A User's Guide to GIS Software Packages for Transport Planning Purposes

S.J. Clement
University of South Australia

J.K. Affum
University of South Australia

M.A.P. Taylor
University of South Australia

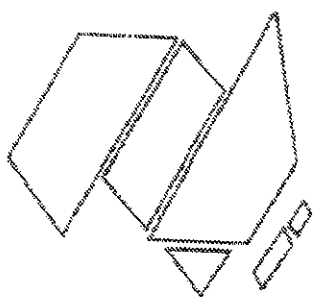
Abstract:

In recent years there has been considerable advocacy for the use of Geographic Information Systems (GIS) software in transport planning, and more recently the first applications of GIS have been reported. These applications have focussed on road safety studies and the compilation of travel demand databases. In the main they have been based on the use of a single GIS package, often with the rider that the package used for the research or investigation or pilot study might not be the one to be used in a full-scale operational system. This paper provides a review of currently-available GIS software. It defines the transport planning needs to be met by a GIS package, and assesses the suitability of various packages for transport planning applications. It provides an in-depth comparison of three common GIS packages: *MapInfo*, *ARC/INFO*, and *TransCAD*. The paper concludes by setting guidelines for selecting a suitable GIS package for different applications and operating environments in transport planning

Contact Author:

S J Clement
Transport Systems and School
of Civil Engineering
University of South Australia
The Levels
POORAKA S A 5095

Telephone: (08) 302 3818
Fax: (08) 302 3807



1. INTRODUCTION

Transportation issues both within and across modes are complex and the information required to consider the various alternatives often reside in a number of databases so that it is not readily available for use in planning and the overall decision making process. To effectively make use of the information from the different units requires the linkage and integration of all the databases. A Geographic Information System (GIS) has the potential to integrate and process data from a diversity of sources. Location is the fundamental concept that underlies both GIS base maps and transportation and the application of this concept provides an efficient and practical means of integrating data from different sources. This feature together with the ability to display the results in an easily understandable map form and the ability to analyse spatial data with consideration given to its location, has resulted in advocacy for the use of GISs in transportation. Transportation applications of GISs have recently been reported and these, some of which are operational and others still being developed, cut across all the different fields of transportation: road inventory; pavement management; bridge maintenance; traffic engineering and road safety; hazardous materials routing; transport modelling and planning; and project tracking. Different GIS software packages are being used in all these applications.

Apart from the cost of a GIS package and the computer hardware platform on which it is to run, other problems limiting GIS usage in transportation include the difficulty in selecting the appropriate GIS software package, mastering the use of the system and building and maintaining an application. Selection of GIS software is based on information received from vendors and sometimes consultants. This paper describes three of the currently available commercial GIS software packages being tried in the transport sector, compares their operational and functional capabilities and provides guidelines for selecting a GIS for transport planning purposes.

2. GIS CONCEPTS IN TRANSPORTATION

GIS is defined as a system of hardware, software, data, people, organisation and institutional arrangements for collecting, storing, analysing and displaying spatial information (Dueker and Kjerne 1989). It is a computerised database management system for managing and analysing spatial data. It uses two types of data: the geocoded spatial data and its associated non-spatial data termed attributes. GIS has served in several different capacities in the transport sector. Three kinds of uses can be identified and these are:

1. General data maintenance which includes data management and display. This involves using the GIS to store the data and then retrieve and transform the existing information into an easily understood, compact, displayable map form. The GIS is thus serving as a database with a graphic interface.
2. Data integration. This involves the use of two or more databases to develop a new information set required for an application such as a Management Information System (MIS).

3. Data analysis. This will eventually be the ultimate use of GIS in the transport sector. Currently, the reported applications of GIS in transport deal mainly with the above two categories. Data analysis will involve the GIS to perform the necessary analysis by linking or integrating programs into it. For example if decision support systems are integrated with a GIS then the results of data analysis can readily support the decision making process.

The GIS concepts to consider in transportation include data organisation, a location reference system, roadway segmentation and the available GIS software packages.

Data Organisation

Data describing the location of spatial features is generally defined by its topology and graphic information. Topology is used to describe the mathematical relationship between one feature and another. Topological considerations here deal with the spatial relationship among features and entities expressed in terms of points such as road intersections and the location of schools, landmarks etc; lines such as road segments; and polygons representing parcels of land or area such as postcode regions or Census Collection Districts (CCDs). The graphical approach uses cartographic principles (symbols, line weights, colours) for describing features, their type and magnitude in the form of a displayed map.

Location Reference System

In highway information systems, location referencing schemes are mainly linearly oriented, where the measure for reference is the distance along the highway and only secondarily embedded in a coordinate system. There are several referencing schemes used by transportation organisations. These include chainage, mile-point, control points and link-node systems. In GIS queries can be performed on the spatial data, the non-spatial attribute data or on both combined through the establishment of a suitable linkage. Hence the data must also be established on a coordinate system to serve as the spatial location reference system. Thus in GIS transportation applications, the location referencing system must include both the lineal sequence reference (location identifier) as well as a coordinate reference system. This affects the roadway segmentation through the way the spatial and attribute data are linked. Location referencing and segmentation determine the way data are retrieved for analysis and the graphic display of roadway information.

Roadway Segmentation

The linkage between the spatial data and attributes determines how data are retrieved for analysis and display. The road network is divided into segments in order to link the spatial data to specific points on a digitised map. In a GIS used for transportation, segmentation establishes the link between the attribute data values and the location data. There are two types of segmentation in place: fixed length and dynamic segmentation. The fixed length segmentation is based on the homogeneous attributes for a control section and the dynamic (or variable length) segmentation is based on run-length coding. The difference between the two is based on whether the attribute value is being measured or controlled (Sinton 1978). In fixed length segmentation the location is controlled and homogeneous attributes are attached to it, while in dynamic segmentation the attribute is held constant and the location and roadway are measured.

Available GIS Software

Currently there are many GIS software packages that can be used in the transportation sector. These include ARC/INFO from ESRI; MapInfo from MapInfo Corporation; TransCAD from Caliper Corporation; Atlas; UltiMap used by the California Department of Transportation; the Intergraph products IGDS and MGE; McDonnell Douglas software packages GDS and PCN; MunMap - a GIS based on AutoCAD; and Geobased used by the Alaska Department of Transport.

3. GIS REQUIREMENTS FOR TRANSPORT PLANNING

Core functions:

1. Produce a graphical display.
2. Allow analysis of geographical regions.
3. Allow selection of and queries about objects of the display
4. Must allow data related to any geographical position or region to be integrated eg population, number of hospitals, work schedules, travel times, peak hour flows etc.
5. Editing of graphical features - adding, deleting, moving and merging.
6. Must store attribute data in a database system.

