Evaluating Restrictions on the Circulation of Freight Vehicles in Brazilian Cities

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Abstract

Restrictions on the circulation of trucks are becoming increasingly frequent in Brazilian cities. Population growth, lack of appropriate urban infrastructure, and concern for the environment compel governments to adopt attitudes to reduce the problems of externalities in large urban centres. Traffic restrictions affect the full logistic chain, from the providers of consumer goods and services to the final consumers. Such restrictions usually apply to city centres, particularly during the peak hours, and for larger vehicles. This paper aims to identify Brazilian cities that have traffic restrictions and to estimate the odds of implementing certain types of traffic restrictions.

Keywords: Truck restriction; Brazil; emerging economies; city logistics

1. Introduction

The logistics of delivery has represented a major challenge to organizations in recent years because the logistics of delivery is not only a source of profit but also a source of high expenses, due to the difficulties in the operationalization of deliveries in urban centres.

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Urban centres aim to minimize one of the most common problems of the present time, namely, the high congestion index, which is explaining by the increasing numbers of vehicles, the large population concentrations, inappropriate street infrastructure, and precarious public transportation (Paulitsch & Toralles, 2010).

Traffic is one of the main problems that affect the residents of urban centres. Its consequences include noise pollution, an increased number of accidents, and environmental degradation (Cruz, 2006).

One of the main challenges for current governments is to find solutions to the population’s complaints regarding traffic while meeting the population’s consumption interests. In particular, people want access to and rapid delivery of industrialized products while demanding less pollution and congestion, among other complications (Lima Jr, 2011).

Large truck restrictions and bans have become increasingly popular in emerging, fast growing economies due to an explosive growth of individual (car) transportation as a simple and effective measure, and thus very popular, to instantly reduce congestion, though cars tend to slowly occupy the free lanes left by trucks and congestion returns in a short period of time.

In order to reduce the negative impacts of freight transportation, such as air pollution, traffic congestion, or noise, many city authorities around the world have implemented a variety of restrictions upon truck movements in urban and metropolitan areas (Russo & Comi, 2010; Browne, Allen, Nemoto, Partier & Visser, 2012). Sometimes these measures are not well evaluated before being implemented and are prone to controversy, as cargo is part of city life and should be considered in a broad, systemic way with the participation of key stakeholders (Taniguchi, Thompson, Yamada & van Duin, 2001, Holguin-Veras, 2008). For instance, Dablanc (2007) argues that, "local governments do not know how to organize freight" and “regulate inner city freight movement through legislation based on a combination of truck size and/or weight, and hard time windows, e.g., truck bans”.

In this work we aim to identify the Brazilian cities that have already implemented certain restrictions and to estimate statistically the odds of other cities implementing restrictions.

2. Problem overview

The main goal of any organization is to satisfy its customers. Logistics is an important aspect of customer satisfaction, as it allows merchandise to be available at the proper place, in the ideal amount, and within a timeframe that is appropriate for the type of business and its customers. Consequently, the supply of products or services to cities must be efficient for their prices to be competitive.

Concomitantly to the growth of market competitiveness, companies must address the challenge posed by delivery in urban centres. The National Transportation Confederation observed that, “a significant increase in the number of vehicles in large urban centres results in road saturation and large traffic congestions—thus increasing the length and costs of trips.”

The Brazilian transportation system is highly diversified and includes airways, railways, roadways, and waterways, as well as 1,610,076 km of highways (Confederação Nacional de Transportes, 2012). Excessive use of the highway network in Brazil is explained by the poor availability of other transportation modalities, which lack sufficient investment and the use of which is often restricted due to economic reasons; the low cost of highway freight; and a lack of appropriate road legislation and surveillance, which contributes to the excess weight of vehicles, thus worsening the condition of the highways.

To address these problems, studies on population displacement, i.e., the so-called urban mobility, began in the United States in the 1950s and aimed to define the best use of the road infrastructure and usually measured in an easy and straightforward way as the ratio of the number of trips to the total population (Correia, 2007).

