Spatial visualization of job inaccessibility to identify transport related social exclusion

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Abstract. An evaluation of the spatial distribution of job accessibility in São Paulo was conducted through the correlation of work trips demand and socioeconomic data of public transport users. It was proposed a gravitational job inaccessibility index (GJI) that identifies higher volumes of home-based work trips with longer durations. Therefore, a characterization of the daily home-based work displacements of low-income population was obtained. The results show that, in general, half of the public transport users spend at least 2h30min daily in commutes. Finally, the GJI spatialization reveals the gravity force of production and attraction of work trips for the low-income population, as well as the city segregation.

1. Introduction

In the recent 21th century, the world witnessed an important milestone: for the first time in history the urban population overcame the rural population. Brazil, in turn, had gone thru this demographic shift 40 years ago, and, now, virtually 85% of the Brazilians live in urban areas [IBGE, 2010]. São Paulo, the main economic pole of Latin America, as well as many others cities in the developing countries [Davis, 2007], faced an extremely accelerated urbanization process: in 120 years it grew from a small city of around 65 thousand inhabitants to a huge urban conglomerate of more than 11,2 million people [IBGE, 2015].

This urban growth was fast and unplanned, mainly from center to peripheries [Carvalho, 2014]. The downtown area became economically developed, with a great variety of jobs and services, whereas the outskirts, the areas farther from the city center, grew progressively with lower-income population and lack of formal economic opportunities, as well as poor infrastructure [Villaça, 2011].

This spatial inequality of opportunities created an enormous transport demand. Today there are around 44 million daily trips with public and private transport in the SPMA [São Paulo metropolitan area]. Historically, in order to answer the increasing transportation demand, governments adopted policies that prioritized the use of private motorized transports instead of public transportation [Carvalho, 2014]. This increase in the use of private transportation is considered to be the main responsible for the urban mobility collapse [Silva Dias, 2014]. According to the São Paulo Origin

Destination (OD) Metro Survey conducted in 2007 [Metrô SP, 2015], the average travel time in the city is 2h42min and for 20% of the population it is higher than 4h.

A central issue in the transport research is the need to quantify and measure accessibilities inequalities [Bocarejo S. e Oviedo H., 2012]. Fortunately the advances on GIS, and Information, Communication and Positioning technologies - such as GPS systems - are nowadays used to monitor buses, increasing the amount of spatial data available, thus there is an enormous potential to use this information to understand the mobility patterns of the cities, as well as the demands of public transports [Yuan *et al*., 2012]. Hence, the GIS became a powerful tool system that can be used for both analyzing urban mobility and evaluating public policy, in order to democratize the public spaces [Salonen *et al*., 2014; Mavoa *et al*., 2012].

This paper uses public transport data to characterize daily home-based work displacements of the low-income population in São Paulo megacity and proposes a gravitational job inaccessibility index (GJI) to identify higher volumes of home-based work trips with longer durations. After this introduction a brief bibliographic review from the main topics is presented, followed by methods description, results discussions and conclusions remarks.

2. Job Accessibility as a mean to analyse social exclusion

Accessibility Definitions

Hansen (1959) defined accessibility as "the potential of opportunities for interaction", in other words, the measurement of the capacity of an individual to access a service, job or location. Thus, the level of accessibility relates closely to the development of the area used in a given location. Around a decade after Hansen's definition on the subject, Ingram (1971) complemented Hansen by defining accessibility as "the degree of interconnection with all other points on the same surface". This degree of interconnection is directly related to the capacity of a certain transport infrastructure to enable the displacement between those areas by overcoming the distance between them in a certain amount of time.

Therefore, accessibility could be understood as a measure in which exchange opportunities can be reached, considering the magnitude and the quality of each activity. This potential spectrum of social and economics interactions is inherent as part of the relative location advantage of a certain area, as well as the displacement conditions of the individual [Hansen, 1959; Ingram, 1971; Handy e Niemeier, 1997; Spiekermann e Wegener, 2006; Mouette, 1998; Spiekermann e Neubauer, 2002; Goto, 2000].

Poverty and Social Exclusion

Although the concepts of poverty and social exclusion are often used together, they are not the same, and it is important to distinguish them in order to understand these concepts in a deeper approach [Sposati, 1998; Church *et al*., 2000].

