

## AN ASSESSMENT METHOD FOR GIS-T SOFTWARE

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**Abstract:** The objective of the research work summarized in this paper was to develop a method to assess, concerning its functional and performance characteristics, GIS software applied to transportation planning (the so-called GIS-T packages). Three computer packages were compared with the developed procedure, which focuses on several characteristics: descriptive aspects (e.g., learning time and customization possibilities, among others), basic GIS operational characteristics, advanced GIS features, and transportation planning routines. In order to conduct a more effective analysis of their potential as a transportation planning tool they were all applied for finding a solution of a problem involving the calculation of a simple, straightforward accessibility measure. The results found suggest that all three systems comply with the minimum configuration desired for GIS software. However, only two of them fit in the GIS-T category, since the third one did not supply the main necessary tools to solve the specific transportation problem proposed.

**Keywords:** GIS-T, software assessment, transportation planning software

### 1. INTRODUCTION

Population growth and the consequent increase in the transportation demand are constantly pushing planners and decision-makers for fast and efficient solutions to operational problems. In addition, user's demands for level of service improvement are also often increasing nowadays. The competing goals of efficiency and effectiveness ask for high standard transportation professionals and for better tools to support the planning process. This need of reliable tools to support decision-makers is certainly one of the reasons that has driven the growing use of GIS (Geographic Information Systems) since they have first appeared, back in the 1960s. There is no doubt that the success of any project is largely determined by the use of adequate tools to its development. Only the use of a tool, however, no matter how good or powerful it is, is frequently not enough to solve all problems, specially when it concerns to transportation and urban planning problems. In the case of GIS, similarly to what happens with any other tool, it is of utmost importance the knowledge of characteristics, functions and

performance of the computer program one intends to use to solve any particular problem.

Bearing it in mind and turning towards a specific area, the objective of the research work summarized in this paper was to develop a method to assess, concerning its functional and performance characteristics, GIS software applied to transportation planning, what is usually called GIS-T. Some works indicating the essential operations and capabilities needed for a GIS-T have already been done in the past (e.g., Jong and Ritsema van Eck, 1991), but they were essentially theoretical. In that way, they were pointing to the general class of GIS-T and not to specific commercial products. Therefore, they were not really evaluating the available software options in a detailed fashion, as is the case of the approach presented here.

Three computer packages were compared with the developed procedure, which focuses on several characteristics: descriptive aspects (e.g., learning time and customization possibilities, among others), basic GIS operating characteristics, advanced GIS routines, and transportation planning routines. In order to conduct a more effective analysis of their potential as a transportation planning tool, they were all applied for finding a solution of a problem involving the calculation of a simple, straightforward accessibility measure. The application of the computer programs for solving that problem is an important contribution to the evaluation procedure. It allows an analysis of the packages tools available for dealing with two elements that are present in many transportation-planning problems: networks and matrices. At the same time, the proposed problem also makes possible an evaluation of the difficulties faced by any regular user when applying basic commands available in each package, such as those for file manipulation (e.g., import and export possibilities, respectively, from and to different file formats), database management, and mapping facilities.

This document is divided in five parts, including the present introduction. Some of the main differences between GIS and GIS-T are highlighted in section 2, which brings some definitions, basic concepts and possible applications of both. In section 3, the evaluation method proposed is briefly introduced along four subdivisions: survey, presentation and description of software tools; definition of comparison parameters; presentation and evaluation of the comparison results; and solving a transportation planning problem. The overall results of the case study involving three packages is discussed in section 4, while section 5 brings the conclusions of this paper.

## 2. GIS AND GIS-T

According to Lewis (1990), GIS is a computer database management system to capture, store, retrieve, and analyze spatial data. When referring to GIS one can certainly find several similar definitions in the literature, such as those quoted by Heikkila (1998):

- GIS can be seen as a system of hardware, software and procedures designed to support the capture, management, manipulation, analysis, modeling, and display of spatially-referenced data for solving complex planning and management problems (NCGIA, 1990)
- GIS is an organized collection of computer hardware, software, geographical data and personnel designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information (ESRI, 1990 - also found in ESRI, 1996)
- All GIS integrate a mapping function with a database manager. The hallmark of a true GIS is its geographical intelligence, or topology that facilitates searches based on map locations, not just data values (Levine and Landis, 1989).

