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THE ACCESSIBILITY MATRIX – A NEW APPROACH FOR EVALUATING URBAN TRANSPORTATION NETWORKS

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Abstract

The use of accessibility indicators in evaluating the compatibility between urban transportation networks and spatial distribution of activities is investigated. Urban socio-economic externalities associated with such compatibility are emphasised. An overview of accessibility and mobility concepts and indicators is included. Some conceptual and analytical refinements in the basic formulation of gravity (or Hansen) type measures are proposed, with emphasis on the accessibility matrix consideration. An evaluation methodology based on the analysis of those matrices in confronting with traditional O-D type ones is developed and applied to Rio de Janeiro metropolitan region.

INTRODUCTION

The relevance of a large city transport system transcends the individual benefit of its users for becoming the master vein that enables the development of the urban region as a whole or causes its atrophy. In what extent and direction will such influence take place will greatly depend on the compatibility level between the transportation network structural characteristics and the spatial distribution of activities which responds for daily trips generation and attraction. This kind of compatibility can be assessed in a quantitative way by means of some so called 'accessibility indicators', specially the 'gravity type' ones, whose concepts and formulations, as well as their use on that evaluation, are the centre of interest of this paper.

Regarding the theoretical field the paper presents a matrix treatment derived from a set of refinements proposed for the basic formulation of those kind of measures which, as far as this author knows, have not yet been approached in any other study concerning accessibility. On the practical application level it is introduced a new approach for evaluating urban transportation networks based on the analysis of those accessibility matrices in confronting with traditional O-D type ones.

The main focus of the methodology is the strategic planning process turned to the medium and long range macro vision of the urban region in which the use of aggregated data and values magnitude are appropriated. The methodology simplicity and functionality allows it to be used in expeditious analysis preliminarily to the development of more detailed studies which is particularly useful in developing countries considering the lack of funds and the multiplicity of guidelines and plausible alternatives that can exist in regions with absence of historical and gradual planning processes.

THE URBAN SOCIO-ECONOMIC CONTEXT

Urban accessibility has much more significance for transportation science and urban and regional planning than just the use of its indicators as internal variables of demand or land use forecasting models. In fact, considering the wider context of urban socio-economy, the accessibility level provided by transport / land use interaction not only directly affects citizens physical access to urban facilities, hence the quality of life of the population, but also has other considerable indirect effects.

Among these 'externalities', no doubt the more important is related to the city 'functioning' workability, regarding its major purpose of facilitating contacts and approaching activities, which by itself, turns the provision of accessibility into a fundamental objective in urban development planning processes. Moreover, in many developing countries major cities, the great separation of origin (e.g. housing) and destination (e.g. working) activities, combined with deficiencies or even the inexistence, of high capacity rail transport systems in major corridors, usually lead to the deterioration of bus systems service levels caused by their inefficacy in transporting large amount of people by long distances (see table 1 and figure 1, extracted from Sales Filho,1990).

Table 1 - Public urban transport mode suitability concerning demand aspects

Trip Distance	**Demand Volume** (pass/h)		
	Low (e.g. 5,000)	**Medium** (e.g. 10,000)	**High** (e.g. 30,000)
Short (e.g. 5 km)	Bus	Bus	Metro
Medium (e.g. 10 km)	Bus	Bus, LRT, Metro	Metro
Long (e.g. 30 km)	Bus, Train	Train	Train

