# EXPLORATORY STUDY OF SPACE SYNTAX AS A TRAFFIC ASSIGNMENT TOOL

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## Abstract

This paper discusses features of configurational (Space Syntax) and traffic assignment (SATURN – Simulation and Assignment of Traffic to Urban Road Networks) models aiming at evaluating the potential of syntax for estimating possible intensely used traffic routes. This theme is related to studies with this approach, intending to broaden the variety of alternative tools for transport projects. The city of Brasilia was elected as a case study and comparative parameters between syntax and SATURN were developed, regarding theoretical, methodological and technical points of view. For the results, two analytical categories were applied: flow (visual and statistical) and routes analyses.

Findings for visual analysis pointed a clear correspondence: space syntax produced results similar to SATURN, with a coincidence between colour integration bands and thickness of lanes obtained from the selected transport model. For the statistical analysis results were also similar, but figures were better for segment mean depth than axial integration: the segment principle is closer to the current transport methodology; it presents coincident characteristics to assignment models – with segmentation between line segments or streets.

On the other hand, in routes analysis, space syntax achieved refined results when compared to SATURN, indicating that configurational logic concerning movement is more suitable than the regular geometrical approach considered as a premise in the transport field.

The study presented a positive result, showing how a configurational tool such as space syntax axial map and, more precisely, segment map, can contribute to transport studies, mainly for the first investigation stage, when researchers explore issues such as zoning, centralities, spaces with high or low potential flows, etc. The use of configuration models proved to be cheaper and faster than traffic models, and configuration tools have offered a general overview which can work as a basis for transport traditional tools. Correlations were high, especially on a logarithmic basis, and the visual interpretation displayed similar scenarios for space syntax and SATURN.

Results suggest the adequacy of configurational models in early stages of traffic assignment, when it is necessary to draw a general picture of potential flows considering segregated and integrated areas, land use, income, and identification of origins and destinations. The assignment models could come in sequence, when the accuracy in terms of actual flows is required. Both models are important to movement analysis, each one in its own specific field.

The use of such models can be complementary, providing the researcher with a wider quantity of analytical categories. Furthermore, they can fulfill the demands in many areas of knowledge for an interactive approach in a way that many subjects are taken into account.

## Introduction

Space Syntax and SATURN are representative examples of the so-called configurational and traffic models respectively.

Space Syntax – a theory developed by Hillier and Hanson (1984) – incorporates the space topological relationships, considering the city shape and its influence in the distribution of movements within the space. The theory's axiality method – used in this study – analyses the accessibility to the street network relationships, by means of the system's integration, one of its explicative variables in terms of co-presence, or potential co-existence between the through-passing movements of people and vehicles.

SATURN (Simulation and Assignment of Traffic to Urban Road Networks), in its macroscopic model, considers traffic flow directions in streets, number of lanes, hierarchy and vehicular flows, reaching a refined representation. Space Syntax, on the other hand, ignores traffic flow directions, representing the network by means of a set of line segments with no other system's characteristic.

Traffic-related problems are often studied and simulated by assignment models – well-established in traffic studies. Space Syntax, on the other hand, is a tool with few applications in transport, an area where configurational models are considered to present inconsistencies when used in traffic flow studies (cf. Cybis et al, 1996). Although this is true in some cases, it should not be generalized.

Another statement that should not be generalized is that, "according to the principles of configurational models, street segments with high accessibility indexes present a high connectivity with other links, thus constituting streets with high potential uses (Cybis et al, 1998).

According to Medeiros (2006), who developed a comparative study between Brazilian cities and urban settlements around the world using the configurational approach by means of the syntactic analysis of space, only 15% of the Brazilian cities present high correlations between connectivity and integration. This means that in 85% of the cases integration value of axial lines are not related to connectivity, but to other factors. As for the other cities around the world, the percentages are similar and low: 12% for Arabic, 18% for Asian, 19% for European, 14% for Latin American and 22% for North American cities (figure 1).

*Figure 1:*

*Correlation between Integration and Connectivity Source: Medeiros (2006)*
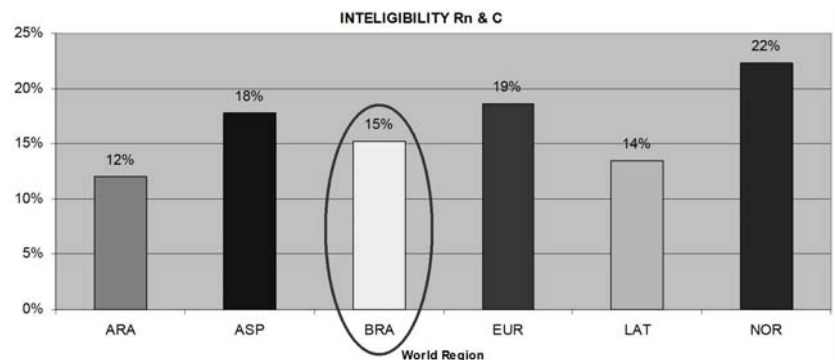


Considering the possibility that some criticisms originate from a general misunderstanding about the role configurational models in general, and Space Syntax in particular, can play in transport studies, the present paper reports an experiment that included visual,

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statistical and routes comparative analyses between results produced by SATURN and space Syntax.

