METHODOLOGICAL PROPOSAL FOR IDENTIFICATION DATA COLLECTION POINTS ON CARGO FLOWS: A CONTRIBUTION TO MATRIX FREIGHT FLOW MODELS

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Abstract

The aim of this paper is to propose a method to support the identification of data collection points on cargo flows, as a subsidy for the application of the synthetic origin-destination (O/D) modeling matrix. This method is based on the use of spatial analysis techniques to: locate and georeference Traffic Generator Poles (TGPs) in the highly critical area of urban cargo transportation; identify and calculate the density of areas of greater dispersion and TGP concentration; identify route intersections that give access to areas with the highest TGP concentration and to critical areas for the urban cargo transportation. The authors identified twenty-three potential cargo flow data collection points in Teresina, Piauí, Brazil. This method brings an innovative approach allowing for better delineation of data collection points and an increase in the quality and speed of data collection in the field research related to urban freight flows.

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1. Introduction

Transportation Planning is conducted in order to adapt the transportation needs of a region to that region's structural characteristics. Through transport systems analysis regarding current and anticipated demand, the authors evaluated the need to modify and/or deploy supply elements within the project timeline (Bruton, 1979). For this performance analysis, it is essential that technicians and decision makers have information about the transportation patterns of people and cargo, defined by Origin/Destination (O/D) matrices. Due to its peculiarities, cargo planning is far less advanced when compared to planning conducted for the transportation of people, and some obstacles hinder the application of the classical transportation model (Ortúzar and Willumsen, 2011). An alternative to overcome these obstacles is the application of the synthetic O/D modeling matrix (Bertoncini and Kawamoto, 2013).

The synthetic O/D modeling matrix allows us to estimate O/D flows exchanged between traffic zones or regions of interest, according to the criteria to be analyzed (Willumsen, 1981). In order for it to function, data and information on the urban form and the transport network are essential. Most of the time, data collection on cargo flows throughout all transport network links is not feasible. If the selection of these points is performed in an arbitrary manner, there is a risk of obtaining a sample of cargo flows with linear dependence, that is, with redundant information. Thus, in order to recreate the areas of interest for the modeling, a proper selection of these points is key to ensuring the applicability of the model and depicting cargo distribution in the area of interest.

This article presents results from the first stage of using synthetic the O/D modeling matrix of cargo in the city of Teresina, Piauí, Brazil. Its main objective is to propose a spatial analysis method to aid in the identification of data collection points on cargo flows in urban areas. In addition, our specific objectives are presented in order as follows: discuss the role of synthetic modeling as an indirect method of obtaining O/D matrices and the importance of data for such a modeling strategy; in section 2, present the methodological proposal for identification of data collection points in cargo flows; in section 3, detail the methodological proposal's application and stimulate discussion about the results in Teresina, in sections 4, 5 and 6; and present conclusions on the proposed method and indicate research questions to be addressed in future developments, in section 7.

2. The role of synthetic O/D matrix modeling

Since the 1970s, several transportation problems in big cities have worsened, leading to widening realization that Transportation Planning has probably failed (Rodrigue et al, 2006). Not infrequently, this problem may occur as a result of the complexity and high costs inherent in making the classical model function, especially in the context of urban cargo. Compared to this model, the synthetic O/D matrix modeling is a simpler and viable alternative and as a result, it has received attention from the scientific community in the last forty years (Bertoncini and Kawamoto, 2013).

The traditional model of transportation, composed of four distinct yet interrelated steps (generation, distribution, modal choice, and allocation), lists information on elements of the population, activity, and travel systems. These links aim to explain the total number of produced and attracted trips within the unit under study. From this total of trips, interchanged trips are distributed throughout the construction of the O/D matrix. Adjustments are necessary, depending on the modeled phenomenon and the modeling goals. For example, transforming the number of trips taken per person in amount of trips per vehicle (Fig. 1).