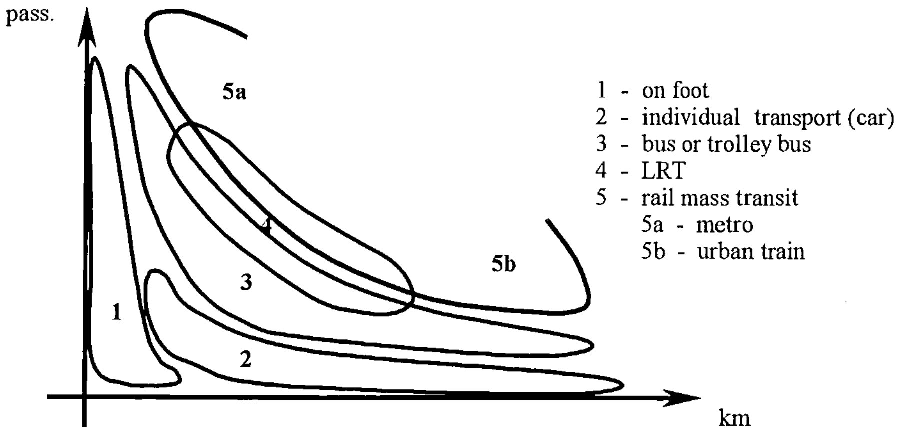


Figure 1 - Urban transport mode suitability concerning demand aspects

The poor quality of public transport stimulates the systematic use of private cars leading to the saturation of the road network and consequently to chronic traffic jam scenarios causing additional penalties to bus services which feeds back the process (figure 2).

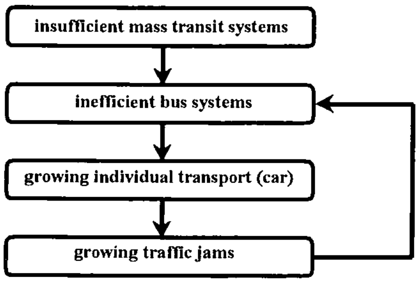


Figure 2 - Typical road system vicious cycle in many developing countries major cities

These kinds of scenarios imply in generalised degradations of accessibility levels and tend to contribute to the aggravation of worrying issues, such as (Sales Filho, 1990):

- economic development atrophy and difficulty in coping with population growth, concerning habitational expansion (due to low accessibility of peripherical regions) and employment generation (considering the low accessibility of secondary attraction centres located between down town and those regions);
- quality of life decay and increasing of emotional stress of public transport users, due to the discomfort caused by overcrowded vehicles and trip time enlargement in traffic jams (which also affects private transport users) with the consequent reduction of leisure and resting free-time (also affecting workers general productivity);
- slum and marginalization increasing processes, which may evolve from the mentioned habitational and employment difficulties and which tend to contribute to the aggravation of social stress, violence and criminality levels.

It is worth saying that the preceding inferences do not obviously have the intention of reducing the enormous urban socio-economic complexity to issues related exclusively to accessibility, nor to suggest that accessibility provision could be a panacea for urban development and welfare problematic. They just intend to emphasise the existence of relevant indirect effects which should not be neglected in urban development and transportation strategic planning process, and could also have much influence on the establishment of objectives and criteria to be followed as well as on the directresses and public policies arisen from that process.

ACCESSIBILITY AND MOBILITY INDICATORS - A SYNOPSIS

Accessibility indicators

The notion of urban accessibility can be assimilated from current literature as something like "facility of accessing activities by transportation system" which matches with the concept of "potential of opportunities for interaction" originally suggested by Hansen in 1959. By mixing both concepts, 'urban accessibility' is assumed in this paper as a "potential of opportunities for physical interaction between spatially separated activities by transportation system (allowing to include in some contexts 'on foot' displacements)".

Starting from Hansen's pioneer work and with emphasis on the 70's, a great quantity of studies and researches has enlarged the participation and relevance of urban accessibility concept on integrated urban transportation and development planning. Many different kinds of indicators have been suggested, and application possibilities went much beyond the residential land use planning focused by Hansen's paper, as can be seen on the synopsis shown in table 2 (see also Viekerman, 1974; Morris *et al*, 1979; Pirie, 1979; Jones, 1981; Sales Filho, 1996; Lee & Goulias, 1997).

Mobility indicators

Urban mobility concept is usually associated and, many times, confused with accessibility one. Having in mind that this is just a question of definition, that is, the way in which it is stipulated to understand this or that concept, and considering current literature (see Popper & Hoel, 1976, and Jones, 1987), it is assumed here that mobility is related with daily displacements (trips) of people on the urban space, not only their effective occurrence but also their facility or possibility of happening. The first two cases would correspond to behavioural measures while the last one (frequently represented by a traditional accessibility measure) would correspond to a potential indicator. The synopsis on table 2 clarifies these points.

