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Mapping different forms of mobility in the Milan urban region

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The increase in urban mobility is one of the key issues of contemporary cities. The need for new types of data and representations useful to describe the new forms of daily urban mobility is widely known. The wider urban scale – named urban region – is the scale at which most of the urban and socio-economical phenomena are visible. Urban growth patterns, settlements and activities distribution, demographics and economics dynamics can be fully understood and interpreted at this macro scale, which is not recognizable on the administrative boundaries. The aim of this paper is to present three approaches to mobility mapping based on different data sources, both traditional and innovative, for the Milan urban region (Northern Italy). Traditional sources for the analysis of daily mobility are Census data or surveys based on interviews to mobile populations. They provide a very partial picture of the mobility practices in urban areas, because they collect only flows for job and study purposes. Innovative sources of data are mobile phone activity data that have been used for building a sequence of mobility maps in a typical working day. The Main Map is therefore composed of two parts: a representation of systematic and non-systematic mobility in the Milan urban region; and a sequence of maps created by using telephone traffic data showing daily mobility patterns. These maps can provide useful information for understanding the recent changes that had occurred in the Milan urban region, but they can also offer a methodological reference for the analysis of mobility in general.

Keywords: mobility mapping; mobile phone data; Milan urban region; Italy; spatial analysis; GIS

1. Introduction

The subject of mobility is a key to interpreting changes in town and cities and in contemporary societies (Amin & Thrift, 2002). Complex mobility practices take place at different temporal and spatial scales and define new relationships between people and territories. Mobility studies include research on migration, tourism, residential mobility and urban daily mobility – the latter is the central interest of this paper. Urban daily mobility refers to all the ways people relate to change of place on a daily basis, which means that it considers the sum of the journeys made, the time it takes to make them, the mode of transport. Daily mobility for working or for studying reasons, defined as systematic mobility, represents less than half of all movements in European cities. Most of the daily trips are therefore non-systematic, i.e. they do not occur regularly or they occur in a manner not directly attributable to the traditional origin – destination model. In fact, there are many more reasons why people move than commuting and studying, i.e. meeting persons, shopping, tourism, visiting friends and relatives, doing personal activities. Individual travel behaviors indeed point out to a more articulated chain of daily mobility. The multi-directional mobility grows and defines an increasingly complex network of relationships (Pucci, 2008). In this general context, it is important to build maps and representations of these phenomena in order to analyze and to interpret spatial and, where available, temporal mobility patterns in cities and regions.

The aim of this paper is to present three approaches to mobility mapping based on different data sources for the Milan urban region (Northern Italy). Milan is an urban region which goes far beyond its administrative boundaries (Figure 1). The core city and the whole urban area have been affected in the last 20 years by changes in their spatial structures and have generated new relationships between the centre and suburbs. At the moment, the urban region

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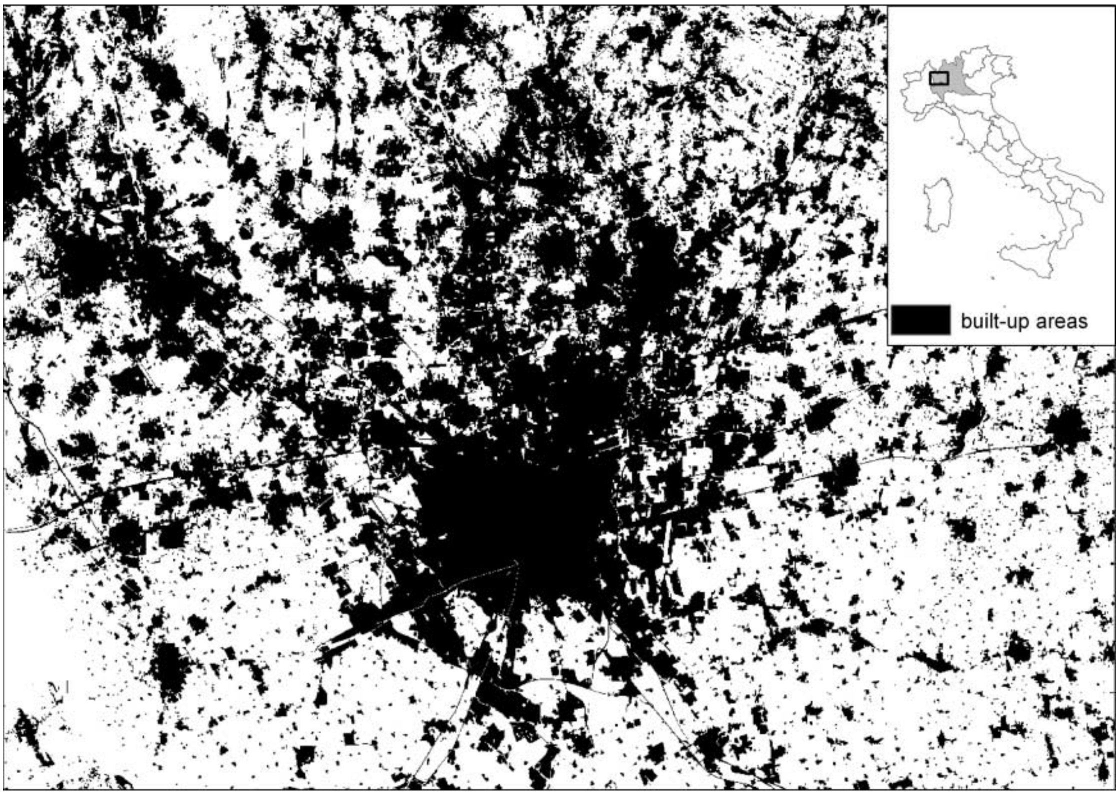

