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ROTERISATION ALLOCATION FOR URBAN FREIGHT TRANSPORT, USING DATA FROM ELECTRONIC TAX INVOICES: CASE STUDY FEDERAL DISTRICT OF BRAZIL

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ABSTRACT

Cargo transport is an important element for the economy and the development of a region. However, most studies are focused on the movement of people. Additionally, the movement of cargo is seen as a problem by the other elements involved in mobility. On the other hand, the scarce availability and high cost of obtaining data limits the study of cargo movement patterns. In this work, using transport modelling tools, we studied the possibility of using the data stored in electronic tax invoices as the main input for the allocation process by generating distribution routes for each of the cargo vehicles in the urban area for a specific cargo segment. Thus, the case study seeks to present the applicability that this process would have and the potential of the data from the referred documents, which could be used as additional input during the urban strategic planning process.

KEY WORDS: Urban freight transport, routes, electronic tax invoices, logistics.

1. INTRODUCTION

Cargo dynamics in the urban area are part of a complex transport system due to the multiple and interdependent factors involved in the distribution process as well as the variety of participating groups and actors with diverse interests and perspectives. Urban Freight transport (UFT) is relevance not only because of the negative externalities it produces that affect urban mobility. But also, because it is essential for the economy of a city. In spite of that, this transport system has not been treated with due importance, initially it can be intuited that the factors that lead to this scenario are the lack of knowledge of it.

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In this context, there are some studies that seek to address this deficiency and make progress on the issue. However, these studies are limited by the low availability and high cost of obtaining data that allow for example, exploring the generation and patterns of cargo movement in urban areas.

In order to attack this problem, the studies consulted present alternatives for obtaining data from this transport system, at a lower cost and good quality. One of these alternatives is the use of information from databases of electronic tax invoices. Which, through specific methodologies, provide data and information of origin and destination of the cargo useful for generating travel cycles used for cargo distribution demanded daily in the cities. Therefore, this article presents through a case study, the rasterization process for cargo transport in the urban environment, using the data provided by the electronic tax invoices as the main input. As a result, the potential of this type of alternative data source for this type of study and for others related to the UFT is presented.

2. ELECTRONIC TAX INVOICES

Muñuzuri et al. (2009) and Tavasszy and De Jong (2014a; 2014b) quote that currently data in cargo transport research projects are scarce and not suitable for planning purposes. In addition, obtaining them usually represents a waste of high resources mainly due to the complexity of the transport system. In addition to these economic factors, authors cite that there is still resistance from companies to provide information as most companies operate in a competitive market environment. This, in a dynamic environment such as Urban Freight Transport causes another negative effect which is the lack of obtaining this data in a systematic and reliable way (TAVASSZY and De JONG, 2014a; HOLGUIN-VERAS et al. (2010).

As a consequence, there is a gap in obtaining representative samples for the modelling of Urban Freight Transport with a minimum of detail. This fact induces decision makers to proceed in planning without appropriate data and thus not treat the flow of freight vehicles considering their low participation in the total urban flow (MUÑUZURI et al. 2009).

That scenario indicates an unpromising prospect for progress in the modelling of Urban Freight Transport. On the other hand, this is partly due to the fact that researchers have concentrated their analysis on the premise of collecting data by traditional methods (Santos, 2015). It can be inferred that the analyses carried out previously did not consider a vision based on technological and knowledge advances, such as the use of the so-called "Big Dada".

As Santos interpreted (2015), in Brazil there is a significant *Big Data* of cargo flow, since almost all commercial transactions with goods and services are by law covered by electronic tax invoices. From which information is structured in a standardised way and with a robust storage process, used and continuously

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updated under the same database controlled by the States and the Brazilian Federal Revenue Service.

As a result, there are currently several documents in digital format with cargo transport data records such as, the Electronic Tax Invoice (NF-e), the Electronic Transport Knowledge (CT-e) and the Electronic Invoice Manifest (MDF-e). For the development of this study, data from the Electronic Invoices were used since the other documents described above do not present sufficiently disaggregated data and are not mandatory in the case of the UFT (SANTOS, 2015).

