cooperation between mobile operators and researches is not necessary, as several private companies offer mobile phone location data for purchase, but these have a high financial cost. The character of the data that can be obtained for (geodemographic) research is also dependent on a relationship with a mobile operator or company to provide the data. If we omit cases where the written consent of the mobile phone user is necessary, we can say that it is possible to get data about the area of a mobile phone's location and cross-border movement based on the active use of mobile phones by their users or regular location updates. These data require subsequent processing before they can be used in social research. From our experience, data on the number of mobile phone users (sorted based

13) Mobile phone data research is being developed in geography more than in demography.

14) More people in Czechia probably use mobile phone location data for their research; however, the outcomes are not easy to trace.

on the location of mobile phone [residents, commuters to work, other users] or origin of SIM card [Czechs, foreigners]) in basic settlement units for each hour are of relatively sufficient accuracy. In addition data on traffic flows have been already tested in Czechia. Indeed there are other kinds of data that could be obtained from databases of mobile operators; however, the possibility to use them is always based on the willingness of the mobile operator to provide them and also on data accuracy, which needs to be tested. Establishing cooperation between mobile operators and national statistical offices (*Novák*, 2010) would offer the greatest benefit to researchers. However, such cooperation is at present unlikely in Czechia.

Overcoming other disadvantages goes hand in hand with using these data in the research. For demographers, the lack of information on the social characteristics of mobile phone users and the ambiguities and inaccuracies in the data are the two main deterrents to using these data in their research. However, both these problems can be addressed within the framework of interdisciplinary cooperation with, for instance, social scientists. The first problem has already been solved to some extent by supplementing mobile phone location data with data derived from questionnaires (*Ahas et al.*, 2007a; *Liccope et al.*, 2008; *Ahas et al.* 2010a). Developing other methods for linking anonymous data with users' identification details by, for instance, obtaining data from the contracts of mobile operators' clients or by connecting mobile phone data with other available data sources could be the next step in overcoming this drawback. However, the adoption of such methods raises the issue of privacy, which is another problem that needs further discussion (*Ratti et al.*, 2006; *Novák – Temelová*, 2012). It is, of course, essential to establish rules for using data that are not completely anonymous as well as for preventing data from being misused. As *Jakub Novák* (2010) points out, we could find inspiration from how census data are managed in this regard. However, it is necessary to add that not all identification details jeopardise the anonymity of mobile phone users. For instance, in Estonia, researchers obtain information about the ethnicity of mobile phone users from the language used for communication with the operator (*Silm – Ahas*, 2014a). The second disadvantage mentioned above, that of ambiguity and inaccuracy, lies in the lack of knowledge about the practices of mobile phone users (such as their use of two or more mobile phones or SIM cards, the times and reasons for switching the phone on and off, discrepancies in the movements of the mobile phone and its user, etc.), incompatibility of spatial and administrative units with network cells, and related decision-making procedures about the final location of mobile phones.[15] Other issues with respect to accuracy include, for instance, the rapid movement of a mobile phone (e.g. on the road) or the connecting of a mobile phone to a BTS other than the one nearest to it. All these issues need further research, which should ideally be coordinated to avoid the simultaneous and repeated search for solutions to the same problem. Czech research teams could also obtain inspiration from Estonia in this regard. However, it is possible to say that all of these discrepancies do not significantly reduce the data quality if triangulation of data sources is applied. This technique is very often employed by mobile phone data providers before the data reach the end users. To conclude, we are convinced that, despite some shortcomings, the use of mobile phone location data offers great potential for Czech geodemographic research and we think that it would be a missed opportunity if these data were not used. The aim of this paper has been not to prescribe how this should be done, but to initiate a wider discussion among demographers and those working in the field in Czechia in particular, and thereby to open the door to new ways of using mobile phone data and to new insights into (geo)demographic processes.

15) In the example of Prague presented in this paper, some inaccuracies can also be seen: in some urbanistic districts a large number of mobile phones were recorded even though there is no apparent reason for their presence. They were probably located in adjacent districts.

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