

THE DEVELOPMENT OF TPM:
A 'MICROSCOPE' FOR THE TRANSPORT PLANNER

M Taylor
Reader in Transport
Engineering
Department of
Civil Engineering
Monash University
Clayton, Victoria

ABSTRACT

The new information technology provides transport planners with new opportunities to apply computer-based methods. This paper describes the development of an integrated modelling system (the 'Transport Planning Microscope', TPM) for the identification of road transport user needs and the prediction of the traffic and environmental impacts. The technology used includes the personal computer, information management systems, transport network models and interactive graphics. The resulting system may be seen as a 'microscope' for the planner, facilitating the study of regional, metropolitan and local area networks, individual link sections, and activity sites to be made. The system comprises a connected hierarchy of models and software packages that allow planners to move the focus of an investigation between the broad and detailed levels.

INTRODUCTION

Recent developments in information technology have provided transport planners and engineers with new and unparalleled opportunities for the application of computer-based methods in the study of travel demand. These developments are most timely given a demise in interest in the use of 'black box' planning and analysis tools by transport practitioners. This paper describes the development of an integrated modelling system (the 'Transport Planning Microscope', TPM) for the identification of road transport user needs and the prediction of traffic and environmental impacts.

The technology used in TPM includes the personal computer, information systems management software, computer networks and interactive graphics. These provide powerful means for the capture, display, analysis, retrieval, modelling and interpretation of data relating to the way people use transport systems, and the performance of these systems. The resulting system is a 'microscope' for studies of regional, metropolitan and local area road networks, individual road sections and activity sites. TPM consists of a connected hierarchy of models and software packages, that enable the engineer to move the focus of an investigation between the broad and detailed levels.

The TPM system is built around the combination of geographic information systems (GIS) and interactive transport network models. TPM includes two transport network models, MONTRANP and MULATM, that cover the fields of strategic and dense road network analysis, together with an interactive transport data analysis and display package (DIAMONDS) that provides a powerful interrogation and interpretation capability for the examination of travel demand data. The system also provides links to other models.

Transport planners and engineers find themselves increasingly required to make quantitative assessments of the impacts of transport systems. To do so requires the use of numerical modelling techniques, which are usually computer-based. Further, engineers are also expected to communicate the results of their studies in intelligible form to the community that they serve. The TPM system may be seen as an integrated database and modelling system for transport planning, which spans all facets of the planner's work from the identification of user needs to network planning, detailed design and impact assessment.

COMPUTERS IN TRANSPORT ENGINEERING

The computer is essential in modern transport planning. Computer-based models provide the only practical means for the study and analysis of flows on transport networks. Since the 1950s, engineers and planners have been involved in the development of powerful modelling systems for the study of the component elements of transportation networks, and of the networks themselves. Until recently, however, these models remained in the domain of the specialist and were not suited to widespread application in engineering design and analysis. The advent of the personal computer (PC) drew computer modelling into the design process,

- (1) by making computing capacity readily available to the engineering profession at large;
- (2) by providing a readily accessible means for the application of the latest computer-based methods in the design office, and
- (3) by providing interfaces (e.g. through interactive graphics and CAD systems) that planners and engineers can use directly in their work and in their communications with other parties and the community.

A full account of the new roles of computer-based methods in transport engineering is given in Young, Taylor and Gipps (1989). This paper examines some of these recent developments in the state-of-the-art in computing for transport planning, and indicates the development of a unified framework with the following levels of interest:

- (a) the *sketch planning level*, where a 'broad-brush' approach that reveals the needs of transport users and provides simple answers to broad, 'ill-defined' questions is sought;
- (b) the *strategic level network*, representing the metropolitan or sub-metropolitan level network of classical transport demand modelling;
- (c) the *local area* (or 'dense') network, which is the detailed representation of a small part of a (typically) urban network. This level represents the transition between traffic engineering and transport planning, and has assumed great significance in contemporary transport analysis;
- (d) the *individual link or junction* in a road system, where questions of operational and design details are important, and
- (e) *transport impacts*, notably environmental impacts.