GIS software packages have different functions, capabilities, and limitations. Some features such as using a coordinate reference system; windowing or zooming; and editing are available to all GISs while other features such as statistical and other analytical procedures, theme saving and legend control may or may not be present. This suggests that some GISs are suitable for some applications while others are not. Hence not all GISs are appropriate for use in transport planning. Following is a list of capabilities and functions required in a GIS in addition to the common features necessary for transport planning purposes.

Location Identifier

A key feature of GIS technology in transport planning is the location identifier. Whereas point and polygon features are well catered for in almost all GISs, linear data as required in transport planning is not supported in some. A GIS deals with both the spatial and non-spatial attribute data. A unique location identifier is needed to relate the data about the physical entities to the object that represents them on a map (Huxhold 1991). The location identifier should be a unique code that is used as a record identifier in the attribute database to differentiate one record from any other and also to represent a unique feature identifiable on a map. Examples of location identifiers used include x,y coordinate pairs, an address, start point plus the length of a segment, unique codes (a number or combination of numbers and letters), and from-node and to-node. The x,y coordinate pairs are complex, take up much disk space and in specific circumstances not unique. An example is the situation where two street segments have the same start and end point coordinates. The same can be said of the start-point plus length of a segment and from-node and to-node methods. This leaves the only unique location identifier suitable for transport purposes as that employing the unique codes.

Topological Relationship

Topology creation in GIS is the fundamental principle governing the way spatial data are analysed and integrated. Topology establishes the relationship between map features. Three kinds of properties relevant in transport related issues can be defined: these are adjacency, connectivity and containment. Adjacency is normally associated with polygons and is defined as being 'next to' For example two polygons sharing the same arc are said to be adjacent. Connectivity is a property of linear features. For example two street segments sharing the same node are said to be connected. Connectivity is thus of prime importance in network modelling. Containment occurs when an object lies entirely within the confines of another one. The way the GIS package stores or treats the topological relationship of the above properties determines the extent of both the spatial measurements and the analysis queries that can be performed on the stored data.

Data Overlay Analysis

The capabilities of a GIS for transport planning should include support for data overlay (polygon on polygon, line in polygon and point in polygon) and data overlay analysis dealing with union, join, intersect and clip (Zwart and Williamson 1988). The ability to support other overlay analysis like point-in-line and point on point will facilitate the analysis of point features such as the determination of the total number of accidents occurring on a particular link or intersection.

Network Analysis

For transportation network analysis the street network is represented as abstract interconnected lines made up of links and nodes. A GIS used for network modelling and analysis should therefore have spatial operators able to handle points, lines and areas (Shaw 1989). The system should also be able to read in network spatial and attribute data by the use of simple commands. Procedures for the definition of impedance with the capability of interactive updating during the assignment process, path construction and naming should be available in the GIS. The ability to support various transport modelling techniques including traffic assignment models, shortest path and optimal route algorithms, resource allocations, trip distribution and generation models is also necessary. These features should be able to be built into the GIS or the GIS should provide the necessary tools or a macro language to enable the user to develop such features.

Data Integration

Comprehensive transport planning at all levels involves interaction of land use modelling, transport modelling and environmental modelling. This calls for the planning system to be able to integrate data from all these sources. Location is the key in tying land use, transport, travel and environmental information together, and this can be effectively done using a GIS (Wigan 1990). Since this feature of location as the key is fundamental to all GISs, a criterion for the selected GIS is the level and extent of its data integration capabilities bearing in mind the level of the required transport planning.

4. COMPARISON OF PC ARC/INFO, MapInfo AND TransCAD

Origins and Overviews of ARC/INFO, MapInfo and TransCAD

ARC/INFO is a product from Environmental Systems Research Institute Inc, Redlands, USA. It is a fully-fledged GIS system which comprises a toolkit of functions that are used to manipulate screen images and associated data. It is a software package that brings sophisticated geographic information analysis and mapping capabilities to mainframes, workstations and PCs. It is flexible, versatile and the availability of the PC, workstation or mainframe versions gives users a range of options depending on their application needs. Hence ARC/INFO can be used by any organisation of any size. Development and use of an application can start on the PC version and as the application increases in size and complexity it can be moved to the mainframe version. An added advantage is that the PC version can be networked to the mainframe version. ARC/INFO however uses a command line user interface and for most operations the user has to type in a command or a series of commands before the system performs the various processes. Thus the user must develop a level of experience before being able to make good use of the system. This problem can however be overcome by grouping the commands into macros which can then be run. Users are thus encouraged to use macros and customise ARC/INFO to their own needs and way of working. The ARC/INFO system is composed of several individual modules each of which contains groups of functions for specific purposes and its own set of commands. Below is a brief description of these modules:

1. The ARC/INFO Starter Kit is the main module and driving kernel of the ARC/INFO software. It is used for creation and digitisation of maps, topology creation, driving of the other modules, attribute data creation and hosting of inter-computer communication. It also provides the plot system for viewing maps on screen and sending them to a plotting device. It also contains the programming language that is used to create a user interface.
2. ARCPLOT is the cartographic and mapping module of ARC/INFO and is used for the interactive creation and display of maps, graphical queries, and the generation of high quality maps for presentations and reports.
3. ARCEDIT is the graphic and database editor of the software. It combines the capabilities of CAD and the power of a geographic database for the creation, editing and updating of map layers and for final cartographic production.
4. Data Conversion performs the transfer between ARC/INFO map format and other data formats.
5. Data Overlay supports polygon overlay, line and point-in-polygon overlay and the generation of buffer zones around features.
6. Network performs two main functions: address geocoding and geographic network analysis. It contains the analytical functions for analysing and modelling real world networks such as city streets and telephone line networks, and provides the tools for vehicle routing; resource allocation; zoning and districting; optimal route selection; and time/distance flow analyses.

MapInfo was designed as a desktop mapper readily available to and useable by the mass market: it is relatively cheap, has basic functionality and is useable in many environments.

TransCAD is a GIS developed specifically to deal with transportation applications such as planning, managing and analysing the characteristics and performance of transportation systems and facilities. The system was developed for use on a DOS-based PC and compared to other GISs has the ability to perform a broad range of transportation analysis tasks. TransCAD has a database utility, TCBuild, with which databases can be built and maintained.

The details and comparisons which follow apply to the PC versions of the packages and in the case of MapInfo, the Windows version is analysed due to its greater functionality compared to MapInfo for DOS. There are occasional references to MapInfo for DOS and for the Macintosh and it should also be noted that the Macintosh version of MapInfo is very similar to MapInfo for Windows and users of one have little difficulty transferring between the different environments.

