# Assessing the impacts of shopping centers on urban road systems

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**This paper presents a methodology designed to assess the impacts of shopping centers on urban road systems in a manner compatible with the situation in Brazil. This methodology is the outcome of an analysis of the existing procedures, stressing the development by Grando (1986) and in the USA.**

**The main reason behind this paper is the fact that US methodologies do not take into account the characteristics and requirements of Brazilian town planning and transportation entities, failing to make provision for the specific characteristics of Brazilian malls. It also briefly describes the stages constituting the proposed methodology, stressing Trip Generation and Modal Split. It is hoped that this project will help ensure more effective planning and designs for these enterprises.**

## INTRODUCTION

As shopping centers are hubs generating trips, they cause concentrated vehicular demands on the nearby road system, resulting in a series of imbalances in terms of traffic flows, parking facilities and the use of neighboring land.

In Brazil and elsewhere in the world, countless studies on this topic have been undertaken, developing various methodologies that attempt to measure the impact of shopping centers on urban road systems.

It is very important for the entities responsible for these facilities to be well aware of these impacts in order to foresee and prevent possible future traffic jams. This becomes more visible in settings lacking proper land use and transportation planning, with severe traffic problems, as normally noted in large Brazilian towns and cities. Offering a better overview of this situation, in 1970 there was only one shopping center in Brazil, while by 2001 there were 168 malls.

However, it has been noted that there is a high proportion of bus trips to Brazilian shopping centers, topping 60% in some cases, in addition to over 10% of visitors arriving on foot. This is because many Brazilian malls are located in densely populated areas, close to residential complexes with easily-available public transportation facilities. This differs greatly from the situation in the USA, where some 90% of trips to shopping centers are typically made by automobile.

These figures and their specific characteristics, in parallel with an awareness that many government entities are poorly prepared in technical terms to assess the consequences on urban road networks of new shopping centers, strengthen the need for appropriate models and procedures that are compatible with these conditions.

Consequently, the main purpose of this paper is to suggest a new structure for a traffic impact assessment methodology that is tailored to the situation in Brazil and supported by an analysis of the current methodologies found in the bibliography, based largely on the methodologies drawn up by Grando (1986), the US Department of Transportation/Institute of Transportation Engineers (1985) and the Institute of Transportation Engineers (1991). Attempts are made to deal with the technical constraints found in Brazil in terms of the lack of up-to-date research information on origins and destinations, as well as other data required for transportation planning, in addition to the technical capacities of the transportation entities dealing with this matter. Additionally, new or upgraded models or parameters are suggested for some stages of the methodology, particularly Trip Generation and Modal Split.

## KNOWLEDGE BASE

In order to achieve the purpose of this work and overcome constraints imposed by limited information, this study is supported by a broad-ranging bibliographic review, focused on malls that are members of the Brazilian Shopping Centers Association (ABRASCE). The bibliographical review was basically used to prepare the methodology and procedures associated with each stage, as well as identifying the models and parameters to be proposed and fine-tuned, whose development requires additional research.

In order to obtain the necessary data, forty-five shopping centers were selected (based on a representative sample of the total number of ABRASCE members) to whom questionnaires were mailed, with replies received from fifteen of them (approximately 33%). These materials were used to draw up the Trip Generation models.

In order to study the Modal Split at the disaggregate level, it was necessary to undertake on-site surveys, interviewing 400 users through specific questionnaires in two shopping centers in the City of Rio de Janeiro, one located in a densely-populated urban area with good public transportation facilities and the other located in a less densely-populated area with more limited transportation facilities. These malls reflect two characteristic cases, with the former more common, called respectively the 'central' and 'outlying' malls in this paper.

In order to survey the data using the Stated Preference Technique, 100 interviews were completed following a specific script, with a total of 750 interviews at the parking lot exit gate of the shopping centers, in order to define the trip categories (meaning the proportion of trips that were actually new and undertaken in function of the enterprise). Additionally, the administrators of the shopping centers were consulted, and historical series of hourly traffic flow data were analyzed in order to establish the peak period percentages compared to daily traffic.