## SATURN (Simulation and Assignment of Traffic to Urban Road Networks)

SATURN is a network analysis software. Developed at the University of Leeds Institute of Transport Studies, United Kingdom, the model basically comprehends two functions, with different goals: the traffic assignment module – which selects the network routes to be used – and the simulation module – which models how the system's intersections behave (Van Vliet, 2004). In this study only the first module is used.

The process of building models in SATURN goes through five stages:

Conception of the model – where the modelling initial hypotheses (such as the definition of the study area, the selection of the streets to be modelled, excluding the local ones, and the division of traffic zones on the basis of land use) are defined.

Data collecting and codifying – those data represent supply  (network data, such as street hierarchy, number of lanes, connection between links, and flow directions) and demand (data related to the O-D mat, number of lanes, connection between links, flow directions) and demand (data related to the O-D matrix, such as flow counts and land use-based structure of the matrix).

Calibration – this is the input data adjustment in order to assure a high correspondence between simulation and reality.

Validation – based on flow counts data, this stage verifies how consistent with the studied area the model is (in terms of routes and saturation degrees).

Modelling – of the present and future scenarios under assessment.

There are two types of network used in SATURN – simulation and buffer networks. The simulation network is considered to be mesoscopic because it focuses on intersections; this emphasis is adequate to small networks applications. The buffer network is simplified, adequate to wider networks applications as it emphasizes links and uses information with high aggregation levels, thus requiring a smaller amount of data.

Generally speaking, the buffer network is used in studies of wide areas or, as is the case of this research, in studies limited to the macroscopic network scale .

## Space Syntax (Axial Map and Segment Analysis)

This is a theoretical and methodological approach, constituted by several techniques aimed at understanding how the shape of a city, or of part of a city, influences the displacement standards by means of its topological, not only geometric relationships.

According to Medeiros (2006), topology is the study of space relationships that do not depend on shape and size, but on the connection between parts, whereas geometry is the description of physical elements in terms of its dimensions, proportions, scales etc.

In other words, the topological analysis ponders the way the parts – streets and built space – relate to each other and to the whole network, and how those distinctions interfere in the social relations developed in that space – especially with respect to flows and potential trip generation, when the space is an urban space.

Space Syntax comprehends, among other techniques, the axiality, which uses axial maps in its analyses. Several studies have

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demonstrated the strong correlation between the potential flows suggested by axial maps and those actually measured in site. For instance, Medeiros and Trigueiro (2001) demonstrated the correlation between integration and land use, and Holanda (2002) studied correlations in terms of magnets.

Apart from axial maps, a new approach has been developed under what is known as segment maps. In the transport area, one can say that segment maps are an improvement from traditional axial maps, as the former feature all the stages the latter do, but also divide each axis at every connection point with other axis (Turner, 2004). This brings segment maps closer to transport studies than axial maps do, because traffic assignment processes use street segments (Barros, 2006).

Instead of the integration provided by axial maps, segment maps use a measure called depth to evaluate segments, and the mean depth to evaluate the whole network.

Depthmap®, a software in which the segment map approach was implemented, uses the innovative measure called routes choice. It processes the route selection in a simplified way that does not consider origin or destination (as transport tools do), but is based on the most integrated streets of the system.

**Methodology of Analysis**

Any comparison between tools requires the use of parameters that are common to both tools. The visual analysis reported in this paper compares the bandwidths of links produced by SATURN with grey scale produced by Space Syntax, both representing traffic flows. It should be mentioned that axial and segment maps present equal intervals for the whole grey scale.

It is also important to stress that this analysis is qualitative, not quantitative, so it is the visual correspondence between link bandwidths and colours produced by the axial map that are analysed, according to the following:

- A very wide flow bandwidth corresponding to a black axis;

- A wide flow bandwidth corresponding to a dark grey axis;

- A medium flow bandwidth corresponding to a medium grey axis;

- A narrow flow bandwidth corresponding to a light grey axis;

- very narrow flow bandwidth corresponding to a little grey axis.

The statistical analysis made in this study correlated data from SATURN (vehicular flows) and data from segment analysis (mean depth) and from axial maps (integration) with flow counts data obtained from electronic speed control devices operated by DETRAN and DER (the local traffic agencies). Only the streets for which counts were available [i] (some points of the studied area have no data stored) were subjected to the correlation analysis (in contrast, all streets in Space Syntax have data integration and/or mean depth data ascribed to them). Statistical analysis was based on "r" and "r²", as described below:

-"r", or Pearson's r, which reveals how much two or more variables are related and/or associated, either in a positive or negative way, with values between "1" and "-1" (the closer to "0" the weaker the relation, the closer to "1" or "-1" the stronger);

-"r²", or determination/simple regression coefficient, which corresponds to the measure of the proportion of variability of one variable explained by the variability of the other, being one variable

independent – the counts from DETRAN and DER – and one dependent – outputs from the traffic and configurational models.

