TRIP GENERATION IN SÃO PAULO METROPOLITAN AREA: A CASE STUDY

RESUMO

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RESUMO
O rápido crescimento da população urbana no mundo aumentou a necessidade de otimizar o acesso a recursos em ambientes urbanos em todos os países, e o transporte é uma das vinte maiores prioridades de desenvolvimento no Brasil. Este trabalho tem como objetivo investigar o modelo de geração de viagens de fretes na Região Metropolitana de São Paulo (RMSP), por número de funcionários, área construída e frota. As viagens foram classificadas por setores econômicos de acordo com seu perfil de frota de veículos, aplicando a técnica k-means clustering. A análise foi estendida para cada macrozona e zona que compõe a RMSP. Os resultados classificaram setores econômicos em três clusters e cada um apresentou diferentes variáveis explicando o número de viagens. A posse da frota explicou o número de viagens de carga para todos os clusters. As principais zonas e macrozonas que geram viagens foram identificadas, e alguns insights sobre políticas públicas discutidos.

ABSTRACT
The rapid growth of the urban population in the world has increased the need to optimize the access to supplies in urban environments in all the countries, and transportation is one of the top 20 most important development priorities in Brazil. This paper aims to investigate freight trips generation model in the São Paulo Metropolitan Area (SPMA) by number of employees, built area and fleet ownership. Trips were classified by economic sectors according to their fleet profile of vehicles, by applying k-means clustering technique. Then the analysis was extended to each macrozone and zone that compounds the SPMA. Results classified economic sectors in 3 clusters and each one presented different variables explaining number of trips. Fleet ownership explained the number of cargo trips for all three clusters. The main zones and macrozones that generate trips were identified, and some insights about public policies discussed.

1. INTRODUCTION

The rapid growth of the urban population in the world has increased the need to optimize the access to supplies in urban environments in all the countries (Sánchez-Díaz, 2017). According to Felzer *et al.* (2016), transport is one of the top 20 most important development priorities in Brazil, such as economic growth. Urban planners, researchers and policy makers have identified some elements that can be helpful in promoting a more efficient transportation system – mixing land-uses, promoting the use of public transportation and the use of cleaner vehicle technologies (ICMA, 2002). However, freight transportation has had very limited measures made by public interventions that often have not being effective or even generated adverse effects (e.g., access restrictions based on time of de the day, vehicle size) (Holguín-Veras *et al.*, 2017). Therefore, there is an urgent need for the research community about this subject to find new ways of transporting supplies in urban centers in a more efficient way, thereby hampering the city's livability.

As freight flows in metropolitan areas increase, there is a growing interest among the urban researches in developing better methods for tracking and analyzing commodity flows and their impacts on transportation networks (Giuliano *et. al.*, 2007). However, it is important, for starts, that the freight system and its factors (e.g. socio-economic and vehicle characteristics and resource availability) that determine the amount and type of supplies consumed in this cities are understood (Lawson *et. al.*, 2012).

This paper aims to investigate freight trips generation model in the São Paulo Metropolitan Area (SPMA) by number of employees, built area and fleet ownership. This paper presents a different approach, analyzing if different economic sectors may present similar fleet composition in the freight flows generated by the establishments located in the São Paulo Metropolitan Area (SPMA). This research discloses a set SPMA zones where a public agency could reduce taxes for a company to build their warehouse, avoiding more traffic impacts in others over concentrated zones. Fleet ownership significantly explained the number of trips generated for all three clusters, representing those different economic sectors.

The following section presents a literature review on important concepts for this study: freight generation and freight trip generation. The third section describes the methodology used, along with the data description. The fourth section presents results and its analysis, and the last section presents conclusions.

2. LITERATURE REVIEW

There are two different approaches to estimate the urban freight generation, and it is crucial to establish the difference between them: Freight Generation (FG) and Freight Trip Generation (FTG) (Tavasszy and de Jong, 2014). The first is the generation of commodities transported by vehicles, referring to production and consumption of actual cargo, measured in weight or volume. The latter is the generation of vehicle trips that carry the cargo, the freight traffic required to transport the cargo, measured in number of vehicles trips (Sanchez-Diaz *et al.*, 2016).