The urban mobility system, “comprises the traffic of pedestrians, cyclists, human- and animal-powered vehicles, individual automobiles (cars and motorcycles), and collective and cargo transportation” (Paulitsch and Toralles, 2010). The urban mobility system aims to orient urban planning, decrease the circulation of motor vehicles that are occupied only by their drivers, provide the infrastructure necessary to increase the number of pedestrians, grant access to disabled individuals, provide high-quality collective transportation, reduce the fare price, train and improve the efficiency of the transportation management staff, and formulate comprehensive urban mobility plans (Correia, 2007).
The 8.89% annual increase in the number of Brazilian vehicles in the last five years, as represented in Fig. 1, poses increasing challenges to the corresponding governmental agencies. The number of vehicles has a direct effect on urban problems, such as traffic congestion, lack of parking places for private and (mainly) freight vehicles, noise and air pollution, traffic accidents, global warming, quality of life degradation, “chaotic occupation of dwelling places,” and “unplanned circulation” (Junior, Diniz, Rutkowski & Lima Jr, 2008).

The total Brazilian fleet has experienced significant expansion in the last few years due to steady economic growth (see Fig. 1). This has impacted individual transportation, especially in larger cities like São Paulo (10+ Million population) which incorporates about 1,000 new cars every day, with increasing pollution, noise, congestion and other negative externalities.

![Fig. 1. Evolution of Brazilian Fleet in the last five years. Source: DENATRAN (2012)](image)

To minimize these problems, municipal traffic and transportation agencies may enforce traffic restrictions. These restrictions usually affect city centres, roads that lack the infrastructure necessary to support the competition for space between trucks and passenger vehicles, and traffic peak hours—as well as affecting freight vehicles by regulating their size and the times and places for loading and unloading.

In the city of São Paulo, the restriction of the circulation of freight vehicles started in 1982, with the publication of Road System Operation Department (Departamento de Operação do Sistema Viário - DSV) ruling no. 002/82, which banned trucks with gross weights over 15 tons from circulation within an area delimited by the Marginal Tietê Expressway, Doutor Ricardo Jafet Avenue, and the University City area from 6:00 to 9:00 hours and from 16:00 to 21:00 hours. Currently, the following restrictions apply in the city of São Paulo:

- Maximal circulation restriction zone (zona de máxima restrição de circulação - ZMRC): “area in the city of São Paulo with a high density of commercial establishments and vehicles and restrictions on the circulation of trucks, delimited by the roads listed in Fig. 2” (DECREE no. 48,338, 2007).
- Restricted structural roads (Vias estruturais restritas – VER): “fast-traffic or arterial roads with high vehicle volume, which are important urban-connecting axes” (Silva, 2011).
- Special restricted circulation zones (zona especial de restrição de circulação - ZERC): “areas or roads in exclusively residential zones” (DECREE no. 48,338, 2007).
The resulting congestion growth has generated increased political pressure on local governments, which implemented a set of traffic restrictions over the last decade. Some of them affected automobiles and are very unpopular; one easier target is truck transportation, as trucks are larger and move slower, and use more lane and parking space. Thus, truck restrictions and bans are growing at an alarming rate (for shippers and carriers) all over the country.

A truck ban is here defined as a set of different constraints for truck circulation in inner city areas, as defined by Dablanc (2007). It is different from freight restriction as many smaller cargo vehicles, such as lightweight trucks (smaller than 3.5 tons) and vans, are allowed to move inside the main restraint area (generally defined by a cordon of major avenues). Usually, a truck ban is in effect inside inner city areas, in highways with heavy truck-car competition (as beltways and corridors), in before peak, peak and after peak hours, and considers the type of cargo, vehicle size and parking hours for loading/unloading.

Oftentimes, these constraints are defined, decided and implemented in very short notice, in a typically, “Brazilian mode”, with neither regard for technical and logistic arguments, nor long term effects and impacts. Also, medium and small cities have been implementing truck bans in a crescent way, even when they do not face significant heavy traffic or congestion issues, as trucks bans are "fashionable" (used in big, prestigious cities), particularly prior to and in election periods.

The use of traffic restriction measures might contribute to, “reducing the conflict arising from the disputation of road room, reducing the need for further investment in transportation infrastructure,” and reducing pollutant emission (Cruz, 2006). However, those restrictions affect transportation companies by reducing their logistical efficiency: deliveries take longer, the service level decreases, and nighttime deliveries are more exposed to theft.

To comply with the new rules and to retain their market competitiveness, transportation companies are currently employing smaller freight vehicles. Such vehicles improve the urban distribution and have permission to circulate in restricted areas.