System Requirements

PC ARC/INFO is a DOS-based package that can also be run in a 'DOS window' such as from the Microsoft Windows Program Manager. PC ARC/INFO (v3.4d) requires any IBM PC/AT or compatible with a high-density floppy disk drive. The compatibles must be 100% DOS compatible. It also runs on 80386 and 80486-based computers, running the PC-DOS or MS-DOS operating system version 3.1 or higher; with 640K of RAM and 40MB hard disk drive (higher values recommended) and a maths coprocessor. It supports a wide range of display monitors and adapters. ArcView is a product which embraces GUI technology to display and manipulate databases in ARC/INFO format and hence is a Windows-based application that runs under enhanced mode Windows. Windows itself requires a PC with at least an 80386 processor and 2Mb or more of memory (640Kb conventional and 1024Kb of extended). ArcView requires at least 4Mb of memory with 8Mb recommended, as is a maths coprocessor. Hard disk requirements are for 8Mb free for the ArcView application and tutorial data. ArcView will work with 16 colour EGA graphic displays, however VGA displays for 256 colours are recommended. ArcView menus can be controlled from the keyboard but any graphic selection must be done using a mouse.

MapInfo for DOS requires any IBM PC-XT, PC-AT, PS/2 or compatible microcomputer running PC-DOS or MS-DOS version 2.0 or higher. 640Kb of memory is required (more is strongly recommended) and hard disk space of 10Mb during installation and 3Mb after. MapInfo for DOS will work with a wide range of monitors and adaptors from Hercules monochrome to High Resolution VGA cards (800 x 600).

MapInfo (v2.0) for Windows runs on Windows v3.0 or higher, requires 4Mb of RAM and occupies 2.5Mb of hard disk space while the sample data requires an additional 4.5Mb of disk space. MapInfo is also available for Sun workstations and Macintosh computers.

TransCAD (v2.1) requires an IBM 80386 or higher compatible PC running DOS version 3.0 or above with a minimum of 640Kb of RAM (at least 2Mb recommended), 14Mb of hard disk space, VGA graphics display capability and a Microsoft Mouse or compatible pointing device. TransCAD also requires a maths coprocessor. TransCAD requires 450Kb of RAM available when loaded and uses about 525Kb for normal program operation. TransCAD makes use of a RAM disk and expanded memory if these are available. A performance improvement of a factor of 2 to 3 can be achieved by using disk caching software or a hardware caching disk controller. This is due to TransCAD being a disk-intensive database manager program. It is also recommended not to use any memory-resident software while running TransCAD.

File Conversion Capabilities

The Data conversion module in ARC/INFO enables ARC/INFO to support the transfer of data between ARC/INFO formats and a variety of different data formats. These include *.DXF AutoCAD files, grid format files, ASCII, TIGER files, ATLAS*GRAPHICS format files and several other vector format files such as MOSS, IGES and DLG-3 format files. It also supports data output to business graphics and spreadsheet programs.

MapInfo for Windows can export the contents of the computer screen to a bitmap (*.BMP) file in Windows, Sun or HP format; Windows Metafile (*.WMF); or as a PICT file in Macintosh format. MapInfo for Windows can import dBase, Lotus 1-2-3, ASCII, Excel, *.DXF files from AutoCAD and MapInfo for DOS files. MapInfo can export MapInfo Interchangeable Format, delimited ASCII, dBase and *.DXF AutoCAD files.

TransCAD has utilities to translate files from AutoCAD and ARC/INFO into TransCAD database format though the translation processes are not contained within the TransCAD package: they have to be executed from the DOS prompt. TransCAD can create *.PCX files which are Windows compatible and the PCX file conversion utility converts 16-colour format files. There is no built-in digitising capability which will enable users to convert map information directly to a coordinate system in electronic format. TransCAD supports the import and export of Lotus 1-2-3 *.WK1 and *.WK3 files; Symphony *.WR1 and *.WR3 files; and dBase III and IV files

Display and Output Characteristics

PC ARC/INFO uses a vector based graphic display system and provides several device drivers to permit users the variety of standard display monitors, digitisers and hardcopy devices. Its vector-based graphic display system enables it to produce hardcopies at device specified resolutions. Hardcopy map outputs can be drawn to any scale, the limit dictated by the size of the output device. In ARCPLOT any number of layers can be drawn. Zooming in ARC/INFO can be accomplished in three ways: (1) by specifying the two extreme corners by typing in the coordinates; (2) by the use of the screen cursor; (3) by specifying a layer in which case ARC/INFO then sets the display boundaries so that the display layer fills the entire screen. Redrawing layer features is not automatic once changes have been made; one has to specify the appropriate redraw command.

The graphic display portion of TransCAD was developed using metawindow, which can accommodate a variety of graphic display adapters. However the drivers for hardcopy are limited and can only be produced at the screen resolution level. Metawindow is a raster-based graphics system providing TransCAD with an easy-to-use point-and-click style interface utilising pull-down selection menus. TransCAD allows photographs, plans, drawings, CAD images and scanned documents to be attached to records in a database with the only restriction that they must be stored as * PCX format image files. TransCAD can use raster image data such as an aerial photograph or satellite image as a map background and this background is flexible under zooming; the limit when zooming out being the point where the image data cannot be compressed any further. The speed of redrawing a photograph image background is slower than with the standard black or white background. TransCAD has automatic redraw only under zooming and object selection - at other times two menu selections refresh the display - but a drawing interruption (the <Escape> key) feature can be used to speed up zooming. Draw interruption applies only to the current layer and therefore may have to be applied several times on the current application to completely inhibit redrawing. Changing the display scale in TransCAD requires three menu selections before the desired action occurs. There are a number of standard scales from which to choose ranging from 25% to 90% of current scale and the display can be centred or shown at maximum scale again with three menu selections. TransCAD is cumbersome compared to MapInfo's grabber tool when shifting the view screen to another portion of the displayed map.

Anybody familiar with the Windows GUI would find MapInfo easy to use. Zooming, either in or out, is a matter of selecting the appropriate tool then clicking in the display area at the point that is to be the centre of the new view. The display is then automatically redrawn. In addition MapInfo allows the user to specify the width of the desired display e.g. 2.3km across. MapInfo is capable of displaying an entire layer; the user chooses the layer and MapInfo calculates the boundary sizes and fits the layer into the display accordingly. The speed of redraw is slower than TransCAD but there is no equivalent to the grabber tool in either of the other packages. It is easy to turn layers on and off. Drawing interruption stops the drawing totally and not just for the currently drawn layer as in TransCAD. Photo images cannot be used as backgrounds; documents, images and plans cannot be attached to database records. MapInfo allows the user to output any screen display to a printer and the user is able to add titles, labels symbols etc to the printed output without incorporating them in a layer.

Graphics Editing and Updating

All the three packages support the editing and updating of map layers such as adding and deleting nodes and links; moving independent items; splitting and joining areas; and changing boundaries. In addition ARC/INFO supports the combining of up to 50 layers into a single layer; determination of the geometric intersection of two layers; coordinate rotation and scaling; and a wide range of changes in projections

Transportation Procedure Support

TransCAD was specifically developed for transport purposes hence several analysis tools and methods from the transportation and operations research fields are

implemented as built-in procedures. These include a road network builder, shortest path routines, traffic assignment models for estimating the traffic flow on each link of a network, critical link analysis to identify flows that are affected when a network link is disrupted, routing and scheduling models. Several GIS procedures are also supported: address matching geocoding, postcode geocoding and polygon overlay processing. In addition, TransCAD has a procedure toolkit that allows the user to develop standalone DOS programs that perform operations on a TransCAD database. This uses a series of command directives and can incorporate the extensive array of transportation procedures outlined above.