The definition of poverty is not clear because, besides being a multidimensional phenomenon, it varies according to the social, economic, politic, religious, cultural, and even geographic context. In general, it intimately relates to deprivation of basic needs such as nutrition, health, freedom, dignity and human rights [Sindzingre, 2005]. In order to characterize poverty from a quantitative perspective, it should be considered that numbers related to lack of goods overshadow the "politic core of poverty", that is to say, "*being poor isn't just not to possess, but mainly to be prevented to possess, what makes it more an issue of being than an issue of possessing*" [Demo, 1993].

Thereby, poverty does not exist as an state, but as a situation; situation of lack of opportunities to access services (health and education), urban infrastructure (basic sanitation and drinking water access), culture and justice [Maricato, 2003].

Social exclusion, in turn, consists in the lack of accessibility to jobs and services, being by distance, lack of transportation, social or economic reasons or any other reason [Church *et al*., 2000]. Therefore, social exclusion has, as well, a cultural and ethnic aspect, and is related to discrimination, stigmatization, loss of bonds, to the abandonment and to the fraying of the coexistent relationships [Sposati, 1998].

Kenyon *et al*. (2002) define social exclusion as:

> […] the unique interplay of a number of factors, whose consequence is the denial of access, to an individual or group, to the opportunity to participate in the social and political life of the community, resulting not only in diminished material and non-material quality of life, but also in tempered life chances, choices and reduced citizenship.

Sposati (2000) considers that a utopic referential of social inclusion would be guaranteed with seven fields: autonomy, life quality, human development, equity, citizenship, democracy and happiness.

Therefore, poverty is intimately related to resource, distribution, income and purchase power deprivations, while social exclusion is related to the (lack of) social, participation, coexistent relationships and citizenship.

Accessibility: a tool to tackle poverty and social exclusion

Economically, transport is a vital intermediate good that facilitates the production of a final good, as well as services, and its inefficiency inhibits the cities sustainable growth. Socially, it represents the physical opportunity for the population to access job, health, education and public equipment, required for the society's wellbeing. Furthermore, the lack of accessibility is considered to be the main cause of social exclusion of low-income urban areas [World Bank, 2002].

Kenyon et al. (2002) understand mobility-related exclusion as:

> […] the process by which people are prevented from participating in the economic, political and social life of the community because of reduced accessibility to opportunities, services and social networks, due, in whole or in part, to insufficient mobility in a society and environment built around the assumption of high mobility.

Church *et al*. (2000) discuss a framework that relates social exclusion and transport: physical exclusion, geographical exclusion, exclusion from facilities, economic exclusion, time-based exclusion, fear-based exclusion and space exclusion.

Besides this close relation, few studies relate social exclusion to transport. Most of the researches are limited to identify origins and causes in issues such as job market, housing or social inequality, but rarely take it to the account of transport as being one of the main factors. In general, these studies hardly consider detailed geographical factors, for instance, the relation between residence and desired activities locations, and the required transportation capacity from one to another [Church *et al*., 2000].

Hence, there are few researches that seek specifically to understand the travel needs of residents in areas with high levels of social exclusion, in particular the accessibility guaranteed by available transport infrastructure framework [Church et al., 2000; Bocarejo S. e Oviedo H., 2012]. The present work evaluates the spatial distribution of job accessibility through the correlation of work trips demand and socioeconomic data of public transport users in São Paulo megacity.

3. Methodology

Data

In order to achieve the aforementioned objectives, this study was based on the following data:

- Georeferenced Smart card transactions data of the São Paulo's public transport (2013);
- São Paulo's bus services average travel times calculated from GPS records of public transport (2015);
- Metro OD Survey of São Paulo (2007);
- Demographic Census of 2010 - Brazilian Institute of Statistic and Geography (IBGE);
- Annual Social Information Report of 2012 (RAIS), which contains information regarding workplaces, e.g. wage and job location.

The smartcards data analysis is from August 12th of 2013. It has information of all trips within this day, of all the users of the public transport network of São Paulo, with approximately 12 million transactions of around 4.5 million smart card holders. The smart card share use in São Paulo city is around 96% of all transactions.