Through the bibliographic review, five methodologies are analyzed on this topic. Two of them come from the USA: one from the US Department of Transportation/Institute of Transportation Engineers (1985) and the other from the Institute of Transportation Engineers (ITE, 1991). The remaining three are Brazilian: COX Consultores (1984), and the São Paulo Traffic Engineering Company (CET-SP, 1983), and the Grando option (1986), representing respectively the approaches adopted by consultants, government entities and universities, which are the organizations that normally use or produce these methodologies.

It should be stressed that, in contrast to Brazilian methodologies, those developed in the USA are not focused solely on shopping centers, but are used generically for new local development projects. Continuing this comparative analysis, the following aspects may be highlighted:

- The US methodologies are more broad-ranging and include important stages, but are not fully shaped to the situation in Brazil and require adaptation;
- The Brazilian methodologies are compatible with the local reality, but need fine-tuning, with broader analytical scope.
- For all available methodologies, the main concern focuses on automobile trips to the mall, neglecting other types of transportation. In the US methodologies, this is due to the high percentage of trips using this mode of transportation, reflected in Brazilian methodologies that are adaptations of the US counterparts.
- The US methodology used by the Department of Transportation stresses the study of current road traffic, carrying out a detailed analysis of the traffic conditions outside the Traffic Generation Hub (TGH) for several years after it opens.
- The Brazilian methodologies focused only on the traffic conditions during the year in which the TGH opened through a comparison of existing traffic + generated traffic with the capacity of the road system.