2.1 Electronic Tax Invoice – NF-e

The project called Electronic Tax Invoice (NF-e), was structured in an integrated manner by the Secretary of Finance of the States and the Brazilian Secretariat of Federal Revenue, following the signing of protocol ENAT 03/2005, of 27/08/2005, which attributed to the National Meeting of Tax Coordinators and Administrators (ENCAT) the coordination and responsibility for developing and implementing the Electronic Tax Invoice (NF-e) project (SPED, 2018).

NF-e is defined as:

> “A document of exclusively digital existence issued and stored electronically with the aim of documenting an operation of circulation of goods or provision of services in the field of incidence of the Tax on the Circulation of Goods and Services (ICMS), whose legal variability is guaranteed by two necessary conditions: the digital signature of the issuer and the authorization for use provided by the tax administration of the taxpayer's domicile” (NFE, 2016).

Similarly, Amaro and De Souza (2010) defined the Electronic Tax Invoice as an exclusively digital document to supply the invoice to customers. The objective of this electronic invoice project was to manage the entry and exit of goods by the state tax authorities, in order to facilitate the tax processes of the taxpayer’s and the inspection of operations and tax benefits for the taxes recorded on the Movement of Goods and Services (ICMS) and Industrialised Products (IPI).

In the same way, in the case of Brazil, when companies carry out transactions of goods or services, they are obliged to issue the tax document with information of their registration data and of the recipients of the goods, in addition to other data related to the goods, such as: value, weight and description of the products. Based on the above, the Electronic Tax Invoice (NF-e) is shown as a potential source to generate significant and useful data to describe the dynamics of the movement of cargo, increasingly close to the real behavior (Fernandez et al. 2013). It should be noted that there is currently a restriction of access to this type of data for research purposes, due to fiscal secrecy (SANTOS, 2015), which is an aspect discussed in this paper.

According to NFE (2019) reports, it is estimated that approximately 1.6 million NF-e are issued in Brazil in 30 days, which means directly in load flow data a disaggregated level and with high potential to be used in load analysis.

The data generated in transactions with NF-e are stored in files with XML extension, which contain relevant data for research (Fernandez, 2013; NFE, 2016). Among the main data are the following:

- Issuer's identification and recipient of the e-NF, with their respective addresses.
- Specification of product or service in accordance with the Mercosur Common Nomenclature (NCM).
- Identification of the company's activity consistent with the National Classification of Economic Activities (CNAE).
- Plate of the vehicle transporting the goods.
- Value and weight of the good resulting from the commercial transaction.
- Date of issue of the invoice and departure of the goods.

It is important to inform that, in addition to the extraction methodology developed by Santos (2015) and the data provided by the NF-e, other complementary data sources were used. Such as, the georeferenced address provided by the Federal District Environmental Sanitation Company (CAESB).

3. METHODOLOGY

According to Ortúzar and Willumsen (2011), trip allocation is considered the main element in the analysis of transport systems, represented by the number of trips of cargo vehicles from an area of origin to an area of destination through a road network. In that regard, there are several modelling methodologies used in the transport area (SIVAKUMAR, 2007). In particular, in this study a proposal is structured for the assignment of trips of cargo vehicles through a heuristic roterisation methodology under the premise that all cargo vehicles used in the distribution of goods return to the base (origin) to complete the cycle of trips at the end of the activity period. The considerations referred to are based on the characteristics of the operation evidenced for the market segment that is the subject of this paper's case study and presented in Santos' paper (2008).

The use of the logistics module incorporated in the NF-e tool for transport modelling TransCad, a software by the firm Caliper Corporation, was implemented. The mentioned module is based on the heuristic model developed by Clarke and Wright (1964), which consists of looking for the ideal travel cycle that generates the lowest possible cost (Laporte, 1992). In a complementary way, the algorithm of this model is the best known and most used technique to solve the classical problem of roterisation since the heuristic methodology makes it possible to build the routes considering the time and capacity restrictions, minimising the distance of the travel cycle of each cargo vehicle (NOVAES, 2004).