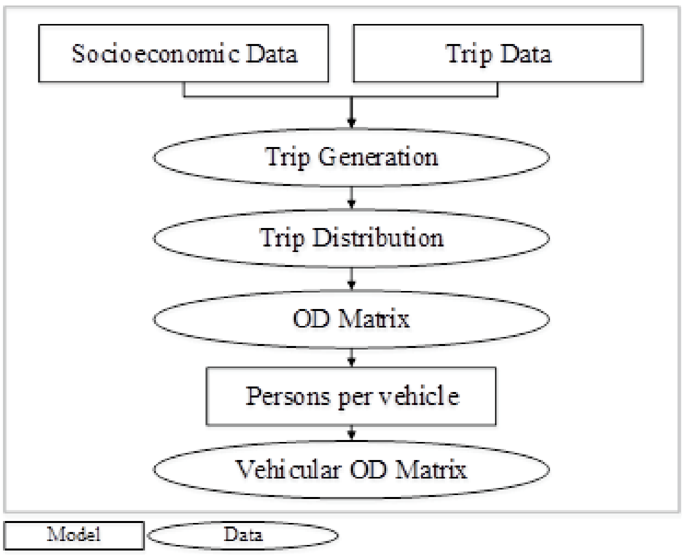

Fig. 1: Modeling structure of the demand for passenger transportation

There are at least three approaches for Transportation Planning related to cargo: 1) the microeconomic approach: considers that the demand for cargo transportation is a commodity, necessary to achieve an objective; 2) spatial iteration model: aggregate in nature, it states that goods and consumption sites are distributed across a network, in which the high production sites serve the high consumption sites. The gravity model is part of this approach; and 3) macroeconomic approach: relations between economic sectors are analyzed, and most of the investments derive from the input-output model. In this case, transportation is accepted as a economic sector, and it is possible to assess the relationship between transportation and other sectors, and transform these consequences into flows of goods. The higher the number of sectors, the higher the accuracy of the model.

However, this aspect is far from Transportation Planning in regards to people. Ortúzar and Willumsen (2011) listed a number of possible explanations for this, which can be attributed to two obstacles. First, cargo transportation has particularities that hinder the functionality of the classic transport model. Demand for cargo transportation is derived from people's desires for products, involves the movement of goods, products, orders, etc.; that is, the motivation is essentially economic. An additional challenge to develop traditional techniques and analysis is the need to make a model to explain such desires and then relate them to cargo transportation. Second, urban traffic caused by private vehicles has generated much concern on the part of authorities, and therefore received the most research funds. There is a methodological flaw in dissociating the transportation of people and the transportation of cargo, even though both share the same transport network and consequently, contribute to the generation of traffic. Obtaining O/D matrices for cargo transportation using traditional techniques requires large investments of financial and human resources, which are most often unavailable. Of course, the transportation of passengers, due to the amount itself, ends up having a higher "weight", but disregarding cargo transportation as often occurs, will at the very least lead to misleading results.

A strategy that could work around these two obstacles is the use of modeling based on indirect data, such as synthetic O/D matrix modeling. This method does not require extensive research that would come at a high financial and labor cost. Moreover, it would not be necessary to make a link with individuals' desires for products, because it is assumed that this might already be reflected in the data on traffic volume. It is believed that this type of modeling could play a significant role in the urban context, as a result of the reduced amount of data, shortening the procedure (Holguin-Veras et al, 2012). Among the various possibilities for applying this type of model, the following can be highlighted: predict the resulting traffic flow if there are changes in the transportation network; generate matrices corresponding to fragmented periods of time; contribute to the process of calibration/validation of the traditional model of demand for transportation; and predict the demand for transportation for distribution of goods in urban centers.

Among the indirect data, traffic counts are notoriously the main sources used to obtain interzonal flows. However, usually the number of unknowns (flow between OD pairs) exceeds the number of traffic counts, making the problem underspecified. This requires the use of analytical devices that allow us to obtain the most likely OD matrix, in the case of reconstruction techniques based on optimization; or estimation of parameters representing the distribution of OD flows in the case of estimation techniques based on statistical methods (Pitombeira et al., 2011). Although they are no substitutes for real data, which could produce very realistic estimates of O/D matrices, indirect methods could play a significant role in increasing efforts toward demand modeling of cargo transportation, a field that still lacks resources (Cascetta, 2009; Ortúzar and Willumsen, 2011).

