A CAUSAL MODEL RELATING URBAN SPRAWL WITH ACTIVITY-BASED TRAVEL PATTERNS

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ABSTRACT

The objective of this study is to analyze the relationship of the spatial effects between urban sprawl and activity-based travel patterns through modeling structural equations. The theoretical structure of "Activity-Based Travels of Urban Sprawl – ABTUS" is grounded in three latent constructs: i) space production; ii) socioeconomic characteristics; iii) transportation system accessibility. This model was tested in a 2000 Brasilia – Distrito Federal case study. Five sprawling vectors have been identified, and the most representative travel patterns are based on a sequence of activities, i.e. Home – Work and Work – Home. Evidences of a relationship between sprawl and activity-based travel patterns were confirmed through the obtained results.

Keywords: urban sprawl, activity-based travels, structural equation modeling.

INTRODUCTION

Transportation is essential for people´s social and economic well-being, and it is related to economic development of cities, especially in developing countries (Zhao, 2010). The fast process of urban sprawl provokes changes in transportation, creating new travel patterns, such as the increase of motorized trips and of travel distances (Gakenheimer, 1999; Kenworthy, 1995).

It is noticeable that North American, Asian, and European realities present sprawl patterns that are different from the Latin America´s reality (Cervero, 2004). The lack of public policies, urban plans, and effective controls in the majority of the cities end up creating chaotic urban sprawls that impact the quality of life of citizens (Ewing, 1997). Few Brazilian cities could integrate a controlled urban sprawl to an efficient transportation system, as for example, the case of Curitiba city in the state of Parana, Brazil (Vasconcellos, 2005).

According to Giuliano and Narayan (2003), the relationship between urban sprawl and urban mobility patterns varies accordingly to the context and conditions of cities. This can be seen, for example, when one studies the relationship among population density, dependency on private transportation, and use of public transportation.

This is not so easy to define the relationship between urban sprawl and urban transportation because there is no unique or common understanding about this theme. Urban sprawl does not mean solely a quantitative process of territorial expansion and population density dispersion, it also includes qualitative changes in the urban environment (Castells, 1974). Based on the spatial organization scenario, it is correct to assume that transportation is an important element that interacts not only with quantitative, but also with qualitative factors of the urban system, influencing and being influenced by the urban sprawl process (Cervero, 1998).

For Ewing (1997) and Cervero et al. (2011), urban sprawl has an important influence on the development of transportation, especially in relation to demand generation, travel time, and mode choice. Besides, public policies and investments in transportation, as a way to improve the infrastructure and provision of urban services for public transportation, may guide the urban sprawl.

In this study, sprawl pattern is defined as the set of spatial factors, land use, and socioeconomic characteristics within an environment of spatial production and socioeconomic configuration that frequently occur in relation to urban sprawl processes, whereby the set of spatial factors and socioeconomic characteristics deal with each other and find their own outcomes.

Urban sprawl and transportation

Urban sprawl patterns (suburban dispersion and the establishing of polycentric metropolis) tend to augment the trip distances, generating a higher dependency on private transportation and, consequently, increasing the costs to operate public transportation. Besides, the provision of urban public transportation services becomes inefficient, considering that the demand for urban public transportation is low; the distribution of the demand over the territory is high; and, the increase of the distribution of destinations is caused by the suburbanization of areas that generate employment (Cervero, 1989; Cervero and Kockelman, 1997; Newman and Kenworthy, 1999).

The first factors to be linked to travel patterns are population density and its distribution over the urban area. Low population density and population dispersion create higher dependency on the usage of private transportation (the individual's own vehicle) and generate long-distance trips. High population density and its concentration provoke shorter trips and usage of non-motorized modes of transportation (walking, biking, etc.) and/or usage of public transportation (Friedman et al., 1994; Steiner, 1994; Duany et al., 2000; Cervero, 1998). For Cervero and Kockelman (1997) and Ewing (1997), the major impacts on travel patterns, besides the socioeconomic factors, occur in reason of three sprawl conditions, which are: the density (or concentration, increase, and population or household distribution); diversity (which is the mix land use and urban occupation); and the urban shape (or the mix land use and urban occupation).

Urban sprawl factors directly related to density (especially low densities) and with a diversified land use (residential vs. industrial) have a causal influence on the travel patterns formation (Frank and Pivo, 1994; Camagni et al., 2002; Ewing et al., 2002; and Travisi et al., 2010).

In this situation, some empirical modelings have been developed to improve the understanding of the relationship between urban sprawl and the observed travel patterns. The majority of the researches are related to European, Asian, and North American countries. A comparative study between the U.S. and England was conducted by Giuliano e Narayan (2002). The objective of their study was to compare how the factors of the urban sprawl format influenced the travel patterns, beyond the socioeconomic factors. Travisi et al. (2010) empirically analyzed the relationship between urban sprawl and the daily work trip within seven Italian urban areas. The modeling of relationships between the spatial development and the explanatory factors related to change in urban density were analyzed through multivariate techniques of regression of cross-sections. Schwanen et al. (2001) analyzed the impacts of monocentric and polycentric urban structures in the mode choice and travel distance for diverse activities in different cities of Netherlands. Logistic regression models and multivariate regression analysis models were utilized to establish the relationships among the variables. Working with a specific study, García-Palomares (2010) analyzed the relationship between urban sprawl and work trips within Madrid’s metropolitan area. Multiple linear regression models have been built to analyze the relationship between urban sprawl factors and mobility.

The applied approaches just represent the relationship between urban sprawl and travel patterns in a linear condition among the explanatory variables. What this means is that those variables act in an independent way among them and follow a linear tendency that explains the demand for trips. In reality, however, the variables do not act upon the behavior for travel demand in a direct and linear way. In fact, they are explanatory of processes that interfere with the generation of activity-based travel patterns.

This study aims to model the relationship between urban sprawl and activity-based travel patterns, considering the urban sprawl as a set of interdependent latent constructs that intervene in the generation of travel patterns through the utilization of structural equation modeling.