Freight Trip Generation and Freight Generation are important to study because their quantification is critical to identify the traffic impacts, evaluate potential initiatives to reduce the impacts and, for FG, to design and evaluate the usefulness of those initiatives (SánchezDíaz, 2017). Thus, it is possible to adopt measures to reduce the externalities caused by these trips in the system, being they environmental such as pollution; social, as the reduction of the quality of life in those regions; or of infrastructure, such as congestion (Gonzalez-Feliu & PerisPla, 2017).

For the development and study of FTG models, six factors should be considered: (i) dependent variables, as vehicle-trips, cargo weight and value; (ii) independent variables, as employment, building area, vehicle type and other economic data (e.g. sales, industry segments and type of business); (iii) level of aggregation, as disaggregate or aggregate; (iv) level of geography, as metropolitan, statewide, national, corridor or special facility; (v) estimation technique, as spatial regression, time series, or another type; and (vi) model structure, as linear or non-linear (Holguín-Veras *et al.*, 2012).

Previous works have shown the increasing interest in applying FTG models in different cities around the world, collecting data direct from establishments or using researches made by local government institutions, such as this study. For instance, Alho and de Abreu e Silva (2014) used an establishment-based freight survey to predict the demand in retail establishments in Lisbon, Portugal. The authors used linear regression models and linear model frameworks, concluding that employments models perform better than area models. Priya, Ramadurai and

Devi (2015) estimated freight trip generation models at the establishment level in Chennai City, India, developed with disaggregated survey data, giving significant insight into the freight trips' characteristics. De Oliveira et al. (2017) used a linear regression for trips generation to develop an FGT model for pubs and restaurants in Belo Horizonte, Brazil, crossing the survey data with geographic, demographic and socioeconomic data. The author's study highlights the necessity of an urban mobility plan and public policies for this region. Brogan et al. (2001), Nuzzolo, Crisalli and Comi (2011), Kawamura, Shin and McNeil (2005), Bastida and Holguín-Veras (2009), Middela, Pulipati and Prasad (2018) and Ducret and Gonzalez-Feliu (2015) have also used regression analysis to obtain freight trip models.

Truck-based models are appropriate to be used for the simulation of the current region's scenario but can be difficult to apply it in forecasting analysis (Comi *et al.*, 2012). In general, multiple regression equations are used for trip generation models, vehicle and commodity based (Kulpa, 2014). These models estimate the number of trips in large zones or districts by regressing the trips against independents variables, measuring different flows of cargo in each zone (NCHRP Synthesis 298, 2001).

3. METHOD

This study was developed for the São Paulo Metropolitan Area (SPMA), the largest urban agglomeration in South America, with a population of 21.4 million people, about 50% of the population of the São Paulo state. With 39 municipalities, according to Figure 1, the SPMA is distributed in 7,947 km², with a population density of 2,691.80 inhab/km² (IBGE, 2015). In 2015, its Gross Domestic Product (GDP) corresponded to 17.63% of Brazil's GDP and 54.48% of GDP of the state of São Paulo. (IBGE, 2015).

In order to answer the research question, a clustering analysis grouped all the economic sectors by fleet composition profile. Then an investigation about the number of trips generated was conducted to analyze how the number of trips generated could be explained by the number of employees, built area and the number of own vehicles.