The problem of estimating the O/D matrix from a synthetic model basically comes from a technique that is the opposite of the process of allocation of traffic flow in a transport network. According to Willumsen (1981), the key to solve the problem is to find the solution to the equation (1). The volume counted in one arc in a transportation network (Vobs) is obtained by the sum of all trips between traffic zones using the link, in other words the sum of the product of the trip parcels using the (pij) and the amount of trips between ij (Tij). In this equation, the variables correspond to the actual values for the system and the studied time interval.

$$V_{obs}^{a} = \sum_{ij} p_{ij}^{a} \cdot T_{ij} \tag{1.1}$$

The problems of obtaining the O/D matrix and the traffic assignment - essential for modeling the relationship between supply and demand in transport networks - are closely connected (one's input is another's output), and can be combined into a single math formulation with a hierarchical solution structure on two levels, as initially proposed by Robillard (1975) and Nguyen (1977) for road networks (Fig. 2). In the case of urban cargo transportation, if the proposal is based on the goods, it is expected that decisions are made without considering traffic, whereas if the purpose is to model the number of vehicles for cargo transportation between a certain O/D, it is believed that the traffic effects should be taken into account.

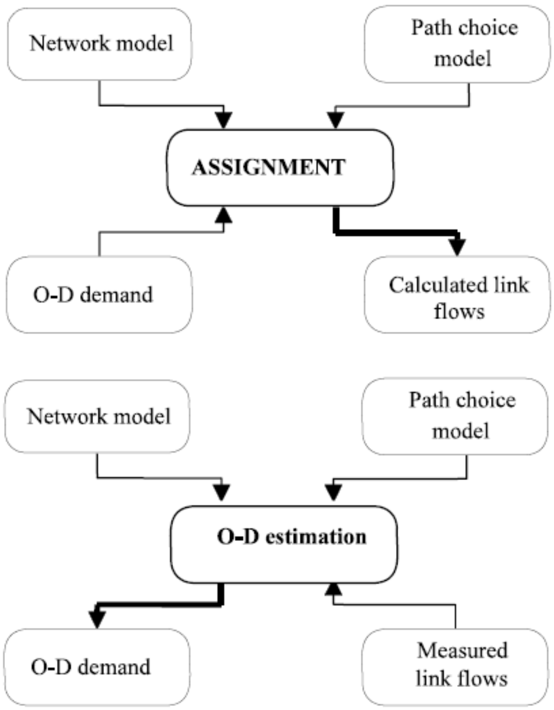

Fig. 2: Relationship between traffic allocation and estimation of synthetic O-D matrix (Adapted from Cascetta, 2009)

In an attempt to bypass the issue of inconclusivity (or lack of specification in the model), reconstruction techniques have been based on optimization arrangements, in particular the principle of entropy maximization and information minimization (Van Zuylen and Willumsen, 1980). The objective is to determine the most likely O/D matrix among the possible solutions from the minimization of a function of errors in the estimation of demand, or in replicating the observed volume - subject to a number of flow restrictions. Or, as stated by Cascetta (1984), finding the O/D matrix that minimizes a measure of distance, "entropic" or Euclidean, compared to a target or seed matrix (generated from a behavioral model of demand or predicted based on an earlier period) subject to the restriction that, once allocated in the network, the matrix represents shipments observed in the field.

Following this segment, Zargari and Hamedani (2006) proposed a reconstruction model of the synthetic O/D matrix, considering a cargo transportation network in Iran. The proposed research considers the optimization model developed by Van Zuylen and Willumsen (1980), and the choice of routes would be defined by a method of discrete choice, based on the Logit Multinomial model. According to the proposal, a prior matrix would be obtained by crossing origin and destination information contained in the bills of lading issued by tax authorities; and the volumes would come from counting the number of trucks traveling on the analyzed routes. According to this proposal, the volumes considered are not random variables and the results cannot be replicated. This conclusion is due to the entropy maximization model, which does not allow inference analysis.