Applications of accessibility and mobility concepts

Accessibility and mobility concepts have currently a wide and diversified field of application in transport planning and in urban and regional planning, ranging from internal analysis (*stricto sensu*) of these disciplines, e.g. in forecasting trip demand models and housing tendency studies, to external analysis (*lato sensu*) involving multidisciplinary aspects with social, economic, political, technological, environmental and other connotations. In general, the applications, with some correspondent references found in the literature, can be classified into the following major groups:

- description and diagnoses of urban spatial structure (Hansen, 1959; Savigear, 1967; Weibull, 1976; Black & Conroy, 1977; Murayama, 1994; Spencer & Linneker, 1994; Gutiérrez & Urbano, 1996; Vickerman, 1996);
- alternative plans evaluation for transport system enlargement, considering the interaction with land use (Neuburger, 1971; Pike, 1976; Popper, 1976; Koenig, 1980; Sales Filho, 1990, 1996);
- urban development models, with transport / land use interaction (Hansen, 1959; Davidson, 1977; Black & Conroy, 1977; Heikkila & Peiser, 1992);
- equity, quality of life and social impact studies, involving specific segments of the population (Wachs & Kumagai, 1973; Black & Conroy, 1977; Boer, 1986; Hägerstrand, 1986, 1987);

Table 2 - Accessibility and mobility indicators synopsis

	Accessibility Indicators						Mobility Indicators		
	Spatial Separation	**Contour Measures**	**Gravity-type (Hansen)**	**Travel Cost Measures**	**Micro-econ. Measures**	**Time-space Measures**	**Observed Trip Meas.**	**Trip Facility Measures**	**Trip Potencial**
Characteristic	transp. network (without land use)	graphic representation	transportation / land use combined effect	average trip time (or gener. cost)	micro-economic foundation (disaggr. appr.)	graphic of an indiv.'s sphere of action in 24 h	daily trips parameters (per person)	facilities provided by transp. system	possibility of occurrence of trips
Theoretical Foundation / Approach	empirical / aggregate	empirical / aggregate or disaggregate	empirical / aggregate	empirical / aggregate	micro-econom. / behavioural (disaggregate)	empirical / behavioural (disaggregate)	empirical / aggregate or disaggregate	empirical / aggregate	empirical / aggregate or disaggregate
Formulation	a) graph theory b) imped. funct.	isochr. curves; accessibility profile	$A_i = \sum_j B_j f(c_{ij})$	$\sum_j c_{ij} T_{ij} \Big/ \sum_j T_{ij}$	analytical-deductive (trip liquid benefit)	2D or 3D graph. (dist. or space) X (time)	trip length; trip time; quant. of trips (p/pers.)	operat.statistics; V/C ratio (for roadways)	tradit. accessib. indicators; time-space measures
Variants	a) node degree; Shimbel meas. b) relat./ integr. accessibility	area under the accessility profile curve	normalised; weighted; with compet. demand	observed trips; expected trips	consumers' surplus; utility theory	observed and potential displacements	desaggr. by socio-econ. groups	quantity of movement (pass. x veloc.)	minimum levels socially acceptable
Advantages	a) simplicity / few data b) more precise	visualisation; computation facility	combined effect (transp. & urban planning link)	object. and easy understanding results	theoretical foundation consistency	visualization; acc. impact of sched. constr.	obj. and easy understanding results	object. and easy underst. results; few data	ditto acc. ind.; objective result (for variants)
Limitations	without spatial distribution of activities	aggregation difficulties; relative values	diffic. in isolat. separ. / attract. influences	inconsistencies as a 'well-being change' proxi	data demanding; user's view point (not society eff.)	data demanding; aggregation difficulties	inconsistencies as a 'well-being change' proxi	based on behaviour (not on potential)	ditto acc. ind.; localised studies (variants)
Applications	prelim. analysis for identifying gross deficienc.	sect. diagnosis by socio-econ. groups	sect./ glob. diag; plans evaluation; urb. dev. models	plans evaluation (not concluding information)	land use and forec. demand behav. models	equity and 'qol' analysis for specific groups	equity and 'qol' analysis (not concl. inform.)	diagnosis and management of transp. systems	ditto acc. ind.; equity and 'qol' studies (var.)
References	[1],[18],[23],[38] [42],[45],[51]	[4],[26],[28],[29] [39],[47]	8][9][10][13][16] [18][19][20][22] [23][28][35][41] [44][45][46][48]	[22],[28],[35] [42],[51]	[6],7],[22],[25] [28],[30],[31] [49]	[14],[15],[19] [20],[36]	[5],[14],[15],[32],[33],[40] (mobility indicators references)		