In all of the above areas, PC-based packages involving interactive graphics and database management have provided the impetus for the general introduction of computer-based tools into transport planning practice in the design office. Some examples are:

- (1) **DIAMONDS** and **TIP** (Taylor, Young and Newton, 1988), which provide means for the interpretation of travel demand data and the extrapolation of trends and developments in transport, land use and other interacting systems;
- (2) **MONTRANP**, an educational and practical tool for the analysis of strategic level transportation networks;
- (3) the **MULATM** local area traffic package for local area network studies (Young, Taylor and Gipps, 1989);
- (4) **SIDGRA**, a graphics-based interface for data entry, editing and interrogation of model outputs in the **SIDRA** package (Chung, 1989);
- (5) the **POLDIF** model for environmental impact assessment, and its linkage to **MULATM** (Taylor and Anderson, 1988), and
- (6) **TRANSTAT**, a special-purpose statistical package for the analysis of transport data (Thompson, Taylor and Young, 1988).

These packages are connected into an integrated unit through TPM, the 'Transport Planning Microscope'. The means by which TPM can function depends on the availability of GIS software.

GEOGRAPHIC INFORMATION SYSTEMS

Wigan and Kenyon (1988) defined two principal requirements for a transport database management system:

- (1) the system should have an interactive graphics interface, so that the geographic dimensions of the data can be clearly (and quickly) seen, and
- (2) care is needed to ensure that the information system and its data files may be easily applied in the widest number of environments, i.e. the information system should be able to run without modification on a wide number of host computers (e.g. IBM and Apple microcomputers, workstations, minicomputers and mainframes. The use of a standard query language (such as the Structured Query Language, SQL) is also necessary.

There are commercially-available GIS that meet these requirements. The ARC/INFO system developed by Environment Systems Research Institute (Zwart and Williamson (1988), Newton, Davis, Simberg and Crawford (1988)) is one example that is already finding widespread application in land use and environmental planning. MAPINFO is another GIS package that has already found application in transport planning (Kurt and Connolly, 1989). Besides providing an established and proven data management system with powerful graphics interface, GIS also offer flexibility in zone definition. Restriction to a pre-determined zoning system has been a substantial problem for the analysis and application of travel data, and has limited the opportunities for cross-comparisons between alternative data sets.

GIS structures allow the representative of the exact site of each data record (e.g. household), say on the basis of digitised co-ordinates), and thus the ability to superimpose a range of zoning systems on the data. A significant feature of GIS is an ability to overlay maps of the distribution of a number of variables in the database, which provides enhanced opportunities for data analysis and the development of an understanding of behaviour and characteristics in the study area.

Zwart and Williamson (1988) defined the requirements of a GIS in terms of two sets of procedures, *refinement and manipulation of data and data analysis*.

The refinement and manipulation procedures transform data, to facilitate handling or subsequent analysis. No analysis functions are performed, the process is that of editing and transformation. In many cases this is all that may be required to provide valuable planning information. The new forms of the data may be valuable in their own right, or may be more readily comprehended. Typical operations include classification of both the spatial and attribute data elements on a map, aggregation of the spatial (zonal) elements to provide simplified data sets, interpolation (e.g. to make contour displays more informative), and map projection changes to permit the merging of regions or highlighting of sub-regions.

Table 1 Desirable Data Handling Capabilities of a GIS for Use in Transport Planning

Data Refinement and Manipulation

Reclassification of attributes (add, remove, select and join)

Coordinate manipulation (shift, rotate, scale)

Projection change

Generalise

dissolve, merge and eliminate boundaries
line thinning
line smoothing

Generate (points, lines, corridors, polygons)

Data Analysis

Overlay

- * point in polygon (union, join identity, intersect, clip)
- * line in polygon (union, join identity, intersect, clip)
- * polygon on polygon (union, join identity, intersect, clip)

Measure

- * count (number of items)
- * distance (between points, along network, along curvilinear alignments)
- * areas
- * calculate (arithmetic and Boolean conditions)

Network Analysis

- * route selection (shortest path, quickest path, optimum tour)
 - * allocation (acceptable separation between centres, location of facilities and resources)
-

[source: Zwart and Williamson (1988)]

The data analysis procedures involve the extraction of data from a system for use in decision making. This may be merely the retrieval of the contents of all or part of a data file, or involve complex space-time-attribute queries to such questions as size of area, attribute combinations, distance separation, shortest route, etc. Table 1 provides a list of desirable data handling capabilities for GIS applications in transport planning.