In the city of São Paulo, such permission is granted to urban freight vehicles (veículos urbanos de carga – VUCs) of up to 2.20 m in width and 6.20 m in length (these limits might vary among towns applying traffic restrictions).

There are certain exceptions in the city of São Paulo, namely, vehicles that may circulate all day long, or at certain times of day, after being granted special permission by the DSV. Such exceptions include vehicles for the following purposes: car emergency mechanical assistance, news coverage, emergency operations and services, private parking places, urban infrastructure operations and services, open market fairs, moving, garbage collection, perishable food transportation, earth removal from civil constructions, rubbish removal and dumpster transportation, dangerous product removal, essential public services, money transportation, postal services, and traffic emergency signaling services (Silva, 2011).

Indeed, the aims of the restrictions imposed on freight vehicles are positive, to reduce congestion and the resultant noise and air pollution. However, the absence of studies demonstrating the efficiency of these restrictions renders them doubtful to the population and negatively perceived by the affected companies.

Recently, the Institute of Logistics and Supply Chain (ILOS) conducted a study of 60 representatives of large transportation companies. The results revealed that 68% of these individuals believe that the lack of standardization of the traffic rules among cities hinders the global planning of their operations; 55% believe that the ban on the circulation of large vehicles increases the number of smaller vehicles; 97% believe that the creation of a larger number of loading and unloading facilities would help to improve the congestion indexes in cities; and 95% believe that if the quality of the public transportation system were improved, then the number of vehicles would decrease.

3. Proposed approach

Using a sampling method that combined several sources of information, such as content analysis of published material (including Internet searches), direct interviews with traffic officials, and up-to-date operational data from a nationwide food and beverage company (which has to comply with all truck constraints), we have identified 33 cities in Brazil with truck bans (Fig. 2). The smallest one is Novo Hamburgo, whose population is 238,940, which
establishes our cut-off value. Thus, all 108 Brazilian cities whose population is greater than 235,000 inhabitants comprise our sample (universe). Smaller historic towns are left out of the analysis as their constraints are due to street dimensions or vibration issues other than the externalities found in bigger cities (air pollution, congestion and noise).

Direct interviews were an important source of information, as many times the crisscrossing of content analysis and true operational data was not consistent; surprisingly, one could find actual legislation for truck bans which were not enforced by local authorities.

A set of seven independent variables or attributes has been proposed and evaluated. Firstly, descriptive statistics and box plots were employed for variables; bar graphs were used for attributes. Then, a logistic regression model was adjusted to allow proper statistical inferences. Using a backward exclusion rational, non-significant variables ($P > 0.05$) were removed from the model, resulting in a logistic model with four independent variables and attributes.

To explain the response variable, or if the city has or has not a truck ban (yes/no), the explanation variables and attributes are: 1) population density (people/area); 2) state capital or not (an attribute, meaning the political importance of the city); 3) adjacency to another city with truck ban or not (a proxy that the city are sharing negative externalities, as in large metropolitan regions); 4) ratio of population per total vehicle fleet; 5) ratio of population per bus fleet; 6) truck ratio (truck fleet per individual car fleet); and 7) automobile ratio (car fleet per total fleet, which also includes trucks, buses and vans).

Initially, a logistic regression model was adjusted using all seven explanation variables (Model 1), given by (1):

$$p_i = \frac{\exp(\beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots + \beta_7 x_{i7})}{1 + \exp(\beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots + \beta_7 x_{i7})}$$

where:
$p_i$ is the probability that city $i$ exhibits truck restriction;
$\beta_0, \beta_1, \ldots, \beta_7$ are the unknown parameters to be estimated;
$x_{i1}$ is the value of variable Density of city $i$ expressed as inhabitants/100 km²;
$x_{i2}$ is the value of variable State Capital for city $i$, that is; $x_{i2} = 1$ if city $i$ is a state capital; $x_{i2} = 0$ otherwise;
$x_{i3}$ is the value of variable neighbour for city $i$; $x_{i3} = 1$ if city $i$ is adjacent to a another city with truck ban; $x_{i3} = 0$ otherwise;
$x_{i4}$ is the value of variable ratio of population/total vehicle fleet for city $i$ (hab/vehicle);
$x_{i5}$ is the value of variable ratio of population/bus fleet for city $i$ (hab/bus);
$x_{i6}$ is the value of variable truck ratio for city $i$ (% of trucks with respect to the total automobile fleet);
$x_{i7}$ is the value of variable Auto ratio for city $i$ (%automobiles with respect to the total fleet);
Set of cities; $i = 1, \ldots, 108$.