- transport system supply monitoring (Popper & Hoel, 1976; Black & Conroy, 1977; Giannopoulos & Boulougaris, 1989);
- land use planning, in the sense of facility location (MacAllister, 76; Orloff, 1977; Bach, 1981);
- trip demand models (Vickerman, 1974; Cochrane, 1975; Burns & Golob, 1976; Black & Conroy, 1977; Willians, 1977; Ben-Akiva, 1978; Leake & Huzayyin, 1979; Koenig, 1980; Giannopoulos & Boulougaris, 1989; Handy, 1993; Kockelman, 1997);
- scientific research in transport planning and in urban and regional development fields, including literature review (Echenique *et al*, 1969; Niedercorn & Bechdolt, 1969; Neuburger, 1971; Ingram, 1971; Zakaria, 1974; Cochrane, 1975; Weibull, 1976; Williams, 1977; Leonardi, 1978; Morris *et al*, 1979; Pirie, 1979; Koenig, 1980; Jones, 1981; Tagore & Sikdar, 1995; Lee & Golias, 1997).

CONCEPTUAL-ANALYTICAL IMPROVEMENTS

Taking into account the empirical characteristic of gravity type accessibility indicators theoretical foundations - expressed by the search for mathematical expression which reflects in the best possible way an intuitive and qualitative concept - and taking the accessibility concept as a "potential of opportunities for physical interaction between spatially separated activities by transportation system" some analytical conceptual improvements have been searched (Sales Filho, 1996) concerning the formulation of the relative accessibility between two sectors, whose basic expression according to Hansen has the following form (see table 2):

$$A_i = \sum_{j=1}^{n} A_{ij} = \sum_{j=1}^{n} B_j f(c_{ij}) \qquad (1)$$

where: A_i - accessibility of sector i;
A_{ij} - relative accessibility between i e j
B_j - attractiveness of opportunities in j;
c_{ij} - time or generalised cost;
f (c_{ij}) - impedance function, e.g. potency (Hansen, 1959), exponential (Pike *et al*, 1976; Dalvi & Martin, 1976) or Gaussian (Echenique *et al*, 1969; Ingram, 1971);
n - number of zones or sectors of the region in study

Combined effect of origin and destination attractiveness

The B_j parameter, which represents only one of the two attractivenesses involved in the interaction, has been replaced by the geometric average of the origin and destination attractivenesses. In order to simplify, it was assumed that O_i and D_j have the same weight in "the potential of opportunities for interaction", correcting values, whenever required, so that considering all the region sectors, the total sum remains the same for both attractivenesses. Thus, at this point:

$$A_{ij} = (O_i . D_j)^{1/2} . f(c_{ij}) \qquad (2)$$

where: $$O_i = O_i' \times \frac{\sum_{i=1}^{n} O_i' + \sum_{j=1}^{n} D_j'}{2 \times \sum_{i=1}^{n} O_i'} \quad ; \quad D_j = D_j' \times \frac{\sum_{i=1}^{n} O_i' + \sum_{j=1}^{n} D_j'}{2 \times \sum_{j=1}^{n} D_j'} \qquad (3)$$

being: O_i and D_j - corrected values of origin and destination attractivenesses
O_i' and D_j' - original values of origin and destination attractivenesses

It is worth noting that the inclusion of the second attractiveness in the accessibility calculation, as conceived here, has a conceptually different meaning from the 'weighted accessibilities' proposed by Pike *et al* (1976) and Vikerman (1996), and mentioned as a variant for gravity type formulation in table 2. In fact, the geometric average consideration not only takes into account the dimensional problem as well as turns evident the combined effect of both attractivenesses in the composition of the 'potential of opportunities for interaction' (facts not verified in those variants).

Exclusivity effect

Exclusivity is here defined as the characteristic present in some types of trips (interactions) which causes the use of certain attractiveness in a interaction to prevent its use in any other interaction (e.g., in home-job interactions, exclusivity can be accepted in both origin and destination. This is valid when we consider that each individual has only one job and that each job is occupied by only one individual. Other situations have not been taken into consideration).