An example of the application of the GIS concept is given in Figure 1. This diagram shows a set of individual databases (topography, land ownership and use, transport network, socio-economic and demographic data, transport system use, and environmental impacts (e.g. noise contours)) that can be combined within the GIS framework. The GIS software enables the user to isolate particular elements from the available data, or to fuse combinations of elements. Thus the performance and structure of particular parts of the transport system can be gauged, whilst keeping the spatial perspective of the study area in full view. The GIS package can focus on small sub-areas within the full region, or take the broader regional perspective. In the case of Figure 1, the types of models that may be applied with the particular databases are also indicated.

The ability of the GIS to examine and display transport-related data for a full study area, or any sub-region within it, provides essential support for the concept of a connected hierarchy of transport models.

HIERARCHICAL APPROACH TO MODELLING

Modelling provides a powerful means for understanding the needs of the users of transport systems, and for assessing the ability of a given system to cope with the demands placed upon it. Further, the new generation of transport models provides unparalleled opportunities to use models in project design and evaluation (Young, Taylor and Gipps, 1989). The new interest in modelling to serve community needs has lead to the observation that there is no one universal model. Different problems and applications require different models, because the level of detail needed in model output and the demands for valid input data vary between applications.

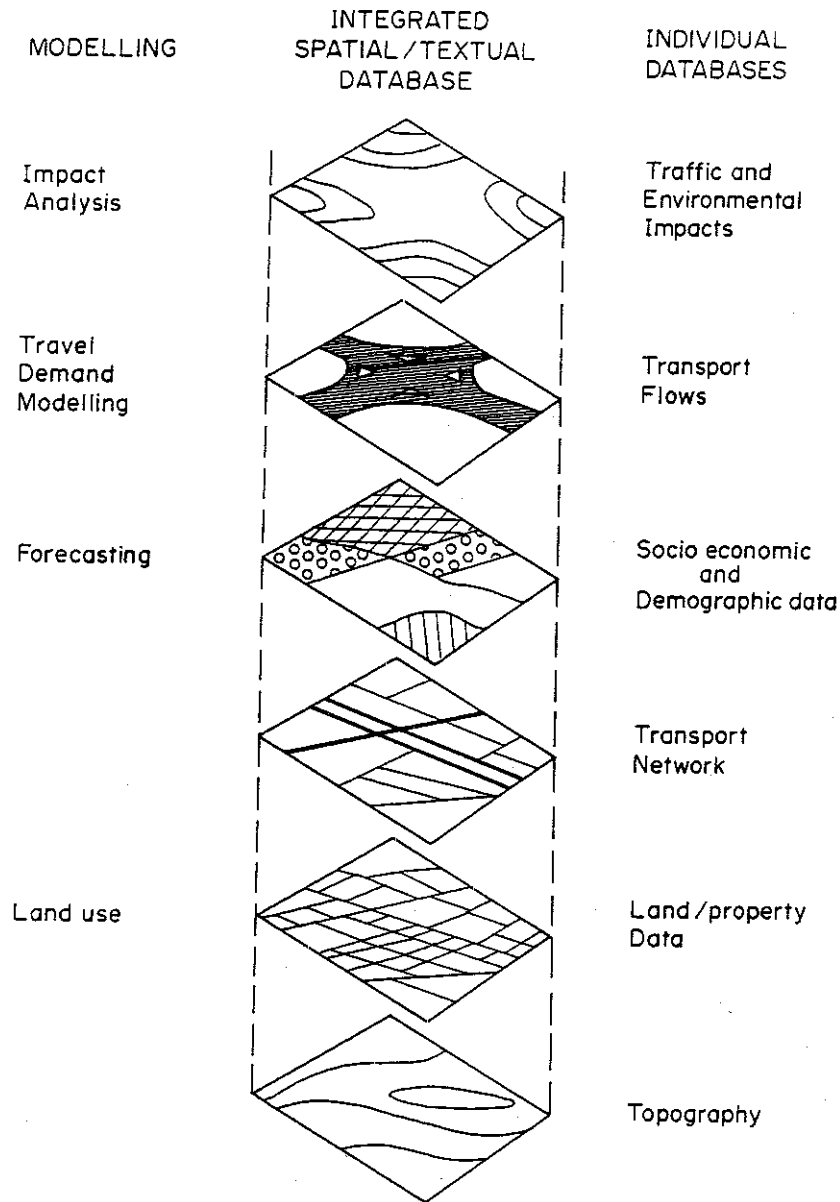


Figure 1: The Geographic Information System provides a framework for integrating several transport-related databases