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Fundamentally, according to a variety of possible route alternatives, the above methodology refers to the advantage in distances that a freight vehicle could obtain by serving several destinations (nodes) in succession (chain) and returning to the base (origin, distributor, depot) after completing all deliveries. This results in the optimal route of the vehicle from the base to the number of stops used to make the deliveries, according to the referred variety of possible route alternatives (CLARKE and WRIGHT, 1964).

To understand the heuristic methodology, it starts by adopting the least convenient solution to solve roterisation, where each point (node, clients) is served individually by a cargo vehicle from the base distribution point (base node, depot) by independent routes, as illustrated in Figure 3-1. Thus, the distance travelled by the cargo vehicle to carry out the distribution is represented by the following mathematical expression:

$$\mathrm{D} = 2\mathrm{d}_{\mathrm{FS_i}} + 2\mathrm{d}_{\mathrm{FS_j}} = 2(\mathrm{d}_{\mathrm{FS_i}} + \mathrm{d}_{\mathrm{FS_j}})$$

Where

D: distance travelled by the freight vehicle

$\mathrm{d}_{\mathrm{FS_i}}$: distance between base F and stop S_i; and,

$\mathrm{d}_{\mathrm{FS_j}}$: distance between base F and stop $\mathrm{S_j}$

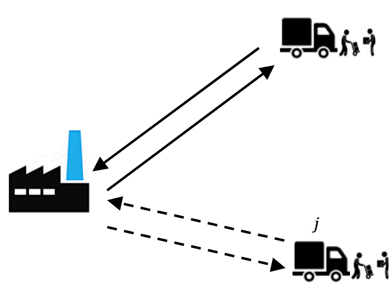

Figure 3-1. Individual service

Then, the optimal solution would result when the vehicle manages to attend the deliveries from stop $\mathrm{S_i}$ and uses the same trip to attend the deliveries from stop $\mathrm{S_j}$, as illustrated in Figure 3-2. In this way, the distance travelled by the vehicle is represented by the following expression:

$$\mathrm{D}' = \mathrm{d}_{\mathrm{FS_i}} + \mathrm{d}_{\mathrm{S_iS_j}} + \mathrm{d}_{\mathrm{FS_j}}$$

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Where

$d_{S_iS_j}$: distance entre la base F y la parada S_j;

d_{FS_i}: distance between base S_i and stop S_j; and,

d_{FS_j}: distance between base F and stop S_j

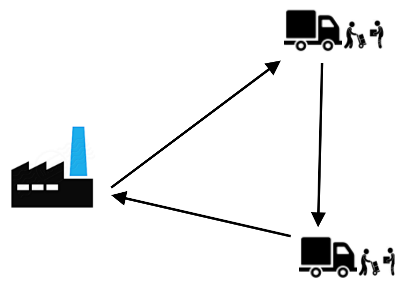

Figure 3-2. Chained service

Comparing the two alternatives presented in Figure 3-2 and Figure 3-3, the improvement is obtained, through the combinatorial analysis of the routes, expressed mathematically as:

$$G = D - D' = 2(d_{FS_i} + d_{FS_j}) - (d_{FS_i} + d_{S_iS_j} + d_{FS_j}) = d_{FS_i} + d_{FS_j} - d_{S_iS_j}$$

Consequently, a sequence of routes is elaborated selecting the alternative that generates the best economy, considering the restrictions and/or impediments, according to the attributes of the road network used for the analysis, such as: capacity, time, cost, speed, etc.

Having made the previous observation, for the application of the heuristic methodology in reference to routing, Novaes (2004) and Laporte (1992) propose a sequence of steps or consecutive stages that serve as a guide for control, better understanding and use. As presented below:

Stage 1: all points (stops for the distribution of goods) are combined two by two and the profit for each combination is calculated (G).

Stage 2: all combinations S_i, S_j are organised in a descending order, according to the values of the profit (G).

Stage 3: It initiates with the combination of points (nodes) that presents the highest utility. Thereafter, on the analysis of other situations it goes down the list of combinations, always obeying the decreasing sequence of the utility.