In such cases only one partition of O_i and another of D_j participate effectively in the potential of opportunities for interaction between i and j sectors - not O_i and D_j total values. Thus exclusivity factors p_{ij} and q_{ij}, which respectively represent the percentage of O_i attracted by sector j and D_j percentage which attracts i sector (considering the destination attractiveness of all the sectors in relation to i and those of origin in relation to j) have been added (fig.1).

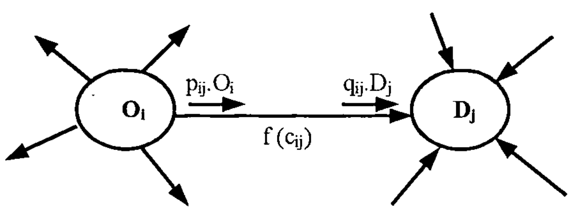


Figure 3 - Attractiveness decomposition concerning exclusivity

To eliminate the inconvenient of using proportions instead of absolute values which would make the global accessibility of the region (the sum of all relative accessibilities) of little sensibility to significant improvements in the transportation system, the expression of the relative accessibility has been corrected by a factor ($Atot_{ne}/Atot_e$). This factor brings the total accessibility to an identical value obtained without considering exclusivity.

Grouping activities

The enhancing effect caused by the grouping of activities in certain types of interaction (e.g., in the case of shopping centres considering home-shopping/leisure/services interactions) was conceptually considered by the introduction of a grouping factor (fa_j) capable of increasing the value of destination attractiveness (D_j) when appropriate.

Capacity constraint

The increase in travel time or generalised cost (c_{ij}), owed to capacity constraints because of the potential level of utilisation in certain connections of the transportation network was considered by including a portion (k_{ij}) to be added to c_{ij} value in the impedance function argument. This portion was multiplied by an adjustment factor (fk) which allows to modify it according to adopted assumptions as, for instance, in alternative scenarios evaluations. In this way we can treat differently a railroad and a bicycle track both integrating the same multimodal transportation network (which is not possible in the traditional formulation). Considering these parameters separated from c_{ij} (time without traffic jams) make the considered hypothesis clearer.

New relative accessibility formulation

Taking the previous considerations into account we came to the following expression for relative accessibility between sectors i and j:

$$\boxed{A_{ij} = \left(p_{ij}.O_i.q_{ij}.D_j.fa_j\right)^{1/2}.f(c_{ij} + fk.k_{ij}) \cdot \frac{Atot_{ne}}{Atot_e}} \quad (4)$$

where: $$p_{ij} = \frac{D_j.fa_j.f(c_{ij} + fk.k_{ij})}{\sum_{s=1}^{n}\left[D_s.fa_s.f(c_{is} + fk.k_{is})\right]} \quad (5)$$

$$q_{ij} = \frac{O_i.f(c_{ij} + fk.k_{ij})}{\sum_{r=1}^{n}\left[O_r.f(c_{rj} + fk.k_{rj})\right]} \quad (6)$$

$$Atot_{ne} = \sum_{i=1}^{n}\sum_{j=1}^{n}\left[\left(O_i.D_j.fa_j\right)^{1/2}.f(c_{ij} + fk.k_{ij})\right] \quad (7)$$

$$Atot_e = \sum_{i=1}^{n}\sum_{j=1}^{n}\left[\left(p_{ij}.O_i.q_{ij}.D_j.fa_j\right)^{1/2}.f(c_{ij} + fk.k_{ij})\right] \quad (8)$$

The accessibility matrix

The main consequence of the consideration of the combined effect of the origin and destination attractiveness mentioned before is the possibility of a matrix treatment for accessibility indicators in modes similar to doubly constrained trip distribution models. Such treatment, as far as this author knows, has not yet been approached in any other work concerning accessibility and it opens a wide field for research.