Figure 1. Map of built-up areas in the Milan urban region (2007).
Source: DiAP elaboration of the DUSAF 2.1 data.

of Milan is a densely populated, integrated area where 4,000,000 inhabitants live, where there are 370,000 firms and large flows of people moving daily in this wide area (Balducci, Fedeli, & Pasqui, 2010).

The first approach represents systematic mobility, i.e. fluxes of population moving between municipalities for job reasons and it is based on the Italian Census data.

The second approach refers to mapping of non-systematic mobility, i.e. mobility for purposes others than employment (tourism, shopping, leisure, etc.) and it is based on data derived from a survey, named Indagine O/D 2002 Regione Lombardia (Direzione Generale Infrastrutture e mobilità, 2002).

The third mapping approach relies on the mobile phone network data and is based on a temporal sequence of representations during a working day, highlighting different patterns of urban usages.

The paper analyses and comments the different spatial configurations and morphologies resulting from the maps produced using the three approaches.

2. Methods

2.1 *Systematic mobility mapping*

Work-trips are characterized by a high level of regularity; they constitute a structural element of the relationship between residence and workplace; they are, together with study-trips, collected every 10 years within the Population and Housing Census (Istat – The National Institute for Statistics) (ISTAT, 1991, 2001). The data set used for the current research was therefore extrapolated from the 1991 and 2001 Census data. The complex origin destination matrix adopted by Istat provides indications of the number of individuals who start out from their municipality of residence for work and study purposes and commute either within the municipal boundaries or toward other municipalities. Besides the commuters' destination municipalities, the original data sets reveal transport means used, departure times from home and the relevant home/work-trip lengths. In the present case, since the focus was on the most relevant spatial relationships emerging from commuting, information about means of transport, departure time and trip lengths were not used. Only commuting flows of more than 100 workers are shown by non-oriented lines that connect the municipality centroid of the origin with the municipality centroid