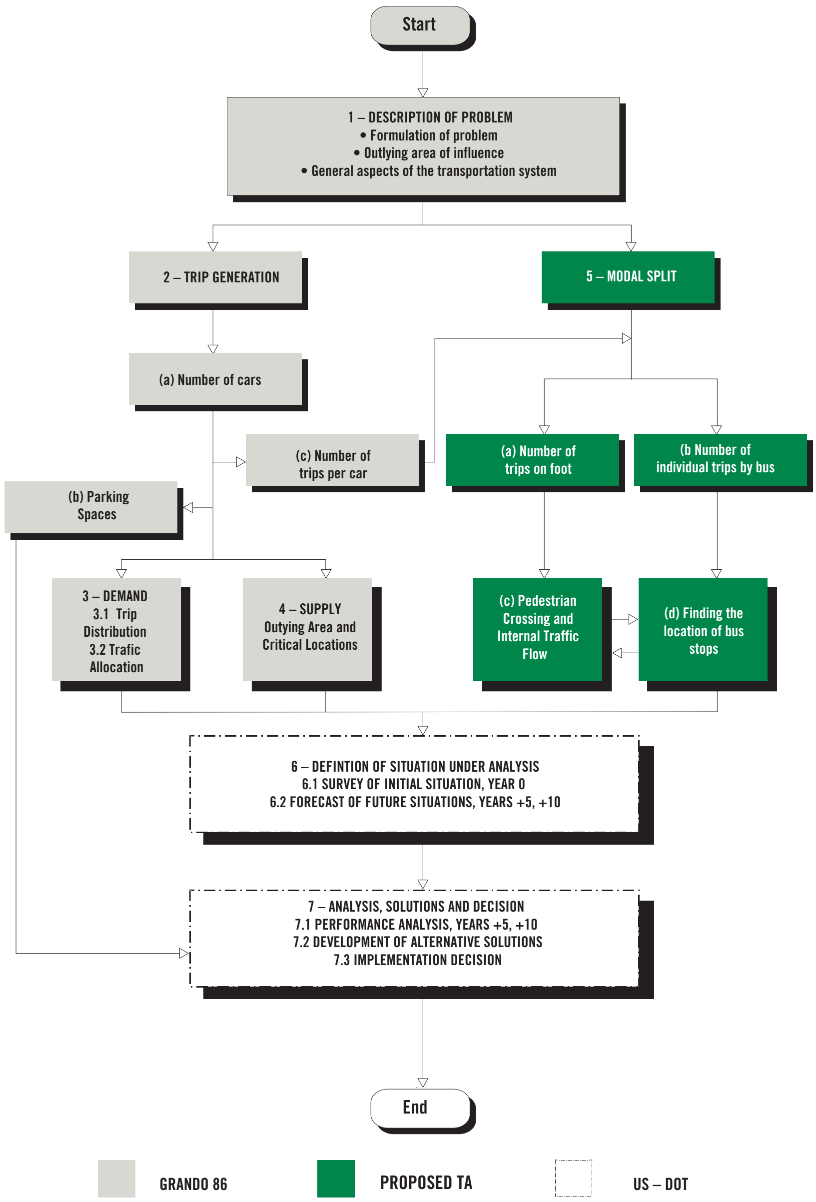


**Figure 1: Structure for analysis of the impacts of shopping centers on traffic**

## PROPOSED METHODOLOGY

The bibliographic review led to the conclusion that some important elements should be included in the existing methodology in order to forecast the impacts of shopping centers on the road system. The main aspect is the inclusion of the Modal Split stage, taking into account a specific characteristic of Brazilian shopping centers: they attract a large number of trips by bus. It was also decided to include visitors on foot as they are a significant factor in terms of traffic safety, although not accounting for such a large proportion of traffic

Fine-tuning the available methodologies results in a structure divided into seven major stages that are shown schematically in Figure 1. These stages are described briefly below, stressing Trip Generation, Trip Distribution (Demand) and Modal Split, offering more detailed contributions and suggestions for upgrades in terms of models, procedures and parameters.

### 1 – Description of the problem

This consists of defining the elements that constitute the problem within their context and generally related to the purposes of the study. During this process, it is usually necessary to establish the location of the shopping center to be built, its size, the planned number of parking spaces and other relevant characteristics. The definition of its area of influence when not available, in the market studies, is based on travel time and distance criteria, as well as the location of competing shopping areas. The road network and public transportation system are also studied in order to meet the additional demands generated by the mall. (see Hsu, 1984).

### 2 – Trip Generation

The vehicular traffic should be generated according to the Project Day defined by Grando (1986) as a typical average Saturday and Friday under the conditions of a representative week of the year. As Saturday is usually the busiest day for malls, it is taken as the benchmark for sizing the parking area and other internal facilities. As Friday is usually the second-busiest day with more intensive external traffic that results in more critical conditions, it is used to estimate the impacts on the road system. In both cases, the average flow noted on these two days is calculated, covering the entire year.

After several attempts and statistical tests, traffic generation models were produced reflecting the daily flow of vehicles for an average Saturday (SatFlow) in function of the Gross Leasable Area (GLA):

**For 'central' malls in general:**

*SatFlow= 2057.3977 + 0.3080 GLA* (1)

*Where:* $R^2 = 0.7698$; $R = 0.8774$; *Test* $t = 4.839 > tmin = 2.365$ *for* $g = 7$ *and* $a = 0.025$ *(95%). Estimated standard error = 2783.6*

**For 'central' malls with supermarket:**

*SatFlow = 1723.73 + 0.3054 GLA* (2)

*Where:* $R^2 = 0.8941$; $R = 0.9456$; *Test* $t = 5.032 > tmin = 3.182$ *for* $g = 3$ *and* $a = 0.025$ *(95%). Estimated standard error = 2192*

For 'outlying' malls with or without a supermarket, it is not possible to prepare a specific model due to limitations on the data obtained. However, the use of the model proposed by Grando (1986) is recommended:

*SatFlow = -2066.64 + 0.3969 GLA* (3)

*Where:* $R^2 = 0.785$; $R= 0.886$; *Test* $t = 5.72 > t\ min = 1.83$ *(95%)*

With regard to the average Friday traffic flows, the following relation was found:

*Average Friday traffic flow/Average Saturday traffic flow = 0.74*

The study of the peak period traffic flow percentage compared to the daily level produced the results given in Table 1, for 'central' type malls. For the 'outlying' shopping centers, the value defined by Grando (1986) is recommended, equivalent to 10.5%.

Based on the suggested Trip Generation model (Equation 1, 2 or 3) and the peak period percentage given in Table 1, the number of peak period automobile trips is obtained, generated by the shopping center. This same Trip Generation model gives the number of individual trips by automobile when multiplied by an index representing the average number of people in each automobile, taken as being 2.8.