To verify the quality of Model 1, the Hosmer-Lemeshow C statistic test was performed. The C value equaled 10.363. The P-value associated with the C test was 0.240. Since the P-value was greater than 0.050 (established as the level of significance), the logistic regression model was concluded to exhibit a satisfactory goodness of fit.

All economic city data has been obtained from current public data (Brazilian Institute of Geographic Statistics, IBGE) in September 2012.

4. Results

Table 1 describes the estimates of the Model 1 parameters and their significance at a 5% level. Based on the results in Table 7, the parameters associated with the variables Closeness, InhabB, TrAu, and Auto are not significant (all P > 0.05).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard error</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_0$</td>
<td>1.64338</td>
<td>6.41633</td>
<td>0.798</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>0.02301</td>
<td>0.01020</td>
<td>0.024</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>1.88410</td>
<td>0.71228</td>
<td>0.008</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>-1.37417</td>
<td>0.71228</td>
<td>0.054</td>
</tr>
<tr>
<td>$\beta_4$</td>
<td>-0.37849</td>
<td>0.32434</td>
<td>0.243</td>
</tr>
<tr>
<td>$\beta_5$</td>
<td>-0.00949</td>
<td>0.00492</td>
<td>0.054</td>
</tr>
<tr>
<td>$\beta_6$</td>
<td>-0.00233</td>
<td>0.09351</td>
<td>0.980</td>
</tr>
<tr>
<td>$\beta_7$</td>
<td>0.00908</td>
<td>0.06971</td>
<td>0.896</td>
</tr>
</tbody>
</table>

Next, Model 2 was adjusted, in which explanatory variable TrAu was excluded because it exhibited the greatest P-value (among all of the variables with P > 0.05). Table 2 shows the estimates of the Model 2 parameters, with their significance set at the 5% level.

Based on the results, Model 3 was then adjusted by excluding the explanatory variable Auto because it exhibited the greatest P-value (among all of the variables with P > 0.05). Table 3 shows the estimates of the Model 3 parameters, with their significance set at the 5% level. Finally, Model 4 is determined by excluding explanatory variable ratio of population/total vehicle fleet (Table 4).
Table 2. Estimates of the Model 2 parameters (with the corresponding standard error and P descriptive levels).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard error</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_0$</td>
<td>1,49995</td>
<td>2,82804</td>
<td>0,596</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>0,02304</td>
<td>0,01013</td>
<td>0,023</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>1,87695</td>
<td>0,653028</td>
<td>0,004</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>-1,37607</td>
<td>0,70821</td>
<td>0,052</td>
</tr>
<tr>
<td>$\beta_4$</td>
<td>-0,37990</td>
<td>0,31943</td>
<td>0,234</td>
</tr>
<tr>
<td>$\beta_5$</td>
<td>-0,00945</td>
<td>0,00467</td>
<td>0,043</td>
</tr>
<tr>
<td>$\beta_7$</td>
<td>0,01057</td>
<td>0,03591</td>
<td>0,768</td>
</tr>
</tbody>
</table>

Table 3. Estimates of the Model 3 parameters (with the corresponding standard error and P descriptive levels).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard error</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_0$</td>
<td>2,26235</td>
<td>1,15281</td>
<td>0,051</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>0,02409</td>
<td>0,00952</td>
<td>0,011</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>1,86480</td>
<td>0,64798</td>
<td>0,004</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>-1,36922</td>
<td>0,70632</td>
<td>0,053</td>
</tr>
<tr>
<td>$\beta_4$</td>
<td>-0,38970</td>
<td>0,31688</td>
<td>0,219</td>
</tr>
<tr>
<td>$\beta_5$</td>
<td>-0,00989</td>
<td>0,00442</td>
<td>0,025</td>
</tr>
</tbody>
</table>