A useful perspective from which to view model strategies is that of a hierarchy of models, as described by Taylor (1988) and Young, Taylor and Gipps (1989). The hierarchy offers a combination of:

- (a) relevant *model theories* and concepts, to identify the ideas and relationships that are directly applicable to a given problem;
- (b) appropriate *levels of detail* for input data;
- (c) appropriate *choice of computing methods*, and
- (d) relevant *model outputs* that describe the performance of the system under study at a level commensurate with the validity of the theories used and the input data.

The following seven-level hierarchy has been found useful for traffic analysis and modelling. Starting at the most detailed (micro-) level, the hierarchy is:

- (1) *microscopic simulation* of individual units in a traffic stream (e.g. at a junction or along a link);
- (2) *macroscopic flow models* in which the flow units are assumed to behave in some collective fashion, e.g. aggregate models of flows for a link or a junction;
- (3) *simulation models of flows in networks* for the optimisation of network performance for fixed route choice (i.e. invariant travel demands);
- (4) *dense network models*, including both trip assignment models and models for creating synthetic O-D matrices. This level of the hierarchy introduces a direct demand response to changes in system performance;
- (5) *strategic (or large scale) network models*, typically involving the 'four-step' process. This level is that of the typical transport network analysis package;
- (6) *land use impact assessment models* for the analysis of the local and regional impacts of new or revised facilities, such as retail centres, and
- (7) *sketch planning models* of land use-transport interactions. At this level the spatial connections between system elements need only occur as notional representations.

This hierarchy provides a means of classifying and comparing transport models. Its levels may be distinguished on the basis of spatial aggregation and time duration, with both area and duration increasing as one moves from level 1 to level 7. Areas increase from the isolated junction or road section (individual site), to areas of several hectares (district centre), to several square kilometres (dense network), and to an entire metropolitan area. Study period durations for the microscopic simulations are

generally of the order of a few minutes, increasing to a peak 'hour' for the local area models and a 24 hour period for the sketch planning models.

Information Flows in the Hierarchy

The linkages between models in the hierarchy are of great importance. In TPM the outputs from models at one level become the inputs to the next level. This process allows for the overall study of a given area or situation and the concentration on some particular aspects of it. Information flows occur in both directions, and these flows may be seen in terms of travel demand or system performance:

- (a) *from the higher levels down*, outputs from one level of TPM represent inputs (or constraints) to the next level. These may be seen as the transfer of *demand information* (i.e. who will attempt to use some part of the transport system over a given time period), and
- (b) *reverse direction flows*, where model outputs from a more detailed level are measures of performance, i.e. *system response information*.

Interactions between Levels in the Hierarchy

Figures 2 and 3 provide illustrations of the spatial relationships and information flows between the levels in the hierarchy. Figure 2 shows a large scale network, say representing the main arterial roads and highways in a region, with a dense (local area) network inside it. The flows across the cordon line of the local area represent the demand information that comes from the large scale network to the local area network, i.e. how much traffic enters and leaves the local area, and at which points. The local area network comprises the main road system within it as a skeleton, with less important ('local') roads and streets added to it.

Figure 3 shows further magnification within the local area, enabling the analyst to focus on one or more elements within the area. These elements can include individual junctions, road sections, or development sites.

The hierarchical approach provides a framework by which to judge the appropriate position and use of a particular model, and its relationship to other models.