This type of technique presents a large potential to model cargo flows, especially in urban areas. The inconvenience of the methodology presented by Zargari and Hamedani (2006) is the need for a previous matrix, considering that crossing of bills of lading would already result in an O/D matrix, also because the method proposed by them does not allow for expansion and inferences in future scenarios. Thus, there are techniques that do not require the use of this information, or if available, enable a better analysis, guaranteeing that estimates can be obtained for future situations. It is also possible to add another data type which is easily observed, for example, traffic counts at intersections. With this information, it is believed to be possible to solve a major problem for planners and transportation managers, which is understanding the movement of cargo in urban areas.

3. Method

This section presents the research method used for this article, consisting of three steps.

The first step is the presentation of the study area, according to literature socio-demographic information, general characteristics of urban transportation, and problems related to cargo accessibility in Teresina.

The second phase deals with the identification of Traffic Generated Poles (TGPs) in places with large concentrations of problems related to the transportation of cargo. The research focus were trip points both generation and attraction, located within a commercial area of traditional retail. Other flows, e.g., internet purchasing deliveries are few representative for this area and they will be estimated and included in future phases of modeling process.

Different vector files, data sources, and matrix maps were generated to map three types of spatial information: the Teresina road network; areas and routes of critical accessibility in Teresina; and critical accessibility routes in Teresina, according to some of the stakeholders involved in urban cargo transportation. From these sources, different base maps were generated and combined with the use of the natural breaks technique. According to Ferreira (2013), this technique aims to eliminate the researcher's subjective interference, whether in choosing the width of each class or the number of observation units included in each class. In this study, the widths of the classes were located in the existing natural breaks in the series of original data, identified by placing the “criticality index” variable values in ascending order in a frequency value diagram. The number of classes and the size of intervals were defined after the construction of the model. As a result, an overlay of criticality classes for the urban cargo transportation was generated. An area with high criticality was highlighted, and points of location of three TGPs types were georeferenced (gas stations, commercial establishments, and food services) with Google Earth.

In the third step, points were selected for collecting data on cargo flows in the highlighted area. The georeferenced TGP points were exported from Google Earth and imported into ArcMap 10.2. In this software, the density of TGP points was calculated in order to identify areas of major concentration and dispersion of these phenomena in the space. The Kernel Density estimator was used, which counts points or lines within a region of influence, weighting them based on the distance of each, as shown in Fig. 3 (Câmara and Carvalho, 2001).

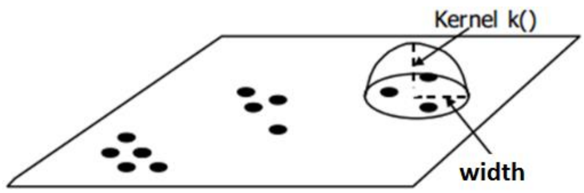

Fig. 3: Example of the Kernel estimator's operation (Câmara e Carvalho, 2001)

Through the Kernel Density estimator, the area with very high criticality for urban cargo transportation in Teresina was classified into two major groups: 1) areas with higher concentration of TGPs; and 2) areas with higher dispersion of TGPs. Then, the density of TGPs was calculated. To achieve this density, different radius of coverage were tested for the interpolation of points and density calculation (radius ranging from 50 to 150 meters). Also were tested different sorters of intervals class in order to obtain best results (Fig. 4).