Unlike TransCAD, MapInfo does not contain any transportation analysis procedures but it does have a fully functional programming language MapBasic (Windows) or MapCode (DOS) with which the user can build procedures for use in an application. It does however support address matching and geocoding.

Even though ARC/INFO does not have built-in transportation routines as in TransCAD, its network module provides all the necessary tools needed to create these routines. Geocoding and address matching, network building, route and path creation, optimal path determination and resource allocation are all supported. With the above capabilities ARC/INFO can be applied to the planning, administrative and operational activities that distribute resources throughout a network. These include: vehicular and pedestrian routing; emergency services planning and operations; zoning and districting; facility siting and design; and natural resource management.

Selections and Queries

Selection of an object in ARC/INFO can be accomplished using logical expressions or with the help of the screen cursor after issuing the relevant command followed by the wild card '*' . The selection criteria can be based on either location or on attribute values. When using the ARCEDIT module the user can only query an object contained in the current edit layer whereas in ARCPLOT querying an object can be performed on any displayed layer. Depending on the command issued the query can obtain all the attribute details of features or obtain the user-id and position. If the query uses the IDENTIFY command or a select with the wild card '*' option, the selected feature will instantly be highlighted. ARC/INFO has the ability to add to the selected set and also to switch between the selected and unselected features. Logical expressions or the wild card '*', which gives the user the option of selecting from the screen, can be used with any of the selection commands in the query of an object. ARC/INFO also supports sequential searches; these are a sequential refinement on the selected set using additional constraints.

Selection of an object in the display in both TransCAD and MapInfo is primarily achieved using the mouse: the selected feature is then instantly highlighted by a colour change or pattern in the display.

The TransCAD user can query any object contained in the current layer by activating the Query menu option, choosing the type of selection to be made then clicking on the object using the mouse. MapInfo queries are effected by choosing the information tool

then clicking on the object. In both packages information such as its position is displayed in a pop-up object on the screen. Selection of several objects is achieved in a variety of ways typically by utilising mouse-driven polygon features; for example all those objects within a certain radius of a point can be selected, as can objects within a polygon. TransCAD has the added advantage of easily performing selection inversion by switching its selection to all the unselected objects of the current layer. TransCAD allows a database to store up to 32 conditions which can be used to select objects; for instance there may be a condition associated with the roads database concerning the speed limit of each road link and the condition may be: 'All the links with a speed limit greater than 60km/h'. Conditions can be combined for a selection on one layer and TransCAD has the capability to display selections from several layers simultaneously.

TransCAD has an SQL Module to query a database and generate tabular reports. Unfortunately this module is difficult to use as it is not intuitive and the current manual has proved deficient in its explanations. Queries are typed in using the Query Editor and the module's biggest failing is that there is no way to store the actual query for repeatability: the user can only store the results of the query. The second big failing is that the asterisk commonly used in SQL to select all fields of a database is not supported and each field has to be named explicitly. The current layer must be chosen before starting up the module and the names of the fields of this layer only can be shown using the cumbersome '*show field* *' command. Caliper Corporation needs to work on the module to make TransCAD's SQL capabilities easier to use.

MapInfo has two commands for selecting objects through querying: *Select* (the simpler of the two) and *SQL Select* both of which apply whether in the table browser or map display. *Select* is used to build a query that finds records that satisfy certain conditions in column(s) of a table. This method is simple to use and the query assist mechanism is very helpful for the novice. *SQL Select* enables the user to derive information from several columns and to combine queries over two or more tables and is more powerful than *Select* as query tables that contain information which was only implicit in the base table(s) can be created. *SQL Select* supports the join operation to combine two or more tables. *SQL Select* is easy to use due to the typical dialog box input methods of the Windows environment and because MapInfo also checks the SQL statement and responds by displaying a message if a syntax error is detected in the query. The MapInfo SQL supports the aggregation of data across records using the *Group by Column* option and mathematical functions such as *sum* and *average*.

In all three packages objects can be selected while browsing the attribute table associated with a layer. In ARC/INFO and TransCAD the table can only be that of the currently selected layer whereas in MapInfo tables associated with each active layer can be displayed and objects selected from any of these tables without regard to the current layer.

Database Management

TransCAD utilises the db_VISTA Database Management System (DBMS) for database storage and other manipulation tasks. db_VISTA is a network DBMS that has many features not available in a relational DBMS. TransCAD databases are built with a utility

program, TCBuild, which can import data from files in either fixed-format or comma-delimited format.

MapInfo utilises relational database technology and supports the relational database join with the *Join Tables* function. This joins two tables on common values contained in one field from one table and one field from another table. The *Join* function can combine records from two tables using a common descriptive field (as in *Join Tables*) or graphically/geographically. For example if each postcode is to be shaded according to how many accidents have occurred therein and there exists a geocoded database of accidents, then MapInfo can examine the coordinates of each accident location and determine the postcode where the accident had occurred.

Further database query and retrieval functionality in MapInfo is provided by SQL Datalink which enables users and developers to query and retrieve data from remote database servers for use in MapInfo applications. These databases include Oracle, INGRES, BTrieve, Paradox, Sybase and Microsoft SQL Server and since the queries are formulated in MapInfo, users do not need to learn the language or syntax for the server; this can improve productivity and reduce both training and support costs.

ARC/INFO also utilises relational database technology and supports the relational database join with the join command. However ARC/INFO has the added advantage of being able to join more than two data files at a time. ARC/INFO can join database files even if there is not a common item between them using the join link command. The second situation is possible if the joining files are arranged in the same order. Once related in this way item values from all files are available for use in further analysis and report generation. ARC/INFO currently supports dBase, Info and Oracle database systems.

Browsing and Editing a Database Table

MapInfo for Windows has powerful database table browsing and editing capabilities as it employs the Windows type display: therefore scroll bars, arrow keys and the tab key are used during browsing. MapInfo browsing and editing is easy to use; objects selected in the browser and changes made in the browser are automatically reflected in the graphical display.

TransCAD employs keys to move quickly around a table in either the data or table editors, and editing and selection functions are similar to that of MapInfo with only the table associated with the editable layer able to record any changes to attribute values. As with MapInfo changes are automatically reflected in the graphical display

ARC/INFO, unlike TransCAD and MapInfo, does not employ keys that can be used while browsing and editing a database table. It provides access to external database managers such as dBase and Excel and these can be used for browsing tables and data maintenance. In ARC/INFO, items and item values display and editing are carried out by typing in the appropriate commands. All changes made, except changing the 'user-ids' of the object features, are automatically reflected in the graphical display. If the user-ids are changed in the database tables then the ARC/INFO command 'IDEDIT'

should be run so that the changes are also made in the graphical database. The operation is reliable with no loss of data whatsoever.