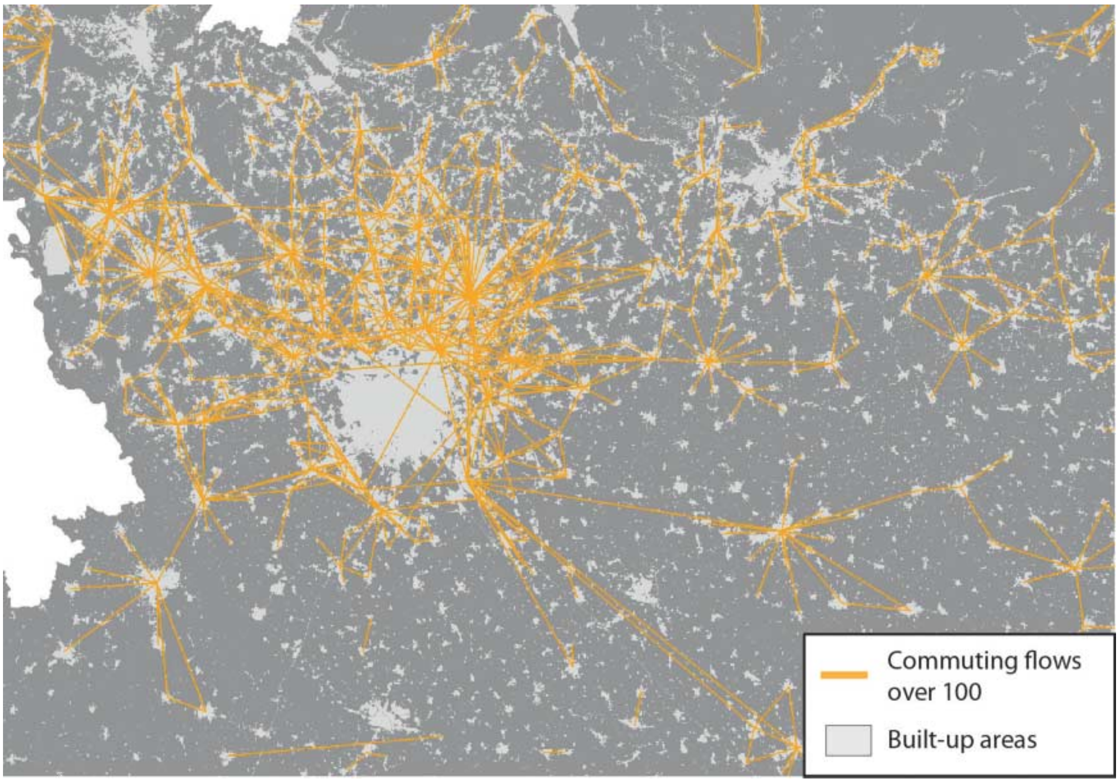

Figure 2. Commuter flows over 100 units with the exception of those to/from provincial capitals in 1991.
Source: DiAP elaboration of the Istat data.

of the destination. In order to facilitate the readability of the map, in and out flows from/to provincial capitals were excluded.

The 1991 representation (Figure 2) shows a significant concentration of spatial relationships in the northern area, named Brianza, where there are several job center attractors and along the main roads (for example, the Sempione Road) in the northern-western side of the region; even the municipalities surrounding Milan, placed along the highway system are significant attractors. The radial lines to Milan show a consistent local flow, in addition to those directed toward Milan, not represented on the maps. The Milan southern area presents fewer relationships and connections than those visible in the northern area, highlighting a more Milan-dependent mobility profile, with the exception of a few situations which are more interconnected. In fact municipalities in the southern side of the region have been affected by huge residential mobility of people who moved from but still working in Milan. Since the direct connections toward the city have not been depicted in the map, it is possible to conclude that the mobility profile of this part of the region is highly dependent on Milan (i.e. many workers travel daily to their job place in Milan).

The 2001 map (Figure 3) shows more complex and intense relationships, especially in the northern-eastern area; there are also visible transverse flows which involve several cities in the north. The comparison between the number of home–job relationships at the two dates (1991 and 2001) shows a rise of flows by about 20%; this is an effect of the increasing complexity of home–workplace relationships caused by the recent trends in economic activities and demographic structure. Among these trends (Balducci et al., 2010):

- *Fragmentation of economic activities*: The crisis in the manufacturing industry went hand in hand with the atomization of production. The average dimension of local units decreased and the number of local units increased. Today there are 370,000 firms in the Milan Province, an increase of 65% compared to 1981.
- *Demographic dynamics*: The city of Milan has lost almost one-third of its population in the last 30 years (480,000 inhabitants). This population relocated first to the Province of Milan, until the beginning of the 1980s and afterwards into a wider area.