In order to establish limits to the research and to make data interpretation easy, the Cohen scale (Hopkins, 2002) was adopted. This is an auxiliary tool that explains the intensity of "r" or "$r^2$" on the basis of the correspondence between the numeric value obtained (either positive or negative) and the categories shown in table 1.

| Category | Correlation |
|---|---|
| Inexistent | 0.000 - 0.099 |
| Medium | 0.100 - 0.299 |
| Moderate | 0.300 - 0.499 |
| High | 0.500 - 0.699 |
| Very High | 0.700 - 0.899 |
| Almost Perfect | 0.900 - 0.999 |
| Perfect | 1.000 |

*Table 1:*

*Relation between Category and Correlation*
*Source: Cohen (apud Hopkins, 2002)*

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In routes analysis, routes selected by SATURN between O-D (origin-destination) pairs randomly chosen were visually analysed, and in segment analysis the route choice tool was used, which produced results similar to SATURN, although the former does not incorporate the O-D parameter largely used in transport studies.

## Case Study

The studied area is the Pilot Plan of Brasilia (2b), Brazilian Federal District (2a) (figure 2). The urban site presents several express and arterial long roads, each one with 3 to 6 lanes (figure 2), which stimulates high speeds.
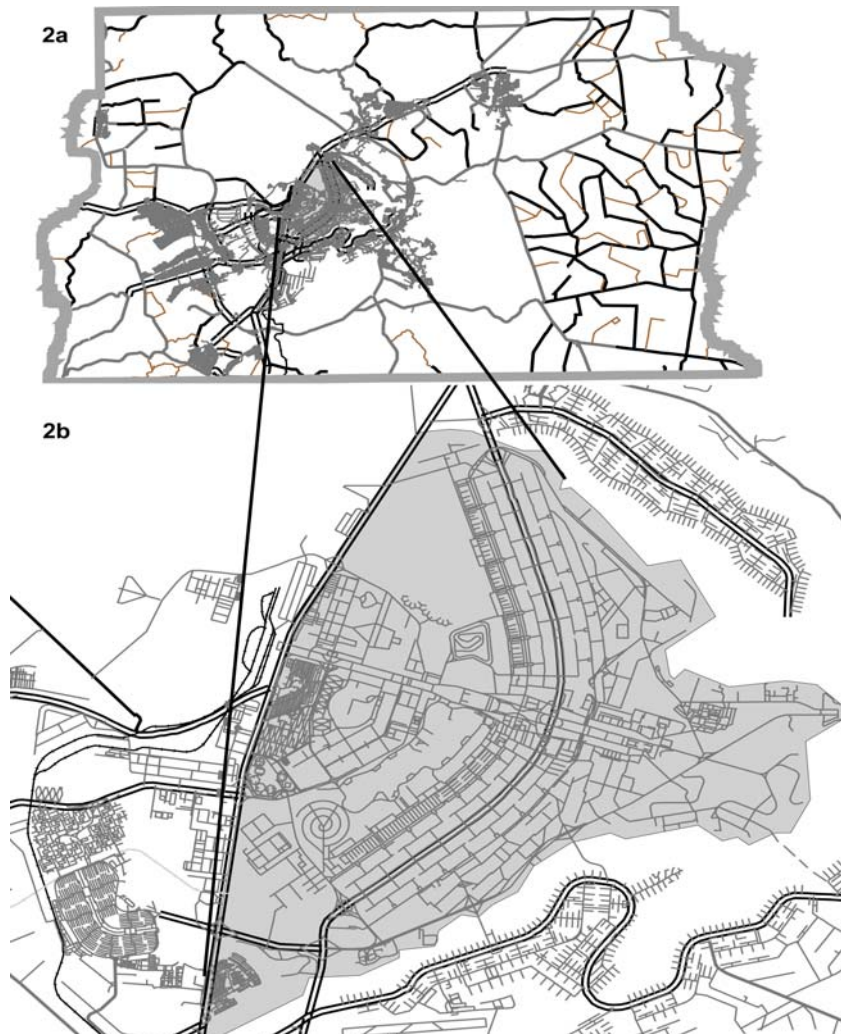


*Figure 2:*

*Brazilian Federal District Map and Pilot Plan Map*

### *Visual Analysis*

There is good visual correspondence between bandwidth of links produced by SATURN and grey scale resulting from integration values, although refined for high, and imprecise for low flows.

In most cases the widest bandwidths correspond to the black axes, which in turn correspond to the system's highest potential flows, estimated from the integration values. This is what happens with the North Aixs (figure 3a) and with segments of the Monumental Aixs, near the Central Zone, where the axes intercept each other (figure 3b). This, however, does not take place at South Aixs, for which SATURN produces a very wide link (figure 3a) and the axial map produces the colour dark grey (figure 4). What explains the dark grey colour is the fact that the geometric form of the south end of the "Eixão" does not have the same continuity as its north end. On the other hand, the segment map and SATURN produce corresponding outputs (figure 4).

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One can see that the Monumental Aixs has different widths (figure 3b), being narrow near Ministries Esplanade, very wide near the Pilot Plan Bus Station and again narrow near "EPIA", at the west end. That behaviour is not seen either in the axial map or in the segment map, which present the Monumental Aixs in black all along (figure 4).

For the road at the "Setor Policial" (figure 3b) SATURN produces a wide link – it should be very wide – which does not represent its actual high flow level. Space Syntax, on the other hand, presents the black colour in both axial and segment maps (figure 4).