In order to select only trips related to job activity, the focus of present paper, trips were filtered considering the time interval from consecutive transactions. Two trips with a time difference superior than 7h were selected as job related. The 7h parameter, called here by permanence time, equivalent to a work day period, is similar to the methodology presented by Munizaga *et al*. (2014). In addition, it was assumed the "destiny transaction" as the location where the transaction immediately after the longer permanence time occurred; and the "origin transaction" as the first of the day made by certain user. According to the hypothetic trip illustration showed below (Figure 1):

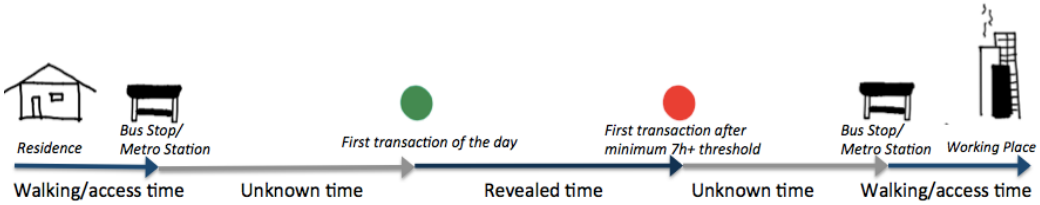


Figure 1: Schematic resume of the concepts

Where:

- Revealed time: Time difference between the transaction that occurred before the time interval of 7h+ hours and the transaction that occurred after this time period.
- Walking/access time: Time needed for the user to access the bus stop or metro station. This segment of the trip is unknown in smart card transaction records, and thus the walking distance is from the centroid of its related traffic zone to the bus stop will be used.
- Unknown time: As some few users don't tap immediately after boarding the bus, there is an unknown time gap between the boarding in the bus stop and the real observed transaction from smart card database. The authors are conducting an ongoing research to better study this issue in order to reduce this trip origin uncertainty.

From the GTFS data processed it was developed a network at a GIS environment, with the real velocity of the public transport system in São Paulo. From this network, a time matrix of the trips for each OD pair was calculated, for real travel time values of the average business day at 7 am.

4. Methods

In a GIS environment a spatial analysis was made in order to relate jobs supply georeferenced data, smart card inferred origin and destination locations and socio demographic data from census, as described in figure 2.

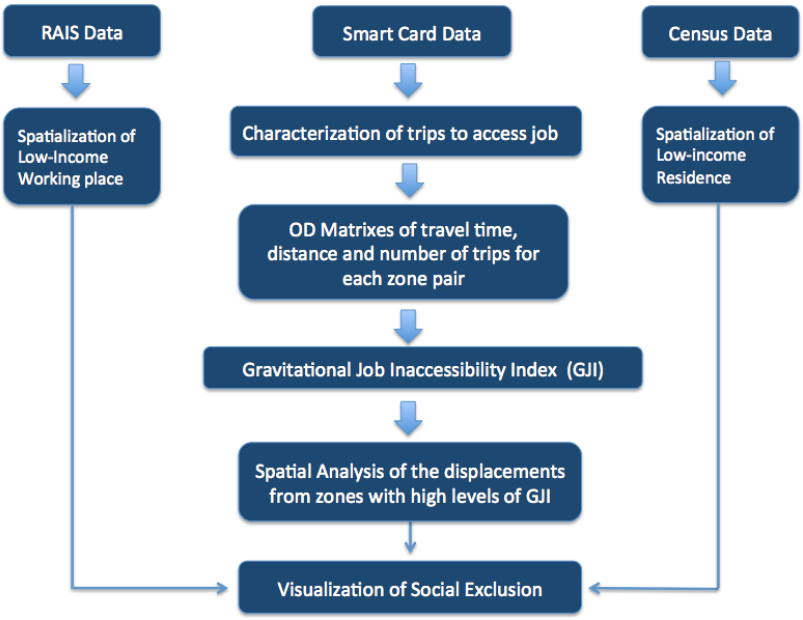


Figure 2: Proposed methods.

Gravitational job inaccessibility index (GJI)

A main issue in the transport research is the development of accessibility analytic tools that can quantify and identify access inequalities, evaluate existing projects and likewise prioritize needs [Bocarejo S. e Oviedo H., 2012].