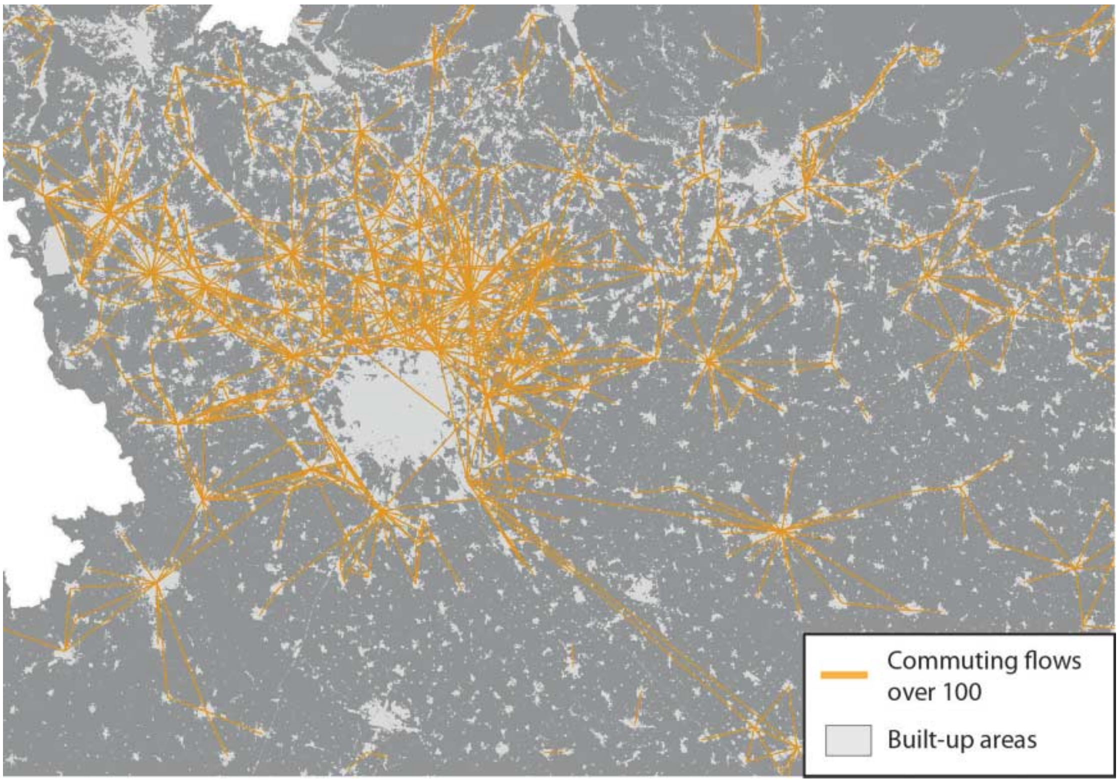

Figure 3. Commuter flows over 100 units with the exception of those to/from provincial capitals in 2001.
Source: DiAP elaboration of the Istat data.

- *Fragmentation of households*: The number of families increases while they become smaller. The average number of family members decreased in the past 15 years from 2.6 to 2.3 (1.9 in Milan).

2.2 *Non-systematic mobility mapping*

The commuter flows describe only a part of the overall urban movements. In fact, in the Lombardy Region job-related travels represent about 29% (excluding returning home) of all daily mobility practices. Today, daily mobility is generated by many other reasons which are becoming increasingly relevant. These non-systematic flows are related to individual habits and are the effects of diversified and complex uses of the Milan urban region. For the intrinsic characteristics of this kind of mobility, it is difficult to measure its dimension and its intensity, in space and in time, and studies which provide this information in Italy do not exist. In 2002, the Lombardy Region interviewed more than 580,000 inhabitants. This survey provides data on all population flows for the whole territory of the Lombardy Region during 24 h of a typical working day. For the first time, it has been possible to analyze the intensity and the duration of all kinds of movements.

The map represents the density of all non-systematic movements, other than study and work, which occur in the Milan urban region on a typical working day (Figure 4).

Despite the fact that information on density of movements has been derived from data at the municipality scale, its representation varies in a continuous way across the urbanized territory. This representation is typically used for visualizing environmental and meteorological phenomena. The map has been built through IDW interpolation – Inverse Distance Weighted – from a point GIS layer of people movement densities (number of trips per square kilometers per day), by using Indagine O/D 2002 Regione Lombardia 2002 data. The result is a new representation of the Milan urban region, a fluid image where the administrative boundaries disappear but where the territorial structure (urbanized areas and main roads) is clearly visible.