Despite its definition, GIS is nowadays a powerful and perhaps the best tool to solve problems of data storage and management in spatial models. Thus, it is not surprising that several public

and private agencies currently use GIS tools for managing and processing data in their regular decision-making processes.

The main functions of GIS are: spatial and non-spatial data input capabilities (data from digitizing tablets and scanners; import routines for different file formats, such as CAD files; survey data; etc.), data management (edition of spatial and non spatial-data; database management), data analysis (query and overlay functions), and data output (maps, reports and images). As a result, GIS must allow the creation of fast graphic outputs and the analysis of statistical data relationships in a geographical context. The visualization of the results, which is enhanced by data storage and graphical representation GIS capabilities, helps the users in finding solutions to their problems. According to Hsiao and Sterling (1992), that already was more ten years ago an effective method to evaluate the results of analyses, particularly those based on large data sets.

Additionally, GIS is a convergence of technological fields, which provide many of the techniques and tools available in the system. Due to the multidisciplinary nature of GIS, applications of the computational tool are found in several areas, such as: geography, engineering, urban planning, forest management, environmental analysis, data processing, operational research, infrastructure management, transportation, and many others. However, the interest GIS has generated particularly in the field of transportation analysis was so strong that soon a variation, named GIS-T (Geographic Information Systems for Transportation), was specifically produced to meet the needs of the transportation community. The new tool was then thought to bring to the market a series of tools (for instance, for network analysis and related topics) that were rarely available in the original GIS packages.

The possibilities of application of GIS-T in the field of transportation are vast in part because they are spread out in both planning and operation activities. Among the specialized applications of GIS-T are: pavement management system; transportation hazard analysis and incident management; travel time studies; representation of freight transportation networks; multicriteria evaluation of route alignments; planning and management of regional road network; search for optimal routes; traffic congestion studies; web-based transit information systems; and many others mentioned by Verma and Dhingra (2001). A similar inventory of GIS-T applications limited to the case of Brazil has been conducted by Silva (1998). Although the use of GIS-T in the country did not start before the early years of the nineties, the author was already able to find in 1998 a relatively large number and variety of applications: association of satellite images with mathematical models for transportation planning; transit planning; assessment of the impacts of urban growth on public transportation; routing for newspapers distribution and solid waste pick-up; transit stops location; definition of traffic analyses zones; accessibility assessment; among others. Such a fast response in terms of applications in Brazil clearly shows the importance and potential of GIS as a tool in the transportation field also in developing countries.

Other recent works (e.g., Lang, 2000; Thill, 2000; Miller and Shaw, 2001) also focus specifically on GIS-T while showing areas of application and giving an indication of the future research developments trends in the field. The importance of the topic is widely recognized and it has already been highlighted in 2000, during the annual meeting of the American *Transportation Research Board*. GIS-T was then pointed out in a specific document (Fletcher, 2000) as a research area that should receive special attention in the near future, due to the need of efficient strategies to cope with the growing data availability for planning purposes. This is only one of the challenges of GIS-T future development trends. Miller (1999) had previously presented a review of spatial analytical issues and their potential contributions to GIS-T in a document that stressed the benefits of closer linkages between spatial analysis, GISci (*Geographic Information Science*) and transportation. More recently Verma and Dhingra (2001) emphasized the following topics as the future of GIS-T: knowledge-based GIS;

web-based GIS; GIS coupled with customized software or optimization techniques; integration of GIS and GPS technologies for intelligent transportation systems; temporal GIS; integrated urban transport/land use transport planning; facility location planning; real-time traveler information systems; cargo fleet management and routing; etc.