Therefore, the objective of the gravitational job inaccessibility index (GJI), proposed in this paper, is to identify zones with high production of long trips. Thereby, this index is in directly proportional to the trip duration and to the number of trips produced in certain zones, and inversely proportional to the trip speed:

$$I_i^n = \frac{b_i}{B}\sum_{j=1}^{n}\frac{t_{ij}}{v_{ij}} = \frac{b_i}{B}\sum_{j=1}^{n}\frac{t_{ij}^2}{d_{ij}}$$

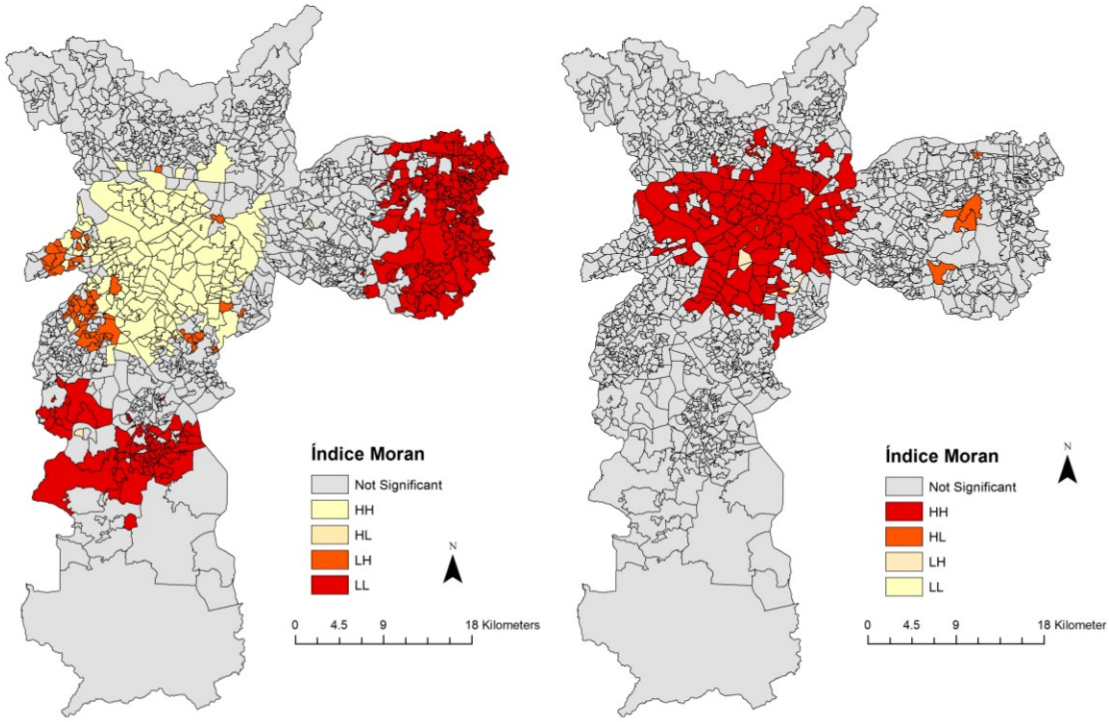
Where: n= number of OD zones; i= zone of trip production; j= zone of trip destination; v= speed; b= number of smart card transaction for this OD pair; t= trip duration between zone centroids; d= length between centroids; e B= total number of smart card transactions.

5. Results and Analyses

Spatial analysis of low-income population and its working places

A Moran spatial correlation and two Local Indicator of Spatial Association (LISA) maps were prepared from the average income data in São Paulo (figure 3a) and the workplaces with salary till two minimum wages (figure 3b). The Moran index obtained for the average income was 0,615 and for the working places were 0,620, indicating in both cases a positive spatial correlation.

In the average income Lisa map (figure 3a) it is possible to observe that there are low-income clusters in the east and south of São Paulo, as well as a high-income cluster in the central areas. In contrast, the Lisa map of working places with salary under two minimum wages (figure 3b) show a huge cluster in the central area of the city and virtually no significant clustering in the zones of low income residences.