Stage 4: To a pair of points, removing the sequence of combinations, it is verified that the two points that were already selected are part of an initiated route.

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a) If S_i y S_j of those points do not belong to any of the routes already started, then a new route is created for those two points;
b) If point S_i already belongs to a route already started, you must check whether that point is the first or the last point of that route (not counted on CD). If the answer is yes, add a couple of points (S_i, S_j) at the most appropriate end. The same analysis is done with point S_j. If none of the points satisfy that condition separately, it is decided to move on to the next item c).
c) If each of the points S_i and S_j are part of a route initiated separately, it should be checked whether both ends are of the respective routes. If the answer is positive, the two routes are merged into one, so S_i is joined to S_j. Otherwise, it is moved to step 5.
d) If the points S_i and S_j belong to the same route, it is moved to step 5.

Stage 5: Each time you increase one more point on a route or when you combine two routes into one, you must check that the new configuration complies with the time and capacity restrictions. If it meets the limits of the restrictions, the new configuration is accepted.

Stage 6: The process ends when all points (stops) have been included in the distribution route (trip cycle).

However, the stages mentioned above are incorporated into the logistics module of the tool used for this study. Where there is a process of data entry, processing and presentation of results of the optimal routes. In addition, the tool makes it possible to generate a geo-referenced geographical file of each distribution route, which allows a better understanding of the results and through treatment external to the module, consolidates the flow of vehicles. Resulting in a road network loading map for the distribution vehicles in the segment under analysis (CALIPER, 2017).

3.1 Criteria for the roterisation process

In order to execute a roterisation process of this type there are several criteria that must be considered. Such as, access restrictions and vehicle loading/unloading, schedule priorities for deliveries to customers, maximum operating speed, among others.

Regard to restrictions on loading/unloading vehicles Daganzo (2005) cites three main limitations: weight and space in volume required by the goods up to the limit of the capacity of the vehicle body; weight, referring to the transport capacity of the vehicle and the road infrastructure; and the number of deliveries, related to the delivery time. For this work, the quantity of deliveries was used as a reference, for the following reasons:

- According to Manzano Dos Santos and Sánchez-Díaz (2016), in a research with the fractionated cargo transporters of the Federal District, the results showed that the number of deliveries is the most significant limitation of the

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urban space (65% of the cargo of the transporters interviewed used this criterion for the distribution of their fractionated loads in the Federal District).

- The NF-e database consulted presented a strong consistency for the data related to the vehicle plates of the segment analysed in this study (beverage). Consequently, this made it possible to extract the number of deliveries made per day and per vehicle, which in turn reflects the other limitations if they were considered.

Santos' paper (2008) presented a reasonable explanation for this case, showing that distributors in the beverage segment in the Federal District use the plates of cargo vehicles to orient and build the roterisation. This information is deposited in the NF-e with the aim of avoiding errors in deliveries. However, it is important to verify and validate whether this feature exists for other cargo segments. It is expected that this type of information will be increasingly accurate within the evolutionary process of the use of the NF-e in transport studies.

Another relevant aspect is that standard vehicle departure and arrival times were adopted for the beverage segment, and no time restrictions were stipulated. All this was done to simplify the model, because this type of parameterisation is normally avoided by the respective distributors (Santos, 2008).

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4. ROTEIRISATION OF THE UFT IN THE FEDERAL DISTRICT/BRAZIL

The UFT is a transport system directly related to the population. Due to 50% of the population lives in urban and metropolitan areas, it is estimated that by 2050 this proportion will increase to 85% and 91% in Europe and the United States respectively (Russo and Comi, 2016). In the case of Brazil, according to IBGE (2010), 84% of the Brazilian population lives in urban areas.

In the specific case of the Federal District, this percentage participation is higher, approximately 96%, with an estimated population according to the 2010 census of 2.98 million inhabitants. In addition, Santos (2015) comments that 63% of the

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cargo is distributed internally, which means that the movements of cargo distribution have as origin and destination the region itself.

