INTEGRATION OF GEOGRAPHIC INFORMATION SYSTEMS AND MODELS FOR TRANSPORT PLANNING AND ANALYSIS

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Abstract

This paper deals with some different methods of integrating traffic assignment models with available commercial GIS packages for transport planning purposes. The principles and the applicability of the various approaches will be assessed and discussed in particular reference to the PC ARC/INFO package. It details two ways by which the various flow-control rules can be simulated in PC ARC/INFO to implement the all-or-nothing, the incremental and equilibrium traffic assignment models. The merits and demerits of these two methods are discussed and compared using case studies. The comparison include the time taken and for that matter the cost of running the system, ease of usage and the nature and quality of the final outputs. The paper concludes with a set of guidelines as to what approach to adopt and under what conditions.

INTRODUCTION

Transportation planning models are quantitative and analytical tools used in transport planning. These tools are computationally more complex than the analytical capabilities currently found in most Geographic Information Systems (GIS) with the exception of TransCAD. These models however, appear inherently limited in their visual interface and data management capabilities including general graphical editing and data query. In particular the assembly of the input data, especially the network data is very tedious and can affect the attractiveness of a particular model to potential users. Another consideration in using transport planning models concerns the quality and ease of interpretation of their outputs. The appropriate output format is normally visual representations that are easy to understand and more sophisticated than those obtained by the usual graphs and tables. GIS on the other hand, has the ability to acquire, store, retrieve and analyse spatial data and above all the capability to integrate data from various sources. Its visual map display capabilities have been recognised for their effective communication of complex model results. The ability to integrate the models and GIS can overcome the disadvantages of both systems for transportation network analysis and will be of immense benefit to the transport planner decision-makers. It will make the capabilities of GIS available to transport planners thereby providing new tools for analysis.

This paper deals with some different methods of integrating traffic assignment models with available commercial GIS packages for transport planning purposes. The principles and the applicability of the various approaches will be assessed and discussed in particular reference to the PC ARC/INFO package. It details two ways by which the various flow-control rules can be simulated in PC ARC/INFO to implement the all-or-nothing, the incremental and equilibrium traffic assignment models. The merits and demerits of these two methods are discussed and compared using case studies. The comparison include the time taken and for that matter the cost of running the system, ease of usage and the nature and quality of the final outputs. The paper concludes with a set of guidelines as to what approach to adopt and under what conditions.

INTEGRATION METHODS

Various methods of integrating GIS and transport planning models and related tools have been discussed in the literature (Trinidad and Marquez, 1994; Shaw, 1993; Lewis, 1990). Three main integration approaches can be envisaged namely:
*   embedding the model entirely within the GIS (GIS dominant approach);
*   embedding the GIS entirely within the model (Model dominant approach); and
*   linking of GIS and model by providing some form of interface.
These approaches are depicted diagrammatically in Figure 1. The two dominant methods provide what is termed a complete coupling. The 'model dominant approach' implies a model with added GIS capabilities built into it. Due to its structure it has the disadvantage of being of use only for the specific task for which it was designed to accomplish. Since the majority of users of GIS are in the commercial and market area, this approach will have limited usage. Commercial organisations are more prepared to take the risks in developing software with multiple uses than a specialised one. The embodiment of models entirely within GIS is seen to be favoured by most GIS developers. This involves implementing the models (possibly as a routine) within the GIS. However, up to date only a