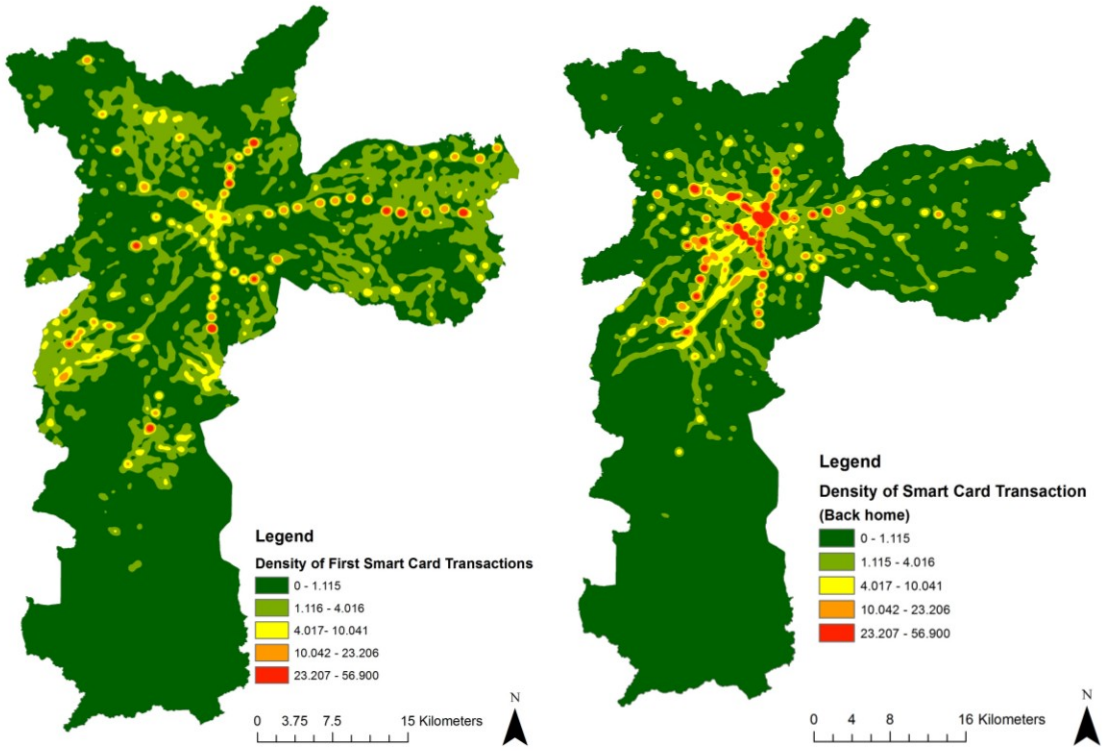
(a) **(b)**

Figure 3: Local Indicator Spatial Association - LISA map [(a) Average income in São Paulo/ (b) Working places with salaries under two minimum wages].

Spatial analysis of smart card transaction records

The Kernel estimator maps showed in figure 4 represents the spatial distributions of all the first smart card transactions (4a) and the first return home transaction (4b) made by

around 1.8 million public transport users whose trips are assumed as work trips (those trips with permanence time higher than 7h between two single transactions). It is possible to notice that there are some relevant aspects of this spatial distribution. Firstly, the high density of first transaction in metro and train stations evidences the users' behavior of tapping the smart card only near alighting for the first transfer, fact that brings the origin uncertainty discussed previously. Secondly, the high density of transactions in terminals of the metro and train lines (figure 4a) demonstrates the gravity force that the rail transport network has over the areas with low accessibility indexes, as the São Paulo public transport network has a trunk-feeder system in those areas, concentrating bus lines to metro and rail network stations. Thirdly, it is also noticed (figure 4b) the high density of first transaction to residency (return) in the center of the city, evidencing the monocentric structure of São Paulo.



(a) (b)

Figure 4: Kernel estimator of the first transaction (a) and the first return home transaction (b)

Spatial analysis of the gravitational job inaccessibility index (GJI)

The thematic map of figure 5 was generated from the gravitational job inaccessibility index (GJI). It is clear that, in general, central zones have a lower GJI than the peripheral, what is consistent with the respective transport infrastructure and workplaces characteristics. In addition, it is noticeable that virtually all the zones with high GJI are also outliers of low-income represented in the map of figure 5. Another aspect that is worth discussing is the influence of São Paulo metropolitan area (SPMA). Thereby many users start their journey in a neighboring city, which is in some cases even farther from the job opportunities of the central areas. That is in part

responsible for the spatial pattern of peripheral zones with high GJI showed in figure 5. Far zones with low GJI indicate that the number of users is relatively lower.