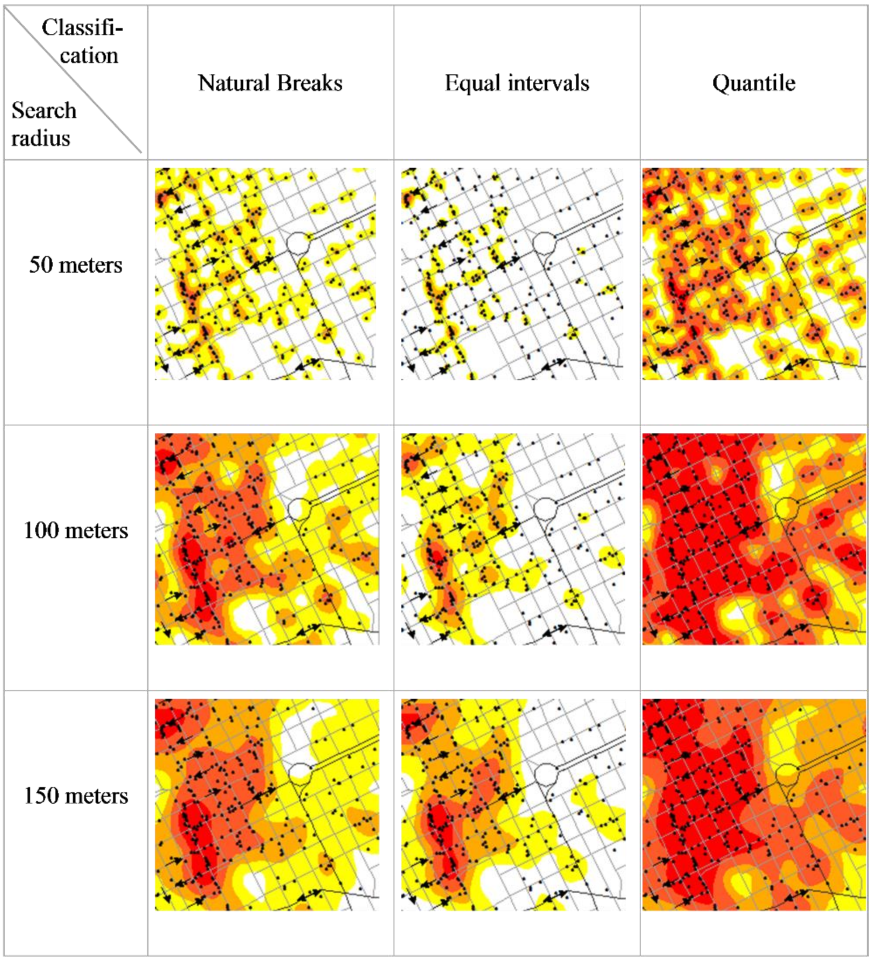

Fig. 4: Test of interpolation points with different class interval and radius.

The best results were obtained with the 100m radius and the classifier of natural breaks intervals, obtaining the following density classes: very low (from 0 to 92.5 points/km2), low (92.6 to 246.8 points/km2), medium (from 246.9 to 462.8 points/km2) high (462.9 to 814.6 points/km2), very high (814.7 to 1573.5 points/km2).

4. Presentation of the study area

Teresina is an important regional center of services, industry, and trade in the Brazilian Northeast. It has a territorial unit area of 1 391 981 km2. Its privileged location within Piauí gives it a strategic advantage linking the other northeastern capitals with the North of Brazil (Fig. 5). Its population was estimated at 840 600 people in 2014 (IBGE, 2014.b).