modest progress has been made. The most prominent package is TransCAD. Some GIS vendors have started building some transportation routines into their systems. For example ARC/INFO has some transportation planning routines such as route selection and allocation built into it. These routines can be used to re-program and implement some of the transportation models with the help of the ARC/INFO programming languages.
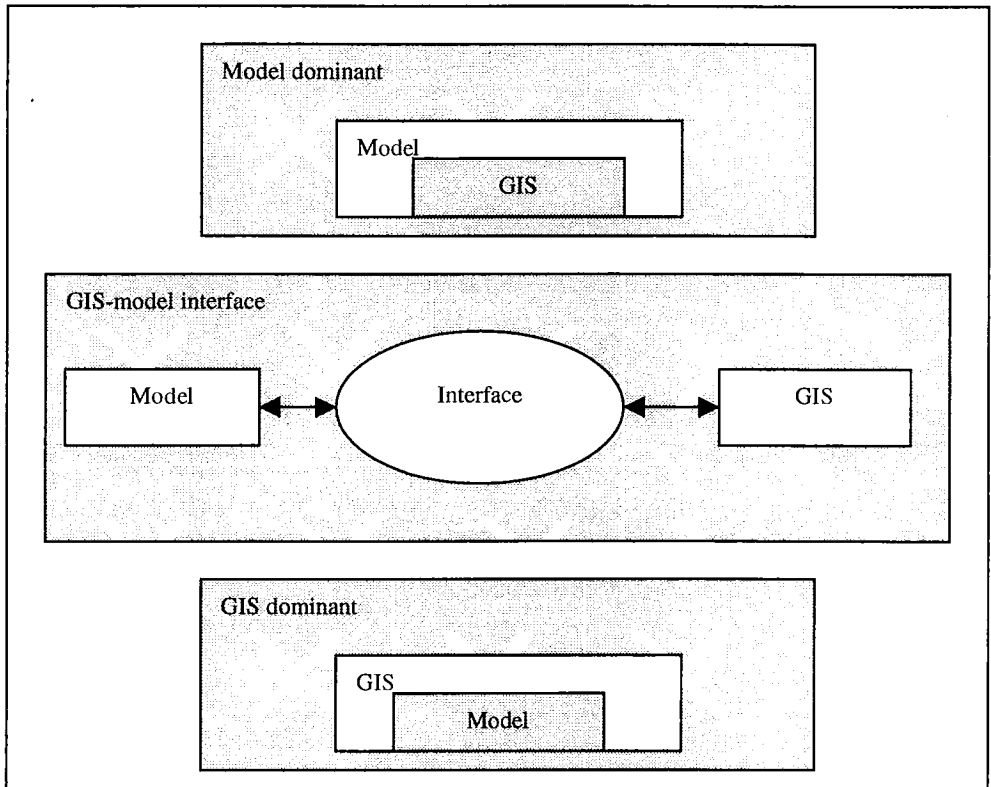

Figure 1: Linking GIS and transportation models

Shaw (1989) successfully simulated the all-or-nothing, incremental and capacity restraint algorithms in ARC/INFO, but not the equilibrium assignment method. Models implemented using the built-in routines in this way use the same GIS internal data files thereby reducing data redundancies and duplications. It maintains the interactive character of the GIS, provides an efficient data management and eliminates problems associated with data conversion and transfer between model and GIS. The main disadvantage with this approach lies with the limitations of the GIS stated earlier, namely limited analytical capability and inability to handle complex computations (such as the handling of matrix structures). The implementation of traffic assignment models in a GIS using this approach will thus require re-formatting of the O-D trip matrix. Another disadvantage is re-programming of the entire model using the programming language of the GIS.

The interface approach can be classified to range from very loose coupling to strong coupling linkage. The main advantage here is that it can be applied to any combination of GIS and an existing model without much modification required of the model. The very loose linkage involves importing

and exporting various data between the model and the GIS. In this case the model is run separately and its results saved to a file which is then brought into the GIS for display. An improved form of this is the use of dynamic data exchange (DDE) to communicate between the two packages. This is achieved by establishing an inter-process communication (IPC) link between the model and the GIS (Trinidad and Marquez, 1994). With this approach, usually the GIS is used as a server and the models as the client. The server supplies information to the client in response to a request. A request may be refused if the server is busy or engaged. Thus some mechanism must available so that in the event of the server being engaged the client can be made to wait or perform other processes. This procedure requires that both model and GIS be run simultaneously. This results in increase in computer processing time. Another disadvantage is that the GIS must support this DDE protocol.