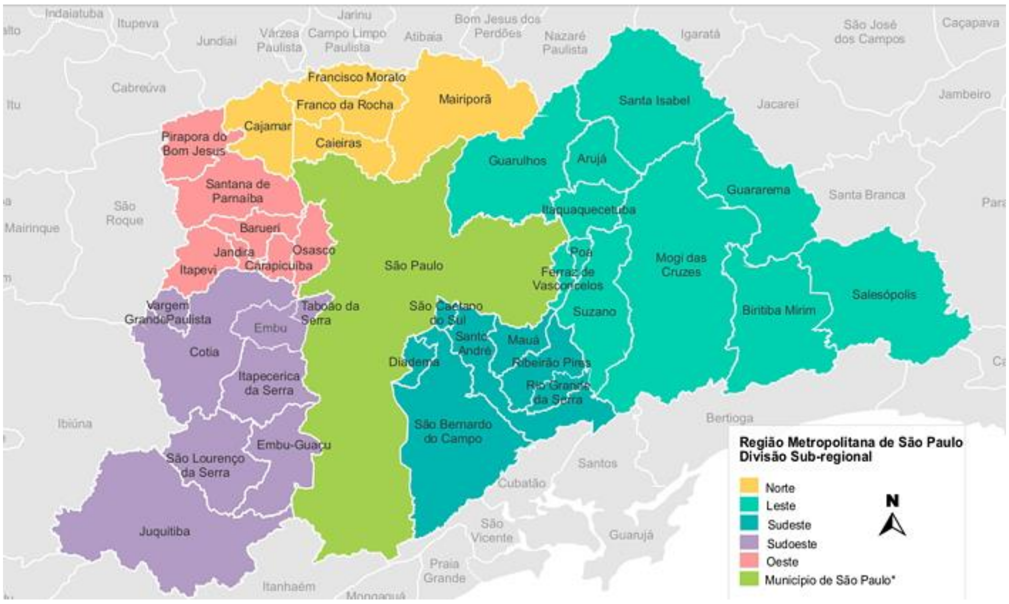

Figure 1. Map of São Paulo Metropolitan Region (Emplasa VCP/UDI, 2011).

3.1. Data description

In 2015, the Traffic Engineering Company of São Paulo (CET-SP) carried out a survey with companies in the transportation sector, located in the SPMA, with the objective of collecting data on the urban freight. This research aimed to understand the logistics of each economic sector, assessing the impact of investment infrastructure and policies to better manage congestion and emissions (CET, 2017).

The O-D survey, published in December of 2015, stratified all target companies by economic sector and size, based on the archive of the Annual Social Information Ratio (RAIS) of 2011. Through this it is possible to identify the freight flow number and location of logistics facilities (factories, distribution centers and warehouses). In the second semester of 2015, questionnaires were sent to companies, with 3.001 answered questionnaires.

The available O-D data were analyzed using multivariate regression, and their variables were compared with other variables used in the national and international literature of freight trip generation models. The number of trips was selected as the dependent variable. The independent variables used were the installation area, the average number of employees of the facility, and the total number of vehicles owned by the facility.

In order to study the regions with higher flows, the data were aggregated into macrozones and zones, as defined by the O-D survey The research carried out enumerated the zones of the facilities from 1 to 100, identified as districts of the municipality of São Paulo (1 to 49), municipalities in the Metropolitan Region and the state of São Paulo, other localities in Brazil or abroad. Data from several zones can be aggregated into a macro zone, where each value corresponds to a set of zones where an installation is located. There are only 13 zones related to the municipality of São Paulo, such as the South and Northwest macrozones, as well as the macrozone Rest of the State of São Paulo. It is noted that the eastern region, being territorially extensive, was divided into three macrozones: East 1, East 2 and East 3.

3.2. Fleet Grouping by Economic Sector

In order to find a fleet profile by economic sector, this study used a cluster analysis method for grouping the different types of vehicles presented in the O-D survey of CET-SP. Originally, each type of vehicle was presented as a percentage of how many trips were performed by each out of nine types of vehicles, per company. Then, those percentages were weighted and grouped by number of trips of each company, finding the percentage of each type of vehicle per economic sector. To determine the number of clusters it was used the silhouette method (Rousseeuw, 1987).

The silhouette method determines a measure of how tightly grouped all the points in a cluster are. This measure ranges from -1 to 1, where values closer to 1 indicate that data was properly clustered. In order to remove effect of having variables with different range, all variables where scaled. After determining the number of clusters, it was implemented the k-means clustering technique.

The k-means algorithm aims to partition n observations into k clusters, minimizing the sum of the squared error over all k clusters (Jain, 2010). Let's consider a set of observations $(x_1, x_2, \dots, x_n)$, where each observation is a d-dimensional real vector. The k-means clustering aims to partition the n observations into k ($\leq n$) sets $S = \{S_1, S_2, \dots, S_k\}$ so as to minimize the within-cluster sum of squares (WCSS) (Celebi *et al.*, 2013). Then k-means objective is:

$$\arg\min_{S} \sum_{i=1}^{k} \sum_{x \in S_i} \|x - \mu_i\|^2 \qquad (1)$$

where μ_i is the mean of points in S_i.