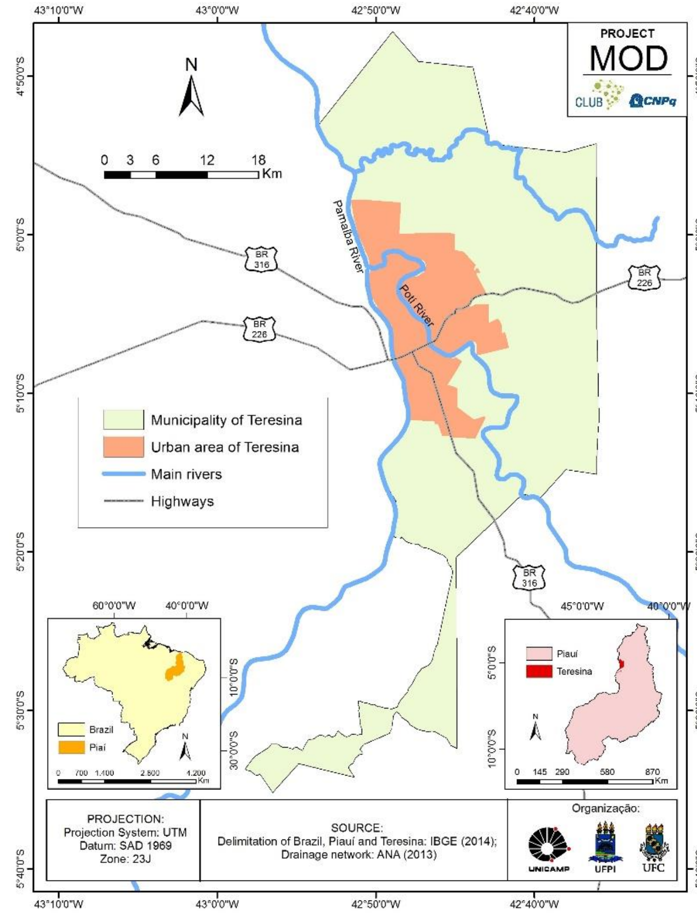

Fig. 5: Map with the location of the city of Teresina, Piauí, Brazil (Messias et al., 2015)

The economy of Teresina is concentrated in services, followed by industry, and has little economic participation in agriculture (PNDUD, 2013). In the first decade of the 21st century, Teresina and other Brazilian municipalities experienced production and consumption changes attributed mainly to three government actions focused on social inclusion, which mainly benefited the poorest regions: direct income transfer policies, increase in the real minimum wage and the extension of credit (Medeiros, 2014). As a result of these government actions, in 2010 its Human Development Index - HDI was 0.751, higher than the numbers observed in 1991 and 2000 (0.509 and 0.620, respectively). In this municipality, an increase in income and a change in people's consumption habits was observed, which resulted in the growth of the vehicle fleet and cargo transportation, resulting in worsened transport-related problems, including increased levels of air pollution, traffic, and accidents.

Teresina grew in an unplanned fashion, resulting in very dense population areas in regions lacking adequate infrastructure and public services, including urban transportation. This scenario is worsened by the lack of integrated planning taking into account all activities that relate to transportation, especially regarding the dynamics of urban transportation of cargo. As a result, there are several areas and routes in Teresina where the accessibility is considered critical for the urban transportation of people and cargo (CLUB, 2013).

5. Mapping critical areas and identification of TGPS

In the second stage of applying this method, Messias et al (2015) built a spatial database on the road network and land use in Teresina, highlighting the concentration of TGPs by districts. Spatial data was collected from research agencies and the internet (Apontador, 2014; DNIT, 2014; IBGE, 2014.a); and the density of sites with accessibility problems was identified from the point of view of the stakeholders involved in the urban cargo transportation by searching the literature, (Prefeitura de Teresina, 2008; CLUB, 2013) and from an interview (Bezerra, 2014). By combining this spatial information with the method of natural breaks interval classification, the map of criticality for urban cargo transportation in Teresina was obtained (Fig. 6.a).

The center of Teresina and districts such as Piçarra and Vermelha have very high criticality for the urban cargo transportation, with high street density, critical points, as well as high TGP density. The areas of high criticality are also of great importance, since malls, bridges causing traffic bottlenecks, and the airport are located there. As we move away from the city center, there are lower rates of criticality and the peripheral areas have very low criticality. In the area with very high criticality for urban cargo transportation in Teresina, 688 TGPs were identified and georeferenced with the help of Google Earth; among these, 170 were Food Services; 492, Trade in Goods; and 26 Fuel Stations (Fig. 6.b). In this area, there are a total of 413 route intersections.