The wide links correspond to dark grey axes, with flow levels lower than the first ones. The correspondence is identified in the cases of the access to the first bridge at south Wing and the South L4 road (figure 3b), although in the latter case the grey scale produced by the axial map presents not only dark grey, but also some segments in black. The segment map (figure 4) presents the "L4" road all in black, the axial map (figure 4) presents parts in black – near "EPIA" and "Setor Policial", and near JK bridge – and others in dark grey – near the first bridge – whereas SATURN shows a medium width all along the road (figure 3b).

Because traffic counts lack for the central part of "EPIA" and are not significant for its south part, SATURN results present inconsistencies, as the flow level is very low – or non-existent at all – in central and south part of "EPIA" even after the matrix is updated (figure 3c). On the other hand, both Space Syntax maps present "EPIA" in black (figure 4), which is compatible with the flow that actually occurs in the road.

The medium bandwidths correspond to the axes in medium grey and present lower flow levels than the former links. In SATURN, there is a good correspondence for streets as North W5, South W5 and the accesses within the University of Brasilia (UnB) campus (figure 3d).

The narrow bandwidths correspond to the light grey axes. As SATURN's modelling does not consider the local streets, there are segments with high flows for which narrow links were generated. This, for instance, is the case of parts the "North L4, access to the Alvorada Palace, the connection between the "Setor Militar Urbano" and the motor-racing circuit, the connection between the Extra Hypermarket and "EPIA" (figure 3e). In all these cases, the axial map (figure 4) produced the colour dark grey, indicating high potential flows, which corresponds to the actually found condition – all mentioned segments are important accesses from and to Pilot Plan's Central Zone and North and South Wings.
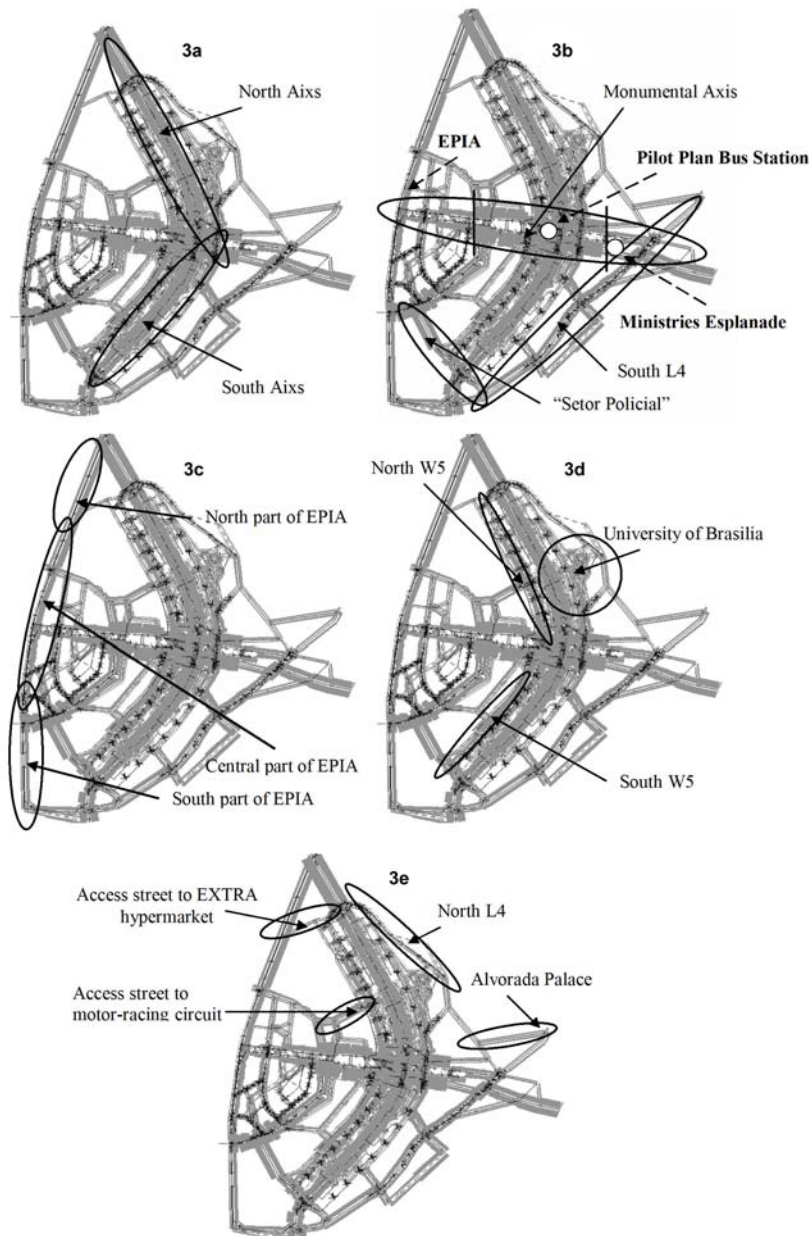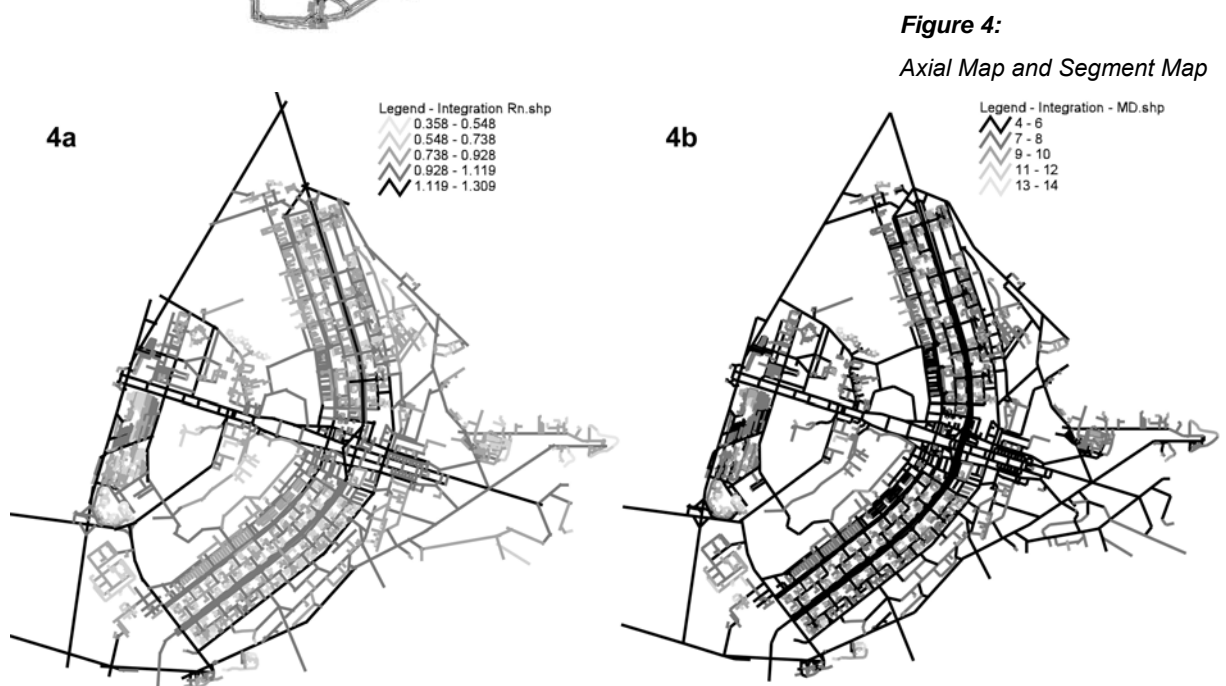
**Figure 3:**