The O-D survey classified the companies in 17 economic sectors. Those sectors were grouped in k clusters according to their fleet composition, such as the percentage of different types of light and heavy vehicles.

3.3. Freight Trip Generation Model

The freight trip generation model considers that facilities located in some geographic region attracts inbound and outbound trips. The objective is to understand the variables that contribute to these trips.

For each cluster, authors investigated how the total number of employees, total built area of facilities and the total number of own vehicles could describe the number of trips, including inbound and outbound trips. A multivariate linear regression was conducted and its adjusted R^2 was analyzed. In addition, authors analyzed which zones and macrozones are trip generators.

4. ANALYSIS OF RESULTS

4.1. Economic Sectors Grouped by Fleet Profile

Figure 2 presented the average silhouette width, indicating that the number of clusters that presented the highest separation among its points was when k = 3.

When running k-means algorithm for k = 3, the economic sectors, where grouped according to Table 1. Cluster 1 included the sectors construction, maintenance and repair of vehicles, transportation and warehousing, and other services such as light trucks and small packages.
This cluster corresponded for 23.8% of all trips. This cluster grouped large vehicles used by construction sector, third-party logistic companies, and small packages deliveries. The vehicle utilization rate, calculated as the number of trips generated by number of own vehicles, was 4.0 trips per vehicle.

Cluster 2 corresponded for most trips generated (66.6%) and included economic sectors such as capital and consumer goods, retailers, food and mining. It is noteworthy that retailers and wholesalers were grouped together with the mining sector. The vehicle utilization rate was 1.9 trips per vehicle.

Finally, cluster 3 presented the smallest representation with 9.6% of the trips, including road freight transportation, and water treatment and waste collection. Those economic sectors mainly present large vehicles but were classified differently than cluster 1. The vehicle utilization rate was 2.3 trips per vehicle. Despite the utilization rate was not considered for clustering economic sectors, a higher utilization rate could implicitly explain differences of fleet profile from clusters 1 and 3.

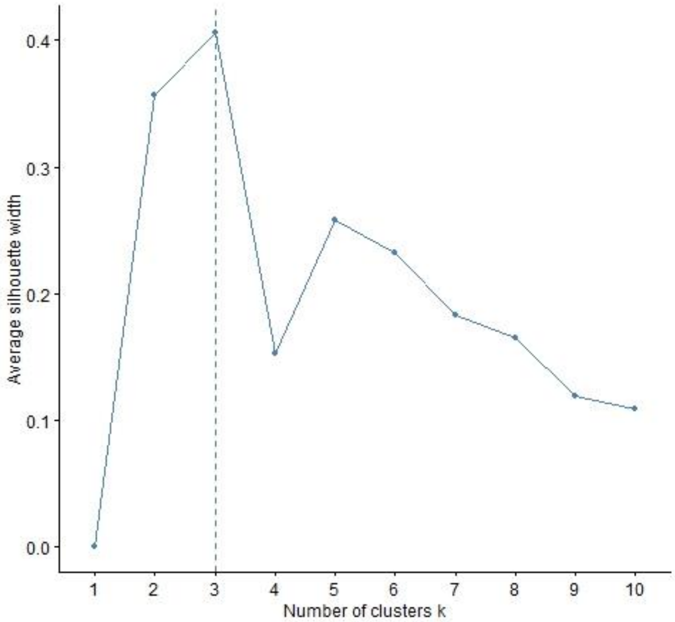

Figure 2. Silhouette method results.

Table 1. Economic sectors grouped by fleet composition, for k=4.