Table 4. Estimates of the Model 4 parameters (with the corresponding standard error and P descriptive levels).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard error</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_0$</td>
<td>1,93035</td>
<td>1,11444</td>
<td>0,083</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>0,02167</td>
<td>0,00913</td>
<td>0,018</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>1,67572</td>
<td>0,61380</td>
<td>0,006</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>-1,58627</td>
<td>0,68233</td>
<td>0,020</td>
</tr>
<tr>
<td>$\beta_5$</td>
<td>-0,01199</td>
<td>0,00419</td>
<td>0,004</td>
</tr>
</tbody>
</table>

Thus, the final adjusted logistic regression model (Model 4) is given by (2).

$$\hat{p}_i = \frac{\exp(1,93035 + 0,00022x_{i1} + 1,67572x_{i2} - 1,58627x_{i3} - 0,01199x_{i5})}{1 + \exp(1,93035 + 0,00022x_{i1} + 1,67572x_{i2} - 1,58627x_{i3} - 0,01199x_{i5})}. \quad (2)$$

Table 5 shows chance ratios and their respective confidence intervals (CI), calculated using confidence levels of 95%. From these results, one can conclude the attribute ‘Capital’ is, by far, the most significant. This result can be confirmed from the chance ratios and CI’s with confidence intervals of 95%.

The interpretation of the results based on the logistic regression model is as follows:

- When the demographic density increases by 100 inhabitants/km², the odds for a city to implement traffic restriction increases by 2% (with the value of the remainder of the model variables being fixed);
- An increase of one unit in the variable inhabitants/buses reduces the odds of a city implementing traffic restrictions by 1% (with the values of the remainder of the model variables being fixed);
- The odds of a city implementing traffic restrictions are 5.34 times greater when it is a state capital than when it is not (with the value of the remainder of the model variables being fixed);
• The odds of a city close to another city with traffic restrictions implementing traffic restrictions are 0.99 less than when it is not close to such a city (with the value of the remainder of the model variables being fixed).
• Increasing the ratio population/bus in one unit lowers the chance of truck ban by 1% (all other variable values kept constant).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Odds ratio</th>
<th>95% CI of the OR</th>
<th>Lower limit</th>
<th>Upper limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>1.02</td>
<td>1.00</td>
<td>1.04</td>
<td></td>
</tr>
<tr>
<td>Capital</td>
<td>5.34</td>
<td>1.60</td>
<td>17.79</td>
<td></td>
</tr>
<tr>
<td>Closeness</td>
<td>0.20</td>
<td>0.05</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>InhabB</td>
<td>0.99</td>
<td>0.98</td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>

5. Concluding remarks

The analysis of the cities with restricted roads or areas for freight vehicles revealed that these restrictions are not established only in large cities, such as São Paulo, because Novo Hamburgo, which is a relatively small city, also implemented restrictions on trucks.

The statistical model used in the present investigation allows for calculating the odds of whether the cities included in the sample would implement traffic restrictions. For instance, two state capitals, Manaus (in the Amazon region) and Aracaju (in the Northeast shore) have probabilities of 72% and 75% respectively, but have no truck bans; if they can be considered outliers, this means that any shipper or 3PL carriers should plan for such an occurrence. The probabilities of Jaboatão dos Guararapes and Gravataí implementing traffic restrictions are 5.9% and 5.5%, respectively, and indeed, neither city has restrictions on the circulation of freight vehicles.

In future studies, the logistic regression model should also be applied to the study of variables other than the IBGE data, e.g., the political party that implemented traffic restrictions in a given city, the cities’ congestion indexes, or the total road network length.

The model might also be used to explore the response variable by dividing it into two parts, i.e., one sub-variable for estimating the odds of cities implementing road restrictions and the other sub-variable for estimating the odds of cities implementing zone restrictions.

An interesting piece of information supplied by the statistical analysis relates to the number of inhabitants/number of buses, whereby the odds of a city implementing traffic restrictions decrease when the value of that ratio increases. For instance, suppose that city A has one inhabitant/bus. If the ratio were to increase to two inhabitants/bus, then the odds of city A implementing traffic restrictions would increase by 1%. Although, intuitively, one would infer that the availability of public transportation ought to reduce the odds of a city implementing traffic restrictions, the model demonstrates that the opposite case applies.

As predicting whether a city will implement restrictions on trucks is difficult, the present study provides a tool for calculating the odds of cities implementing traffic restrictions based on simple data, such as the demographic density.

References