Other forms of integration between GIS and models lie between the loose and strong coupling approaches. This include the use of other programming languages to develop routines which when run behave like modules within the GIS via a user interface developed using the programming language of the GIS. This approach differs from the GIS dominant approach in that it does not make direct use of the GIS internal data files. It, however, does make use of the programming language of the GIS and depends on it for data input and output and display capabilities. Data flow between the GIS and the model are depicted in Figure 2. It shows the GIS receiving raw data which are used to generate the various map layers. These raw data may include road infrastructure data, zonal data and demographic data. From the GIS map layers created out of the raw data, the GIS generates process data as input data for the model and then receive model out-put for display. The entire process runs transparently to the user via the user interface. The main disadvantage of this method is the lost of the interactive character of the GIS. The approach can be made more efficient if the model is able to read directly from the GIS internal data files. This will require knowledge of the GIS source code, which in turn requires permission from and possibly some form of agreement with the vendor.
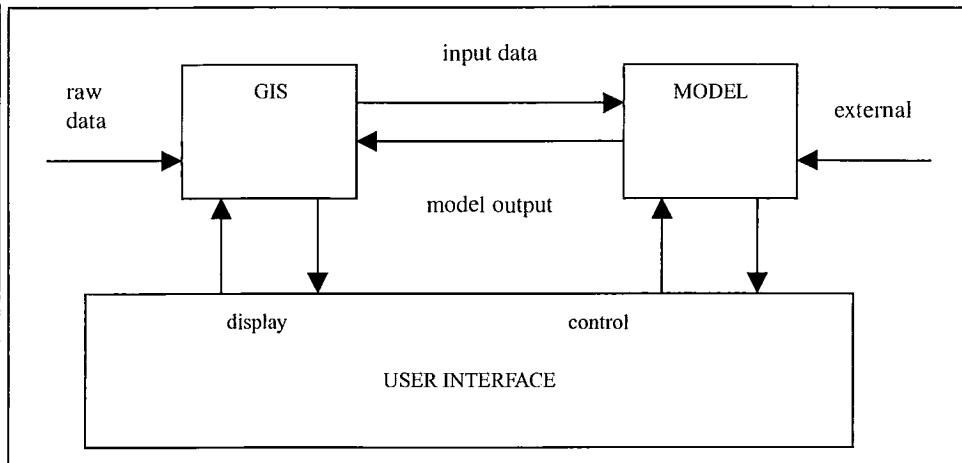

Figure 2: Data flow in user interface approach in integrating GIS and model (Source: Fedra, 1994)

TRAFFIC ASSIGNMENT METHODS

The commonly used network assignment techniques can be grouped under all-or-nothing, incremental, capacity restraint and equilibrium assignment methods. The all-or-nothing method is

the oldest, simplest and most economical traffic assignment method in use. Its continued application despite its various flaws stems from its ease of usage. It merely assigns all traffic flow between each O-D pair to a single shortest path between them. The main disadvantage of this method is its inability to cater for network capacity or multiple shortest routes. The assigned traffic flows therefore require some amount of hand tuning to generate realistic flows on the network, a process which can only be done by experienced modellers.

The incremental assignment method belongs to the class of capacity restraint assignment methods if, in the determination of the link impedance (cost), the capacity of link is taken into consideration. With this method, a portion of the trips from the O-D matrix is assigned to the network in successive stages using the all-or-nothing technique, until all trips are loaded unto the network. After each loading new impedance or travel costs are calculated based on the accumulated trips, and a new shortest path determined.

The equilibrium assignment method generates flow patterns that satisfies Wardrop's first principle (Wardrop, 1952). This principle states that the travel times on all routes actually used are equal and less than those which would be experienced by a single vehicle on any unused route. This principle is also termed the user-optimal assignment procedure and implies that traffic will distribute itself until an equilibrium is achieved in which case no one traveller can reduce his travel time by choosing a new route. For a fixed travel demand, this principle may be formulated as the mathematical programming problem (e.g. Taylor, 1984):

$$z = \min\left\{\sum_e \int_o^{q(x)} c(x)dx\right\}$$

subject to the flow constraints:

$$T_{ij} = \sum_r X_{rij} \qquad \text{for all } i,j$$

$$q(e) = \sum_{rij} \delta_{erij} X_{rij} \qquad \text{for all } e$$

$$q(e) \geq 0 \qquad \text{for all e}$$

and
$$X_{rij} \geq 0 \qquad \text{for all } r,i,j$$

where $q(e)$ is the traffic flow on network link, e, T_{ij} is the number of trips from origin i to destination j, X_{rij} is the trips using path r between i and j and

$$\delta_{erij} = 1 \text{ if } e \text{ is on path } r \text{ for pair } ij$$
$$= 0 \text{ otherwise}$$

The function $c_e(q)$ is the link congestion function and relates the travel cost (impedance) on the link to the link flow. The above minimisation problem is found based on the Frank-Wolfe feasible direction search procedure using an all-shortest-paths assignment

METHODOLOGY

The study design adopted involved the selection of appropriate link impedance function, approaches used in implementing the assignment models in the GIS, the development of a user interface and the application of the system to case studies.