The number of peak period automobile trips multiplied by the average time automobiles remain in the parking lot gives the minimum number of parking spaces required. The study carried out by Goldner (1994) suggests an average parking time of 1.92 hours on Saturday and 1.76 hours on Friday. Other factors may be taken into account (see Steiner, 1998) such as considering employment in the parking lot sizing simulation (Gonçalves, 1990; Brasileiro, 1999). For the purpose of forecasting impacts on the road system, the derived Friday hourly flow, should be reduced, bearing in mind that only part of this consists of new trips to be added to the existing traffic. Goldner (1994) suggests that this portion represents 43% - 48% of the total flow of automobiles generated by the mall.

## 3 – Demand

This stage consists of trip distribution and generated traffic allocation.

For trip distribution, it is suggested that the gravity-based model constant be used, noting that the value of the constant 'b' appearing in the model (Equation 4) normally reaches values of less than 1. Table 2 gives the figures found for isochronic trip distribution values by type of shopping center.

**Table1 : Peak period percentage**

| Week Day | Peak Period | Percentage |
|---|---|---|
| Friday | 18:00 – 19:00 h | 9.88% |
| Saturday morning | 11:00 – 12:00 h | 8.29% |
| Saturday afternoon | 18:00 – 19:00 h | 8.98% |

**Table 2: The figures found for isochronic trip distribution values by type of shopping center.**

| Isochrone Duration | Central Shopping Center | Outlying Shopping Center |
|---|---|---|
| Up to 10 minutes | 48.3% | 55.4% |
| 10 - 20 minutes | 20.1% | 36.2% |
| 20 - 30 minutes | 18.3% | 7.2% |
| More than 30 minutes | 13.3% | 1.2% |

The suggested procedure for the trip distribution stage is the following (TRB, 1978):

1. divide the area of influence into quadrants, centered on the mall;
2. number the traffic zones by quadrant according to the available isochrones;
3. calculate the resident population by traffic zone, which is normally obtained through the population distribution by district for the city in question;
4. through a mobility rating, calculate the number of shopping trips generated by each zone;
5. estimate the total number of trips attracted by the shopping center through the suggested Trip Generation models (Equation 1, 2 or 3).
6. apply the gravity-based model consisting of the following steps:

i) Calculate the accessibility index of sector 's' of the area of influence (xs)

$$xs = \sum \frac{AB}{tsB^b} \quad (4)$$

*Where: B = isochrone; AB = trips attracted by isochrone B within sector 's'; b = exponential constant for the gravity based model – function of the purpose of the trip, in this case b=3 ;ts = travel time from the zone center to the shopping center*

ii) Calculate the trips generated by the shopping center (origin i) for sector 's' (by geographical orientation) (Tis):

$$Tis = \frac{Pi \bullet xs}{\sum xs} \quad (5)$$

*Where: Pi = trips generated at origin 'i'*

iii) Calculate the trips generated by the shopping center (origin i) for each 'B' time isochrone within study sector "s" (attenuation effect) (Tis,B)

$$Tis, B = \frac{\dfrac{Pi \bullet AB}{tsB^b}}{\sum xs} \quad (6)$$

Moving onto the traffic allocation stage, one of the available methods is used, such as 'All or Nothing', allocating the existing traffic together with the traffic generated in the region around the shopping center or the critical area. Provided that they are available, computer programs may also be used during this process, such as EMME/2, TRANPLAN, TRANSCAD, SATURN, TRIPS, CONTRAM, CORSIM and INTEGRATION.

## 4 – Supply

The supply includes outlining the critical area and critical location. A critical area is defined as being that located around the shopping center on which the traffic converges. The critical points are intersections, crossroads and stretches of roads within the critical area that are rated as potentially sensitive to the probable impacts caused by the shopping center and that are consequently covered by traffic studies. The number of critical locations selected for analysis also depends on the availability of resources for carrying out the necessary surveys and procedures.

## 5 – Modal Split

The Modal Split stage is dealt with differently from other stages, as it is an important factor in the contribution offered by this paper, and was studied in depth through aggregated and disaggregated approaches.