The Milan urban region is one where services and activities are distributed across a wide territory and where there is a plurality of places with specific meanings for mobile populations. Milan, Bergamo, Brescia, Como (some provincial capitals of the Lombardy Region) have a high movement density, as well as some municipalities in the dense Northern Milan area; the same process can be observed for municipalities placed along the Sempione Road

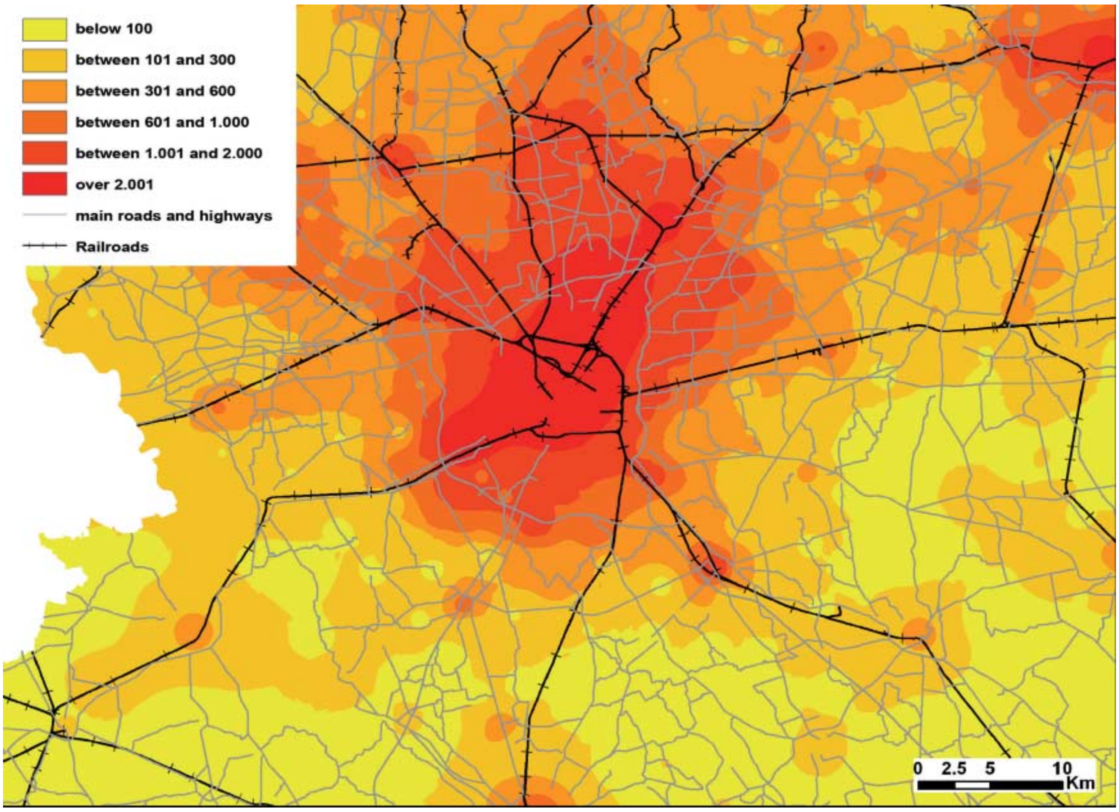

Figure 4. Density of non-systematic mobility: number of trips per square km in 2002.
Source: DiAP elaboration on the OD Regione Lombardia 2002 data.

(in the Northern-Western Milan area). This part of the region is a vast area without evident territorial hierarchies but with high movement density, which has been affected in the recent years by the location of important commercial activities and services. In the Southern Milan urban region, it is possible to observe lower flow densities except in the municipalities surrounding Milan and in the Southern provincial capitals (for example Lodi, Pavia); this area is characterized by the presence of a territorial system with hierarchies, urban polarity (i.e. cities with the presence of urban functions and attractors) and smaller towns, which is easy to recognize.

2.3 *Mobility mapping through mobile phone data*

Contrary to the exploration of Goodchild (2007), where the web 2.0 phenomenon of people providing geographic information voluntarily has been taken into account, it is possible to talk here about un-volunteered geography, where users provide information about the (use of the) territories by simply using a technology that is more and more ubiquitous or, in the words of Weiser (Weiser, 1999), a technology that disappeared woven into the fabric of everyday life: mobile phone data.

Mapping overall mobility in space and in time requires new data sources, able to describe mobility patterns adequately (Manfredini, Tagliolato, & Pucci, 2012). In recent years, a new approach for estimating population movement in cities has emerged through mobile phone communication positioning. As opposed to the more traditional methods of urban surveys, the use of aggregated and anonymous cellular network log files has shown promise for large-scale surveys with notably smaller efforts and costs (Caceres, Wideberg, & Benitez, 2007; Calabrese, Colonna, Lovisolo, Parata, & Ratti, 2011; Gonzalez, Hidalgo, & Barabasi, 2008; Phithakkitnukoon & Ratti, 2011; Reades, Calabrese, Sevtsuk, & Ratti, 2007). Mobile phone users can be considered to be sensors in a widely distributed network, which indirectly provides updates and fine information about the usage of urban spaces. Passive and anonymous monitoring of mobile phone activity can, therefore, be evaluated as a valid alternative or complement to the traditional methods, since it is able to avoid some limitations of traditional surveys (Ahas, Aasa, Silm, & Tiru, 2010). Cellular network information can be easily retrieved in real time, and it is available at a high spatial and temporal resolutions.