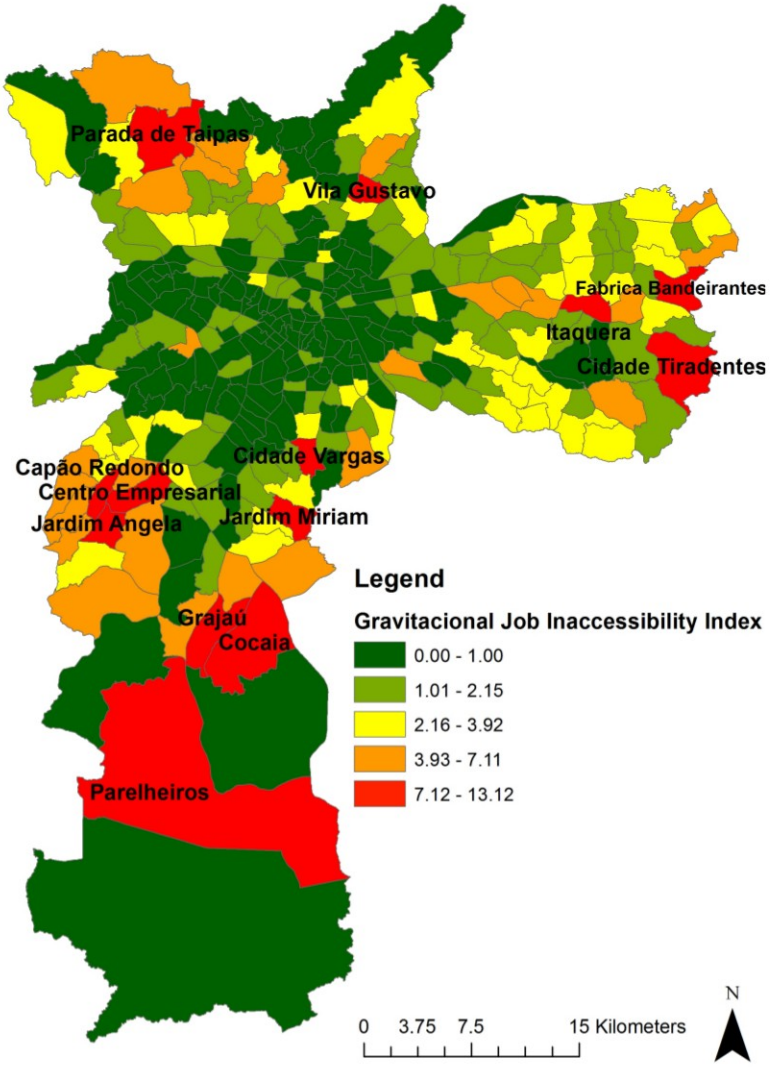
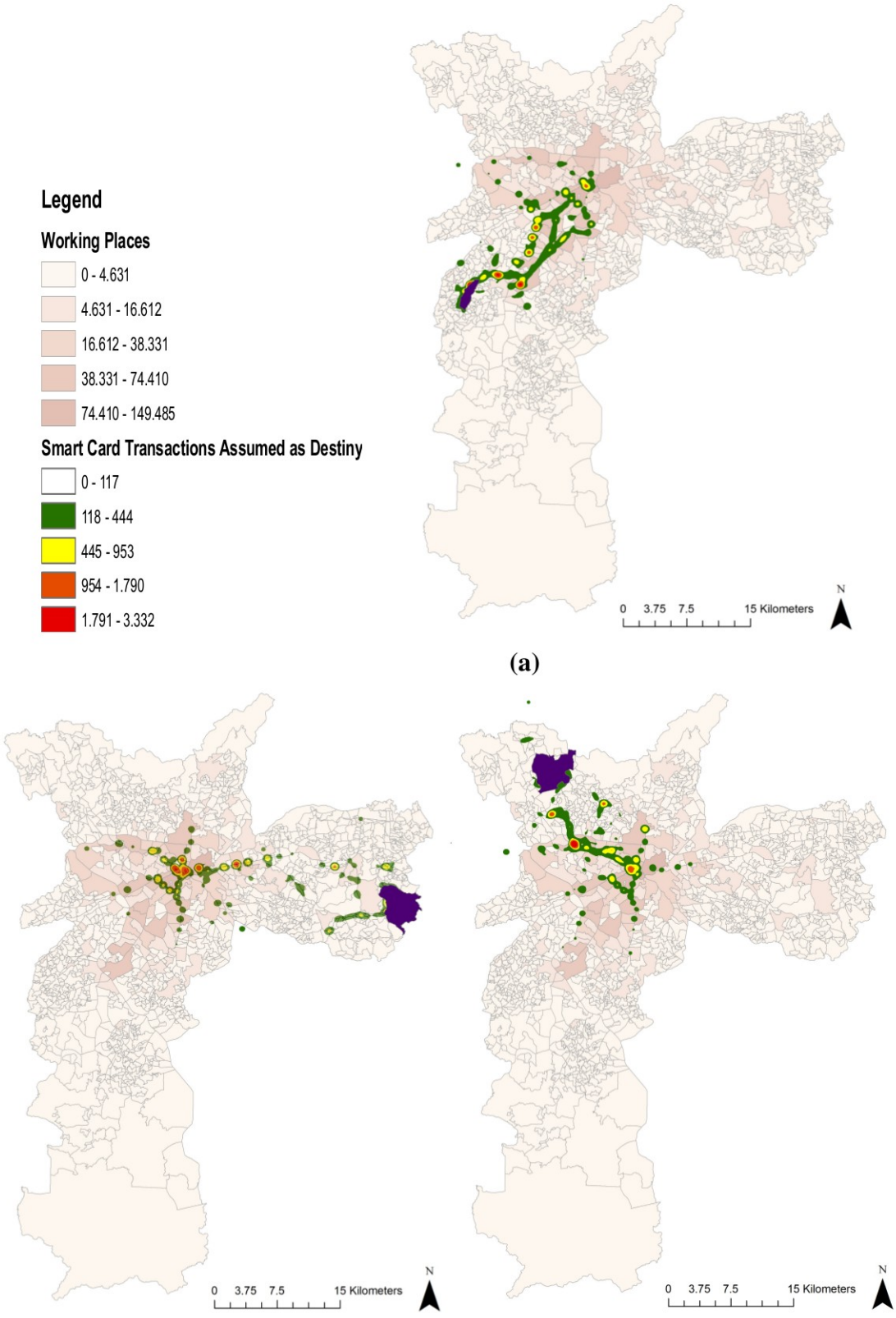