An exploratory analysis of the NF-e data issued in the Federal District for the first four months of 2016, using the NCM code of the products and total deliveries made, shows the beverage segment (NCM = 22) as the one with the largest share in the distribution flow in the Federal District, representing 14.96% of the total. This result is equivalent to that presented in Santos' paper (2015) for the 2014 period, 14.40%. This preliminary exploratory analysis also revealed that there are three main large distributors in this segment, which account for 80% of movements.

This characteristic and based on the classification of the types of large surfaces (size) in charge of the distribution of the product under study, in the urban area, and in accordance with the size of these surfaces, proposed by Portugal (2012). For this study it was proposed to adjust the classification, adding the large surfaces with areas over 1000 m^2 as a special size which, in turn, represent 95% of the movements of drinks in the study area.

In this way, using the NF-e data with geo-referenced deliveries and identified with the plate of the vehicle used in the distribution process of the load segment under analysis, which were reconfigured to maintain the confidentiality of the data, the origin/destination matrix and the number of vehicles used for distribution were obtained, as well as the average variation of daily deliveries throughout the week. In addition, data from one of the main distribution sectors was used in order to obtain and provide the number of deliveries per vehicle, a criterion adopted in the roterisation process.

For the roterisation process, the base distribution points of large surfaces (depots) were adopted as the points of origin, and the destination points as the stops. In addition to this, a vehicle roterisation matrix is created, minimising the distance or time of distribution. Similarly, in accordance with the real data from distribution companies in the segment under study, a table of vehicles is drawn up which consolidates the type, number and capacity of these, attributed to each depot. It is important to mention that in order to use the logistics module of the analysis tool used, it is necessary to have previously generated the road network of the urban area with all its attributes, since this network will serve as the basis for structuring the routing process.

As a result of processing the data through the *routing/logistic – vehicle routing* module, the most suitable routes were obtained for the distribution of the load segment from each point to each large distribution area. This result was compiled in a file compatible with the Geographical Information System (GIS). Figure 4-1 shows the summary of the total routes obtained in the process described above.

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Figure 4-1 Routes, NCM:22 cargo segment

Subsequently, based on the attributes of each arch that make up the road network of the Federal District, it was possible to load it, through the grouping of trips of all the vehicles that use each arch in their distribution trip of the cargo segment. Figure 4-2 shows the result of this grouping. A load map is generated, which represents the number of load trips. This allows for the observation of the main corridors used in the distribution of the beverage segment in the internal area of the Federal District.

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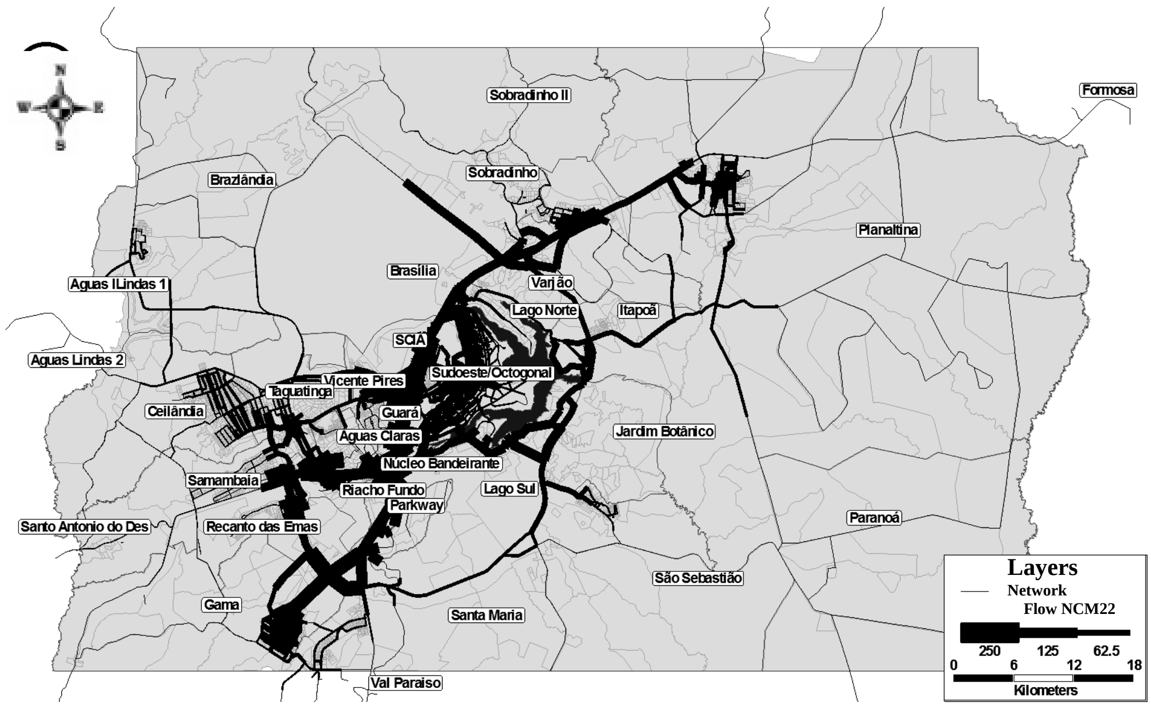