### Aggregated Models

i) Calculation of the probability of selecting the car for a trip to the shopping center (PROCAR)

$$LnPROCAR = -8.8611 + 2.2504\ LnAINCOME + 0.5504\ LnNPGLA \quad (7)$$
$$(5.534) \qquad\qquad (3.145)$$

*Where: Ln = Neperian logarithm ; AINCOME = average income of the shopping center consumer; NPGLA = number of parking spaces divided by the Gross Leasable Area (GLA) of the shopping center.*

*Where: t min = 2.776 for g = 4 and a = 0.025 (95%); R2 adjusted = 0.8730; R2 = 0.9153; R multiple = 0.9567*

ii) Calculation with probability of selecting a bus for the trip to the shopping center (PROBUS)

$$LnPROBUS = 9.8274 + 0.4030\ Ln\ EMPROYEE - 3.2929\ Ln\ AINCOME - 0.0520 LnDIST \quad (8)$$
$$(2.517) \qquad (-6.538) \qquad (-2.572)$$

*Where: Ln = Neperian logarithm; EMPROYEE = number of shopping center employees; AINCOME = average income of the shopping center consumer; DIST = distance from the shopping center to the center of town*

*Where: t min = 1.886 for g =2 and a = 0.10 (80%); R2 adjusted = 0.9020; R2 = 0.9608; R multiple = 0.9802*

It is felt that the preceding models should be used only for preliminary studies, as the disaggregate models are recommended for the definitive studies.

### Disaggregated Models

These models were obtained through calibrating the LOGIT Multinomial model with data obtained on-site through interviewing users at two shopping centers in the City of Rio de Janeiro, as already mentioned. The final specifications of the model are presented below.

*Where: U car = b1 TT1 + b2C/I1 + b3D; U bus = b1TT2 + b2 C/I2U on foot = b1TT3 + b2 C/I3*

*Where: TT = travel time; C/I = travel cost / family income; D = Dummy variable: is there an automobile in the home? Yes = 1 No = 0*

After calibration, the models were drawn up. As shown, all the variables in the three proposed models run through the t statistical Test, which assumes the critical value of 1.96 for the level of confidence of 95%, with the exception of the model for the 'central' shopping center, where the cost/income variable shifts to a level of confidence of over 90%, with a critical t of 1.645.Looking at the signs, the trip time and cost/income variables present negative coefficients as expected, as they are 'non-utility'; the dummy variable posted a positive value, also as foreseen.

These *r2* values are better for the 'outlying' shopping center model, and for 'both shopping centers', although the *r2* value for the 'central' shopping center is still acceptable.

It is felt that one of the reasons for the differences between the 'central' and 'outlying' models – particularly in terms of the cost/income variable ratio – is the fact that the latter

**Tables 3,4 and 5: The specifications of the LOGIT model.**

| Coefficients | b1 | b2 | b3 |
|---|---|---|---|
| **Variables** | TT | C/I | DUMMY |
| **1- Car** | TT1 | C/I1 | D |
| **2- Bus** | TT2 | C/I2 | 0 |
| **3- On foot** | TT3 | C/I3 | 0 |

| VARIABLE | SHOPPING CENTER | | | |
|---|---|---|---|---|
| | CENTRAL | | OUTLYING | |
| | Coefficient | Test t | Coefficient | Test t |
| Travel Time | -0.03083 | -4.7 | -0.03124 | -3.9 |
| Cost/Income | -0.1611 | -1.9 | -0.3301 | -3.9 |
| Dummy | 0.8663 | 3.9 | 1.623 | 6.7 |
| r2 | 0.2590 | | 0.4734 | |

| VARIABLE | FOR BOTH SHOPPING CENTERS | |
|---|---|---|
| Travel Time | -0.03043 | -6.1 |
| Cost/Income | -0.2349 | -4.0 |
| Dummy | 1.223 | 7.6 |
| ρ_ | 0.3580 | - |

charges a parking fee, which increases the cost considerably compared to family incomes for this case.

For the 'both shopping centers' model, it was noted that its values fall between those produced by the 'central' and 'outlying' models, which was expected.