In this general context, a methodology for mapping overall mobility through mobile phone data in the Milan urban region has been tested. The sequence of images presented in the map represents, therefore, an experimental mapping of mobility through the data supplied by Telecom Italia, the leading mobile phone company in Italy. The map uses two different types of data: Erlang and Handover. Erlang, namely the average number of concurrent contacts in a time unit, is the measure of the telephone traffic. Erlang is a unit of traffic density in a telecommunications system. It is not, therefore, directly attributable to the number of people using the phone. The data were available at a high spatial (thousands of cells, distributed in the Milan area) and temporal resolution (15 min).

The term Handover, in cellular telecommunications, refers to the process of transferring an ongoing call or data session from one antenna to another. It, therefore, provides information on the movement of mobile phone users through the network. Handover data were available at the same spatial resolution of the Erlang data.

A Handover/Erlang experimental adimensional indicator was built, aimed at measuring users' movements according to the mobile phone traffic data. The indicator has been calculated for the central part of the Milan urban region, an area that comprises more than 2000 antennas (Figure 6). General statistics for the Handover/ Erlang indicator are shown in Figure 5.

According to other works in the literature (Calabrese, di Lorenzo, Liu, & Ratti, 2011; Horanont & Shibasaki, 2009), point data on mobile phone traffic have been interpolated. An IDWmethodology was applied in order to obtain a continuous surface covering the whole territory. The high numbers of antennas within a flat dense urban area and their spatial distribution were two key factors for deciding to use the IDW interpolation method. Moreover, the spatial distribution of the interpolated indicator evidences relationships between the intensity of mobility with the location of relevant activities and infrastructures. It is, therefore, useful to provide information on mobility patterns in the study area. The dimension of the cell (490 m $\times$ 490 m) is instead related to the average distance between the antennas. The idea is that this overall mobility indicator can express the degree of cell mobility or, in other words, the propensity of cell phone users to move in urban spaces.

The sequence of maps presents the trend of the indicator during different hours in a typical working day in September 2009; each image also shows major infrastructures (railways and main roads), main shopping centers, railway stations, the city airport and the trade fair center in order to facilitate the interpretation of the map.

The spatial patterns of the indicator highlight some parts of the region with high mobility; in particular, the center of Milan, the convention center in the northern-western side of the map, the circular infrastructure surrounding the Milan and the Linate airport appears to be characterized by a consistent mobility intensity. These places are important attractors of mobile populations, coming from a vast territory that goes far beyond the administrative boundaries of the city. In particular, the Milan trade fair center in the northern-western side of the region is characterized by a decrease in intensity after 8 pm: indeed, at 12 pm, this specific place does not present significant activity while the surrounding neighborhoods, where residences and infrastructures are located, maintain a high level of mobile phone traffic. At the same hours, huge malls in the Southern Eastern side have a high density of mobility decreasing after 8 pm. The temporal sequence of maps shows, in the Milan city center, a trend of mobility, which is pertinent with the profile of the city; in fact, it is possible to observe how the indicator intensity changes at the different hours of the day. From late morning until afternoon, the value is relatively low. After 5 pm, when people working in city and living outside the city, are starting to move, the mobility increases until 8 pm. Afterwards, mobility decreases. Early in the morning, from 6 am, the mobility intensity is high; that means that most of the people use their phone while moving. This phenomenon is clearly evident along the main infrastructure surrounding Milan. The images show a changing territory, which is characterized by specific temporal patterns of mobility, and puts in evidence spatial ambits with a major propensity toward mobility. Despite the fact that further investigations are needed to make conclusions about the relevance of this information for urban

Hours	Minimum	Maximum	Mean	Median	Standard deviation
06.00 a.m.	0,00	1.200,00	243,98	224,34	126,79
10.00 a.m.	0,00	821,17	177,98	164,44	81,16
02.00 p.m.	0,00	811,27	175,04	162,47	79,84
05.00 p.m.	0,00	854,46	182,61	166,82	85,46
08.00 p.m.	0,00	836,94	178,33	162,29	88,30
12.00 p.m.	0,00	1.000,00	170,62	155,76	98,28

Figure 5. General statistics for the Handover/Erlang indicator.