According to Kagan *et al.* (1992), the main advantages of using GIS in combination with transportation models are: data integrity provided by GIS can help users to grasp the physical characteristics of these data; predefined operations in GIS can reduce or even eliminate manual tasks or the need of isolated software modules; easy graphic representation and edition; proper topological representation that makes easy to edit geographical databases; storage and edition at relatively low cost; analyses and representations formerly not possible with traditional processes. In practical terms, in addition to the functionalities commonly found in any GIS package, GIS-T software must have some additional tools needed for the solution of transportation problems. These are at least:

- Matrices – they can contain different types of data (e.g., origin/destination, distances), which are in general extremely useful in transportation analyses
- Configuration of Traffic Analysis Zones – definition of boundaries of areas that can be used as zones to represent locations that produce and attract trips
- Trip generation – a process consisting in the three following steps:
  - Trip production – step to estimate the total number of trips produced in each zone
  - Trip attraction – step to estimate the total number of trips attracted by each zone
  - Balancing – step to adjust the total numbers of trip attracted and produced estimated in the previous steps of the trip generation process
- Trip distribution – it consists in the use of models to estimate the spatial pattern of trips connecting a certain number of origin and destination zones in a planning horizon year. The most well-known models for it are:
  - Growth factor models
  - Fratar model
  - Gravity model
  - Entropy model
- Modal split – the modal split models were developed with the aim of analyzing users' choice when facing several transportation modes as options
- Traffic assignment – the most common traffic assignment methods used to estimate traffic flows on a network based on a flow matrix are:
  - All-or-nothing assignment
  - Incremental assignment
  - Equilibrium
  - Capacity constrained assignment
- Route system – a set of several paths taken by vehicles made up by lines (links segments) and points (stops)
- Routing – the routing process looks for solutions to logistics problems, such as the determination of the number of vehicles needed to connect a certain depot to a certain number of points (clients) as well as the respective routes to be followed in order to reduce the displacement costs on the entire system.

In summary, Verma and Dhingra (2001) listed the essential operations and capabilities for a GIS-T as follows: to manipulate existing link attributes to produce entirely new attributes which have applications in transportation planning; to edit data spatially; to import raster images as background information for the vector transportation database; to allow buffer and overlay analysis; to combine spatial searches and conditional queries; to allow address geocoding; to create, modify and edit such matrices; to carry out Shortest Path Analysis and vehicle routing; and to conduct the necessary steps for building the Urban Transportation

Model System (i.e., trip generation, trip distribution, modal split and traffic assignment).

In addition, Silva and Waerden (1997) stated that two mathematical elements, which are frequently found and hence very important in the transportation planning process, are the bases for most of the procedures listed above: networks and matrices. Networks are a combination of nodes and arcs that link the nodes. Passenger, cargo and vehicle flows can then be associated to network arcs. A matrix can contain, for instance, shortest path values that are associated to minimum cost routes between selected points of a network and that can be the starting point of more complex transportation network analyses. Thus, any GIS-T must necessarily have tools for creation, edition and manipulation of both networks and matrices.

### **3. A METHOD FOR GIS-T SOFTWARE ASSESSMENT**

The proposed method for GIS-T software assessment is made up of a sequence of activities, which are briefly introduced in the four subdivisions of this section. These activities were thought to provide a framework for an essentially comparative analysis of Geographic Information Systems for Transportation software. The first one deals with the survey, presentation and description of software tools. The definition of comparison parameters is discussed in subsection 3.2, while the presentation and evaluation of the comparison results is commented in subsection 3.3. The developed procedure focuses on several characteristics: descriptive aspects (e.g., learning time and customization possibilities, among others), basic GIS operational characteristics, advanced GIS routines and transportation planning routines. In order to conduct a more effective analysis of the software potential as transportation planning tools, the packages were all applied for finding the solution of a problem involving the calculation of a simple, straightforward accessibility measure, as described in subsection 3.4.

#### **3.1 Inventory of Software Tools**

After the selection of the GIS-T packages that at the first sight meet the user needs, the first step of the evaluation process is to identify the general characteristics and functionalities of each option. In order to conduct a thorough evaluation of the tools and options available in each package, the first necessary step is to list all items to be analyzed in a clear and objective way. This inventory can make easy the identification of the distinct resources available in different computer packages. Although one can find a variety of information available in documents posted on Internet, care should be taken when choosing them as the basis for any deeper analysis because these sources are often biased to serve marketing purposes. Even considering that the purpose of this phase is only to gather general information, commercial documents are usually not sufficient for a realistic survey of the resources available in the packages, what can jeopardize the intended comparative analysis.