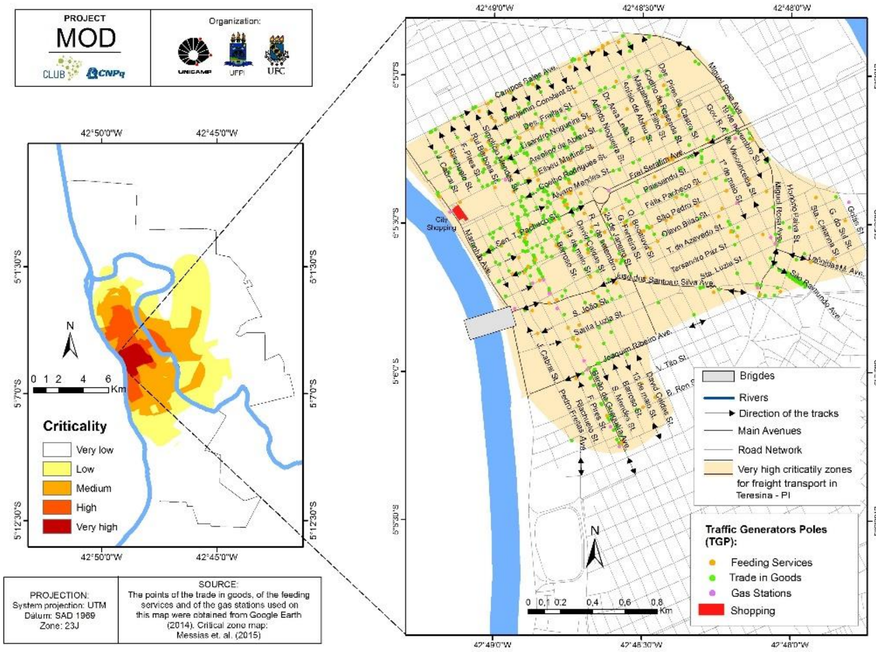

Fig. 6: Criticality map for urban cargo transportation (a) (Messias et al, 2015); TGPs identified in the high criticality area for the urban cargo transportation in Teresina (b)

The map of Figure 6.a shows the various levels of criticality for urban cargo transportation obtained from secondary sources. The map of Figure 6.b shows the TGPs identification in the area with major criticality, what shows the existence of many enterprises that, in turn, results in transportation flows to this area, which explains the criticality of previous map.

6. Selection of points for data collection on cargo flow

By applying the third step of the method, the map in Fig. 7 was generated. Please note that the Midwest region has areas of very high concentration of TGPs.

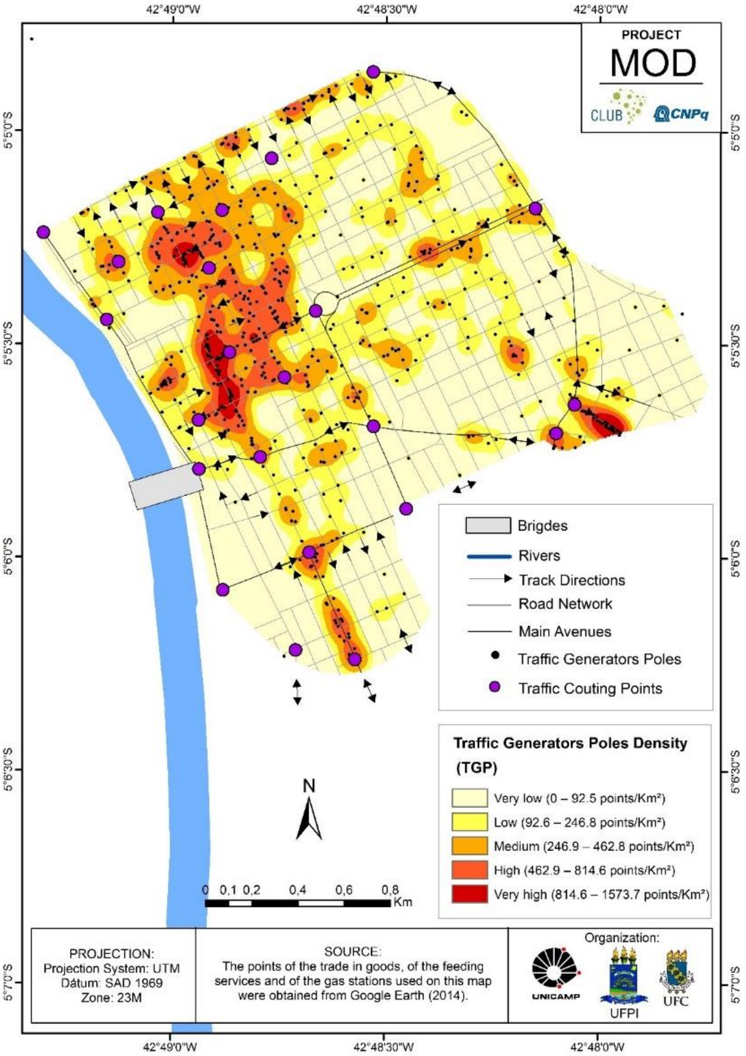

Fig. 7: TGP density and selection of traffic counting points in the most critical area of urban cargo transportation in Teresina