The current study is organized as follows: the upcoming section will present the conceptual antecedents, which is the base for the initial model. The general description of the method and the data utilized in this study will follow. The adjusted model, which adjusts itself with the data, and the analysis of the results from the model are then presented. Finally, the study's conclusion is presented and discussed.

HYPOTHESIS AND THE CONCEPTUAL MODEL

In order to define the model, we consider three exogenous latent processes of the demand for trips behavior that explains the activity-based travel patterns. These processes are distinct and separated from each other but they keep an interdependent relationship through interacting simultaneously in the generation of travel patterns for types of activities. Figure 1 illustrates the conceptual structure of the model, which is also the initial basis for the specifications of the model within the structural equation modeling (SEM).

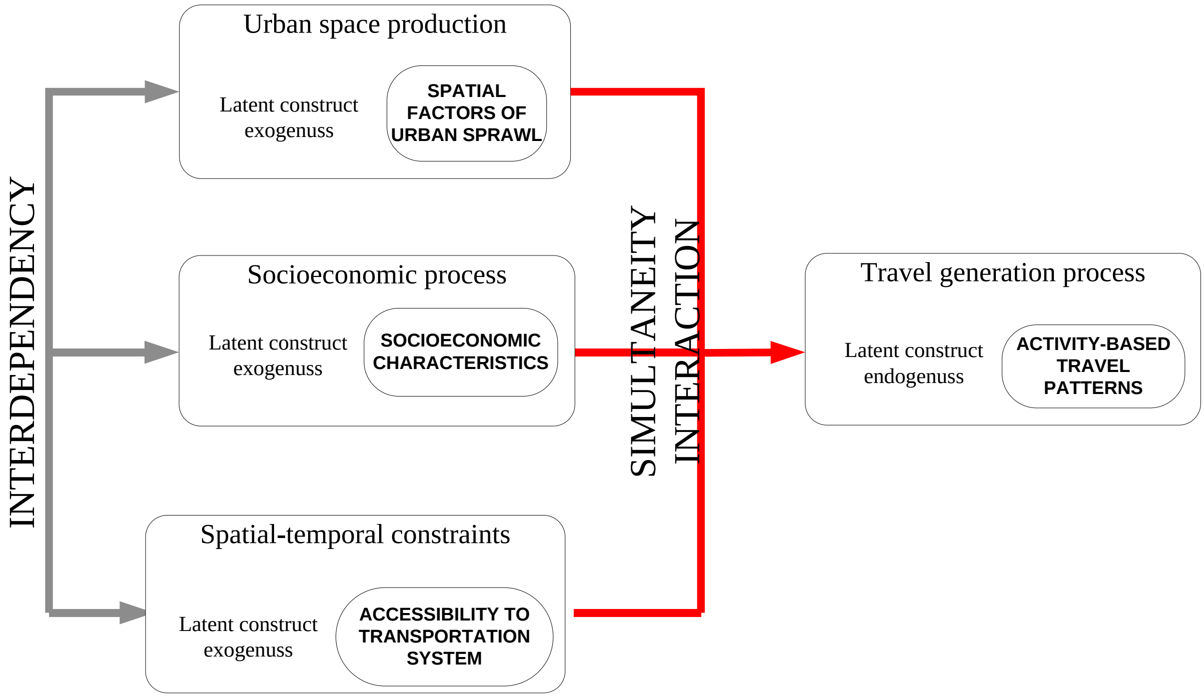


Figure 1 – Conceptual structure of the relationship between urban sprawl and the activity-based travel patterns

Considering the proposed conceptual structure, the model formulation is based on the assumption that the spatial factors of urban sprawl (FEXU – Fatores Espaciais da Expansão Urbana) are directly linked to generation of activity-based travel patterns generation (GVA – Geração de Viagens por Atividade). Socioeconomic characteristics (CSE – Características Socioeconômicas) of individuals are also directly related to generation of travels. Accessibility to transportation systems (AST – Acessibilidade ao Sistema de Transporte) is directly related to generation of travels as well.

The model is defined as follows:

$$FEXU \rightarrow GVA; CSE \rightarrow GVA; AST \rightarrow GVA \tag{1}$$

The spatial factors of urban sprawl influence the travel demand, and this influence can be understood as a relationship of causality. However, those factors do not act directly, but through a latent construct denominated “spatial factors of urban sprawl” (FEXU – Fatores Espaciais da Expansão Urbana). Since each urban sprawl differs from each other, the developmental dynamics is also different among them. Therefore, the activity-based travel patterns are distinct for each urban sprawl.

The causal relationship of the socioeconomic factors over the travel demand is widely discussed in the literature (Maat and Timmermans, 2009). These factors also vary for each urban sprawl, indicating that socioeconomic configurations are also subject to a dynamics that acts distinctly to each urban sprawl. Therefore, this relationship of influence is understood through the latent construct designated “socioeconomic characteristics.”

The accessibility varies according to each pattern of urban sprawl, and this is because the spatial and temporal factors are distinct for each urban sprawl. Thus, the accessibility to transportation system is a latent construct which relates to generation of travel patterns per types of activities.

