Temporality of urban space: daily rhythms of a typical week day in the Prague metropolitan area

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ABSTRACT
The aim of this paper is to reveal, describe, explain, and map variations in diurnal population in the metropolitan area of Prague. We use an alternative data source to traditional census-based cartographic presentations and employ location data from mobile phones to identify types of daily rhythm that shape the region at different times during a typical weekday. These rhythms are influenced especially by residential and commercial suburbanization and the consequent dynamic development of new working centres, services, and leisure-time facilities within the metropolitan region. The main output consists of three maps. The first map contains a typology of the main functions — residential, work, transportation, and services — and is used as the main analytical tool for sorting settlements, resulting in classification of nine types of settlement in all. The other two maps show a plastic image of the day- and night-time populations of the metropolitan area.

1. Introduction
Most social sciences describe cities as dynamic systems, the main characteristic of which is their changeability (Burgess, 1925; Colby, 1933). Changes occur at various stages in the development of a city, and they take a variety of forms; some changes are gradual, while others are abrupt. Cities can be viewed as open organisms with material and non-material inputs and outputs. The flows of people, goods, money, and information create all urban life, for example. In this sense, far from being stable, a city and its localities are constantly changing, and a dynamically oriented approach to the study of cities or metropolitan areas is needed in order to understand them fully.

Although it is impossible to grasp fully the complexities and dynamics of cities, for some time several scholars have called for the inclusion of temporal aspects of urban life (and thus also short-term changes of the urban environment) in research on urban geography (Allen, 1999; Amin & Thrift, 2002; Engel-Frisch, 1943; Foley, 1954; Goodchild & Janelle, 1984; Hägerstrand, 1970; Schmitt, 1956; Simonsen, 2017; Taylor & Parkes, 1975; Thrift & May, 2001). In this respect, the spatio-temporal behaviour of urban inhabitants and the diurnal variations of population in urban localities, which come together to create specific urban rhythms, are the main focus of interest of urban geographers (Axhausen, Zimmermann, Schönfelder, Rindsfüsser, & Haupt, 2002; Mulíček, Osman, & Seidenglanz, 2016; Muller, 1982; Pospíšilová, 2012). These interests are a response to descriptions of cities as static, which show the socio-spatial patterns of their inhabitants in the middle of the night. In other words, they are a response to most studies of socio-spatial differentiation, which are based on census data relating to the residential population.

In 1975, two geographers, Peter J. Taylor and Don N. Parkes, attempted to respond to this challenge by using artificial data for a hypothetical British city of 200,000 people (because no appropriate data were available) to explore diurnal variations in population distribution (Taylor & Parkes, 1975). Later, Michael F. Goodchild and Donald N. Janelle (Goodchild & Janelle, 1984) continued this effort by using actual data from space–time diaries for around 2,000 people living in Halifax, Canada. The aim of both papers was to demonstrate the need for a new dynamic (temporal) understanding of a city and its localities, the limitations to the use of census data, and the need to go beyond descriptions of the socio-spatial patterns of the residential population.

More than 30 years later, we face a similar challenge: that of how to grasp the constantly changing socio-spatial differentiation of urban population, in a time, moreover, of increasing mobility in terms of the...
number and length of movements, forms, and meanings (Sheller & Urry, 2006). Diurnal variations in population can be understood as an outcome of the spatial differentiation, diversity, and rhythmicity of urban functions (Janelle & Goodchild, 1983; Mulíček, Osman, & Seidenglantz, 2011). However, the location of these functions has little in common with the classic models of functional differentiation presented by the Chicago School. Today, a location is to a great extent formed randomly due to the unpredictable effects of globalization (Dear & Flusty, 1998). The new, and to an extent unorganized, distribution of individual functions in a city, and the increasing fragmentation of the individual parts thereof, lead to the creation of new routes and directions of movement in metropolitan areas and to a weakening of the relationships between traditional nodes of communication.

Until recently, the only socio-spatial population pattern we could describe apart from the residential one was the spatial distribution of the working (and studying) population based on census data related to the commute to work or school. This applies not only in the Czech Republic but also elsewhere, in countries where national statistical offices have not been collecting sufficient data on spatio-temporal movements of the population (McPherson & Brown, 2004). In terms of diurnal variations in population, census data have a number of weaknesses that have been described elsewhere (Novák & Novobilský, 2013; Pospíšilová & Novák, 2016). However, the question of whether it is possible to capture commuting patterns reliably also arises, given the significant changes in the commuting behaviours of the urban population, such as the increased variety of work type, location, and flexibility as reported recently (Svoboda & Ouředníček, 2015). Several studies aimed at revealing real socio-spatial differentiation covering the entire urban population have therefore used qualitative methods to account for these behaviours (Bromley, Tallon, & Thomas, 2003; Pospíšilová, 2012).