Figure 5: Gravitational job inaccessibility index map.

Following the maps presented in figure 6 illustrates the gravity forces that the working places exert over the zones with high GJI, which are, in general, lacking job opportunities. It is also interesting to observe the magnitude of the attraction force that the central area exerts over even really distant zones. In addition, it is noticeable that the trip destination of the south areas users are more distributed to multiple poles of attraction in the south region, whereas in the east the displacements are lengthier and the main destination areas are more concentrated in the downtown region of the city, and highly concentrated around metro stations (figure 4).


Legend
Working Places
0 - 4.631
4.631 - 16.612
16.612 - 38.331
38.331 - 74.410
74.410 - 149.485
Smart Card Transactions Assumed as Destiny
0 - 117
118 - 444
445 - 953
954 - 1.790
1.791 - 3.332
0 3.75 7.5 15 Kilometers
N
(a)
0 3.75 7.5 15 Kilometers
N
(b)
0 3.75 7.5 15 Kilometers
N
(c)

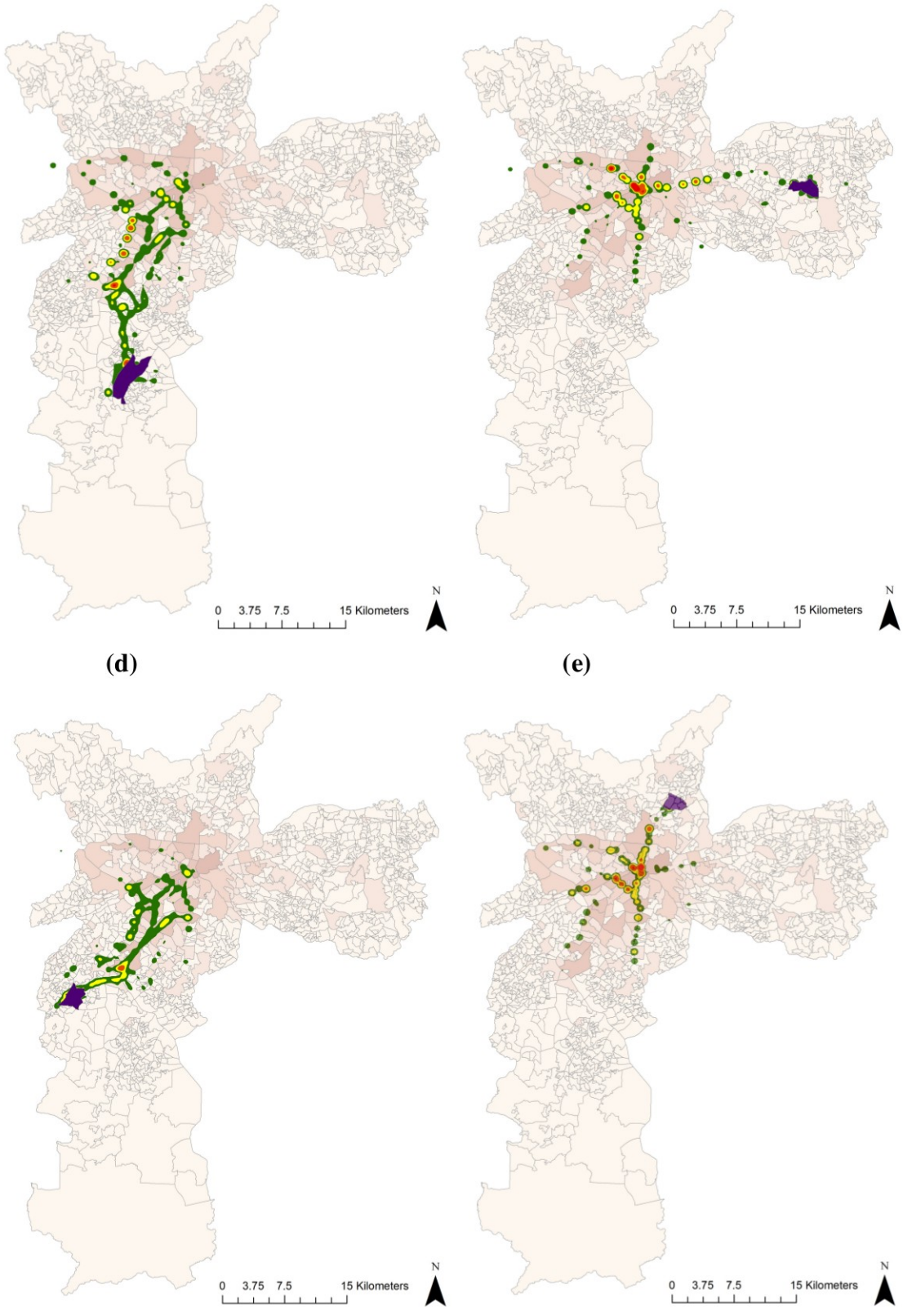


Figure 6: Smart Card Transactions Assumed as Destiny from high GJI zones

[(a) Capão Redondo / (b) Cidade Tiradentes/ (c) Parada de Taipas / (d) Grajaú / (e) Itaquera / (f) Jardim Ângela / (g) Vila Gustavo]

This patterns of lengthier displacement are in part responsable for the long duration of the trips to access the jobs. This study also showes that, in general, people spend, on average, 1h to access their jobs, and half of the public transport users spend at least 2h30min daily in commutes.

6. Conclusions