Selection of cost function or impedance used

One of the parameters required in the flow assignment problem is the definition of link impedance. This impedance can be define in several ways: simple length, time taken to traverse a link or general cost, which can be computed to include some environmental factors (eg Taylor, 1996). The congestion function used is a modified version of the Davidsonís congestion function suggested by Akcelik (1978). It is defined as:

$$c = c_0\left(1 + \frac{Jq}{s-q}\right) \qquad\qquad q \le \mu s$$

$$c = c_\mu + K_\mu\left(q - \mu s\right) \qquad\qquad q > \mu s$$

where $0<\mu<1$ and

$$c_\mu = c(\mu s) = c_0\left(1 + \frac{J\mu}{1-\mu}\right) \qquad \text{and} \qquad K_\mu = \frac{dc}{dq}(\mu s) = \frac{Jc_o}{s[1-\mu]^2}$$

where s is the link saturation flow, q is the flow on the link and c_o is the free flow cost. This function eliminates possible computational problems that limits the use of the original Davidsonís function and allow for short term overloading of the network likely to occur during the processing of the equilibrium assignment model. The parameter μ is explained by Taylor (1984) as representing the point above which standing queues begin to occur. This impedance function was chosen because of the theoretical justification using queuing theory (Davidson, 1978) and its ability to include road type and road environment factors (Taylor, 1984).

Approaches used

The goal of the study was to implement the traffic flow assignment procedures in PC ARC/INFO using the resident path finding algorithm specified earlier, and a second method based on integrating the GIS and an externally developed model and compare their performances. In order to do that for the incremental and equilibrium assignment methods, which require the update of the link cost after each iteration, the same measure of impedance was adopted in both cases. To facilitate the use of both systems a user interface was developed using the PC ARC/INFO simple macro language (SML). This user interface, which is described in detail in a later section, runs in the form of pull-down menus. As a result of the menu, the main difference between the two assignment options as far as the user is concerned is the type of module in ARC/INFO under which it is run and the processes gone through as the program executes. The GIS is used to describe and maintain the street network. As PC ARC/INFO stores the attribute of each link in the network in a relational database the developed programs used the actual attributes of each link and not an average value. For example the actual speed measured on the links, and not say the average speed for the particular road class, is used. This implies the actual network operating conditions are used by the program. Below are

descriptions of the development of the two approaches in implementing the traffic assignment models in PC ARC/INFO.

Implementation using PC ARC/INFO resident route-finding algorithm.

This option uses the PC ARC/INFO built-in route finding routine. The implementation of the all-or-nothing assignment was straight forward since it did not require any updating of the cost function. The program therefore assigns the O-D pairs of flow to the shortest path between each O-D pair. The assignment of each O-D pair is handled separately. The incremental assignment requires the updating of the cost function after each iteration since the cost function depends on the link flows. The link cost function will increase with increasing flows and thus need to be adjusted dynamically as flows are accumulated on the network. An SML program is used to write back the assigned flows to the network and dynamically adjust the cost function after each iteration. This means temporary quitting the NETWORK module where the route finding are performed and using the relational database under TABLES to assign O-D pair flows and update the link cost impedance.

Another SML was written to implement all the steps for the equilibrium assignment model as outlined in Wigan and Luk (1976). The built-in path finding algorithm was used to find the shortest path between each O-D pair and the Golden Section search used to determine the step size length for modifying the determined flows during each iteration.

Currently, PC ARC/INFO has the limitation of being able to handle only 50 separate routes in any session. To overcome this limitation, during each iteration the path for each O-D pair is deleted after writing the details of it to the attribute table using the 'writeroute' command of the GIS. This is then used to add the assigned flows to the network and update the cost function at the end of that iteration. This result in a slight increase in the time taken to complete each assignment. Another disadvantage with the approach is the inability of the software to handle all O-D pairs at once. Each O-D pair is read in separately and then its path determined. It is due to these problems that the second approach outlined below was envisaged and then developed to be compared with this one. Despite these short comings, the approach has some advantages including the ease of implementation (requiring the use of only PC ARC/INFO SML programs) and the interactive nature of the path-finding algorithm. During the processing the selected paths for each iteration are shown on the screen with different colours.

Implementation using external developed route-finding algorithm.

The linked (GIS and model) assignment program was developed using a combination of SML programs and a route finding algorithm developed in the QuickBasic programming language. Any high order language (eg. Fortran, C or Pascal) could be used. The SML programs manipulate the ARC/INFO network line layer and generate the necessary model input data. This involves querying both the spatial and non-spatial attribute data and writing the required data sets into temporary files. These files are used by the developed route finding algorithm to assign the O-D flows onto the network. The assigned flows are then loaded onto the network which is displayed on the screen and output to a plot file for printing as a hardcopy. The QuickBasic runs transparently, with minimum input from the user and acts as an independent modular routine in the GIS. The program itself can run independently if the necessary underlying base data are available. Hence the approach could be applied to any GIS software with its own programming language. The equilibrium assignment model adopted is the multi-path equilibrium assignment routine implemented in the transport planning model SUSTAIN developed as a collaborative research project between CSIRO, the University of Tokyo and the University of South Australia (Roy *et al*, 1996). The steps involved are:

- Apply an SML program to generate one-way analysis links from the model network coverage, by converting all two way links to a pair or one-way links.
- Read in the O-D matrix
- Perform the assignment routine using the modified SUSTAIN method written in QuickBasic. The summary travel parameters are output to a file specified by the user.
- A second SML program called is used to add the assigned flows and travel cost in each direction on each link as attributes to the model network coverage and to generate a display of the network loaded with the assigned flows.