A suggestion to carry out such a comprehensive inventory in a systematic manner is to follow the software menus and commands in the same sequence they are displayed on the computer screen when moving from left to right and from top to bottom. The inventory report must have associated to each menu option or command exactly the same information available on screen, including pictures and dialog boxes. The use of pictures as an aid to better understand the software items may also be useful in the identification of a particular software package later on by the end user, as shown by Rose (2001). In the same process of inventory, an explanation of procedures, parameters and variables required for running each package option must be provided. The icons available on the package must also be identified, and the corresponding commands highlighted. The manuals issued by software developers are usually the best sources to identify the commands, their functions and how to use them, although they are often not presented in the some order as the one suggested here.

A brief example of the description suggested above can be based on Figure 1, which is a screen snapshot produced with the package *ArcView GIS*<sup>1</sup>, version 3.1. The options **NEW PROJECT**, **OPEN PROJECT**, and **CLOSE PROJECT** of the *File* option in the main menu perform the following tasks, respectively: to create a new project, to open an existing project, and to close the active project. The options **SAVE PROJECT** and **SAVE PROJECT AS** are used to store the active project. The first one keeps the current project name while the second one asks for a new project name. Through the option **EXTENSIONS** the user can activate or deactivate the additional modules and extensions available to ArcView. The **EXIT** option ends the program.

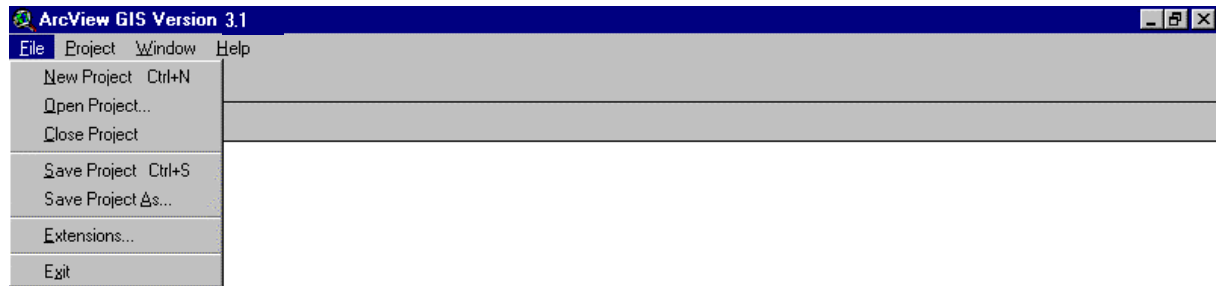


Figure 1 *File* option found in the main menu of ArcView 3.1

Even considering that the construction of an inventory report in the way proposed here is a time-consuming task, the resulting document may give to end users a clear notion of all commands available in the package as well as their locations in the menu bar. That makes easier the future use of any of the selected packages. In addition, the list of commands and options is essential to the next step of the evaluation process, when tools and commands are classified in the following distinct groups: basic commands, advanced GIS features, and specific transportation-planning routines. This division is essential if the purpose of the evaluation of available tools is to distinguish GIS from GIS-T packages.

### 3.2 Setting up Comparison Parameters

Although the organization of the information of the resources available in the distinct packages as mentioned in the previous item is essential for a comprehensive and unbiased evaluation, it is not enough. The definition of comparison parameters is also essential to the process. This can be done by identifying the main tools and applications of the programs and also taking into consideration the needs and doubts of potential users. In order to do that, the work of Kemp (1994) is very useful. She suggested that four aspects should be considered when specifying a GIS: the tasks, the people, the constraints, and the data. She also listed several items for each of those aspects. The list of all items organized by Kemp (1994) was used to identify the basic GIS characteristics that were defined as the first set of *Comparison Parameters*. More precisely, this first set has two subdivisions: *Descriptive Aspects* and *Basic Operational Characteristics*.

While the first elements are mainly descriptive (Table 1), the second and subsequent groups can be evaluated in a check-list form, with the basic operational features spread out in the following sections: Data Handling, Query Language, Report Generation/File Import and Export Capabilities, Data Entry, and Data Edition (Table 2). A next group of comparison parameters was defined as *Advanced GIS Features* (Table 3), in which the tools and options used for data analysis and results presentation are placed. The analysis of the elements that belong to this group required the precise identification of commands that can perform these tasks. The

<sup>1</sup> *ArcView GIS* is a trademark of ESRI - Environmental Systems Research Institute.

locations of the commands were also important and therefore they were carefully registered in the inventory report. Finally, the last group of comparison elements was formed by transportation planning tools, listed under the name *Transportation Planning Routines* (Table 4).