*Visual Analysis in SATURN*

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**Figure 4:**

*Axial Map and Segment Map*

### *Statistical Analysis*

The real data obtained from DETRAN were adopted as independent variables for the linear regression, whereas the other data were used as dependent variable. All variable pairs were also analysed after converted to logarithmic scales.

For the first set of DETRAN counts and SATURN outputs, the obtained Pearson's R was equal to 0.776 (78%), which means a very high relation between the variables. The dependence coefficient reached 60% (high), indicating the high potential of assignment models to represent real flows from the input data (figure 5a).

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It is important to stress that SATURN keeps input data from counts mostly unchanged along the whole processing. The flows of other streets, for which no counts were provided, change and fluctuate during the calibration. The outputs, therefore, tend to present high correlation levels.

When integration values are correlated with DETRAN data, Pearson's R is equal to 0.529 (53%), which indicates high association level between variables. The simple linear regression's $R^2$, however, keeps a moderate level, reaching 30% (figure 5b), half the correlation between SATURN and traffic counts.

For segment analysis, Pearson's R reaches -0.617 (62%), which indicates high association. The values of $R^2$ reach 40% (figure 5c), with the determination coefficient keeping moderate value, but higher than the values obtained with the traditional axial map.

Findings confirm that the segment analysis applies better for transport studies, because of its structuring logic – based on segments between nodes, not only on continuous lines, as happens with traditional axial maps.

When the whole data set is converted to a logarithmic basis (decimal basis), one observes a considerable improvement in all cases, especially for configurational and/or topological modelling.
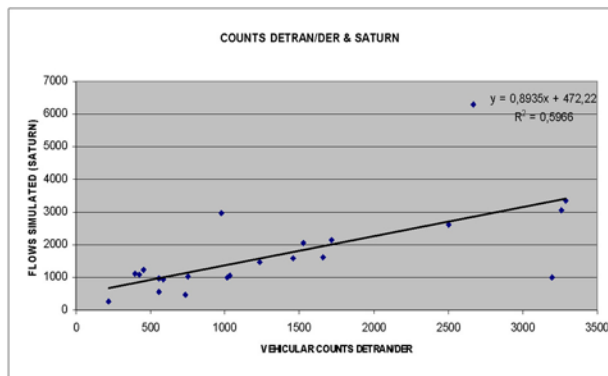
The association between SATURN and the traffic counts is slightly higher, going from 78 to 80% (0.803). For the correlation in logarithmic scale, $R^2$ rose from 60 to 66%, keeping high (figure 5d). Thus, there is no significant alteration compared to non-converted data.