The main disadvantages of this approach are the lost of the interactive nature of the GIS based only approach, and the need to use two different programming languages. Its advantages include increased speed of operation and the fact that it could be applied to any GIS software which has its own programming language. This suggests that the approach could be used to integrate any GIS with any existing transport planning models.

USER INTERFACE

To facilitate the ease of using the system, a user interface in menu form was designed using the PC ARC/INFO simple macro language. The user interface makes use of pull down menus and pop-up menus. There are four main options (Mapping, Shortest paths and Assignment1 and Assignment2) based on their application and functionality each of which is described briefly below (see Figure 3). Choices on the menu are selected by using the mouse or the arrow keys. Selection of an option will pull down its submenus, some of which require the filling in of a form menu before the system performs the required operation. All relevant selection options are presented as pop-up dialogue boxes on the screen. The user then chooses relevant items from the pop-up windows. Only constant parameters like the number of iterations required for the equilibrium assignments are typed in by the user. Default values are provided for the constant parameters. Error traps and help messages are included. These enable the system to detect and reject invalid inputs and guide the user in the selection of input data.

Mapping	Shortest path	Assignment1	Assignment2	Quit

Figure 3: Main menu for initiating traffic assignment in ARC/INFO

The Mapping module is used for data retrieval, map display and interactive spatial query and analysis. The results of any spatial queries and analysis are displayed on the screen, output as hard copy for report preparation, and/or sent to a file for subsequent use by other subsystems.

The shortest path option is an interactive program used to determine the optimum paths between a set of origin and destinations. Once these origins and destinations are selected by the user the program determines the optimum paths based on the impedance previously specified by the user. The determined paths are highlighted in different colours on the display screen. A set of options are available. These options are:
- shortest path between a single O-D pair. For example finding the shortest distance from one's home to the nearest shopping centre.
- shortest path between a single O-D pair passing through intermediate stops

- shortest path from a single origin to many destinations
- shortest path from many origins to one destination
- shortest path between many origins and many destinations

The interactive nature of this option enable the user to test different scenarios and the performance of many different options. The impedance or cost functions used for this option are based on the link speed and delays at the nodes. The delays at the nodes are calculated based on the nature of turning and the type of control employed.

Assignment1 option is used to perform the three assignment models described earlier using the built-in optimum path-finding routines in the GIS. The user has to select the type of assignment model required from a pop-up menu on the screen. During the processing the selected path of each O-D pair is highlighted in a different colour.

Assignment2 option is used to perform the three assignment models described based on the integrated GIS and the external model. In this case the selected path between O-D pairs are not highlighted on the screen during the processing stage. Only the final assigned flows are overlaid on the network, as shown in the next section.

Output presentation from the models

Outputs from the assignment models are shown on the screen and sent to a file for hard copy print out. The outputs are in a form of map displays and a text file. The map displays show the transport network superimposed with the assigned flows. Two types of display are available: (1) the numerical value of the assigned flows on each link, and (2) a network map with the width of the each link drawn proportional to the assigned flow and differentiated using different symbols and colours based on the assigned flows. The output file contains the link identification number, from-node, to-node, the link impedance or cost, and assigned flows. Volume/capacity ratio can also be obtained. In addition, the trip parameters total vehicle hours travelled, total vehicle kilometres travelled, average travel speed, average trip time and average trip distance travelled are also generated.

CASE STUDIES

To test the performance of the two types of approaches, the routines described above were applied to the simple hypothetical network shown in Figure 4 and the Adelaide metropolitan road network.