Table 1 List of the descriptive aspects of the GIS-T packages selected for a comparative analysis

DESCRIPTIVE ASPECTS	Package A	Package B	Package C
Version used for the evaluation			
Latest version available			
Minimum hardware requirements			
Type of data usually processed			
Support material			
Approximate learning time			
Technical Support			
Last actualization			
Programming language			
Customization possibilities			
Costs			

Table 2 List of the main operational characteristics of the GIS-T packages selected for a comparative analysis

OPERATIONAL CHARACTERISTICS	Package A	Package B	Package C
<b>DATA HANDLING</b>			
Data can be described as features with attributes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It supports complex features modeling	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It allows codification of nets	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Interface with relational databases	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It allows topological data structure	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It distinguishes graphical representation from geometrical representation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It supports temporal data series	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Data accessed by	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
High level language	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Structure of menus and icons	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
SQL	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

QUERY LANGUAGE			
Friendly interface	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
SQL editor	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It allows the integration of SQL extensions using logical and mathematical operators	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It allows the logical joining of fields from other tables	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It manages data selections	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It allows data sorting	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It allows alphanumerical data	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
REPORT GENERATION/FILE IMPORT AND EXPORT CAPABILITIES			
It allows customized reports (of both contents and formats)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
WYSIWYG (What You See Is What You Get)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It imports from several file types	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It exports to several file types	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
DATA ENTRY			
It allows feature codification for points, lines and areas	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It provides support to the user for:			
Codification	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Closing polygons	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Proximity recognition	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Topology creation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It allows border adjustment	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It supports database transfer	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
DATA EDITION			
It identifies features based on codes, coordinates, or cursor coordinates.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It allows features manipulation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It allows points union, node insertion, etc.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Automatic placement of texts and symbols	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Manual placement of texts and symbols	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It allows tolerance settings	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Automatic scale definition, edition and symbol insertion	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It allows the insertion of the north reference icon	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It allows the creation of thematic maps	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



Table 3 List of the main advanced GIS features of the GIS-T packages selected for a comparative analysis

<b>ADVANCED GIS FEATURES</b>	<b>Package A</b>	<b>Package B</b>	<b>Package C</b>
Data extraction by code, attribute or non combined criteria	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Geometrical operations (calculation of distances, perimeters, areas, etc.)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Library of formulas for data filtering and column insertion	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Buffer generation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Network creation and handling	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Grouping, partitioning and facility location	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Shortest path calculation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Overlay	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Definition of search areas	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Creation of the digital terrain model	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Creation of contour lines	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Creation of 3D views of the digital terrain model	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Extraction of statistical information from data	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Representation of data on graphics	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Address location	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Table 4 List of the main transportation planning routines of the GIS-T packages selected for a comparative analysis

<b>TRANSPORTATION PLANNING ROUTINES</b>	<b>Package A</b>	<b>Package B</b>	<b>Package C</b>
<b>GENERAL EVALUATION</b>			
Matrix creation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Trip generation			
Productions	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Attractions	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Balancing	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Trip distribution (models)			
Fratar	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Gravity	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Entropy	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Modal split	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Traffic assignment (methods)			
All-or-nothing	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Incremental	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Equilibrium	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Capacity constrained	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Optimal system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Route system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Routing	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

### 3.3 Presentation and Evaluation of the Comparison Results

The evaluation starts with a general analysis of the *Descriptive Aspects* of each package. However, this is a very subjective judgment because it is highly sensitive to user experience. That is the main reason for the essentially quantitative evaluation of the other three groups of characteristics. The results of this process is also summarized in tables, as will be shown in the application discussed in the next section. In addition to the quantitative analysis carried out for the groups *Basic Operational Characteristics* and *Advanced GIS Features*, the group *Transportation Planning Routines* received a different treatment. Even though the number of routines available is important also in that case, there are two basic transportation elements that any GIS-T package has to be able to deal with, which are matrices and networks. In order to check that capability a simple transportation problem is proposed as a reference, as described in the next subsection.