Clusters	Economic Sectors
1	Construction
	Maintenance and repair of vehicle/machines
	Other services – light trucks
	Other services – only small packages
	Transportation and warehousing – other activities
2	Capital goods industry
	Capital goods wholesaler
	Consumer goods industry
	Consumer goods wholesaler
	Food / Beverage / Tabaco industry
	Food and hospitality
	Other wholesalers
	Mining
	Retailers, general – supermarkets
	Retailers – others
3	Road freight transport
	Water treatment, decontamination, waste collection

A multivariate regression was run to explain the number of trips by number of employees, total facilities area and fleet ownership. For each cluster, data was grouped by geographical macrozones (total of 14), being Downtown, East 1-3, West, South, Southeast, Southwest, North, Northeast, Northwest, SPMA (excluding São Paulo city), São Paulo state and Brazil.

Table 2 presented the results for cluster 1. Number of employees and fleet ownership variables were significant for a level of 5%, and regression presented an adjusted R2 of 0.9515.

Macrozones that presented more employees and higher quantities of own vehicles will generate more trips.

Table 2. Multivariate regression for cluster 1.

Variables	Coefficient	Std. Error	t value	Pr(>|t|)
Intercept	-7.573e+00	2.140e+01	-0.354	0.730812
Employees	8.330e-02	1.772e-02	4.700	0.000841 ***
Area	-7.372e-05	1.532e-04	-0.481	0.640672
Fleet	1.590e+00	4.777e-01	3.328	0.007650 **

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

For cluster 2 (Table 3), all variables were significant for a level of 5%. Regression presented an adjusted R^2 equals to 0.9004. Number of employees and fleet ownership presented a direct relation with trips generated, meaning that as both independent variables increase, number of trips generated increase as well. Total area presented an inverse relationship, so larger areas would generate lesser trips.

Table 3. Multivariate regression for cluster 2.

Variables	Coefficient	Std. Error	t value	Pr(>|t|)
Intercept	-9.527e+01	8.592e+01	-1.109	0.293474
Employees	1.171e-01	3.323e-02	3.522	0.005519 **
Area	-8.184e-04	3.025e-04	-2.705	0.022118 *
Fleet	3.297e+00	6.924e-01	4.761	0.000767 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Number of trips generated within cluster 3 (Table 4) presented a different behavior. For a significant level of 5%, only fleet ownership was significant. Multivariate regression presented R^2 equals to 0.6882. Its direct relationship with the dependent variable means that as more vehicles a company has, more trips it generates.

Table 4. Multivariate regression for cluster 3.

Variables	Coefficient	Std. Error	t value	Pr(>|t|)
Intercept	40.442075	19.736466	2.049	0.0676 .
Employees	-0.204997	0.105487	-1.943	0.0806 .
Area	0.002114	0.002579	0.820	0.4313
Fleet	0.948451	0.233777	4.057	0.0023 **

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

4.2. Macrozones

When considering all generated trips individually, a multivariate regression was run in order to identify macrozones that generated freight trips. Regression included the previous dependent quantitative variables and new dummy variables regarding each macrozone. Table 5 presented the regression results, with adjusted R^2 equals to 0.1114. For a significant level of 5%, macrozones East 1, West, Southwest, North, Northwest, Sao Paulo State and Brazil were significantly different than Downtown. This result suggests that those macrozones are freight trip generators. Also, all three clusters were significantly different from each other, indicating that each fleet ownership profile presented a different behavior for number of trips generated.

Table 5. Numbers of generated trip by employees, clusters and macrozones.

Variables	Coefficient	Std. Error	t value	Pr(>|t|)
Intercept	1.871e+00	2.746e-01	6.814	1.14e-11 ***
Employees	1.487e-02	1.445e-03	10.288	< 2e-16 ***
Area	2.152e-05	1.218e-05	1.767	0.077273 .
Fleet	1.031e-01	2.091e-02	4.931	8.61e-07 ***
Cluster 2	1.190e+00	2.649e-01	4.493	7.29e-06 ***
Cluster 3	6.481e+00	7.497e-01	8.644	< 2e-16 ***
East 1	1.145e+00	4.665e-01	2.455	0.014138 *
East 2	3.488e-04	5.221e-01	0.001	0.999467
East 3	8.271e-02	7.287e-01	0.114	0.909639
West	1.145e+00	3.695e-01	3.098	0.001964 **
South	1.911e-01	2.134e+00	0.090	0.928647
Southeast	6.984e-01	3.710e-01	1.883	0.059844 .
Southwest	2.239e+00	6.008e-01	3.726	0.000198 ***
North	2.249e+00	6.868e-01	3.275	0.001068 **
Northeast	1.431e+00	7.445e-01	1.923	0.054629 .
Northwest	1.791e+00	8.946e-01	2.002	0.045328 *
SPMA	-1.524e+00	1.329e+00	-1.147	0.251561
São Paulo State	-5.086e+00	1.978e+00	-2.571	0.010179 *
Brazil	-6.246e+00	1.424e+00	-4.387	1.19e-05 ***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