The simple hypothetical network

This network is the standard network adopted by Murchland (1974) as a standard test problem for network analysis. It has 17 nodes of which four are zone centroids. The traffic flow demand (O-D matrix) between the zones used for the test network was taken from Wigan and Luk (1976). This matrix contains the elements:

$$T_{ij} = 2500 \text{ for } i=12, 17 \text{ and } j=1, 6$$

The values for the Davidson's congestion function and saturation flow used were taken from Taylor (1989). The network was digitised as connected links and nodes using a digitiser. It was then edited and built to remove any spatial errors. Each link was assigned the attributes which are required by the assignment routines.
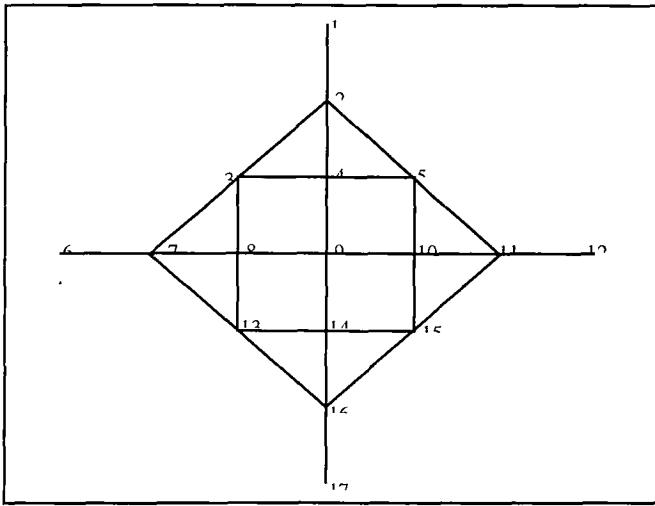
Figure 4: The test network 'GSNET'

Test results for hypothetical network

Tables 1 and 2 show the results obtained with each of the traffic flow assignment models. Note that for each assignment model, the output travel parameters are comparable for the two approaches. The slight differences for the incremental and equilibrium assignment models are due to the fact that the algorithm for the developed routines is based on the multi-path assignment approach whereas that of the built-in algorithm is based on entirely assigning the flows to a single shortest path on each iteration. The execution times for the models based on the external developed routines are almost the same. This is due to the fact that a large portion of this time was used in assembling and reformatting the network data stored in the ARC/INFO format. The time taken for the all-or-nothing assignment for the resident path-finding assignment is found to be better than that using the external developed program. This result is, however, not universal. It applies only to small networks such as the one used here. The reason for the longer time taken by the developed program was mainly due to the time taken to generate the network data to be used by the program from the ARC/INFO map layer. Further work was thus undertaken to determine at what size of network the procedure using the resident shortest path becomes unattractive.

For the incremental and equilibrium assignment models the performance of the developed routines are far better than the built-in ones, even for this simple network. This is expected since the path finding routine in PC ARC/INFO is slower, O-D pairs are read in one by one and the optimum path between O-D pairs are performed one after the other during each iteration. In the case of the developed routine, during each iteration the shortest path tree from an origin is found and all the O-D pair flows with this origin are read in at once and assigned to this tree. The results also highlight the disadvantage of using the all-or-nothing method in flow assignments. While all links with assigned flows were over saturated, some links were without flows a situation which is quite different from the other assignment methods (see Table 1) and is not likely in practice. All links at least had flows in the cases of the incremental and equilibrium assignment models. There was improvement in the assigned flows when the multi-path assignment techniques was used for the incremental assignment method (see Table 1, columns 4 and 5). On the whole the travel parameters

were best for the equilibrium model followed by the incremental model and lastly the all-or-nothing as expected. This can be seen from the values of the average travel distance, time, vehicle hours spent and vehicle kilometres travelled.