The advantage of MapInfo over TransCAD is that MapInfo can have more than one table open for browsing at the same time and switching between tables is achieved in the usual Windows environment fashion.

Thematic Mapping

Thematic mapping is supported by all three packages and is typically effected by using colours, patterns, line types or symbols to distinguish objects with different values. For instance a map can show all Census Collection Districts (CCDs) colour coded by their population. MapInfo cannot save these themes to a file to be used at a later time whereas saved TransCAD and ARC/INFO themes can be used with its associated layer in any application containing that layer. In addition TransCAD and ARC/INFO can produce double theme mapping: for example each CCD can be colour coded by household density at the same time as patterns can be used to display the average number of cars per household. Another example is where the roads in a network can be colour coded by their type (eg. primary arterial, secondary arterial etc) and the number of lanes of each link represented by the width of the line (Line width scaling 1-way). TransCAD goes further by offering line width scaling 2-way which can be effectively used to display flows on the right side of the link and flows on the left side of the link.

Both MapInfo and TransCAD produce an automatic thematic legend which explains what the colours, symbols or sizes represent while ARC/INFO provides the tools for the user to create the legend. In all packages this legend can be customised.

Buffering

A buffer is a polygon which surrounds a line object, another polygon, point or any other object on the map display. One of the powerful features of a GIS package is that information concerning the new area can be calculated from the underlying database(s). For instance a transportation planner may wish to know how many people live within 1km of a main road. A layer of the road network and a layer of Census Collection Districts containing populations can be loaded into the GIS, the main road selected and a buffer zone of 1km radius created on the display screen. The population within the buffer zone is calculated using the underlying population database and the CCD area layer.

Buffering in TransCAD is easy to achieve by selecting the line objects, entering the buffer distance and being patient whereupon a window appears containing the overlay information about the new region. However there is no option to change the type of display of the buffer region and a serious drawback is that the region does not remain on the screen after the <Enter> key is pressed to remove the information window. TransCAD is an American product and the buffer radius must be expressed in miles.

MapInfo buffering is easily accomplished: complicated only by the user having to decide on the smoothness of the buffer radius calculation. The MapInfo manual also warns that the buffer process is time-consuming and gives excellent guidelines to the

values of smoothness the user may require. Buffer radius is given in a variety of units including inches, feet, yards, miles, millimetres, centimetres, decimetres and kilometres The buffer display region type (eg. pattern or colour) cannot be changed and it overlays and obliterates the selected line or area thereby reducing the effectiveness of visual impact.

The ARC/INFO buffer operation is carried out by typing in the BUFFER command followed by its arguments which include buffer distance, input layer, output layer, the buffer distance and the feature class to be buffered. The output from the buffer operation is a complete new independent layer containing its own attributes distinct from the input layer. It can therefore be displayed using different symbols and colours, used in analysis and treated like any other map layer. This new layer does not include any of the input layer features. However one can see the original features displayed within the buffer polygon by simply displaying the layers on top of each other. The on-line help makes the operation simple to use except that it is time consuming. Another advantage of the ARC/INFO buffer operation is its ability to use different buffer distances based on attribute values.

Symbols, Line Types and Patterns

All three packages have an abundance of symbols, line types and patterns from which the user can choose. Although TransCAD has symbols which are more appropriate for transportation purposes, their size is not easily altered whereas the size of the ARC/INFO and MapInfo symbols are readily adjusted. The user can create customised symbols for use in TransCAD and ARC/INFO hence appropriate symbols for use in particular applications can be designed and created. In ARC/INFO a symbol can be digitised.

Statistical Analysis and Graphing Capabilities

MapInfo has a statistics window that tallies the sum and average of all numeric fields for the currently chosen objects/records. This window is either hidden or shown; if shown the data is re-tallied and the window updated automatically as the selection changes. MapInfo can also give statistics on any numeric column of a table. These statistics are: count, minimum, maximum, range, sum, mean, variance and standard deviation.

TransCAD has extensive statistical capability and the user can produce summary univariate statistics such as mean, minimum, maximum, sum and standard deviation; estimate least squares models; produce one-way or two-way tabulations; and compute correlation matrices based on database fields.

ARC/INFO also has extensive statistical capabilities and the user can produce summary statistics of items such as count, mean, minimum, maximum and sum. The calculations of cross tabulation tables between to or more items can be performed. This feature is very useful especially in accident analysis in determining the variations between two or more accident items. Examples are: the variation of accident type by accident severity or accident type by time of day. The graphical capability of ARC/INFO is primitive and limited to the production of histograms only. However it is possible for a user to use the

programming language to assist in producing other graphical outputs or by integrating existing graphical programs into ARC/INFO.

The graphing capabilities of TransCAD are limited to bar and pie charts. However each can incorporate a weighting factor of one column field value applied to the graphed column field value. For example the number of pedestrian accidents in a local government area can be weighted by the population of that area. The graphing facility is easy to use (there is not a great deal of choice) and the display colours are contrasting.

MapInfo has a more extensive range of graphing capabilities which includes area, bar, line, pie and x-y (scatter) graphs. In addition area, bar or line graphs can be stacked; the bars of bar graphs can be overlapped; area, line or x-y graphs can have drop lines from the top of the highest series to the horizontal axis; the graph can be rotated 90 degrees; and area and bar graphs can be represented three-dimensionally. The dialog boxes of MapInfo's graphing facility are easy to use.

User Support

User support embraces online help; startup instructions and tutorials; manuals; vendor support and availability of compatible databases and maps. Support for the MapInfo user is good with a good online help, tutorial and vendor support. There are also MapInfo users groups around Australia. The manuals have good indices and are easy to read and follow but the big plus of MapInfo is the readily-available Australian road network database though as reported by Young (1992) this data is 'good but not ideal'.

TransCAD does not have an online help, it has a good tutorial that suffers from having no index to enable the user to easily repeat an exercise or procedure. There are no tutorials for using the transportation procedures and the manuals are only adequate. There is some progress being made towards establishing firm after-sales support but as yet there are no Australian road networks immediately suitable for TransCAD.

ARC/INFO has a superb online help, complete set of manuals and tutorials, other supporting documentation, training videos and vendor support. There are ARC/INFO Users Groups and an annual ARC/INFO conference in Australia. The manuals are detailed and easy to read and understand. The online help is of two kinds: the first gives the usage of a command (just type the command) and the second gives a detailed description of the command as it appears in the user manual (type help followed by the command). ARCLINK is a utility program which converts ARC/INFO map layers to MapInfo and vice-versa, hence an Australian road network database can be easily obtained in ARC/INFO format from the existing MapInfo format.