At the same time, new ways of living and working have been accompanied by one significant advantage, which offers an interesting alternative to traditional methods of data collection. With the increase in mobile phone usage among the population (97% of the Czech population aged 16 and over used a mobile phone in 2015, Pospíšilová & Novák, 2016), researchers have gained a revolutionary opportunity to research human spatio-temporal movement. Of course, these data do not provide information on the social structure of the population (written consent is required to use the social characteristics of the mobile phone user, Novák & Temelová, 2012), but it is now possible at least to monitor all daily movements for any time period (Novák & Novobilský, 2013). Thus, the processing and interpretation of mobile phone location data represents a new challenge in revealing changes in population distribution, culminating in attempts to develop a real-time model of the city (Calabrese & Ratti, 2006; Calabrese, Colonna, Lovisolo, Parata, & Ratti, 2011; Ratti, Sevtsuk, Huang, & Pailer, 2007). Studies using data from mobile phones have been published since the mid-2000s (Ahas & Mark, 2005; Ahas, Silm, Járv, Saluveer, & Tiru, 2010; Kung, Greco, Sobolevsky, & Ratti, 2014; Ratti, Frenchman, Pulselli, & Williams, 2006; Silm & Ahas, 2010), several of them in this journal (Manfredini & Dilda, 2012; Novák, Ahas, Aasa, & Silm, 2013; Ouředníček, Nemeškal, Špačková, Hampl, & Novák, 2018). In the Czech Republic, Jakub Novák pioneered research in this area (Novák, 2010; Novák & Temelová, 2012; Ouředníček et al., 2018; Pospíšilová & Novák, 2016).

The present study makes connections between reports on diurnal variations of population in urban localities (daily rhythms) and studies using mobile phone location data to reveal patterns of urban life. We use a dataset that reflects movements of the ‘entire population’ (i.e. present in the region) to reveal daily rhythms in different parts of the Prague Metropolitan Area and to identify the processes behind these. In this way, we expand on studies of daily rhythms that were based either on statistical data covering only part of the movements, or part of the population, or on qualitative data. The aim of the paper is to reveal, describe, and explain diurnal variations in population within the Prague Metropolitan Area, which is the most dynamic part of the Czech settlement system, especially given residential and commercial suburbanization and growing centripetal, centrifugal, and tangential mobility within the area (Novák & Šykora, 2007; Ouředníček, 2007). Using mobile phone location data, we wish to identify different types of daily rhythms that form within the region at different times of day. The Prague Metropolitan Area contains most of the daily activities of Prague’s urban and suburban population, and its delimitation is based on a synthetic approach presented in this journal recently (Ouředníček et al., 2018). The mobile phone location data that we use for analysis do not allow us to identify all the activities that occur in the region during the day. Very often, contradictory daily moves ‘smooth out’ any changes in diurnal variations of population, and this is apparent in some localities. Therefore, while the intensity of individual activities cannot be determined accurately, it is possible to grasp the most significant daily rhythms in some localities (cadastral areas).

2. Data and methods

The nature of mobile phone location data makes it possible to generalize the processes that occur, resulting in the spatial differentiation of changes in population at different times of day. One method of
capturing and classifying the key functions and processes in the Prague Metropolitan Area at different times is via the establishment of a typology of daily rhythms using small administrative units. The current arrangement of settlements in the Czech Republic as a whole has its origins in the Austro-Hungarian system. 

Settlement system of the Czech Republic. For easier median area of 4.5 square km in the contemporary There are more than 13,000 cadastral areas with a origin aned set up as a unit for property taxation. A cadastral area usually comprises a cadastral area. A cadastral area whose delimitation originated in nineteenth century compact settlement and its rural hinterland and was originally set up as a unit for property taxation. There are more than 13,000 cadastral areas with a median area of 4.5 square km in the contemporary settlement system of the Czech Republic. For easier understanding we apply the term 'settlement' instead of 'cadastral area' throughout this paper. Use of the term 'settlement' allows us to capture the distinctive character of functions and development in parts of the municipality.