Table 1: Comparison of the assigned link flows and travel cost obtained

| | All-or-nothing | | Incremental assignment model | | | | Equilibrium assignment model | | | |
| | Both methods | | Built-in | External | Built-in | External | Built-in | External | Built-in | External |
Link_id	Flow	Cost	Flow	Flow	Cost	Cost	Flow	Flow	Cost	Cost
1	5000	2.4	5000	5000	2.4	2.4	5000	5000	2.4	2.4
2	5000	2.4	5000	5000	2.4	2.4	5000	5000	2.4	2.4
3	5000	2.4	5000	5000	2.4	2.4	5000	5000	2.4	2.4
4	5000	2.4	5000	5000	2.4	2.4	5000	5000	2.4	2.4
5	2500	48.7	2500	2187.5	48.7	27.8	1826.2	1905.4	9.4	11.3
6	2500	34.5	1875	2187.5	7.4	19.6	1709	1786.5	5.4	6.2
7	0	2.8	625	625	3.4	3.4	1464.8	1308.2	5.7	4.9
8	2500	48.7	2500	2187.5	48.7	27.8	1826.2	1905.4	9.4	11.3
9	0	2.0	1250	1562.5	3.3	4.4	1607.6	1308.2	4.7	3.5
10	2500	34.5	1250	1250	3.3	3.3	1709	1786.5	5.4	6.2
11	0	2.0	625	625	2.4	2.4	1204.8	1308.2	3.2	3.5
12	0	2.8	625	625	3.4	3.4	1347.6	1308.2	5.1	4.9
13	2500	34.5	1875	2187.5	7.4	19.6	1709	1786.5	5.4	6.2
14	2500	34.5	1250	1250	3.3	3.3	1709	1786.5	5.4	6.2
15	2500	34.5	1250	1250	3.3	3.3	1709	1786.5	5.4	6.2
16	2500	34.5	2500	2187.5	34.5	19.6	1709	1786.5	5.4	6.2
17	0	2.8	625	625	3.4	3.4	1464.8	1308.2	5.7	4.9
18	0	2.0	625	625	2.4	2.4	1607.6	1308.2	4.7	3.5
19	2500	34.5	1250	1250	3.3	3.3	1709	1786.5	5.4	6.2
20	0	2.0	1875	1562.5	7.4	4.4	1204.8	1308.2	3.2	3.5
21	2500	48.7	1875	2187.5	10.5	27.8	1943.4	1905.4	12.6	11.3
22	0	2.8	625	625	3.4	3.4	1347.6	1308.2	5.1	4.9
23	2500	34.5	2500	2187.5	34.5	19.6	1709	1786.5	5.4	6.2
24	2500	48.7	1875	2187.5	10.5	27.8	1943.4	1905.4	12.6	11.3
25	0	2.0	1250	1562.5	3.3	4.4	1607.6	1308.2	4.7	3.5
26	0	2.0	625	625	2.4	2.4	1607.6	1308.2	4.7	3.5
27	0	2.0	625	625	2.4	2.4	1204.8	1308.2	3.2	3.5
28	0	2.0	1875	1562.5	7.4	4.4	1204.8	1308.2	3.2	3.5

Figure 5 provides a comparison between the assigned flows obtained for the incremental model, the built-in equilibrium model and the developed equilibrium model. Differences in the absolute assigned flows are observed between incremental results and those based on the equilibrium models. Identical variation in flow from link to link is observed for all three methods with the troughs and peaks occurring at the same links. The results based on both methods for the equilibrium model compare well, with only slight differences being observed. The slight difference observed is due to the fact that with the developed model the flow is assigned based on the superior multi-path assignment techniques. The results suggest that either of the two approaches for the equilibrium assignment are equally applicable. Another important observation from Figure 5 is the large

variations in the assigned flows between the links for the incremental assignment method compared to those obtained from the equilibrium models

Table 2: Average travel parameters

| Travel parameters	All-or-nothing		Incremental		Equilibrium	
	External	Built-in	External	Built-in	External	Built-in
Veh-km of travel	162430.0	162426.4	186102.0	175229.7	188811.2	190614.9
Veh-hr of travel	20416.71	20394.56	8687.48	9965.46	4750.01	4677.52
Total trips	10000	10000	10000	10000	10000	10000
Mean speed (km/h)	7.96	7.96	21.42	17.58	39.75	40.75
Mean distance (km)	16.24	16.24	18.61	17.52	18.88	19.06
Mean trip time (min)	122.50	122.37	52.12	59.79	28.50	28.07
Execution time(sec)	18.19	6.63	18.37	38.63	18.84	93.04
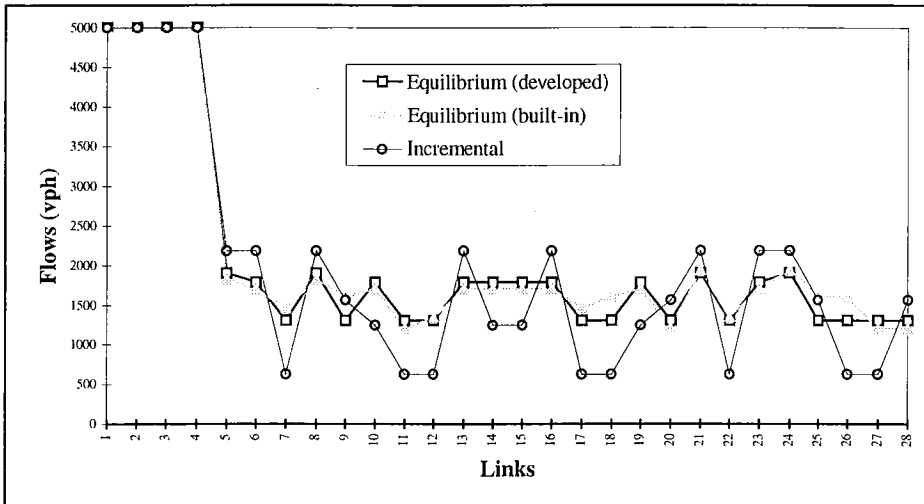
Figure 5: Comparison of incremental and equilibrium models assigned flows

Adelaide metropolitan network.