The crossing point between Simplicio Mendes and Areolino de Abreu streets is one of these sites and presents mainly retail establishments. The same occurs in an extensive part of Rui Barbosa Avenue, between the intersections of Senador Teodoro Pacheco Street and Félix Pacheco Street, with a large number of food services and trade in goods. São Raimundo Street, in the eastern part of the study area must also be highlighted, due to the large number of retail establishments.

The midwestern region has extensive areas of high concentration of TGPs mainly in retail, in the vicinity of the very high concentration sites towards the center. This also occurs at the intersection of Joaquim Ribeiro and Barão de Gurguéia avenues, followed by some sections of the latter and, in this case, in addition to the large number of retail establishments, there is evidence of a large number of gas stations. The high concentration of food services must also be emphasized on sections of Frei Serafim Avenue. The larger areas of average density are also in the midwestern region of the polygon and in some specific locations found scattered throughout the area. Finally, to the east there is a predominance of low and very low densities, showing that the region has the lowest concentration of TGPs.

Among the 413 route intersections, 23 data collection points for cargo flows were identified in Teresina: 10 of them on the outskirts of the network, thus defining the geographical boundary; and 13 distributed within the network, 9 of which are in the region with the highest density of TGPs. These points were distributed in this manner in order to capture the greatest amount of trips from the smallest amount of points – being representative and that do not leading to redundant information (linearly dependent) from traffic counts. Therefore, it assures the maintenance of the original proposal of Willunsem (1981) to employ a method capable of resulting in an O/D matrix of trips with a minimum amount of information, in other words, something synthetic.

7. Conclusion

The proposed method is shown to be feasible by allowing the transportation planner to systematize the definition of study areas. Thus, the planning process is configured to enable us to justify choices and ensure less partiality in the definition of areas of study. Regarding the points for traffic count, it can be said that the selection methodology of critical areas for urban transportation of cargo was of fundamental importance, as it allowed us to select intersections that tend to receive a significant amount of trips by cargo carrier vehicles, as the area of influence of TGPs and the nodes that comprise the possible set of routes for cargo transportation were limited there, influenced of course, by the location of commercial establishments.

This work will assist in the implementation of the synthetic O/D matrix modeling to obtain results indirectly representing trips in the cargo transportation network, providing technicians and decision makers with more reliable information about the dynamics of the urban transportation of cargo in the study area. Furthermore, the use of the Kernel Density algorithm linked to the synthetic models is an innovation in the urban logistics area, especially linked to the application.

Moreover, this method is important for defining the application areas of expeditious methods, such as the synthetic O/D matrix modeling, given the fact that one of the main difficulties in the dissemination of the method and evaluation of its potential for application is in the definition of the study area. The definition of data collection points can be make from different methods, e.g. evaluation of goods deliveries records and household surveys. However, these methods can be unviable due the costs involved. The proposed method combines space information available from different sources, and is therefore a viable option to definition of data collection points. Thus, the presented proposal will contribute to fill this gap.

The next step of work consists in modeling the synthetic O/D matrix from the information to be obtained in the collection points proposed in this paper. To this end, a validation of the method for selection of points proposed here is important. Thus, the authors suggest that some issues are added to the process and, possibly the best way is with field research: Are there cargo transportation vehicles for such sites? How many personnel are available for the implementation of collections? Are such spaces able to shelter researchers and/or equipment for collection? When should the data be collected? Particularly the last issue deserves more attention from the community, especially for situations where the traffic behavior, particularly of trucks, is mostly unknown.

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