Our dataset consists of 961 settlements in the Prague Metropolitan Area (PMA). The PMA delimitation was carried out by Oufredniček et al. (2018) as an initial stage of application of the contemporary EU metropolitan development tool known as Integrated Territorial Investment. In the first of three stages, we used the traditional method of defining the metropolitan area from data on commutes to work and school from the 2011 Population census. Secondly, the delimitation was also based on the connectivity of suburbia with the core of the city, and the intensity of housing construction. Thirdly, a completely new approach was applied for the first time in the Czech Republic, using mobile phone data to show the integrated systems of centres and the average time spent in Prague.

Data on the daily mobility of T-Mobile clients used herein were provided by the CE-Traffic company and extrapolated for the whole population using other kinds of data (internal data, census data, and other data on population structure provided by the Czech Statistical Office). Specifically, we use the data on the population present in settlements for each two-hour period during the day (on the map, 2 represents the interval 2–4, 4 represents the interval 4–6, etc.). If the mobile phone user visited more than one spatial unit during the given interval, these moves were added to the one where the most time was spent. More information about mobile phone data collecting, processing, and accuracy is described by Novák (2010), Novák and Novobilský (2013) or Pospíšilová and Novák (2016).

The analysis is based on data obtained for a typical weekday. We are well aware of the limitations of our dataset, especially with regard to seasonal differences or weekday variations in the daily rhythms of individuals (Ahas, Aasa, Silm, & Tiru, 2009; Sevtsuk & Ratti, 2010; Silm & Ahas, 2010), but the cost of this kind of data is very high and it was not possible to obtain a larger sample of mobile data. We were able to select the day and therefore tried to eliminate some of these constraints. Wednesday 30th September 2015 was chosen as a typical day which did not correspond with any national or school holidays. Moreover, Novák and Novobilský (2013) confirmed the similarity between daily rhythms within the localities of the Prague Metropolitan Area, thus we can at least partially generalize our results for the typical or ordinary week day.

In our typology, we focus on the most important functions of all 961 settlements, primarily residential, working (including the educational function) and service functions. The service function includes commercial (e.g. shopping or retail) and personal services. Another relevant function very often discussed in relation to suburbanization is traffic (Urbánková & Oufredniček, 2006). Mobile phone location data used in this research shows distinctly the volumes and daily patterns of transit traffic. All these functions influence significantly the diurnal variations of population in the Prague Metropolitan Area. Subsequently, absolute values were recalculated into relative numbers according to the daily mean of the administrative unit. The method of classification is shown in Figures 1 and 2.

The principle of the classification is to compare the number of people during a particular time of day in all settlements. The settlement function is expressed using a code for daily rhythm. Firstly, we selected suitable code combinations for the different types of classification. These types were either final and did not require further classification, or partial and requiring subsequent typology (Figure 1). Elementary daily rhythms demonstrate either an increase in population (A shape), a decrease (U shape) or relatively balanced without any significant change. Secondly, a further stage of classification allows us to separate residential settlements into metropolitan or rural, and further divide them by intensity. The difference between metropolitan and rural settlements becomes apparent over the course of a day when rural settlements experience losses and gains of population earlier in the day than metropolitan ones. This time delay between the daily rhythms is about 2 h and is based on findings from research on former and new residents of suburban municipalities around Prague (Doležalová & Oufredniček, 2006). Most of the 'metropolitan' out-of-town settlements are suburbs of Prague.

Thirdly, we focus on settlements with a presumed amount of transit traffic. The main results from previous research were used to select appropriate times of traffic peaks in the morning and afternoon (Axhausen et al., 2002; Järv, Ahas, Saluvere, Derudder, & Witlox, 2012; Manfredini & Dilda, 2012; Ortúzar & Willumsen, 2009). Fourthly, the service category is hard to capture for any particular time period. However, the highest intensities are assumed to be between
16:00 and 20:00 and between 8:00 and 12:00, as seen in three case studies of the daily regimes of inhabitants of Prague suburbs (Doležalová & Ouředníček, 2006) as well as in similar cases elsewhere (Axhausen et al., 2002; Bertolini & Dijst, 2003; Manfredini & Dilda, 2012; Zandvliet & Dijst, 2006). The result is either a working or a working-service type. A combination of these methods has been chosen so that the number of settlements with a significant (working-)service function is as large as possible. However, there may be settlements where a service function is not indicated but which are nevertheless subject to transit traffic or other influences. Objects or communications located close to the boundaries of settlements may also have an influence.

An example of the sequence of stages in the elementary (upper part) and additional (lower part) classifications for one selected settlement is shown in Figure 2. The Hostivice settlement was classified as working type (210) due to the daily rhythms, and additionally as working-service (code 333). This comprehensive classification makes it possible to classify most settlements, although six units had to be assigned by researchers because they remained in residual categories or because errors were detected in the data. The final types are shown in the map and the basic description of daily rhythms and the numbers of settlements are summarized in Table 1.