Considering the relationships presented thus far, one can assert that the generation of activity-based travel patterns is a function of spatial factors of urban sprawl, socioeconomic characteristics, and accessibility to the transportation system, as is represented in Equation 2.

$$GVA = f\{FEXU, CSE, AST\} \tag{2}$$

DATA AND METHOD

Structural equation modeling (SEM)

Structural Equation Modeling (SEM) is a technique that deals with a vast number of endogenous and exogenous variables, as well as latent variables (non-observed) specified as linear combinations of observed variables. The exogenous latent variables are measured through indices whose values have been collected. The endogenous latent variables are also measured through indices, but indicate regression relationship with the exogenous latent variables. The method is confirmatory, not exploratory, because the modeler must propose a model in relation to a system of unidirectional effects whereby a variable impacts another (Golob, 2008), as can be seen in Equation 3:

$$\eta = \alpha + B \cdot \eta' + \Gamma \cdot \xi + \zeta \tag{3}$$

Where:
η = Vector that represents the endogenous latent variables and has mx1 order;
η' = Vector that represents the endogenous latent variables measured by indices and has mx1 order;
B = Matrix of coefficients of m x n that relates the n exogenous factors with the m endogenous factors;

Γ = Matrix of coefficients of m x m that relates the m endogenous factors with each other;
ξ = Vector of nx1 order, and it represents the n exogenous latent variables;
ζ = Vector of residues of mx1 which represents the errors in the equation that relates η and B;
α= Vector of intercepts.

$$X = \tau_x + \Lambda_x \cdot \xi + \delta \qquad (4)$$

$$Y = \tau_y + \Lambda_y \cdot \xi + \varepsilon \qquad (5)$$

The goal of the SEM model is to estimate the coefficients of the linear equations 3, 4, and 5, in which:
τ_x and τ_y = represent the vector of the intercepts;
δ and ε = the vectors of measurement errors;
ζ = the vector of residues of the structural model;
Λ_x and Λ_y = the matrices of coefficients of impact of variables ξ on X and η on Y;
Γ e B = the matrices of coefficients of direct effect of ξ on η and of the interrelations between the endogenous constructs (η).

Instead of the exploratory method, the confirmatory method is utilized. This is because the modeler has to build a model in relation to a system of unidirectional effects whereby a variable impacts another (Golob, 1990). For its wide application in the behavioral science, the utilization of SEM as a tool for modeling is already very promising in what concerns capturing behavioral intentions, current behavior, and specification of tests of alternatives of causality relationships in travel behavior (Golob, 2008).

Sample: the urban context of the Federal District

Paviani (2010) explains the process of conception of the Federal District (DF – Distrito Federal, Brasilia, Brazil). Brasilia, the DF's capital, was outlined under strict principles of a rational and modernist project, conceived by Lúcio Costa and Oscar Niemeyer, during Juscelino Kubitschek's presidency in the 1960 (Figure 2). Brasilia has a population of 2,570,160 inhabitants, according to 2010 Demographic Census (IBGE – Brazilian Institute of Geography and Statistics), and, in 2000, Brasilia had a population of 2,051,146 inhabitants (Paviani, 2010). The city presents a polynucleous structure, with the "Plano Piloto" (Pilot Plan) as the center and with administrative regions (the satellite towns) located outward the lake Paranoa's basin, an idea that guided the restrictive policies of population settlements within the DF territory. At the beginning of the 90's, conflicts of territorial occupation of the DF intensified due to population increase and lack of housing offers, which has made the DF population to be segregated spatially from the central areas. Thus, in the Administrative Regions (RA or satellite towns) of the DF there have been developed urban settlements in the peripheral area of Brasilia.

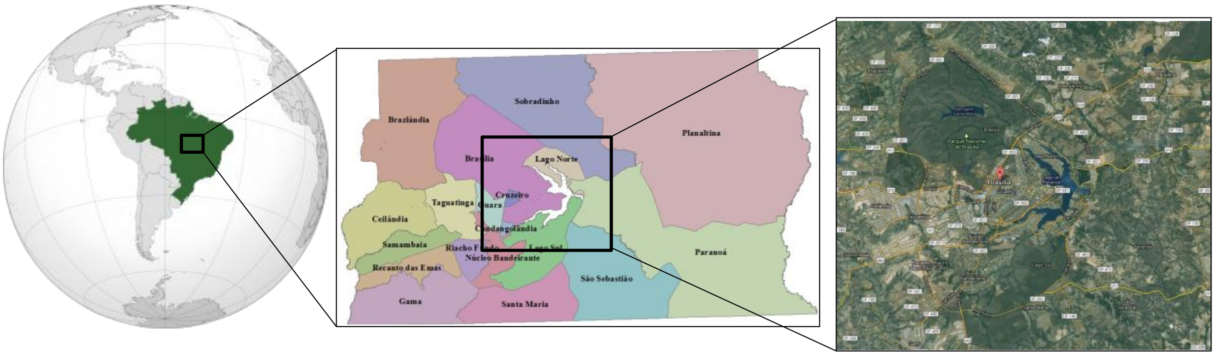


Figure 2 – Brazil, Distrito Federal, Brasília

Data from 2000 Household Survey O/D (Pesquisa Domiciliar O/D 2000) and information related to characteristics of the urban space of the Federal District in 2000, georeferenced traffic zones and satellite images from the Federal District (DF) obtained through Geographic Information System (GIS) have been utilized in this study. As criteria for selection of traffic zones and identification of urban sprawl vectors, the following has been considered:

- First, only traffic zones within the reach of identified axels have been selected.
- Second, only traffic zones with residential density within their attributes have been selected. The traffic zones with residential density equals zero have been rejected.

Consequently, the traffic zones and the axis of expansion of the Federal District in the year 2000 have been inserted in a sole GIS environment of Anjos's analysis (2010). The overlap of layers facilitated the selection of traffic zones in order to identify the urban sprawl vectors utilized in the analysis. As a result, 5 vectors of urban sprawl have been identified: i) Vector 1: Sobradinho; ii) Vector 2: Planaltina; iii) Vector 3: Taguatinga-Ceilandia; iv) Vector 4: Taguatinga-Samambaia; and v) Vector 5: Gama.

Thus, Figure 3 presents the formed vectors of urban sprawl in the DF.