Figure 4-2 Network load, NCM:22 segment

5. RESULTS AND DISCUSSIONS

After the loading of the network, a significant use is verified in the road corridors EPIA/DF-003, EPNB, Structural and EPDB that, according to data of location of great surfaces, a strong relation with these results is demonstrated. Another characteristic revealed has to do with the day of maximum demand for distribution trips, which in this case corresponds to Thursday, a fact which coincides with that noted in Santos' work (2015). On the other hand, in relation to production (origin of the goods), these are consolidated in three sectors, represented by 80% of the distribution of the cargo segment analysed. In addition, it should be noted that these sectors are located in the west of the Federal District, and there are destination regions far from these large areas, which results in greater distances and increased use of the main roadway corridors.

Also, in accordance with the consultations made to the large consolidated surfaces in the distribution of beverages, it is corroborated that one of the main limitations is presented by the number of deliveries per day. This means that vehicles are loaded with less than their capacity, which can lead to cost overruns in the logistical process, increasing the negative externalities arising from the cargo transport system.

This work concludes that this type of information can be useful in the sizing and/or improvement of roads, as well as in the implementation of recommended solutions in the area of urban logistics (MANZANO SANTOS and SÁNCHEZ-DIAZ, 2016).

This is necessary because the demand for goods and services is changing dynamically due to the continuous increase in population, as well as the migration of people to urban areas, mainly with the aim of finding better job opportunities, personal growth and quality of life, which is reflected in the distribution trips of cargo vehicles (Anan et al. 2015). In addition to this, the UFT is shown to be an essential system for the population and an important element for the economy of a region. However, it is not unknown that the dynamics of this transport system generates serious consequences for urban mobility, with different perspectives for the actors involved. In the comparison of research projects related to the UFT, it can be affirmed that they are scarce and limited, in relation to passenger studies. The difficulty or impossibility of collecting and obtaining data related to the above-mentioned transport system is also noted.

In this paper and in correlation with the research of Santos (2015), it is demonstrated that the data provided by the NF-e can be used as an alternative resource of quality and low cost in the attempt to interpret and understand the dynamics of the UFT. It is considered that the result of this work is closer to the actual movement of freight vehicles in the urban area compared to the traditional methods used in data collection, where native aggregated data from samples taken in the field and implemented on structures adapted from passenger transport demand models are usually used. In this context, it is important to mention that this study contributes to the purpose of understanding the dynamics of the UFT, with the aim of transforming it more and more efficiently, with less environmental impact, and contributing to the continuous improvement of urban mobility and in turn to the economy of the region.

Finally, it is understood that there are limitations in the access to NF-e data for scientific research. However, as shown in this paper, fiscal secrecy can be maintained without significant prejudice to the results. It is also hoped that by producing and presenting benefits to society, the managers of this type of document can be encouraged to create mechanisms that facilitate access in a more extensive but organised way to maintain fiscal secrecy.

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