An evaluation of the spatial distribution of job accessibility in São Paulo was conducted through the correlation of home-based work trips demand and socioeconomic data of public transport users. It was proposed a gravitational job inaccessibility index (GJI) that identifies higher volumes of home-based work trips with longer durations. Origin-destination pairs of low-income population work trips were identified, and the proposed index described the job accessibility disparity between regions in the city.

A characterization of the daily home-based work displacements of this group of low-income population was obtained. The results helped to understand the gravity forces of production and attraction of work trips for the low-income population. In addition, the GJI spatialization clearly shows the consequences of social segregation, since the areas with high levels of inaccessibility are mainly peripheral areas with low-income residents and lack of job opportunities. Also, the study shows that, in general, people spend, on average, 1h to access their jobs, and half of the public transport users spend at least 2h30min daily in displacements.

The exploratory spatial analysis enabled the comprehension of the spatial distribution of the low-income population, likewise the city workplaces, representing respective potential poles of origin and destination. It was possible to conclude that São Paulo has in fact a high level of mono-centrality, characteristic that was also appointed by works of Ramos (2014). Bessa, Colli and Paula (2011) showed that not only the central area represents only 7% of the city, it also concentrates more than 2/3 of the workplaces and services.

Furthermore, in consistence with Comin (2011), this paper showed the spatial segregation of the peripheral areas, where in general reside the low-income population. In conclusion, this paper enables to visualize clearly the negative influence that the land use inequality represents on public transport demands.

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