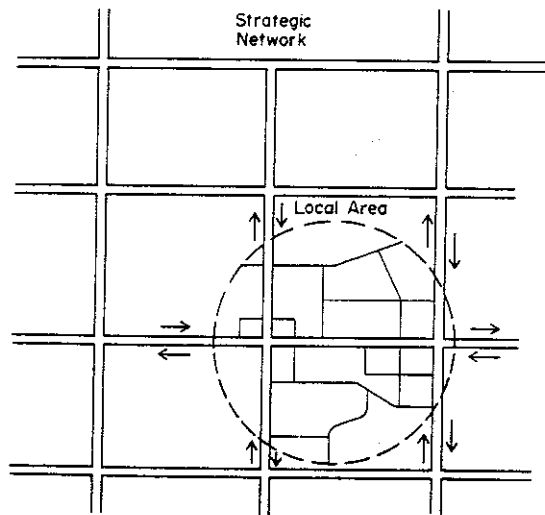


Figure 2: Strategic level network surrounding a dense network

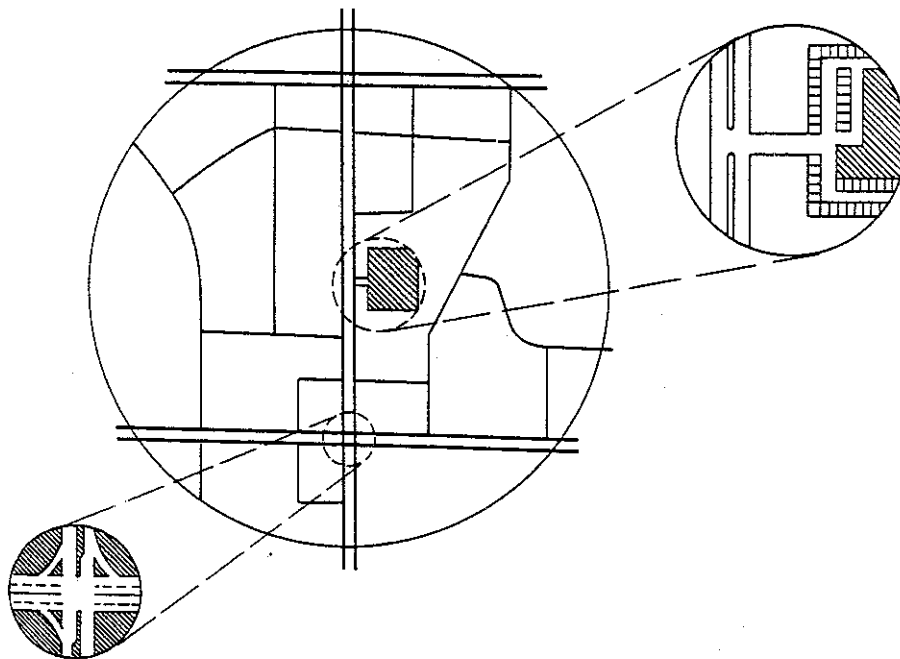


Figure 3: Elements in a dense network: junction, street section, land use development

Extent of Intervention by the Analyst

There is one further dimension to the hierarchy. This is the nature of the linkages themselves, largely reflecting the level of intervention of the modeller in the process of information flow. Brownlee et al. (1988) offered the following definitions of the types of linkages that are available:

- (a) *automatic linkages*, in which all information transfers take place independently of the model user. No human intervention is required;
- (b) *accuracy checking*, in which the output from one model is inspected by the user for general validity and accuracy before becoming the input to the next model;
- (c) *comprehension checking*, which requires the modeller to inspect the output for general validity and to gain a better understanding of the modelling process, by following the process at each intermediate step. The modeller must 'certify' the output as acceptable before the process can continue;
- (d) *knowledge intervention*, where the output may be adjusted by the modeller before being used as input to the next level. Any modifications are made in the light of additional knowledge, exogenous to the model but available to the modeller;
- (e) *knowledge intervention with calibration feedback*, which follows the same steps as in d) above to form the initial input to the next level, but then reverses the direction of information flow to take revised inputs into the previous modelling level. This process may be repeated in iterative fashion until a balance between the two models is achieved (e.g. in balancing observed and modelled trip tables and link flows), and
- (f) *knowledge generation*, where the output from one model is only used to provide insights needed to form the input for the next level. This form of linkage is completely manual in nature.

Example: A Regional Centre

The principles behind the hierarchical approach and its practical advantages may be clearly seen by considering an example. The example chosen is the development of a major retail centre and the transport infrastructure required by that centre. The users of the centre are the retailers and the shoppers, and each user group has slightly different transport needs. For the retailers, the need is for the

efficient delivery of goods. For the shoppers, it is the ease and cost of access to the centre. There may be some adverse impacts from the centre development, for example:

- (a) retail trade in other centres may decline when the new centre is opened. An evaluation of the development might seek to establish which of the competing centres might be affected, and the degree to which these effects would be felt, and
- (b) increased traffic in the vicinity of the centre might overload the existing traffic system, or may lead to undesirable environmental impacts, such as excessive parking demands in surrounding streets.