### 3. Results

The typology obtained by processing mobile phone location data is a useful tool for understanding contemporary changes in the functional structuration of the Prague Metropolitan Area. The main map shows evidence of the proportions of settlements with different functions within the metropolitan area. Among the nine types of daily rhythms (Table 1), settlements with a residential function (U-shaped daily course of population; Figure 3) clearly dominate, representing almost two thirds of the units. Only 72 units were classified as rural residential areas, the remainder of the residential neighbourhoods and settlements represent mainly urban housing estates and suburban satellite villages around Prague. There is a slightly different daily course on the edge of the PMA, which is influenced considerably by the residential suburbanization that has developed over the past 20 years.
A decrease in the number of people present during working hours is followed by a visible increase from the early afternoon onwards. This phenomenon may indicate a weaker link between the inhabitants of a settlement and Prague or other regional centres, and changing locations of shopping and services, which have moved in part from the city to suburban areas.

Areas whose daily rhythms correspond to a typical working centre (A-shape daily course of population; Figure 4) can be found in larger cities in Central Bohemia (Kladno, Mělník, Slaný), but also in those

Table 1. Types of settlement according to daily rhythms.

| Type                                      | Description of daily rhythm                                      | Number of settlements |
|-------------------------------------------|------------------------------------------------------------------|-----------------------|
| Distinctly residential – metropolitan     | Distinctive decrease in population numbers during common working hours | 313                   |
| Residential – metropolitan                | Decrease in population numbers during common working hours       | 249                   |
| Balanced                                  | Balanced rhythm caused either by mutual contradictory factors or by a low fluctuation of the population during the day | 131                   |
| Service                                   | Regular increase in population levels throughout the morning and (or) the present population is above average in the late afternoon | 60                    |
| Transit traffic                           | Less populated settlements with symmetric significant increases in population during the morning and afternoon traffic peaks | 56                    |
| Working – service                         | Distinctive increase in population levels during working time and population above average in the late afternoon | 51                    |
| Residential – rural                       | Decrease in the number of inhabitants during common working hours with a gradual increase in the afternoon | 36                    |
| Distinctly residential – rural            | Distinctive decrease in the number of inhabitants during common working hours with a gradual increase in the afternoon | 36                    |
| Working                                   | Distinctive increase in population during working hours          | 29                    |
shopping centres on the edge of the capital, and also in more distant places with substantial leisure time activities located in peripheral parts of the PMA. While these areas see a high intensity of predominantly personal commercial services, other settlements of this type can be characterized differently. In some cases, there are larger wholesale warehouses, while others can be characterized as places with intensive tourism and recreation or places offering leisure time activities. The castles of Kokořín and Karlštejn are traditional sites that attract domestic and international tourists. As a result of cartographic visualization, it became apparent and somewhat surprising that there are some clearly visible recreational localities, i.e. settlements with various sport and leisure time activities, swimming pools or horse-riding schools. The working-service daily rhythm provides a transition between working centres and service settlements. In Prague they occupy inner-city locations, good access to the metro, and high populations throughout the day. A specific cluster has developed around the Václav Havel international airport in Ruzyně settlement on the western edge of Prague and its close surroundings with the ‘edge city’ as per the development of strong commercial suburbanization (Nemeškal, 2017; Sýkora & Ouředníček, 2007).

Settlements whose daily rhythm does not have a significant peak can be divided into two categories. The first consists of small towns with a peripheral location, where a balanced daily rhythm can be explained by a well-adjusted functional structure with low fluctuations in population during the day. Settlements in this category are located mostly on the north-western and southern edges of the PMA. The second group consists of municipalities with a relatively strong residential component, but the loss of these people during the day is compensated by various other influences. It is possible to assume a major influence of both transitory traffic and services given that these are often local or regional centres. Differentiation of the individual processes in these settlements would most likely be possible with the use of location data from mobile

Figure 3. Residential daily rhythms.

Figure 4. Working and service daily rhythms.
phones, which would show the structure of individual groups of people in the given area according to their place of occurrence during the day.

Finally, the residential areas of the Prague Metropolitan Area are sporadically penetrated by the radial network of the busiest roads, which in some cases reduces the intensity of the decline in population seen during the day. However, in the case of less populated municipalities without the significant occurrence of services or jobs, this creates a specific transit traffic type of daily rhythm (M-shaped daily flow of population; Figure 5), which is visible in the main map as clusters of violet localities around the D1 highway, in the southern part of the Prague city ring road, and at the entrances of the main highways to the outer city of Prague.