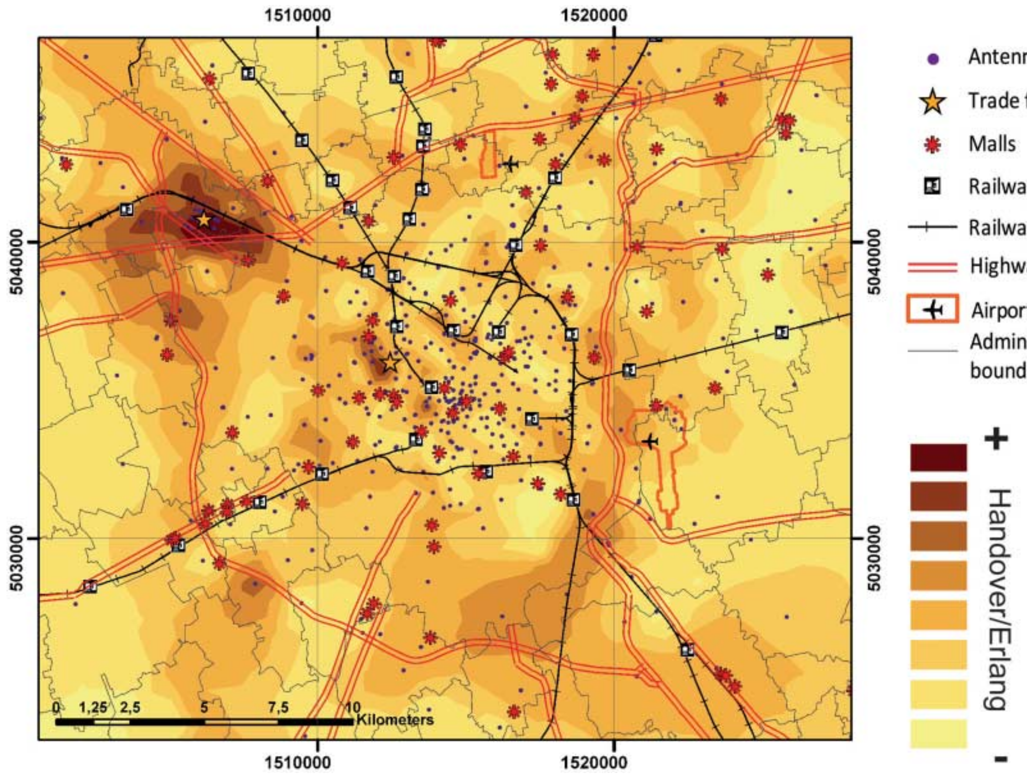

Figure 6. Overall mobility through mobile phone data at 2 pm.
Source: DiAP eleboration on the Telecom data.

analysis and urban planning, it is possible to point out that innovative data sources, such as mobile phone data, can provide new insights into urban mobility, especially the temporal dimension, which is difficult to intercept through traditional methods.

3. Conclusions

The three categories of maps presented here refer to different forms of mobility and make use of different sources of data. They are not mutually exclusive but they can be used in an integrated mode, in order to increase knowledge about urban space usage by mobile populations. The different spatial configurations and morphologies that emerge can also be related to recent demographic and socio-economic processes, which are at the same time causes and consequences of new mobility practices. Residential mobility and fragmentation of economic activities, for example, are strongly related to daily mobility. Analyzing and mapping mobility require an integration between traditional data and new sources of information, closer to users, such as mobile phone data activity or geo-located digital traces, aimed at identifying the complexity and multiplicity of individual behaviors. In other words, it is possible to point out that through new data, we can define who we are by the places we go, overcoming some limitations due to characteristics of traditional sources of data in describing contemporary city mobility. Traditional data, in fact, are frequently not updated and do not take into account the temporal usage of urban space by residents and citizens. This work is an attempt to integrate different approaches to urban mobility mapping in a specific spatial context, the Milan urban region, but it can also offer a methodological reference for the analysis of mobility in general.

Software

All the maps were constructed with ESRI ArcGIS 10. The software was used principally to reproject spatial data from different sources, to create geographic information layers, to interpolate point data through the IDW methodology and to produce thematic maps.

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