On the other hand there may be some advantageous impacts, for example:

- (a) new and enlarged shopping, recreational and community facilities for local users, providing better opportunities, increased quality and range of services, and lower costs, and
- (b) the centre may provide a new focal point for public transport operations, leading to improved level of service of transit supply to travellers.

The analyst would use TPM by beginning at the sketch planning level, with an assessment of likely shifts in level and distribution of travel demand arising from the development, over a reasonably long planning horizon. The next level is the regional transport system, and the changes in travel demand and network performance likely to arise from the development. From these studies, the analyst could estimate the likely travel demand in the local area surrounding the centre and the possible traffic, community and environmental impacts. Finally the detailed performance of the elements of the transport network (e.g. junctions, links and parking stations) in the vicinity of the centre could be considered.

The subsequent sections of this paper introduce modelling methods that are applicable for studying the behaviour of transport users at each of these levels.

SKETCH PLANNING

Taylor, Young and Newton (1988) provided an account of the use of sketch planning models in transport planning and analysis. This sphere of analysis is characterised by the need for quick, broad brush methods that use readily

obtainable data and do not require extensive data inputs for their operation. Two particular means:

- (a) *interactive display and analysis of spatial data*, using a package such as DIAMONDS, and
- (b) *simplified systems dynamics modelling*, for which the TIP program is a useful example.

MELBOURNE REGIONS

LAMM

1000s tri (Y)

358.1

211.3

64.5

199

864

1529

kiloL/day (X)

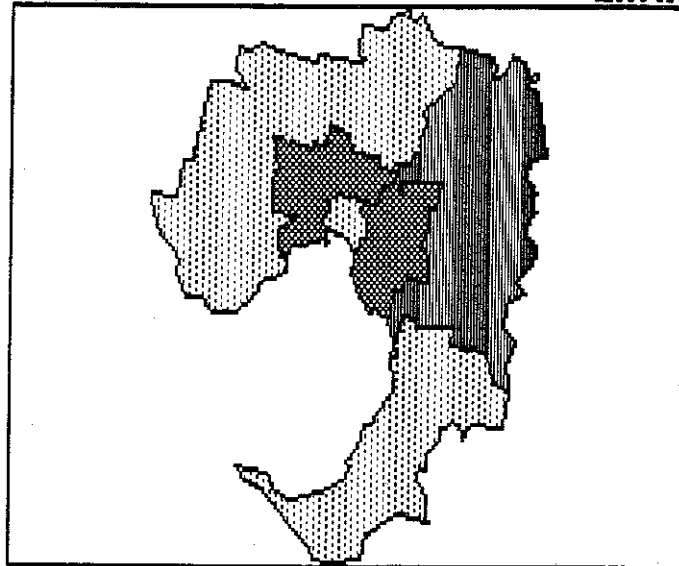


Figure 4: Map display of regional trip flows. The map shows the origins of work trips bound for a specified destination zone (DIAMONDS display)

DIAMONDS combines an interactive mapping program with procedures for the display and manipulation of data matrices (e.g. O-D matrices) by which the engineer and planner can learn about the observed behaviour of transport users. For example Figure 4 shows a map display of the Melbourne metropolitan area, with regional trip flows indicated. This map shows the origins of work trips bound for a specified destination zone, i.e. it displays one column of the regional O-D matrix. Figure 5 is an display of the O-D matrix itself, as an interactive screen display that provides insights into the organisation and structure of the matrix as a preliminary to trip distribution modelling. These figures are for illustrative purposes

only. The true value of the DIAMONDS graphics displays arises when more detailed origin-destination patterns are examined.