Figure 4 shows the basic elements of an O-D type matrix, traditionally used in transportation planning, and those of an accessibility matrix as conceived here. The basic difference lies in the fact that in the accessibility matrix the lines subtotals (AO_i) and the columns subtotals (AD_j) - which respectively represent the sector i accessibility as travel origin sector and sector j accessibility as travel destination sector - are not predetermined values to which the generic term (A_{ij}) should restrict itself to (as in type O-D matrices). These subtotals are values calculated *a posteriori* by summing up the relative accessibilities.

This fact makes the accessibility matrix reflect much more clearly the transport / land use compatibility level (in terms of attractivenesses and difficulties involved) than a matrix type O-D where this point is not practically perceived owed to double constraint imposed which causes major alterations in the transport system only affect the form of trip distribution (without affecting the generated and attracted volume in each sector).

In order to better understand this statement let us imagine a scenario in which two urban sectors have exactly the same origin and destination attractivenesses (for instance, generated and attracted trips). Let us also suppose that one of these sectors is located near downtown being well served by the transport system while the other is a peripheral sector poorly assisted in terms of transport, comprising for this reason much more impedance in its links with all the other region sectors. In this case, both sectors would have practically the same performance concerning O-D type matrix as they would have the same total volumes of generated and attracted trips (O_i and D_j), having only eventual differences in the distribution of these volumes between all the sectors which nevertheless would not explicitly reflect differences in the interaction facility levels. On the other hand, regarding the accessibility matrix these two sectors would surely have unequal performances. The more central sector would have a greater 'potential of opportunities for interaction' (accessibility) as origin sector (AO_i) and also as destination one (AD_j) considering the minor impedance in its links with all the other sectors and having in mind the mentioned equality in the attractivenesses.

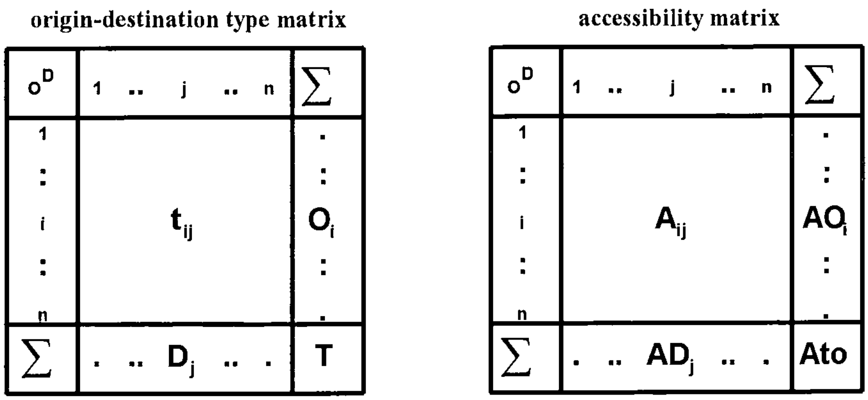


Figure 4 - Visualisation of O-D and accessibility matrices

In short, O-D type matrices inform about trip volumes, concerning the way in which the interactions tend to be distributed, but they are omitted in relation to the interaction difficulty levels involved in the distribution process. Accessibility matrices deal with potentials of opportunities for interaction, which reflect transport / land use combination effects in terms of attractivenesses and difficulties involved, independently of the effective occurrence of the interactions.

The two types of matrix complement one another in certain ways in terms of applicability. The O-D matrix is particularly useful in internal transportation planning studies viewing, for instance, the road network project and the transportation system supply. The accessibility matrix can be applicable to comprehensive and multidisciplinary studies such as welfare and urban development strategic planning, where the transportation network evaluation concerning its compatibility with the spatial distribution activities is positioned. This kind of evaluation is the focus of the following methodology.

EVALUATION METHODOLOGY

The considered methodology (Sales Filho, 1996) basically consists of calculating and analysing accessibility matrices and efficacy indexes taken from the comparison between these matrices and those type O-D. This methodology allows both diagnosing a certain transportation / land use scenario and comparing structural network alternative scenarios for a given spatial distribution of activities. In the first case (diagnosis) the main parameters to be analysed are:

- the specific accessibility values (AOr_i and ADr_j) which represent the relative participation of the potential of each sector as origin and destination sector (related to the total interaction region potential)

$$AOr_i = AO_i / Atot \;\; ; \;\; ADr_j = AD_j / Atot \;\; ; \;\; Ar_{ij} = A_{ij} / Atot \qquad (9)$$

where: $$AO_i = \sum_{j=1}^{n} A_{ij} \;\; ; \;\; AD_j = \sum_{i=1}^{n} A_{ij} \;\; ; \;\; Atot = \sum_{i=1}^{n} \sum_{j=1}^{n} A_{ij} \qquad (10)$$

- efficacy indexes type 1 ($OE1_i$ and $DE1_j$) which inform the efficacy level of each sector in terms of accessibility concerning the expectation given by the existing relation between its origin and destination attractiveness and the total volume of interactions.

$$OE1_i = AOr_i - Or_i \quad ; \quad DE1_j = ADr_j - Dr_j \quad ; \quad E1_{ij} = Ar_{ij} - tr_{ij} \tag{11}$$

where: $$Or_i = O_i / T \quad ; \quad Dr_j = D_j / T \quad ; \quad tr_{ij} = t_{ij} / T \quad ; \quad T = \sum_{i=1}^{n} \sum_{j=1}^{n} t_{ij} \tag{12}$$

- Efficacy indexes type 2 ($OE2_i$, and $DE2_j$), which express, in a specific way (in relation to the total of the region), the participation of the accessibility matrix elements pondered by the weight of their corresponding elements in the O-D matrix.

$$OE2_i = \frac{AO_i.Or_i}{\sum_{i=1}^{n}(AO_i.Or_i)} ; \; DE2_i = \frac{AD_i.Dr_i}{\sum_{i=1}^{n}(AD_i.Dr_i)} ; \; E2_{ij} = \frac{A_{ij}.tr_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n}(A_{ij}.tr_{ij})} \tag{13}$$

In the second case (networks comparison), the efficacy index type 3 is applied. This index was created to substitute with advantage the region total accessibility (Atot) as a global level indicator for comparing alternative scenarios. This index corresponds to the sum of relatives gain and losses in accessibility in each sector (as sector of origin and destination) pondered by the relative participation (in relation to the total of the region) of the effective impacted segments in each situation.

$$E3_{II,I} = \sum_{i=1}^{n} \left[\left(\frac{AO_{i,II}}{AO_{i,I}} - 1 \right) \times Or_i + \left(\frac{AD_{i,II}}{AD_{i,I}} - 1 \right) \times Dr_i \right] \tag{14}$$

where: $E3_{II,I}$ - efficacy index type 3 of scenario II in relation to scenario I;
$AO_{i,II}$ - accessibility of sector i as origin sector regarding scenario II;
$AO_{i,I}$ - accessibility of sector i as origin sector regarding scenario I;
$AD_{i,II}$ - accessibility of sector i as destination sector regarding scenario II;
$AD_{i,I}$ - accessibility of sector i as destination sector regarding scenario I;

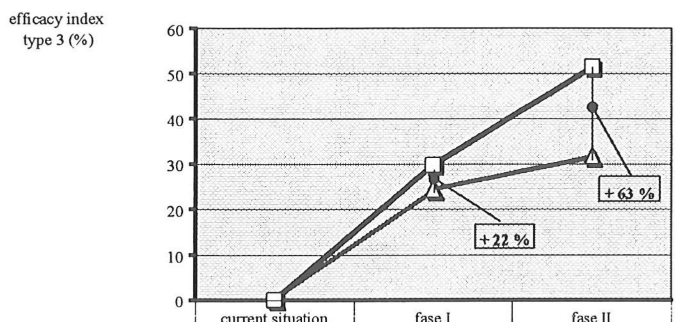
CASE STUDY - RIO DE JANEIRO METROPOLITAN REGION

The calculating procedures previously described were computerised in two different programs (URBAC1 and URBAC2) allowing the application of the above mentioned methodology in real situations which demand a great amount of data and calculations.

Rio de Janeiro metropolitan area was chosen as case study (Sales Filho, 1996). Starting from the current transportation multimodal network (scenario RJ1) two alternative scenarios were investigated involving mass transportation systems enlargement (scenarios RJ2 and RJ3) in two implementation stages, comprising a total of five basic multimodal transportation network scenarios. The RJ2 scenarios (phases I and II) corresponded to a consolidation of plans elaborated by the operating companies of the current subway and urban railroad systems. Those named RJ3 were based on proposals taken from the author's M.Sc. thesis (Sales Filho, 1990), whose main focus was the use of Rio-Niteroi bridge not only as a highway but also as a mass transit railway.