The stability of values indicates that SATURN data had already a linear behaviour and the conversion did not change the dispersion significantly. However, a significant change does take place for configurational variables.
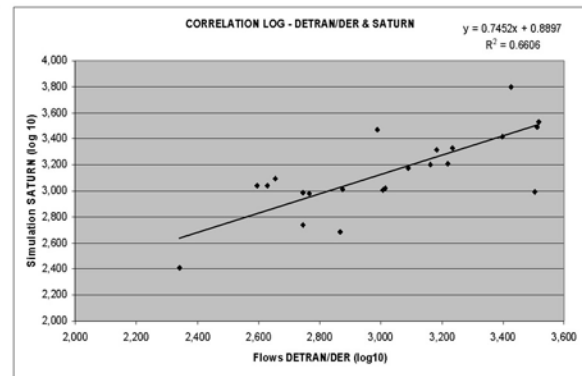
For the comparison between traffic counts and integration, Pearson's R rose to 0.646 (65%, high) and the correlation value in logarithmic regression was equal to 44% (medium to high) (figure 5e) – a significant change compared to the previous value of 30% (medium to low).

When the association is between flow counts and segment analysis data, Pearson's R reaches -0.763 (76%) which means a very high association, similar to SATURN's. When the determination coefficient is investigated, $R^2$ reaches 61%, a value close to SATURN's 66% (figure 5f).
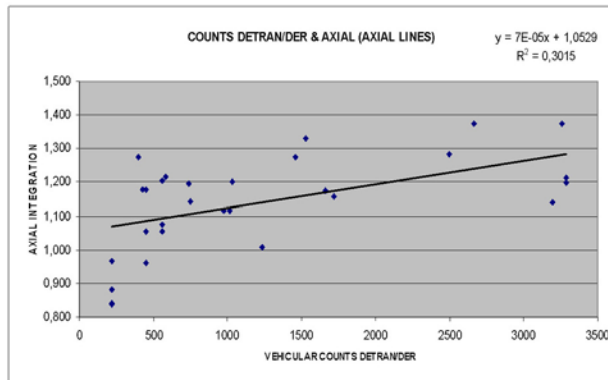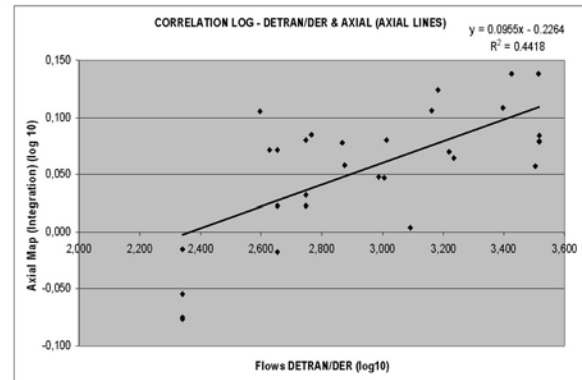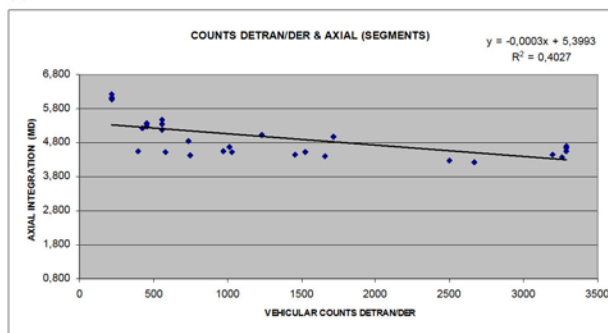
5a



5b

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5c



5d



5e



5f

*Figure 5:*

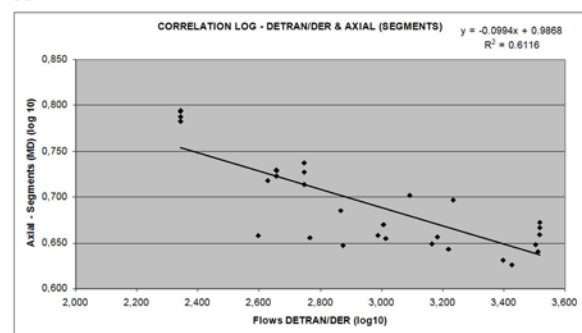*Correlations between DETRAN x SATURN, Axial Map and Segment Map*

### Routes Analysis

Some simulations were run in SATURN to verify the shortest routes chosen by the model. Although it is not possible to obtain a result that can be considered as "suggested" by Space Syntax, it is possible to identify the most likely routes expressed by the most integrated streets leading from A to B as produced by axial or segment maps. The most integrated streets are those with higher potential flow generation – topologically, thus, they are the most likely to be used.

In the first case, the route from the end of North Wing to the Ministries Esplanade was simulated. One can see that the streets adopted by the model were "Eixinho W Norte" and Monumental Aixs (figure 6a). One can also infer that the same choice would be made from Space Syntax's results, as the same streets are the most integrated to the system between the considered pairs.