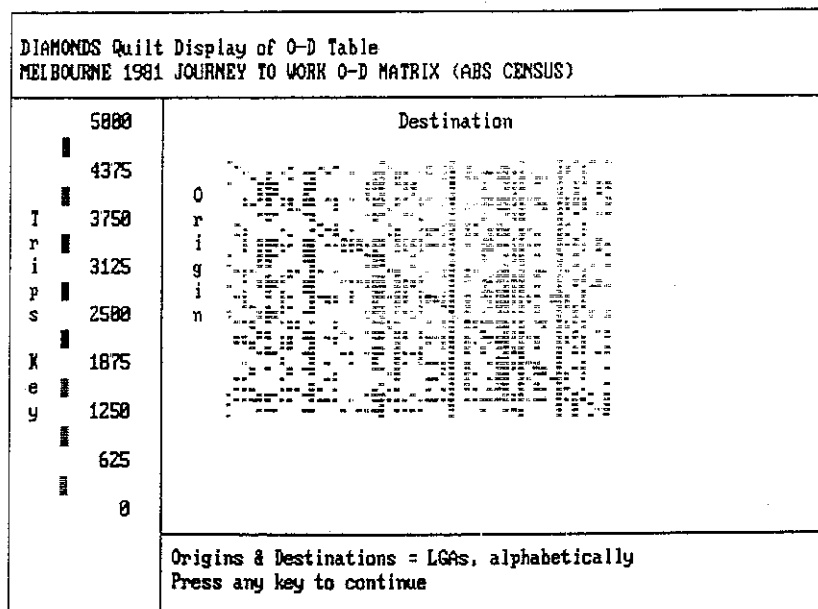


Figure 5: Schematic display of a (regional) O-D matrix, indicating relative importance of each cell in the matrix

The analysis module in DIAMONDS allows for conventional modelling of origin-destination flows, through the use of singly and doubly-constrained gravity models. More interestingly, it also allows for exploratory data analysis (EDA) of flows, using techniques such as Q-analysis (Atkin, 1974) and FOCUS (Shaw, 1980) that examine the strength and complexity of the interactions between the origins and destinations.

STRATEGIC NETWORK STUDIES

Transport modelling in strategic networks represents the classical form of travel demand modelling, typified by the 'four-step' process. There are a number of useful model developments on PCs, including EMME-2 (Florian 1977) and QRS-II (Horowitz 1987). The MONTRANP package is another such development, aimed at providing an educational system for travel demand modelling. A feature of MONTRANP is the

strong use of interactive graphics for presentation. Figure 6 provides an example. It shows a modelled set of link flows on a strategic network. An internal window has been drawn, corresponding to a local area within the strategic network.

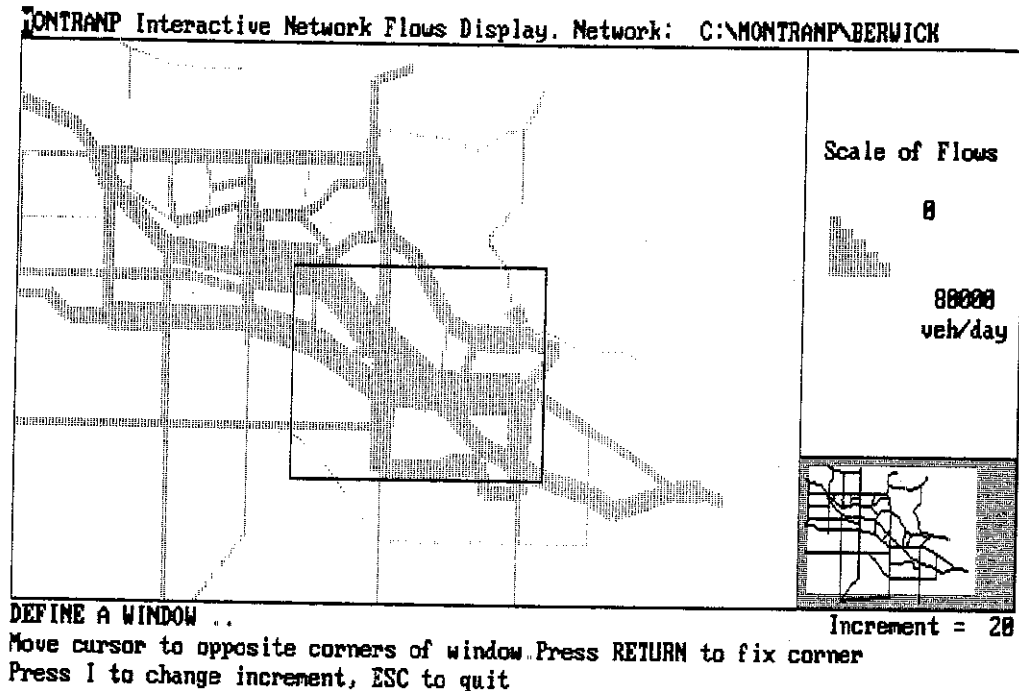


Figure 6: Interactive display of link flows on a strategic level network, showing a window defining a dense network inside it (MONTRANP display)