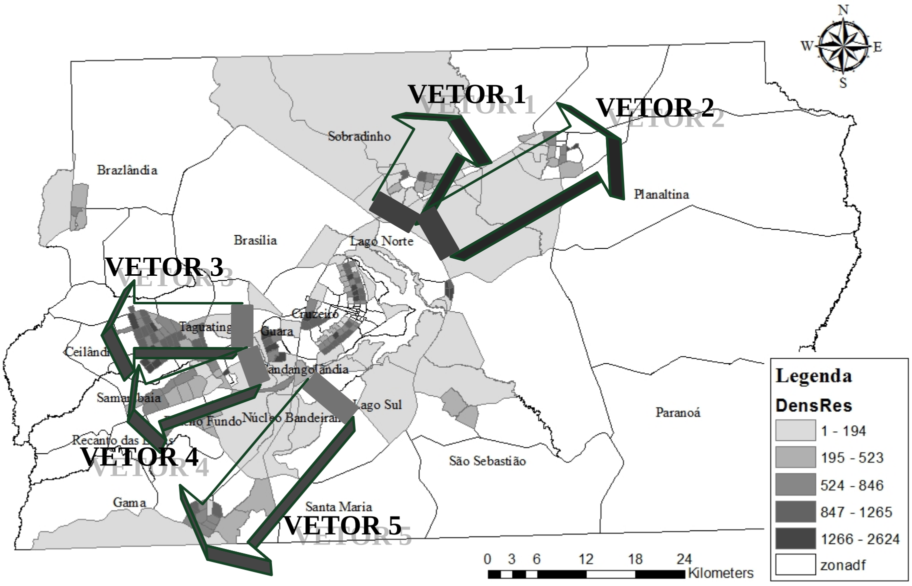


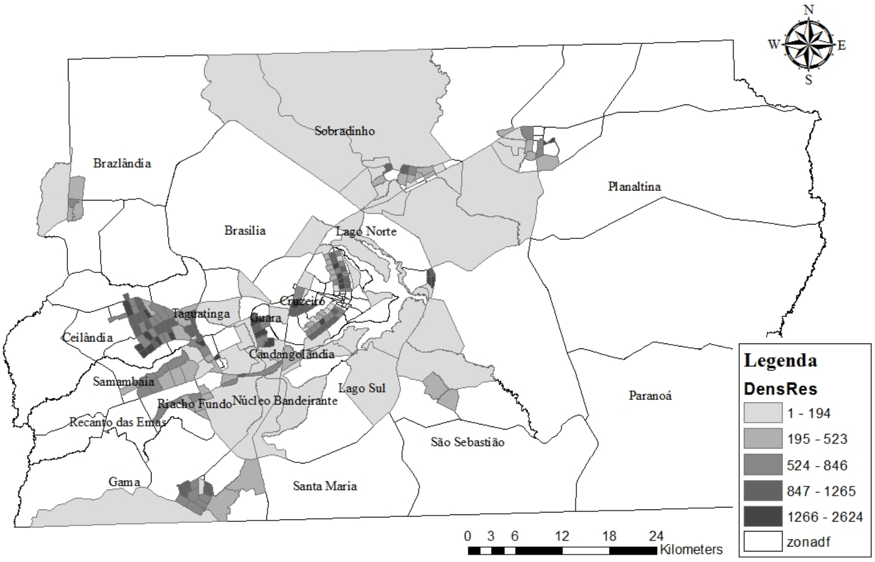
Figure 3 – Vectors of urban sprawl

Variables

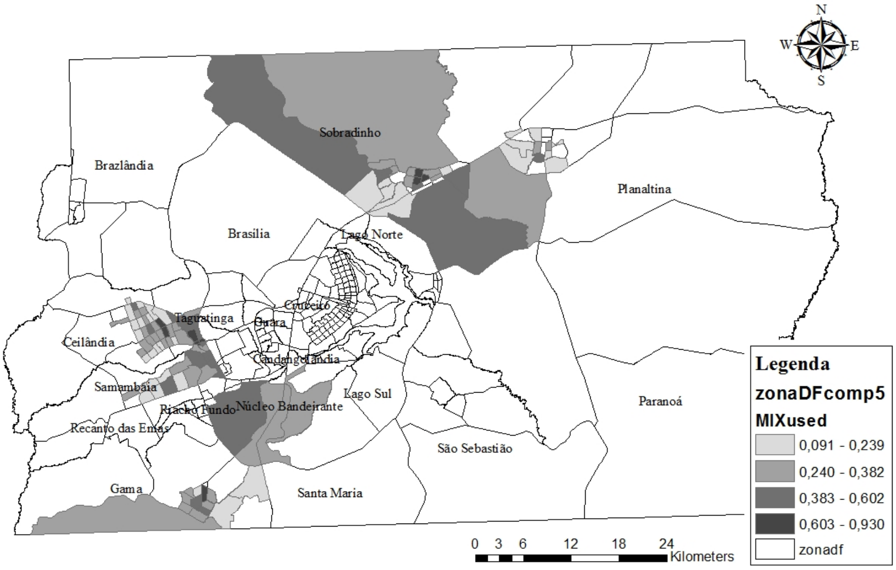
The database containing the traffic zones has been classified by urban sprawl vectors in a total of five: the first with 18 traffic zones that produce a total of 362,645 trips; the second with 15 traffic zones that produce 286,386 trips; the third with 42 traffic zones that produce 2,197,066 trips; the fourth with19 traffic zones that produce 871,705 trips; and the fifth with 17 traffic zones that produce 842,044 trips. Based on these urban sprawl vectors, the indicating variables for latent constructs have been proposed.

Spatial factors of urban sprawl: as indicating variables there have been utilized the residential density (DENR) and the mix land use density (MIXUS). Figure 4a shows the spatial distribution of residential density per traffic zone within the DF split in 5 classes. Besides the "Plano Piloto", there is a concentration of high density zones in the Taguatinga-Ceilandia axle, whose axle forms the expansion vector 3. The vectors 1 and 2 present the lowest density.

In the case of the mix land use (MIXUS) density indicator, figure 4b presents the spatial distribution of this variable in the traffic zones selected for expansion vectors split in 4 classes: i) values in between 0.091 and 0.239; ii) 0.240 and 0.382; iii) 0.383 and 0.602; and iv) 0.603 and 0.930.