A program written in SML was used to generate a model network for Adelaide from the detailed Adelaide metropolitan network layer. The model network contained the centre lines of all the main streets (arterial and sub-arterial roads). The approach used was to strip the detailed metropolitan street network map of all the local and minor streets not needed. A three stage process was used in removing these details: removal of all links not required in the model network, removal of excess nodes and building the new topology. The removal of all unrequired links was accomplished using the 'select' and 'nselect' commands. A file containing the names of all main roads and streets to be included in the model network and their respective suburbs was created. Using this file all the required links for the model network were first selected. Then using the 'nselect' command this

selected set was exchanged for the unselected set. The now selected set which contains all unwanted links were then deleted and the coverage saved to a new name. The new map layer created by the above process deletes all the unwanted links but leave the 'pseudo' nodes in the new coverage. A 'pseudo' node is a node or a point at which an arc connects itself or to only one other arc. It is a node connecting two arcs only. 'Pseudo' nodes increase the number of features or records in the underlying database therefore have the effect of increasing computer processing time. Step two was to remove these excess nodes by converting them to vertices. In ARC/INFO the 'unsplit' command is used to join two adjacent links or arcs by removing the pseudo nodes between them if their user-id is the same. These nodes between any two adjacent links of the same street were removed after first assigning them the same user identification number. Each remaining link is assigned a new unique identification number and a new topology created using the 'build' command. The new created coverage contains the centre lines of all streets needed in the model network.

The final model network contained 936 links and 655 nodes with a further 297 zone centroids including 12 external cordon points. An SML program was used to capture the zonal centroid and to automatically generate dummy links to connect the zone centroid to the nearest node in the network. Including the dummy links the network contained 1232 links. The O-D matrix was generated using 1991 am peak hour trips in metropolitan Adelaide. Initial attempts to apply the in-built all-or-nothing algorithm on this network *using only 50 zones* took over an hour of execution time on a DX4 100 PC! As a result further use of the algorithms based on the in-built routines was abandoned. The network was tested using the developed algorithms only.

The summary travel parameters obtained for the assignments to the Adelaide network are shown in Table 3. The equilibrium assignment method yields the best travel parameters as expected. The execution time of 11 minutes (for 9 iterations) for the equilibrium assignment is also found to be acceptable for a network of this size.

Table 3: Summary travel parameters - Adelaide network

Travel parameters	All-or nothing	Incremental	Equilibrium
		Assignment model	
Veh-km of travel	2670637	2753615	2973553
Veh-hr of travel	363521	105166	87507
Total trips	265893	265893	265893
Mean speed (km/h)	7.35	26.18	33.98
Mean distance (km)	10.04	10.36	11.18
Mean trip time (min)	82.03	23.73	19.75
Execution time (min)	1.70	3.88	11.15

CONCLUSIONS

All of the common assignment models can be successfully simulated in PC ARC/INFO using its resident route finding algorithm. Since similar routines, (more powerful and well developed) are in the mainframe ARC/INFO, these models can be simulated there to. The case study networks also indicate that the performance of implementing assignment models in PC ARC/INFO can be improved significantly by integrating externally developed assignment models using high level programming languages. This enables the continued use of existing and well tested transport models within a GIS environment. In doing so analysts can make full use of the GIS display capabilities, and thus utilise a substantial basis for the development of new tools. For very small networks the

built-in assignment model all-or-nothing routine performs better than the developed one. However, its use is limited to demonstration purposes with limited practical applications. It could be used interactively to test the effect of various scenarios such as road closures or new traffic generators. For practical planning of large networks the external assignment models should be used. It takes a shorter time to complete and the quality of the final display output is the same as those from the built-in models. The interactive nature of some of the procedures also provides the user with the opportunity to test various scenarios. The study has shown that when integrate with other analytical tools and techniques, GIS can provide the spatial framework and many of the tools for the quantitative analysis and visualisation of the results of transportation network analysis

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