Two additional maps show the highest and the lowest numbers of people captured during the day in our two-hour slots. The strong influence of the residential function of most settlements is shown on the map, with the smallest number of people during the day. Even in this case, there is a certain gradient in residential locations, where the most remote areas show the smallest number of people recorded mostly between 8 and 10 am, which is one to two times lower than for locations closer to Prague. Conversely, most settlements with daily rhythms designated as working and working-service fall to the lowest number of people from midnight to 4 am. Similar patterns can be seen in Prague neighbourhoods with a significant service sector. In the case of the daily maximum, a concentric gradient is again noticeable in residential locations, where the increasing proximity to Prague increases the daily maximum up to midnight. For other settlement types identified with the service function, daytime peak values are usually reached in the morning and at noon. Generally, the two maps create a plastic image of the daily and night-time populations of the metropolitan area. In the day (upper) dark colours depict the population of working centres and services in visible clusters and transportation axes, and light colours are used to identify clearly concentric zones of different types of residential area. In the night (lower) map dark colours indicate residential areas with the peak of population present during the middle of the night, while light colours represent hours around noon for the inner parts of Prague and the largest regional centres.

4. Discussion and conclusions

The typology of daily rhythms and maps of the peak hours during the typical week day introduces a new approach for evaluating the functional structuration of the Prague Metropolitan Area. The advantage of mobile phone data lies in the opportunity it affords us to use these data for a known period (rather than the 10-year period provided by census data). The main disadvantage is the lack of knowledge of the structure of the populations present in different localities, and the purpose of their being there; our idea of function is, of course, a rough generalization. Moreover, the relatively high cost of the data enables the use of a limited dataset covering a typical week day. Although this method has clear limits because the core attributes of the data are fixed and should be accompanied by the evidence of the location of functions to counterbalance the population present within the period of interest, the empirical knowledge of settlements with a dominant function supports the appropriateness of the method used.

While the residential and working functions can be evaluated based on census evidence, the other functions – transport, recreation, leisure and services – can now be visualized for the first time in a comprehensive, synthetic manner. The typology offers a methodological direction regarding how to derive empirically the most important functions in the daily course in different localities. It brings new information about the functional structuration of the Prague Metropolitan Area, the location of the new formation of nodes of transport,
and the new form of leisure time activities in peripheral parts of the PMA. Among the key findings from this research are the levels of similarity and difference between daily rhythms in the metropolitan area. In settlements with a major service or working function, we see no major differences between Prague and other suburban or edge areas, but there is a significant difference in the daily course between metropolitan and residential ‘edge’ neighbourhoods.

In accordance with Manfredini and Dilda (2012) and Novák et al. (2013), we agree that mobile phone data represent an alternative source to other traditional sources such as population censuses and registers and should be used to complement these sources. While mobile phone data can provide an immediate reaction to demands for the analysis of imminent changes within the settlement system, the description of these changes in sufficient spatial detail, and the capture of the daily rhythms of differentiated aspects of mobility, together with census data can add important information on the structure of the population. The mutual triangulation of these data and additional qualitative research in selected case studies (Doležalová & Oufedníček, 2006; Novák & Šykora, 2007; Pospíšilová, 2012) has improved our methods and knowledge of new processes that transform settlement systems.

Although most mobile phone data analyses are mainly used for commercial purposes, and the data are still relatively expensive for academic research, we have described the first experience of using these data for the delimitation of the metropolitan area for planning purposes in Prague (Oufedníček et al., 2018) and have recently also used mobile phone data for the delimitation of metropolitan areas in the whole of the Czech Republic (Oufedníček, Neměškal, Pospíšilová, & Hampl, 2019). The investigation of daily rhythms provides important knowledge on the real use of localities in the city, with all its repeated patterns and changes during the day. Similar analyses were also conducted by the Institute for Planning and Development in Prague (IPD, 2019) who developed the project ‘Location data of mobile operators for urban planning’. Gradually, mobile phone data is beginning to help in the practical tasks of public administration and urban planning in the Czech Republic.

Software

Microsoft Excel 2016 was used for initial data sorting and calculation of variables shown in the map. ESRI ArcGIS 10.6 was used for map processing and final visualization.

Notes

1. T-Mobile is one of the three main mobile operators in the Czech Republic and has the largest number of customers.

2. The extrapolation model is commercially sensitive and is not shared with data users. Our experience with other data providers suggests it is used in all cases.

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