(a)



(b)

Figure 4 – Thematic map (a) of the residential density in the Federal District, year 2000, and (b) of the MIXUS distribution in the selected traffic zones.

Socioeconomic characteristics: For the vector for socioeconomic factors the aggregate indicating variables per traffic zones have been used as follows: i) number of families owning two or more vehicles (Nfam_2car), ii) number of families whose monthly income is above 20 minimum wages (Nfam_r20sm). Table 1 presents the descriptive parameters of the indicating variables grouped by urban sprawl vector.

Accessibility to the transportation system: The indices utilized are: i) total length of the road network per traffic zone (*Longred*); ii) accessibility index based on the matrix distance among traffic zones' centroids (*IndAcc*). Table 2 demonstrates the descriptive statistics of the indicating variables of accessibility of the transportation system corresponding to each urban sprawl pattern.

Table 1 – Indicating variables of socioeconomic characteristics

Variable	Number obs.	Average	Minimum	Maximum	Std.dev
Nfam_r20sm					
Vector 1	18	1,193.00	0	8,130.00	1973.60
Vector 2	15	379.66	0	1,384.00	475.02
Vector 3	42	1,318.50	0	8,569.00	1839.95
Vector 4	19	1,327.05	0	8,923.00	2227.02
Vector 5	17	1,919.47	0	7,453.00	1917.27
Nfam_2car					
Vector 1	18	2,705.27	0	11,174.00	2,787.55
Vector 2	15	796.80	0	2,568.00	811.64
Vector 3	42	3,459.11	0	10,456.00	2,841.15
Vector 4	19	2,151.31	0	7,187.00	1,794.94
Vector 5	17	3,650.94	0	8,876.00	2,624.31

Table 2 – Indicating variables of accessibility to the transportation system

Variable	Number obs.	Average	Minimum	Maximum	Std.dev
Longred (Kilometers)					
Vector 1	18	8.75	0.98	59.99	14.16
Vector 2	15	10.33	1.71	46.42	11.88
Vector 3	42	4.60	1.03	10.13	2.28
Vector 4	19	5.67	1.45	11.97	2.47
Vector 5	17	11.62	3.32	25.53	8.03
IndAcc (Kilometers)					
Vector 1	18	410.30	286.90	476.30	51.68
Vector 2	15	240.10	109.20	469.60	133.30
Vector 3	42	307.60	148.90	501.00	108.50
Vector 4	19	374.40	260.20	508.60	96.17
Vector 5	17	395.40	188.50	480.20	103.10

Activity-based travel patterns: The patterns H - W (Home – Work) and H – S (Home – School) represent the majority of trips made in the vectors, considering the household as the initial point (base) (Table 3). The pattern H – W presents the major percentages of urban trips for vectors 1, 2, and 3. In the case of the vectors 4 and 5, the pattern H – S presents the major percentages.

Table 3 – Frequency of activity-based travel patterns

Activity-Based travel patterns		Number of trips	(%) Related to the total of trips based on residence (H) per vector
Vector 1	HW	204,723	52
	HS	192,084	48
Vector 2	HW	203,031	51
	HS	198,082	49
Vector 3	HW	1,058,349	51
	HS	1,035,170	49
Vector 4	HW	445,092	45
	HS	543,114	55
Vector 5	HW	453,969	46
	HS	542,894	54

It is noteworthy that the “Plano Piloto” is the region that most attracts travelers within the H – W pattern, and, considering the spatial distribution of the travel wishing lines of the five vectors as seen in Figure 5, Taguatinga is the second attractive region, as far as travels type H – W pattern for vectors 3, 4, and 5, considering that there are also internal trips among the vectors of urban sprawl. Similar phenomena of trips to “Plano Piloto” and internal trips can be seen in vectors 1 and 2.

The patterns H – M (Home – Healthcare) and H – A (Home – Other Activities) present lower percentages, therefore there are fewer residents in the five vectors of expansion who perform these activities as primary ones. Thus, it is possible that healthcare and other activities have been performed as secondary activities, which complement the main activities (work and school).