Geocoding

Geocoding is the process of converting information about a data point (such as a street address or a postcode) into a coordinate system to enable that point to be located accurately on a map display. Geocoding is the fundamental method of assigning spatial attributes to data and a description of this process and the method a GIS uses to store the data is contained in Yeomans (1992). For example suppose a table of roads of a network already has location data associated with each link then a table of street

addresses can be geocoded with the table of roads so that entities associated with the addresses (eg service stations) can be displayed on the map at the correct locations.

Geocoding in MapInfo is very easy to use and once the appropriate fields have been designated MapInfo proceeds to geocode the table information. If MapInfo cannot geocode some of the data records the user is given the opportunity to geocode this data by a manual method. Geocoding in ARC/INFO is easy once all the database files to be used are in the appropriate formats. ARC/INFO provides the commands for preparing all the files to be used in the process. During this preparation stage if address ranges overlap or are not in the correct order they can be detected and corrected before performing the address matching. After matching, any rejects are written to a file so the user can determine the cause of the reject. ARC/INFO has options for the different type of address labelling so that features such as churches which sometimes have no street numbers can be geocoded. Geocoding in TransCAD is also easy to use and in all packages the process is slow.

Application Languages

MapBasic is the application language useable with MapInfo for Windows. MapBasic can customise MapInfo for any particular application and therefore broadens the range of MapInfo's usefulness. The language itself is basic in nature, however it is an event driven programming language rather than a linear or sequential programming language such as Fortran, C or Pascal. MapBasic can use standard windows features, for example input and output dialog boxes as human/computer interface devices and MapBasic can interface with other programs through Dynamic Data Exchange (DDE) which allows the realtime exchange of data by Windows programs. This is a very powerful technique if used to its full potential. MapInfo has the capability of tapping into procedure and function libraries called Dynamic Link Libraries (DLLs) written in other programming languages. An example of the use of DLLs would be to link MapBasic with a shortest path algorithm contained in a DLL, with the relevant parameters passed from MapBasic to the algorithm. The solution is then passed back to MapBasic where a graphical representation is formulated to be displayed to the user through MapInfo.

Besides interchanging data with other applications MapBasic can take advantage of other features of the Windows Application Programming Interface (API) such as device independent graphics, multi-tasking and dynamic linking. MapBasic has a simple text editor and compiler though even the compiled code is slow. Some subtle errors may not be detected by the compiler.

The programming language of ARC/INFO is known as the Simple Macro Language (SML) for the PC version and the Arc Macro Language (AML) for the mainframe version. It is a very simple language which is used to combine ARC/INFO commands and directives into programs and so very easy to learn once the user is familiar with ARC/INFO. SMLs and AMLs can be created using a text editor or recorded as the commands are entered during a work session. PC ARC/INFO was designed to take full advantage of PC capabilities. It thus supports inter-computer communications and can therefore be linked to other external programs written in other languages.

TransCAD does not have a programming language of its own but its procedure toolkit allows users to interface TransCAD with external functions and procedures by using command directives set up in script files. An example would be to display changing positional information on a TransCAD map or to display traffic flow through an intersection using the information from loop sensors. The possibility of using this interface technique in realtime is under investigation.

Tabular Comparison

Table 1 Comparison of ARC/INFO, MapInfo and TransCAD

Criterion	ARC/INFO	MapInfo	TransCAD
Environment	DOS, Windows, UNIX, Sun, Vax	DOS, Windows, Sun, HP, UNIX, Macintosh	DOS
CPU required (minimum)	80386	80386	80386
Hard disk space	40Mb	2.5Mb	14Mb
RAM required	640Kb	4Mb	2Mb
Maths coprocessor	Required	Recommended	Required
Price	Expensive	Moderately expensive	Expensive
Conversion compatibility	AutoCAD, dBase, ATLAS*GRAPHICS, IGES, DLG-3, ASCII, MOSS, TIGER files.	*.BMP, *.WMF, PICT, dBase, Lotus, ASCII, Excel, AutoCAD	AutoCAD, ARC/INFO, Lotus, Symphony, dBase III & IV
Graphics system	Vector based	Vector based	Raster based
Load time	Quick	Slow	Quick
Redraw time	Quick	Slow	Moderate
Changing display scale	Easy	Easy	Awkward
Transportation procedure support	Tools and functions available	No	Comprehensive
Realtime external links		Supported	?
Ease of object selection	Easy	Easy	Awkward
SQL support	Good	Good	Poor
Browsing	Easy; single table display and edit only	Easy; can view multiple layer tables but edit only the selected one	Easy; single table display and edit only

Table 1 (cont.) Comparison of ARC/INFO, MapInfo and TransCAD

Criterion	ARC/INFO	MapInfo	TransCAD
Thematic mapping	Very extensive; can save and manipulate many themes	Simple themes only; cannot be saved	Extensive; can save themes
Buffering	Easy, fine display capabilities but time consuming	Easy; moderate display capabilities	Moderately easy; poor display capabilities
Symbols, line types and patterns	Excellent	Good	Very good
Statistical analysis	Extensive	Good; basic	Extensive
Graphing	Minimal	Very good	Minimal
User support	Excellent on-line help, tutorial and manuals; vendor support	Good on-line help, tutorial, and manuals; vendor support	No on-line help; adequate tutorial and manuals; little vendor support
Australian road network	Not available but can be imported from other packages	Available	Not available
Geocoding	Easy	Easy; slow	Easy; slow
Ease of using the package (learning curve)	Very difficult	Moderately easy	Difficult
Programmability	SML & command directives	DOS (MapCode), Windows, Macintosh (MapBasic)	Command directives
Ease of using the programming language	Medium	High	Medium

5. GIS APPLICATIONS IN TRANSPORTATION

The opportunity exists to use GIS to support transport related issues to improve decision making at all levels of government and to aid private companies with strategic decision support and operational planning. The application of GISs is expected to follow the traditional lines of transportation agency responsibilities. These include traffic engineering and safety; pavement maintenance and management; highway inventory; transport modelling and planning; hazardous materials routing; project tracking; and field office support. There are some current operational transportation GIS applications

while others are under development. Below are examples of applications using different GIS software packages.