4.3. Zones

Finally, in order to expand and detail the zones that compose each macrozone, a new multivariate regression was run, but now changing macrozone variables for dummy zone variables. Once again, all clusters are significantly different between each other, and the dependent variables number of employees, built area, and fleet ownership are significant as well, for a level of 5%. Table 6 summarizes and identifies the zones that were significant in the multivariate regression, meaning that they are freight trips generators. They include 11 zones within São Paulo city, 4 major cities within SPMA and 1 city located in São Paulo State. Although the city and SPMA zones are known for the presence of warehouses, the absence of other zones suggests that public managers should primarily focus on these zones to create public transport policies. In addition, it is noteworthy that inbound and outbound trips from other regions of Brazil are significantly different from zero, indicating the economic power of SPMA.

Table 6. Trips generators zones.

Code	Zone
8	Perdizes
9	Tremembé
11	Lapa
16	Artur Alvim/ Cidade Lider/ V. Matilde
26	Vila Mariana
28	Ermelini Matarazzo/ Cangaíba
29	Campo Belo
30	Jaguaré/ Raposo Tavares/ Rio Pequeno
41	Pedreira/ Cidade Ademar
45	Itaim Bibi
46	Vila Leopoldina
53	Osasco, SP
57	Cajamar, SP

59	Guarulhos, SP
75	Diadema, SP
83	Campinas, SP
100	Other regions of Brazil

4.4. Impact on Public Policies
The clustering of economic sectors by fleet profile indicated that public agents may create different policies to deal with warehousing concentrations. Depending on the economic sector, those managers may allow different traffic regulations, authorizations of land usage and/or create economic areas within some specific zones.

Cluster 1 presented approximately the double of trips per own vehicles than other clusters. So companies from construction, maintenance and repair of vehicles, and other services such as light trucks and small packages, do not need much space for their fleet, by they provide many trips. This means that they can install their facilities in small urban areas and still generate many trips, impacting the traffic around them.

In addition, results suggested the macrozones and zones where public agents should focus their effort in order to mitigate traffic impacts, presented in Table 6. For instance, a public agency could reduce taxes for a company to build their warehouse inside a specific zone, avoiding more traffic impacts in an over concentrated zone.

Non-significant zones or macrozones can interpreted as zones that did not present a predictable pattern of number of trips. This could be explained by a wide spred mix of the nature of companies located within those zones/macrozones.

5. CONCLUSIONS
The present work investigated trip generation in the SPMA by number of employees, built area and fleet ownership. Trips were classified by economic sectors according to their fleet profile of vehicles. Then the analysis was extended to each macrozone and zone that compounds the SPMA.

Number of employees and fleet ownership explained number of trips for all three clusters trips, although the first one was significant for a level of 10% for cluster 3. The latter was significant for a level of 5%, meaning it is an important explanation variable for number of cargo trips. The variable built area explained the number of trips only for cluster 2.

Macrozones that have heavy traffic highways were significant as trip generators. In the other hand, zones that concentrate warehouses were identified as trip generators. These identifications allow public managers to focus their efforts in some regions, diluting the concentration of companies to other zones and macrozones.

Within the limitations of this work are the aggregation of different datasets, which corresponds to answers provided by interviewees in different moments over the year. Also, geographic locations from different datasets not often are the same, and it was necessary to build an equivalence among them.

Future studies may combine other public datasets, including more independent variables, such as traffic flow, and categorical variables, such as presence of highways, in order to explain number of trips generated. Also, future studies may consider regression models for count data, to predict the dependent variable number of trips.

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