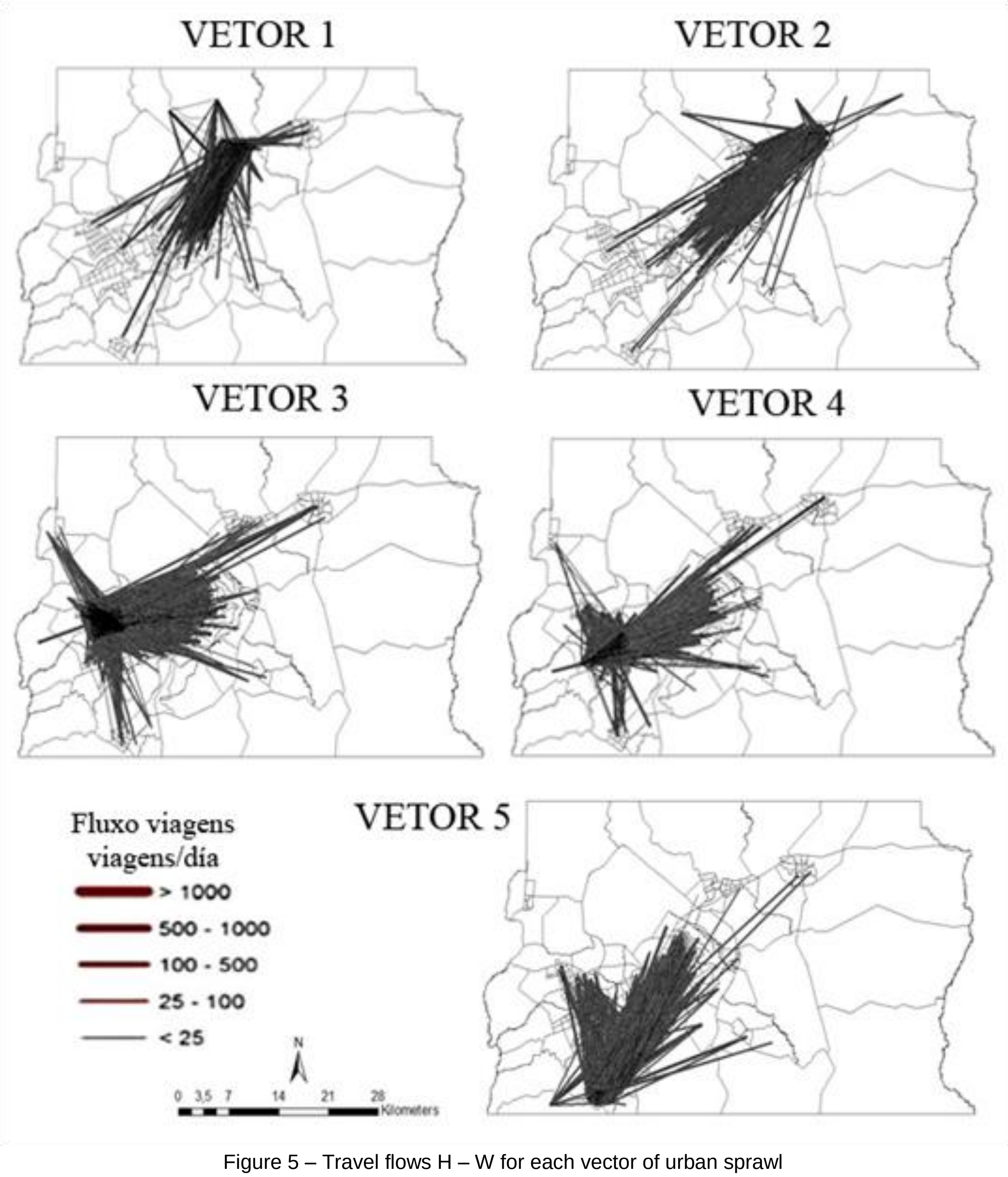


Figure 5 – Travel flows H – W for each vector of urban sprawl

Model generalization Activity-Based Travels of Urban Sprawl (ABTUS)

Based on the hypothesis, the structural model in Equation 6 is represented as follows:

$$\eta = \Gamma\xi + \mathrm{B}\eta + \zeta \qquad (6)$$

Where:

η= {GVA} = endogenous latent constructs: Activity-based travel generation,

ξ= {FEXU, CSE, AST} = exogenous latent constructs: Spatial Factors of Urban Sprawl, Socioeconomic Characteristics, Accessibility to Transportation System;

$\Gamma = \{\gamma_{11}, \dots\dots, \gamma_{nm}\}$ = matrix of parameters associated with exogenous constructs;

$\mathrm{B} = \{\beta_{11}, \dots\dots, \beta_{mn}\}$ = matrix of parameters associated with endogenous constructs; and

$\zeta = \{\zeta_1, \dots\dots, \zeta_n\}$ = vector of error terms associated with estimation.

Thus, when generalizing the ABTUS model we obtain:

$$GVA = \gamma_{11}FEXU + \gamma_{12}CSE + \gamma_{13}AST + \zeta \qquad (7)$$

The complete structure of ABTUS model is present in Figure 7. The latent constructs and indicating variables, as well as the parameters to be estimated are listed in Table 4. The formulation of latent constructs and the indices are not presented in details in this study, but can be found in Medrano's (2012).

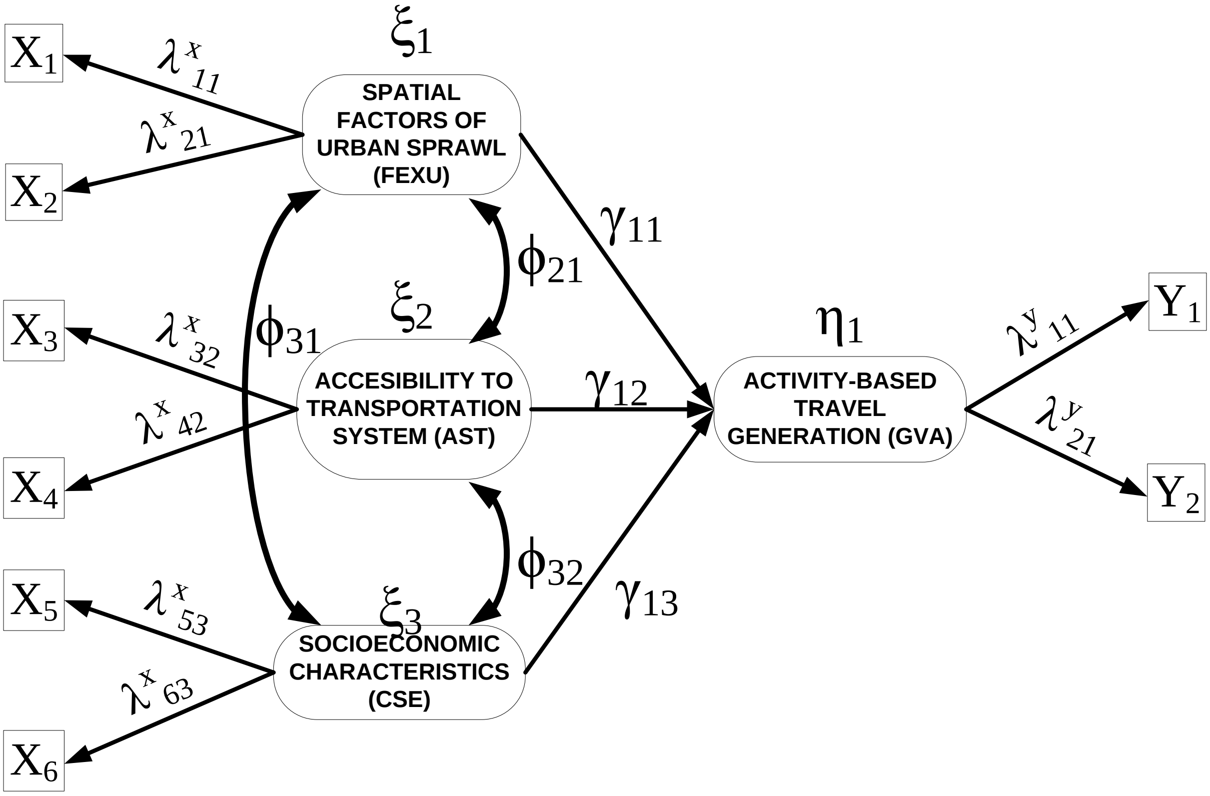


Figure 7 – Model Activity-Based Travels of Urban Sprawl (ABTUS)