Table 2 Examples of GIS Applications in Transport

Vendor/Software	Applications
ESRI (ARC/INFO)	Accident analysis; roadway inventory; pavement management; EIA; electronic atlas; bridge management; maintenance and system management; traffic management; network analysis
Intergraph (IGDS & MGE)	Roadway inventory; bridge management; pavement management; accident analysis; project tracking; EIS; EIA; flood control; HPMS; safety management; project planning; multi-modal modelling; traffic management
MapInfo	Roadway inventory; accident analysis; pavement management; project tracking; vehicle tracking
UltiMap	Bridge management; pavement management; project tracking; system planning
Caliper (TransCAD)	Pavement management; road inventory; accident analysis; bridge management; network modelling
PTNM/GIS	Route distance summation; railroad efficiency analysis; routing
McDonnell Douglas (GDS & PCN)	Traffic management; pavement management; roadway inventory; safety management; EIS; bridge management; transport planning; routing; accident analysis

Integration of Other Technologies

The integration of advanced data collection methods with GISs will facilitate the applications of GIS in the transport sector. These technologies include Global Positioning System (GPS) and realtime systems such as those used for traffic counting or weather conditions. Research in this field is being undertaken. Currently MapInfo GIS has been integrated with GPS in realtime and allows the association of GPS attributes with point data and symbols. An example is outlined in the next section. Another technology that will promote the usage of GIS is the current drive of intelligent vehicle/highway systems (IVHSs). This technology will rely on accurate and easy to produce base maps which can be achieved with a GIS.

The Use of GIS & GPS in Travel Time Surveys

The Transport Systems Centre and School of Civil Engineering at the University of South Australia, in conjunction with the Transport Research Centre at the University of Melbourne are investigating the use of the Global Positioning System (GPS) and GIS to effect travel time surveys in the assessment of traffic systems. GPS is used with appropriate hardware and software to record the position of a vehicle at regular time

intervals and this data can be transmitted from the vehicle to the control centre and displayed in a GIS to give a realtime graphical representation of the vehicle's position. Currently the VTRACK GPS system is being used to record vehicle position and due to a lack of communication equipment between the vehicle and the control centre the graphical representation is displayed later using MapInfo for Windows.

The raw data from the VTRACK system is manipulated by software developed at the University and the output contains a number of attributes associated with each record. These are: the individual record ID number, longitude, latitude, the time the position was acquired, elapsed time from the start of the journey, speed, bearing, distance travelled from the last data point, and the percentage of stopped time up to the current point. This processed data is displayed in MapInfo for Windows and enables both the graphical representation of the data or the textual representation using the browser format. The latter format allows SQL queries to be performed and these are instantly highlighted on the graphical display. For example all the data points where the speed is less than 5km/h can be readily found and displayed; this type of analysis can be used over a limited portion of the data i e. segments of the journey.

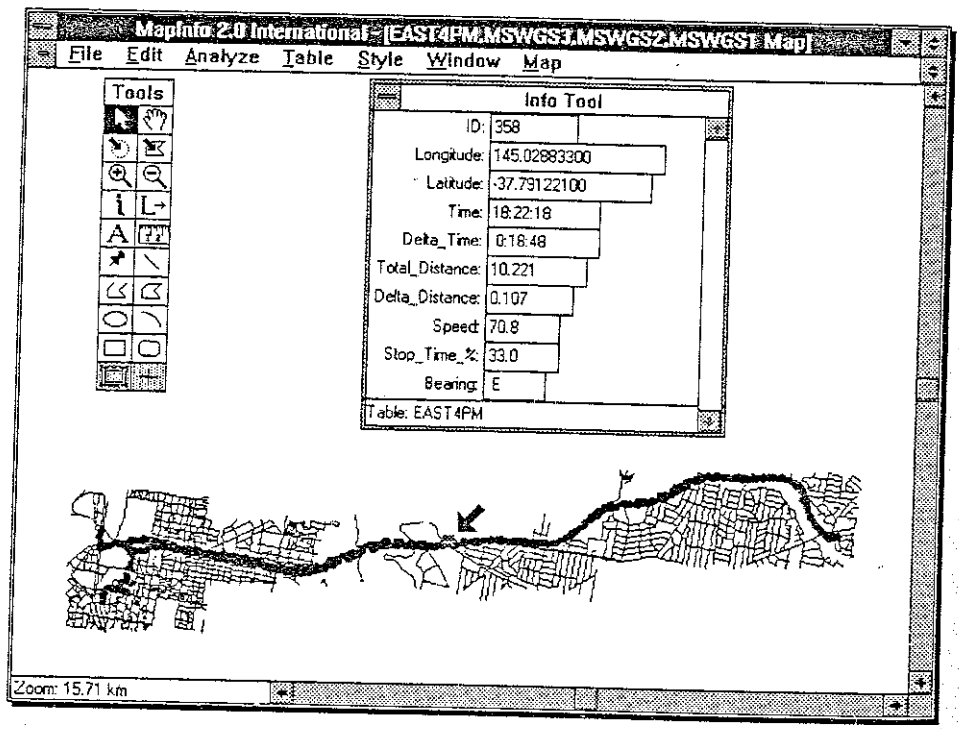


Figure 1. MapInfo display of GPS data collection run on Eastern Freeway, Melbourne

The ability of GPS coupled with GIS to collect and display data for segments and the entirety of the journey with only minimal labour, hardware and software outlay make it

more attractive than traditional methods of collecting travel time survey data and hence may help planners find better solutions to transportation problems.

Turning Flows Study

A GIS can be used to graphically illustrate aspects of a study of traffic flows at intersections. For instance the proportions of flows (left, right and straight) originating from a designated leg of an intersection can be graphically illustrated (colour or width of line) after running the appropriate query on the GIS database. Another example is the known total flows in from and out along each leg can be graphically illustrated for the entire network. The unknown values along links of the network can then be estimated using traffic assignment models such as those found in TransCAD.

Travel Demand Survey

Data gathered during household travel demand surveys can be displayed in a GIS to effectively show the total number of trips and the trip categories (e.g. home-based work, home-based education, non home-based employer's business) stemming from particular regions.

Road Safety and Accident Analysis

GIS has been used in the capture and display of accident data. Other applications of GIS in accident analysis and road safety include data retrieval and display using different symbols and colours, report generation, answering of people's complaints, identification of hazardous locations, and data integration (Affum 1992). These applications help enhance the decision making capabilities of safety managers and engineers. Another application in progress is the use of ARC/INFO to develop a method for evaluating the safety benefit of local area traffic management schemes. The GIS is used to extract and display both accident and installed traffic management device data. The GIS is then used to integrate all this data with that of street links and intersections, analyse the integrated data, and calculate summary accident details for before and after implementation of the scheme. Treatment is for each of the following accident details: severity, road user movement, time variation and vehicle class. The analysis is carried out for internal and external links; internal and external intersections; on an area-wide basis; and for particular devices. The before and after results are tested using the Chi-square test and compared with the results of a control area. Successful capture of accident data using GIS has been reported in New South Wales (Young, 1992)

6. CONCLUSIONS AND RECOMMENDATIONS

The first consideration is the platform required to run the selected GIS package. All three of the reviewed packages require at least an IBM compatible 80386. This hardware power can represent a considerable capital outlay but GIS software is costly and may prohibit an organisation's move into the world of GIS more than the cost of hardware. MapInfo is the easiest package to use overall due to its GUI but it is still only a desktop mapper striving to behave like a full-fledged GIS; hence its relatively small size and cheaper price compared to ARC/INFO and TransCAD.