The route between the "Setor Sudoeste" and the Ministries Esplanade was also simulated and SATURN chose the Monumental Aixs and the collector street that limits "Setor Sudoeste" (6b) to the east, as it is the most direct street linking the zone centroide ("Setor Sudoeste") and the Ministries Esplanade. Space Syntax could use either the same collector street or the one that limits the "Setor Sudoeste" to the west,
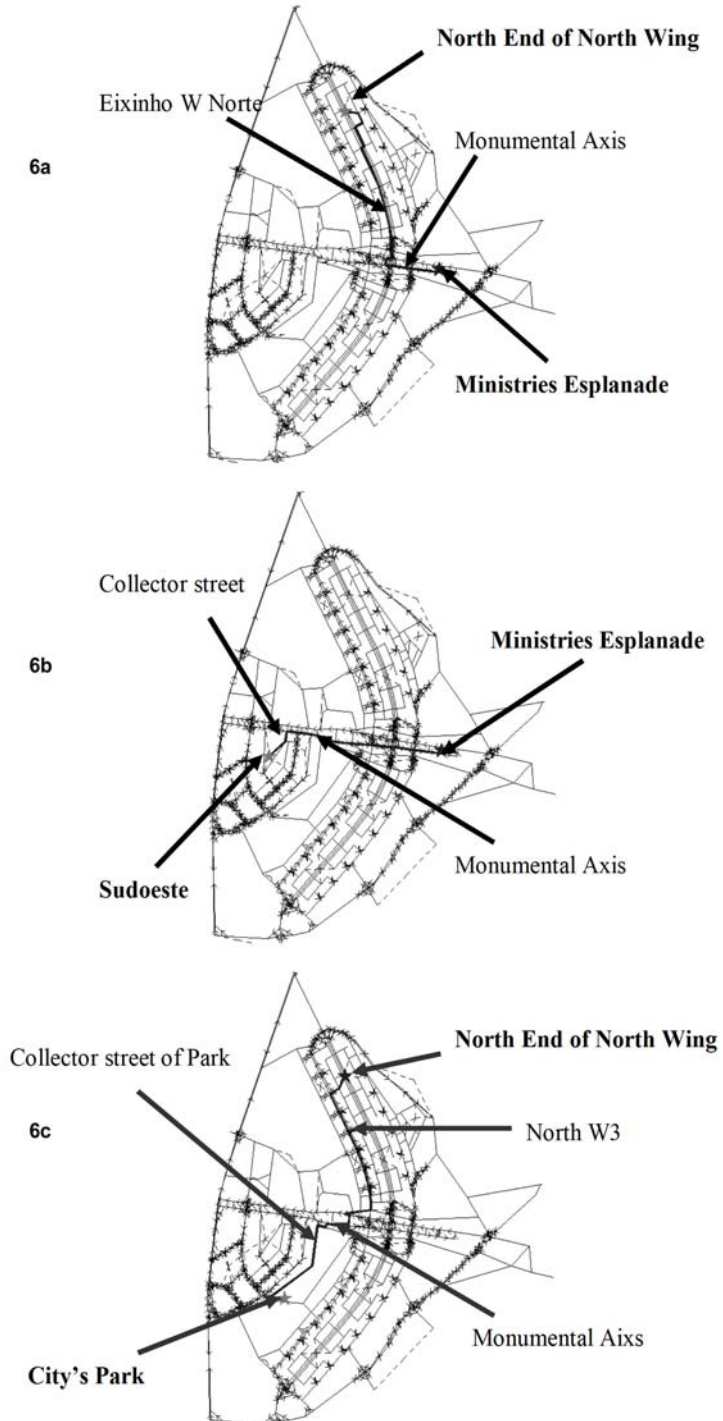
as both present the same number of turns – and would obviously also use the Monumental Axis (figure 5).

In another scenario, the streets defined by SATURN between the City's Park and the north end of the North Wing were the park's internal circle, "Monumental Axis and North W3 (figure 6c), as they represent low travel cost (time).

*Figure 6:*

*Simulations of routes in SATURN*

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According to Space Syntax, the streets that could be used, on the basis of integration values, are the park's internal circle, South W3 and North W3 (figure 4), as they are the streets most integrated to the system and imply only three turns, whereas SATURN's choice implies six turns.

In this case, the axial map does not clearly represent the system's hierarchy, as "W3" is a street with high vehicular flow and would

certainly be chosen by a person demanding travel information (cf. Well Connected, 2000).

This analysis showed that the segment map represents more clearly than the axial map the streets with higher vehicular flow, as SATURN does. On the other hand, the axial map represents better the space centrality. One can observe that the models, although they are of different natures, can be used for different analysis.

On the Space Syntax's side, some approximation effort – although still initially – is being made, which is expected to enable parallel studies with assignment parameters. Depthmap®, for instance, use resources that present the streets more likely to be used, but does not indicate travels' origins or destinations. This resource is called "route choice", as already mentioned.