### 3.4 Evaluation of a Transportation Problem

Based on the statement of Silva and Waerden (1997) that networks and matrices are essential elements in the solution of most transportation planning problems, tools for effectively handling both of them must be necessarily available in any GIS package for transportation planning purposes. With the aim of assessing the tools for creation, edition and manipulation of networks and matrices in the packages under consideration, the use of a simple and straightforward accessibility measure is sufficient, as the one used by Allen *et al.* (1993). According to the authors, that accessibility indicator is a measure of the effort of overcoming the spatial separation between points within an area. For each network node, this index can be mathematically expressed as:

$$A_i = \frac{1}{N-1} \sum_j C_{ij} \quad (1)$$

where:

$A_i$  = accessibility at node  $i$ ;

$N$  = number of nodes used in the calculation;

$C_{ij}$  = the perceived cost to the traveler between zones  $i$  and  $j$ .

The solution of this problem requires the creation of a transportation network and a shortest path matrix containing all network nodes. In addition, there are some calculations carried out only with specific matrix columns. Finally, there is also the need of producing thematic maps to display the results. For the purpose of the comparison suggested here, all steps needed to reach the solution of the problem must be conducted in the packages under analysis. These steps must be carefully registered and analyzed, in order to allow the evaluation of the following aspects:

- Identification of the tools applied (if they are easy to find and to use, and if additional programming is needed)

- Identification of the main operational features (screen regeneration, data update, file handling, operations with matrices, insertion of formulas in tables, etc.)
- Processing time and hard disk demand
- Global evaluation (if satisfactory or not)
- General remarks
- Presentation of the final outcome (maps, tables, graphs, etc.).

#### 4. CASE STUDY

The application of the proposed method to evaluate three commercial GIS-T packages gave good results insofar as the main objective of the process, which was to perform a comparative evaluation of their available resources, was reached. The careful examination of the tools offered by the appraised packages showed that they practically did not differ in two aspects: in the general descriptive characteristics and in the basic GIS features (Table 5). However, the analysis of the advanced GIS features showed some differences, as summarized in Table 6. A close look to the summary concerning the transportation planning routines that was also shown in Table 6 highlighted the fact that one of the packages might not have sufficient tools to be seen as a GIS-T.

Table 5 Quantitative evaluation of the basic GIS features in the GIS-T packages compared

Options availability	Package B	Package B	Package C
<b>DATA HANDLING</b>			
Numbers of available options	10	10	10
Numbers of unavailable options	0	0	0
<b>QUERY LANGUAGE</b>			
Numbers of available options	7	7	7
Numbers of unavailable options	0	0	0
<b>REPORT GENERATION/FILE IMPORT AND EXPORT CAPABILITIES</b>			
Numbers of available options	3	4	3
Numbers of unavailable options	1	0	1
<b>DATA ENTRY</b>			
Numbers of available options	7	6	4
Numbers of unavailable options	0	1	3
<b>DATA EDITION</b>			
Numbers of available options	9	6	6
Numbers of unavailable options	0	3	3
<b>SUMMARY</b>			
Numbers of available options	36	33	30
Numbers of unavailable options	1	4	7

Table 6 Quantitative evaluation of the advanced GIS features and transportation planning routines in the GIS-T packages compared

Options availability	Package A	Package B	Package C
<b>ADVANCED GIS FEATURES</b>			
Numbers of available options	14	12	13
Numbers of unavailable options	1	3	2
<b>TRANSPORTATION PLANNING ROUTINES</b>			
Numbers of available options	16	13	1
Numbers of unavailable options	0	3	15

The procedures used to solve the proposed transportation problem were applied to find the shortest paths connecting all nodes of the road network of a medium-sized Brazilian city. The accessibility measure was then calculated. Every network node was associated to an estimated accessibility value and the values grew from the center to the periphery of the city, as anticipated. If the values did not follow the expected trend, that could be an indication that the network had connectivity problems, as suggested by Raia Jr. and Silva (1998). Those problems could be easily detected through the representation of the accessibility values in thematic maps, which were also built in the application carried out for evaluating the packages.