Selection of an appropriate GIS is related to application needs: for a quick-to-build and easy-to-use application doing mostly display work and querying with minimal analysis use MapInfo; for an application requiring ready-made transportation procedures use TransCAD; for a sophisticated application with scope for growth use ARC/INFO; if using Australian street networks use MapInfo or ARC/INFO (at present point in time); for an application utilising realtime processing and display use MapBasic with MapInfo; for theme-intensive applications and modelling use ARC/INFO or TransCAD. For the best user support purchase MapInfo or ARC/INFO.

TransCAD, a GIS package designed specifically for the transport planning and research market, has great transport applicability as one would expect, however, it suffers in comparison with MapInfo in that it is awkward to use at times. MapInfo is the only package that boasts a full set of roads and streets of Australia; these can be converted into ARC/INFO format but currently there is no conversion facility into TransCAD known to the authors. ARC/INFO has all the necessary tools for linking to external programs; for example ArcView has been successfully interfaced with the Oracle Highways application product from Oracle Corporation and there is a likelihood that many traffic planning procedures will be incorporated into ArcView at least in the near future.

The use of GIS in transportation is burgeoning into Management Information Systems and realtime monitoring and control as well as inventory control, and discussions with people and organisations familiar with GIS technology will stimulate ideas for a wider range of commercial and research and development applications.

Acknowledgments

The authors would like to thank other members of the Transport Systems Centre; Glen D'Este, Jeremy Woolley, Rocco Zito, Troy Young and Farhad Ahmed for their contributions.

References

Affum, J K (1992) GIS applications in road accident analysis, of *Papers of the 14th Conference of the Australian Institute of Transport Research,* The University of Sydney. December 10th to 11th, 1992

Basile, R (1990) The development of a geographic information system in Pennsylvania, pp 245-275 of *Proceedings of the 1990 GIS for Transportation Symposium,* San Antonio, Texas, TRB

Dueker, K J and Kjerne, D (1989) Multipurpose cadastre: terms and definition, pp 94-103 of *Technical Papers ASPRS/ACSM Annual Convention, American Congress on Surveying and Mapping,* Baltimore, Md

ESRI (1991) PC ARC/INFO GIS concepts kits, Environmental Systems Research Institute, Inc. Redlands, California

ESRI (1991) PC ARC/INFO Technical guide to hardware options, Environmental Systems Research Institute, Inc. Redlands, California

ESRI (1991) PC ARC/INFO user manuals, Environmental Systems Research Institute, Inc. Redlands, California

Huxhold, W E (1991) An Introduction to urban geographic information systems, pp 205-213, Oxford University Press, New York

Kornhauser, A L, (1987) Exploring transportation problems using interactive computer graphics, pp 231-239 of *Computers and Graphics* Vol 11, Num 3 1987: Great Britain, Pergamon Press

Kurt, C E and Connolly, T J (1989) Integrating databases and graphics in transportation engineering, pp 305-310 of *Proceedings of the First International Conference on Applications of Advanced Technologies in Transportation Engineering,* San Diego, California: New York ACSE

Newton, P W; Davis, J R; Simberg, K V and Crawford, J R (1988) A microcomputer-based integrated land information system, pp 54-64 of *Desktop Planning: Microcomputer Applications for Infrastructure & Services Planning & Management* (PW Newton, MAP Taylor and R Sharpe; Editors) Melbourne: Hargreen Publishing

Seetharam, K E; Shibasaki, R and Nakamura, H (1990) Multi-level geographical information and expert systems for comprehensive evaluation of urban transportation policies, pp 331-347 of *Papers of the Australasian Transport Research Forum* Vol 15 Part 2, 1990

Simkowitz, H J (1989) An important technology for transportation planning and operations. pp 14-22 of *Transportation Research Record 1236,* TRB

Shaw, Shih-Lung (1989) GIS as decision support tools in transportation analysis, from Urban and Regional Planning/Geography, Florida Atlantic University, University Tower, 220 SE Second Ave, Fort Lauderdale, Florida

Sinton, D F (1978) The inherent structure of information as a constraint to analysis: mapped thematic data as a case study, pp 1-7 of *Harvard papers on Geographic Information Systems* 7 ed Geoffrey Dutton, Reading, Massachusetts, Addison Wesley

Taylor, M A P (1987) Applying interactive colour graphics in traffic planning, pp 241-248 of *Computers and Graphics,* Vol 11 Num 3. Great Britain Pergamon Press

Taylor, M A P (1988) Computer models for traffic systems applications, pp 264-275 of *Desktop Planning: Microcomputer Applications for Infrastructure &*

Services Planning & Management (PW Newton, MAP Taylor and R Sharpe; Editors) Melbourne: Hargreen Publishing

Taylor, M A P (1991) Traffic planning by a 'desktop expert', pp 165-177 of *Computing, Environment and Urban Systems*, Vol 15, 1991: Pergamon Press

Taylor, M A P; Young, W and Newton, P W (1988) PC-based sketch planning methods for transport and urban applications, pp 361-375 of *Transportation*, 14

Taylor, M A P; Young, W; Wigan, M R and Ogden, K W (1992) Designing a large-scale travel demand survey: new challenges and new opportunities pp 247-261 of *Transportation Research*, Vol 26A, Num 3 Great Britain: Pergamon Press

TransCAD Transportation GIS Software Reference Manual v2.0 (1990) Caliper Corporation, 1172 Beacon Street, Newton, MA 02161, USA

TransCAD Transportation GIS Software Manual Supplement v2.1 (1992) Caliper Corporation, 1172 Beacon Street, Newton, MA 02161, USA

Vonderohe, A; Travis, L and Smith, R (1991) Implementation of Geographic Information Systems in State DOTs, *Research Results Digest* Number 180, National Cooperative Highway Research Program

Wigan, M R (1992) Some investigations on image processing techniques applied to road problems, pp 62-83 of *ASCE Journal of Transportation*, 1 (118)

Wigan, M R (1990) How do we tie the transport information we need together and deliver it? pp 319-329 of *Papers of the Australasian Transport Research Forum* Vol 15 Part 2, 1990

Yeomans, G, (1992) Geocoding survey address information, pp 115-133 of *Papers of the Australasian Transport Research Forum* Vol 17 Part 1, 1992

Young, P (1992) Report into the use of geographic information system software for the capture of traffic accident location data, pp 377-387 of *Proceedings 16th ARRB Conference, 1992*

Young W; Taylor, M A P and Gipps, P G (1989) Microcomputers in Traffic Engineering, Taunton U.K: Research Studies Press

Zwart, P R and Williamson, I P (1988) Parcel-based land information systems in planning, pp 44-53 of *Desktop Planning: Microcomputer Applications for Infrastructure and Services Planning and Management* (PW Newton, MAP Taylor and R Sharpe; Editors) Melbourne: Hargreen Publishing