## RESULTS OF MODEL APPLICATION

With the Transportation Selection model defined through the Utility Function, the probabilities can be calculated for the different modes of transportation through the following formulas:

$$\Pr ob(car) = \frac{e^{Ucar}}{e^{Ucar} + e^{Ubus} + e^{Ufoot}}$$

$$\Pr ob(foot) = \frac{e^{Ufoot}}{e^{Ucar} + e^{Ubus} + e^{Ufoot}}$$

$$\Pr ob(bus) = \frac{e^{Ubus}}{e^{Ucar} + e^{Ubus} + e^{Ufoot}} \quad (11)$$

With the probabilities associated with the modes of transportation using the rule of three, the individual bus trips may be calculated (*Xb*) and on foot (*Xf*).

| | |
|---|---|
| *prob (bus)* | *Xb* |
| *prob (car)* | *Number of individual car trips* |
| *prob (on foot)* | *Xf* |
| *prob (car)* | *Number of individual car trips* |

In order to obtain the number of hourly trips by bus and on foot, it is necessary to know the peak hour percentage corresponding to individual trips by bus and on foot, which was not possible during this project. Once the hourly demand values have been established for bus trips and on foot, the pedestrian crossings can be sized, as well as internal circulation facilities and bus-stops.

#### Survey of the Current Situation – Year Zero

Having defined the critical points of the road system, a survey is carried out of the field data from these locations, including classified traffic counts, as well as movement analysis, surveys of bus stops, the timing traffic lights for vehicles and pedestrians, the typical characteristics of the roads etc. Based on these data, the capacity of the road system element is calculated, using the traditional traffic engineering methods.

**Projecting the current situation through to Years +5 and +10**
Early attempts to apply the methodology showed that merely completing the assessment for the year in which the shopping center opens is insufficient, as studies should be extended to cover subsequent years.

As medium and long-term planning is difficult in Brazil, due to limited data and uncertainties caused by government policies in general and the transportation sector in particular, and also based on the experience of consultants in this field, it is felt that a period of ten years offers an adequate overview of the problems that may be caused by opening a mall. According to these specialists, after ten years in operation, it is usual for the shopping center to undergo across-the-board renovations in parallel to upgrading its transportation facilities.

The accuracy of this forecast depends largely on the traffic, transportation and land use data available from government entities in the city where the mall is being built.

## CONCLUSIONS

In general this proposed new methodology offers a broader and more accurate overview of the impacts of shopping centers on road systems. Improvements will help ensure that these estimates are closer to the real situation at various stages, as proven through cases where the methodology has been already applied.

In order to provide upgrades during the current stages and lead to fresh phases, a significant volume of data was used at the global level, based on the universe of Brazilian shopping centers, as well as at the more local level, stressing the differences between 'central' and 'outlying' malls.

The Modal Split stage is studied in depth, offering a better understanding of traffic and transportation aspects related to the shopping center. This also helps estimate the circulation of people in the mall and handle the resultant impacts inside the mall as well.

Some aspects have not been covered, which is to be expected, and will be analyzed in subsequent research projects. Particular reference is made to the study of the peak hour percentages for bus trips and on foot, the proportion of new trips, and the growth rate in the demand for trips to the shopping center over time.

Allied to the common sense of transportation planners, this sequence of stages will offer a better understanding of the many different factors that shape the decision process on whether or not to build shopping centers on sites rated as critical in terms of road system capacities.

In terms of some limitations of the proposed methodology, it is stressed that it was based on malls that are members of the Brazilian Shopping Centers Association (ABRASCE) whose characteristics tends to be similar in terms of the distribution and nature of their tenant stores, although located in different urban areas and built in many different sizes.

Consequently, it is necessary to analyze the area of influence of the shopping center and compare its characteristics with those for which the models were proposed, in order to estimate demands generated by future enterprises.

In general, the models presented were developed for major urban centers and require critical analysis and common sense for applications in other contexts.

The proposed methodology does not include an analysis of the alterations that take place in land use around the shopping center under study, which should also be included for future applications, as well as suggesting further improvements.

For Brazilian towns and cities with severe traffic and transportation problems today, the existence of an easy-to-use methodology offers a powerful tool for government authorities, streamlining the management of problems related to the implementation of shopping centers in the urban road network, as well as other traffic generation hubs, for which this methodology may serve as a basis, requiring only the adaptations inherent to each case.

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