Table 4 – Description of latent variables and structural parameters of ABTUS

Latent Variable	**Description**
$\xi1$	Spatial factors of urban sprawl (FEXU)
$\xi2$	Accessibility to transportation system (AST)
$\xi3$	Socioeconomic characteristics (CSE)
$\eta1$	Activity-based travel generation (GVA)
Structural parameter	
$\gamma11$	Impact of FEXU over GVA
$\gamma12$	Impact of AST over GVA
$\gamma13$	Impact of CSE over GVA
$\phi31$	Covariance between FEXU and CSE
$\phi21$	Covariance between FEXU and AST
$\phi32$	Coviarance between AST systems and CSE

EMPIRICAL RESULTS

Model fit

In this section, the results from the modeling are presented. Figure 8 presents standardized factorial loads for each alternative of relationship between indices and exogenous latent variables and between exogenous variable and the endogenous variable. The results of the model's global assessment can be found in Table 5.

The model was built with the utilization of Maximum Likelihood Estimation (MLE). In sum, the results obtained from the global indices of assessment of the model provide enough evidence to accept the goodness of fit of the ABTUS model.

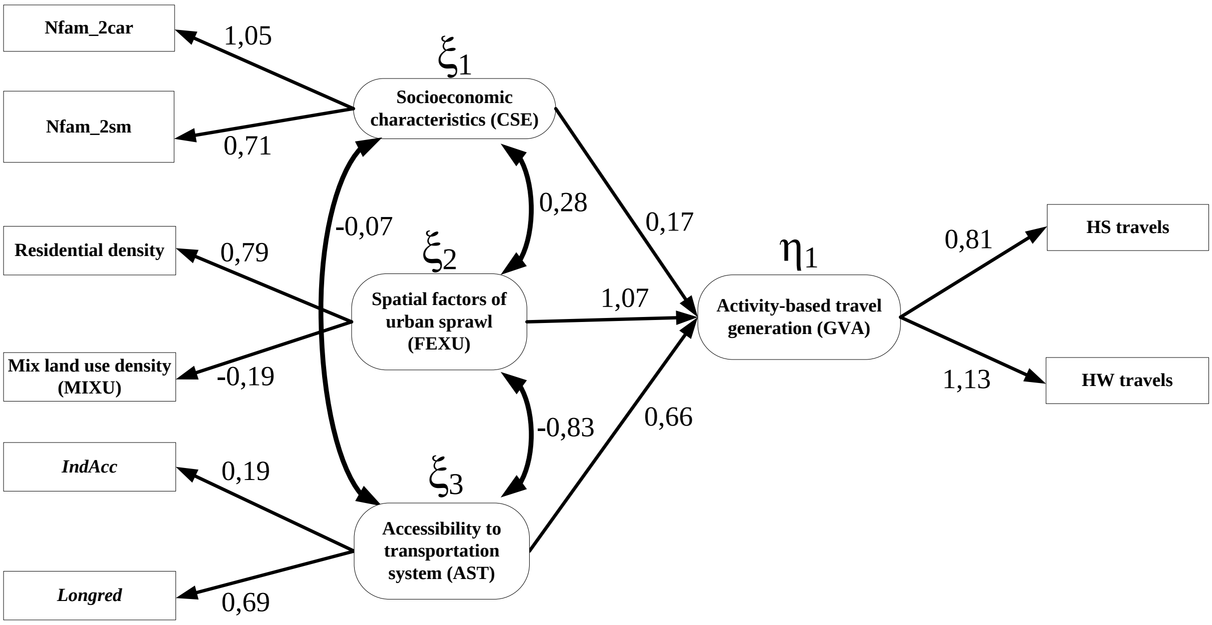


Figure 8 – ABTUS with standardized parameters

In the local assessment of the model, all relationships among variables were taken into account with the purpose of analyzing the relationship between urban sprawl and activity-based travel patterns.

Table 5 – Global indices of assessment of the model

Goodness-of-fit of the model	
Sample size	111
Chi^2-value	29.5
	(P = 0.014)
Degrees of freedom	15
Goodness-of-Fit Index (GFI)	0.94
Adjusted Goodness-of Fit Index (AGFI)	0.855
Normed Fit Index (NFI)	0.931
Comparative Fit Index (CFI)	0.964
RMSA	0.094 (LO90% = 0.041 ; HI90%=0.143)

The impact of spatial factors of urban sprawl, parameter y12, in the travel demand behavior is of 1.07, which satisfies the hypothesis test with a confidence level of 5%. The expansion pattern of urban sprawl explains the generation of travels per activity of 1.07. The total effect of the indicating variable of residential density, DENR, was positive of 0.789 over the urban sprawl pattern. The indicating variable of mix land use density, MIXUS, presents a negative relationship of 0.186 over the urban sprawl pattern. The spatial factors of urban sprawl also present positive standardized indirect effects of 0.869 over the number of trips Home – School (H – S), and, 1.203 over the number of trips Home – Work (H – W).