Besides Rio de Janeiro, the metropolitan region is composed of 16 other neighbouring counties. It was divided into 42 different transportation sectors. For each of those sectors two alternative types of origin and destination attractiveness were considered - population / employment and generated / attracted trips - which resulted in a total of 10 distinctive scenarios for this methodological application. Considering the corresponding public transportation features for all available modes (railway, subway, roadway, and flatboat), travel time and capacity constraints parameters between sectors were established for each of the five basic scenarios.

The final results of this methodology application can be summarised by comparing the efficacy index type 3 of each alternative scenario in relation to the base scenario (corresponding to the current situation). The main conclusion is that regarding accessibility scenario RJ3 is more effective than scenario RJ2 - about 20% superior in the first stage (with the same costs) and 60% in the second (figure 5).



	current situation	fase I	fase II
RJ2 - Metro / PTM	0	24,3	31,6
RJ3 - Proposed	0	29,7	51,4

stage

RJ2 - Metro / PTM   RJ3 - Proposed

Figure 5 - Alternative scenarios comparison

Studying the case, it became evident that the lack of contour restraints mentioned before causes the accessibility indexes to have much more sensibility to the β parameter of the negative exponential impedance function than the matrix O-D elements do. For this reason, the β parameter to be utilised in accessibility calculations should not necessarily be the same as the eventually calibrated in doubly constrained gravitational trip distribution models for the region concerned. In fact, it is reasonable that this parameter should have a minor value.

For instance, in this case study the β value arisen from a sensibility analysis and used in generated / attracted trips scenarios was 0.04 although the calibration by Hyman's method (see Gonçalves, 1992) would have suggested 0.05233 (based on a 35.6 min average travel time by public transport, surveyed in 1995 for the morning pick hour).

Along the same line, it could also be assumed different types of impedance function for the calculation of each matrix. An interesting combination would be the use of the negative exponential function for the O-D matrix, whose suitability has already been theoretically demonstrated by Wilson (1967), and the use of the Gaussian function for the accessibility matrix as proposed and justified by Ingram (1971).

An interesting aspect of the methodology to be noted is its versatility concerning the need of data. It can be used either with traditional O-D matrix data - like trip generation and attraction sectors amounts which are difficult and expensive to obtain, hence not always available - or it can also be used with much more simple data - almost always easily available, like resident population and job amount in each transportation sector.

In this aspect it is important to emphasise that the obtained end results were very similar for both kinds of data above mentioned. Without disregarding the need for more empirical evidences, these results give raise to speculations on the sufficiency of using only simple data when the others are not available - at least for quick pre-evaluations with the purpose of optimising and directing the alternative generation process as well as signalising the continuation of the investigations.

CONCLUDING REMARKS

This paper has investigated the use of gravity type accessibility indicators on the evaluation of urban transportation structural network becoming evident the utility and relevance of these measures in strategic planning processes for large cities.

Among the conceptual analytical improvements proposed, the consideration of the combined effect of origin and destination attractivenesses deserves especial relevance. It allows the development of a new matrix treatment for those indicators and the development of a new transportation network evaluation methodology which opens a wide field for research (in which can be included the conceptual reflections about the value of the β parameter for the impedance function).

The case study revealed not only the practical and operational aspects of the methodology (including the possibility of using easier obtainable data) but mainly its usefulness in real situations as a tool to support the planning and the decision making process related to the enlargement of a transportation network in large urban regions.

This work can possibly motivate future developments such as the use of this methodology in geographic information systems including tri-dimensional graphics (on going research); the use of the suggested improvements in forecasting demand and land use traditional models; the possibility of normalising some of the investigated indexes as to allow comparative diagnoses between cities with different dimensions and characteristics; and the inclusion of this methodology in more comprehensive evaluation methodologies like multicriteria / multiobjective ones. In this last case, the reflections on the relevance of accessibility in the urban socio-economic context could possibly be a contribution to better formulating objectives, criteria, indicators and weight attributions.

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