As expected, the solution of the transportation problem proposed made easy a direct analysis of the two elements previously pointed out as essential in the solution of most transportation planning problems, which are matrices and networks. It was also helpful in the evaluation of the difficulties found in the use of the basic commands available in each package. Two of the three packages analyzed were user-friendly, as can be seen in Table 7. The third package required more learning time, external support and additional time for reviewing the initial inventory of the tools in order to be able to use them. It is important to emphasize here the utility of the inventory report done in the first step of the process, in which it was often faster to find a command path than in the developer's manuals. Additionally, it can be useful not only during the evaluation process, but also when one of the products is finally selected for permanent use.

Table 7 Summary of conditions found for the calculation of the accessibility measure in the three packages examined

<b>IMPORTING THE FILE CONTAINING THE ROAD NETWORK</b>	
Package A	No troubles because the original file was created in the very same package.
Package B	It was necessary to ask for developer's support, which was fast and efficient.
Package C	Straightforward process without troubles.
<b>TOOLS IDENTIFICATION</b>	
Package A	Easy and straightforward identification of tools. The menus were presented in a very logical way. No need for programming.
Package B	The identification of tools and the addition of variables and parameters demanded previous knowledge of the package. Some tasks required additional programming.

Package C	Easy identification of the available tools. It offered less menus than the other packages, what resulted in the absence of some tools needed to solve the proposed problem. Some tasks required additional programming.
MAIN OPERATIONAL FEATURES	
Package A	Fast screen regeneration, data update and file handling. It allowed formula insertion and edition of tables.
Package B	While the manipulation of matrices was slow, the screen regeneration of maps was fast. It allowed formula insertion and edition of tables.
Package C	Map edition process was very slow. It did not allow the insertion of formulas in the tables.
PROCESSING TIME AND HARD DISK DEMAND	
Package A	Fast and adequate processing time. It used around 1 GB of hard disk to store the files created for solving the proposed problem.
Package B	Slower than package A, although acceptable. It also used around 1 GB of hard disk to store the files created for solving the proposed problem.
Package C	It did not handle the proposed network, because of its size. A rough estimation of the required hard disk space for handling the proposed network approached 35 GB.
GLOBAL EVALUATION	
Package A	Satisfactory.
Package B	Satisfactory.
Package C	Very limited.

The use of the commands for network generation and handling, matrices, databases and data visualization in thematic maps was very satisfactory in two packages, which were both able to solve the proposed transportation problem. On the other hand, the evaluation of the third package was not fully possible because it was not capable of supporting the complete road network. Even working with only 550 of the 7000 original network nodes, the solution of the proposed problem required a lot of creativity and flexibility from the user testing the package. The problems that caused the size limitation of the network were associated to the excessive processing time and hard disk space required to store the files created during the process. This program also required an external macro to handle the matrices, differently from the other two packages that have this sort of tool already built-in.

## 5. CONCLUSIONS

The application of the proposed method to evaluate three commercial GIS-T packages showed that the approach can be used to perform a quantitative and qualitative analysis of the tools offered by Geographic Information Systems for transportation. The results found suggest that all three systems comply with the minimum configuration desired for GIS software. However, only two of them fit in the GIS-T category, since the third one did not supply the main necessary tools to solve the specific transportation problem proposed. Although the results of this work could eventually help users in their choice of a more adequate package just selecting among the products evaluated, its biggest contribution lies in the evaluation methodology itself.

It is so due to the extremely fast evolution of computer programs that makes any result of a comparative analysis ephemeral and non-conclusive. In this sense, the proposed assessment methodology might be useful to big companies seeking GIS solutions as well as to individual users, since in both cases it can contribute to the maximum use of GIS as a supporting tool for solving transportation problems. Another interesting outcome of this method is the possibility of relying on more precise cost-benefit analysis for selecting the desired computer package, since the approach somehow makes the benefits of the different options explicit.

Even considering that any computer program tends to become obsolete in a short period of time, the proposed approach can still be used if simply adjusted to the latest changes taking place at the moment of the evaluation. For example, in the case of GIS-T packages particular attention must be directed right now to the need (and likely trend) of integrating spatial analyses tools into GIS-T software, as pointed out by Miller (1999).

### ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the Brazilian agencies CAPES (Post-Graduate Federal Agency), FAPESP (Foundation for the Promotion of Science of the State of São Paulo), and CNPq (Brazilian National Council for Scientific and Technological Development), and to the Portuguese agency ICCTI (International Institute of Scientific and Technological Cooperation), which have supported our efforts for the development of this work in different ways and periods.

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