The impact of the socioeconomic characteristics over the travel demand behavior (y11) presents a value of 0.168, which satisfies the hypothesis test with a confidence level of 5%. This means that the socioeconomic characteristics explain the travel behavior in 0.18 within the ABTUS model. The total effects of the indicating variables are significant at a confidence level of 1%. As far as the number of families that own two or more vehicles, the estimated value was positive of 1.048. In the case of the number of families with monthly income of 20 minimum wages and over (Nfam_20), the estimated value was positive of 0.709. This variable has a greater explanatory power of the socioeconomic characteristics construct, and presents the following standardized indirect positive effects: 0.136 over the travel pattern Home – School (H – S), and 0.188 over the travel pattern Home – Work (H – W).

The impact of the accessibility to transportation system (y13) over the generation of trips based on activities also presents a positive value of 0.663. The total effect of the indicating variable, Longred, over the accessibility to transportation system construct was of 0.692. In the case of the index of accessibility of the average distance among centroids (IndAcc), the total effect was of 0.192. The accessibility to transportation system construct presents the following standardized indirect positive effects: 0.539 over the number of trips Home – School (H – S), and 0.746 over the number of trips Home – Work (H – W).

Model results

The latent spatial factors construct of the urban sprawl (FEXU) has a positive influence on the latent GVA (Activity-based travel generation) construct. As far as the indicating variables, the residential density presents the greatest positive value, deserving comments also the value obtained from the variable of mix land use density, which presents a negative influence on the urban sprawl pattern. This means that the greater the density of the mix land use, the lesser the urban sprawl. Considering these relationships, it can be inferred that the variables tend to equilibrium within the ABTUS model.

The urban sprawl pattern, in this case, results from the balanced interaction between residential density and mix land use or zone attractiveness. It is believed, as per the empirical results, that the urban sprawl has a relationship of positive influence on the travel demand behavior and in the production of patterns Home – School and Home – Work.

The latent socioeconomic characteristics construct (CSE) has a positive influence on the generation of activity-based travel generation (GVA). The latent CSE construct has also an indirect positive influence on travel patterns Home – School and Home – Work. Regarding the indicating variables, the number of families owning two vehicles or more (Nfam_2c) has an important influence, next to 1, on the construct. Both variables represent the configuration of families who live in the analyzed traffic zones.

The parameters obtained in the estimation and the transportation accessibility latent construct have not passed the significance tests for indicating variables. Although the results reject the latent accessibility to transportation system construct hypothesis, this does not mean that the theoretical process of spatial/temporal interaction and the transportation accessibility index do not interact within the process of generation of trips. They, in fact, play an important role in the process of generation of travel patterns, but the indicating variables have not been adequate enough to represent the phenomenon through a model. It is suggested then the exploitation of indicating variables of time attributes. Within the indicating variables' group, it is important to consider also the spatial and temporal restrictions that affect the transportation system performance, which, therefore, influences the travel patterns.

In the current situation, Brasilia's urban sprawl presents characteristics of residential density and increase motorization of single households. The obtained results clearly demonstrate that Brasilia's situation is due to an influence on the process of space production and socioeconomic characteristics of the city, utilized in the modeling with latent variables. Besides, these two processes positively influence the generation of trips per activity. This influence results from an interdependent relationship between the effects of the spatial characteristics of the urban sprawl and the socioeconomic characteristics of individuals who live in the urban sprawls. This relationship can be understood by the parameter $\phi = 0.28$ of covariance.

Therefore, the results demonstrated thus far allow an understanding of the importance of structural relationship of covariance among the urban sprawl characteristics, the individuals' characteristics, and the spatial/temporal restrictions in the generation of trips per activity. In the case of Brasilia, this relationship presents a positive interdependence between the spatial factors of urban sprawl and the socioeconomic characteristics of individuals who reside in urban sprawls that end up influencing the generation of trips per Work and per School. This covariance, in fact, represents the complete history of Brasilia's urban evolution.

CONCLUSIONS

As observed, the urban sprawl process and the distribution of activities in the urban space affect the transportation system. The ABTUS model can support urban planning by providing a good understanding of the relationship between urban sprawl and activity-based travel patterns. Moreover, it is believed that this model can predict the individuals' responses, when they face changes in the transportation system or in the activities' subsystems, as well as in the socioeconomic and demographic environment.

In the case of Brasilia, the urban sprawl is strongly influenced by the residential density and socioeconomic characteristics of its households who own two or more vehicles. Therefore, the employment centralization and the spatial restrictions for downtown housing generate longer trips to work and school within the urban sprawls. Surely, the residential density effect and employment centralization end up influencing the generation of trips in urban sprawls in the United States and Europe; however, Brasilia has households whose members depend on individual private vehicles, and it has, yet, other low income households whose members utilize public transportation, something that generates even more concentrated residential densities.

The majority of the empirical analyses on urban sprawl and transportation consider an approach based on a linear relationship among trips, socioeconomic factors, and the urban shape. The studies have been more focused on statistical correlation among relevant factors than on causal relationships. Once again, this allows us to emphasize the need of understanding travel behavior as a result of the process of urban sprawl, which is subject to a structural covariance relationship between spatial urban factors and socioeconomic factors. Departing from this process, it is possible to identify the factors that best fit the Brazilian reality.

Urban space, socioeconomic, and space-time (spatial and temporal restrictions in the distribution of activities in the urban space) factors have been identified as intervening factors in the process that generates activity-based travel patterns. Thus, it is noticeable that using SEM in the building of the model was adequate because it showed that before one was able to statistically verify the relationship among the elements of the model, any relationship has obtained theoretical support through bibliographic research.

It has been noticed that the latent variables of the ABTUS theoretical model present an interdependent relationship and interact in a simultaneous way in order to exert influence over the generation of activity-based travel patterns.

As a final conclusion, the results presented in this model can be interpreted as evidence in favor of land use regulation and changes in urban sprawls as tools to change the travel behavior. The deepening of this relationship can offer important subsidies to support the pattern abstractions and analysis of travel demands, i.e. instructions and trends that can offer guidance, among other things, to decision-making processes, project implementation, problem solving, and overcome proposed challenges to sustainable transportation.

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