As examples of this, in Brasilia's Pilot Plan, one can see that the first scale shows the most used streets – Monumental Axis, "EPIA", North Axis and "Setor Policial", for instance – in black and dark grey (figure 8). In another scenario, the potential use of South L4 and the streets between W axis and L axis, as also shown in figure 7, corresponds to reality, as these are the closest links between the axes. The other alternative to go from one axis to the other would be around the wing.
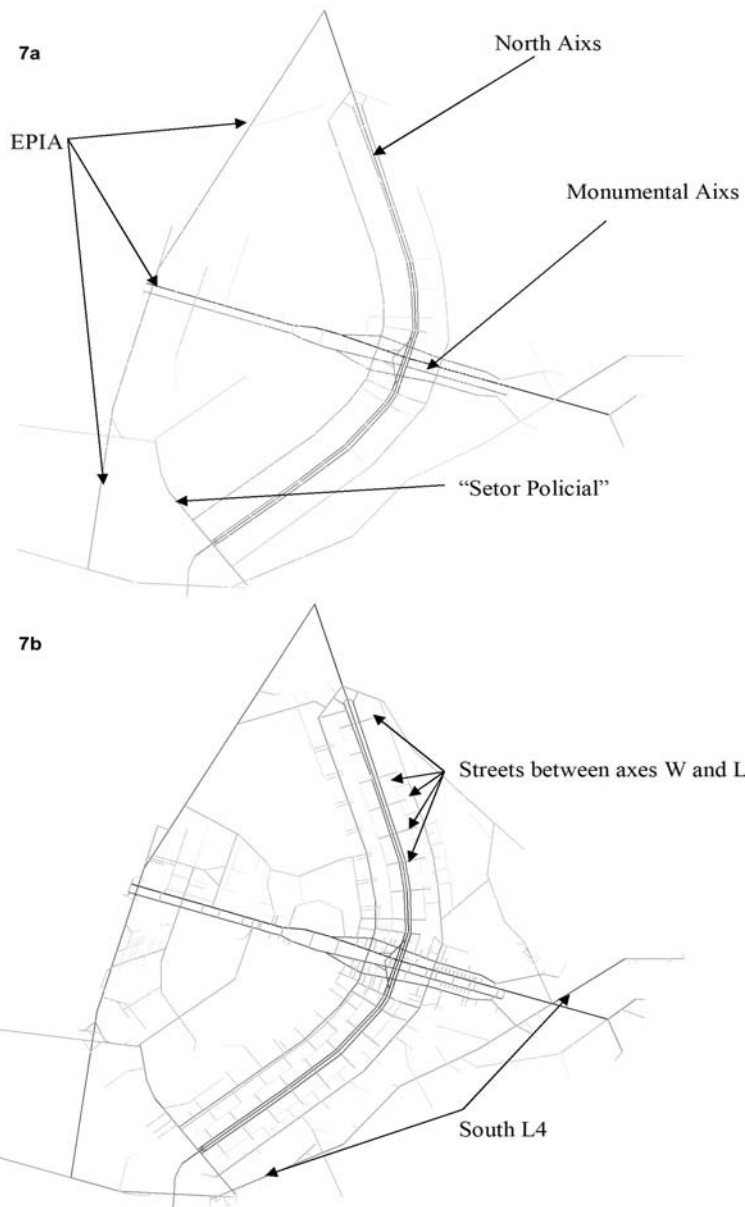


**Figure 7:**

*Simulations of routes in Depthmap*

## Final Considerations

The statistical results indicate a good association between the actual flow values and those obtained by the segment analysis, with the advantage that the latter are generated quickly, with no need of inserting or calibrating a huge amount of data, as usually occurs with transport models.

The values of $R^2$, somewhat high and comparable with those associated to usual and popular transport models, encourage applications of configurational models even if only at initial stages of urban traffic studies.

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Although the comparisons carried out in this study have been made for Brasilia's Pilot Plan – which is a very peculiar case of urban planning and development because of the restrictions imposed by the fact that it is included by UNESCO in the world heritage – the findings create a basis for comparison between the use of applications in planned (formal) and traditional (urbane) cities (Holanda, 2002).

Another point of interest is the amount of time which is necessary to build the models. Traffic assignment models require a vast amount of data and a long time to prepare a database that properly stores network and travel demand data. The network data for Space Syntax require only those related to the configuration of streets, that is, the cartographic basis; demand data, which in fact are its output, can be correlated to other variables.

The modelling processes of traffic assignment models are more complex, as they consist of many interactive stages, demanding calibration. This means that, if a result is too different from a known reality, it is possible and necessary to proceed as many calibrations as needed to reach a reasonable result, close to reality. Space Syntax, on the other hand, requires few data and does not follow an interactive processing – its calibration consists of the comparison of results with pre-existent data, such as land use, traffic counts etc.

However, it is important to stress again that Space Syntax works with the assignment of potential traffic on the basis of topological criteria, whereas SATURN works with flow levels simulated from input of real travel data. In other words, these considerations do not mean that configurational models are better than or can replace traffic assignment models. They use different starting points and aim at generating output values that have particular applications, according to the theoretical background that support them.

The main contribution of this research was to demonstrate that Space Syntax is especially interesting for the first stage of a traffic study, when the analyst searches general indications about zoning, centralities, areas of high and low potential flows etc. As they show a general picture of the movements, the results allow the identification of the network behaviour, of segregated and integrated areas and of active centres, with possible assessment of land use (residential uses tend to be at more segregated and business uses at more integrated areas), income (low and high income groups look for segregated areas – the former, for social exclusion reasons, look for peripheral areas and slums, the latter opt to live at reserved spaces and closed neighbourhoods) and, as a consequence, identification of origins and destinations.

Traffic assignment models, in turn, could be used at a later stage, when precision in terms of flow is required.

This is a case in which the interaction of models would lead to a more precise, clear and, last but not least, multidisciplinary product,

connecting mathematical modelling with geometric and topological approaches, helping to better understand the flows within a city.

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i.  There were 31 streets with flow counts. The set comprised from arterial to collector streets. Local streets were not included, as SATURN does not consider them in wide networks.

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