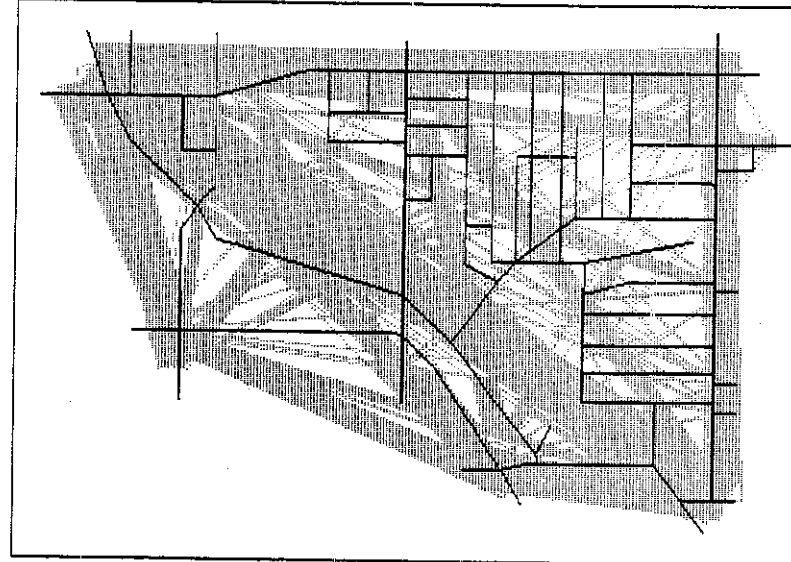
DENSE NETWORKS

The MULATM model is an example of a dense network model. It is, however, a model that has developed its own 'shell', to the extent that the shell - a powerful interactive traffic database package - has subsumed the model (see Taylor (1987) for details). MULATM now has more than 80 users around the world. A feature of MULATM is its complete reliance on interactive graphic displays. Graphic displays

of the network, its components, traffic demands, volumes, and derived variables are always available.

One example is presented, in Figure 7. This shows a desire line diagram for peak period traffic movements. Such displays are commonly used to display traffic data. The difference here is that this display is available as soon as the data are entered. As the display is interactive, separate pieces of the travel demand pattern can be displayed on request. A corresponding display of link flows can also be obtained.

DISPLAY O-D DATA FOR STUDY AREA 2 - 1983 NETWORK



Scale of Trips

0

1000

SEPT 1983
7:30-8:30

All trips in O-D table
Total no. of trips = 8957

Figure 7: MULATM interactive display of O-D flows as desire lines

INDIVIDUAL JUNCTIONS

MULATM also offers the engineer some insights into performance of individual intersections. Interactive displays of intersection geometry and turning movement flows are available for any junction in the dense network. This information can be taken into the next level of interest, the design and analysis of individual junctions.

THE DEVELOPMENT OF TPM

A current research project involves the development of communication links between MULATM and a Computer-Aided Design (CAD) package to permit even more detailed display of road network and traffic data.

Junction design, particularly signalisation, is perhaps the most important part of traffic design. The SIDRA package (Akcelik, 1984) is one of the powerful new procedures available for signal analysis. There are now over 90 SIDRA users, most of whom run the package on a PC. One difficulty with SIDRA has been the complex input data set needed to use it. Here PC-based graphics provides a solution through the SIDGRA program (Chung, 1989), which provides an interface between the user and SIDRA. SIDRA version 4.0 will include SIDGRA. SIDGRA shows a diagram of the junction, with windows to highlight one approach leg, or the signal phasings, as shown in Figure 8.

A current collaborative project between ARRB and Monash University seeks to establish direct links between MULATM and SIDRA for these purposes.

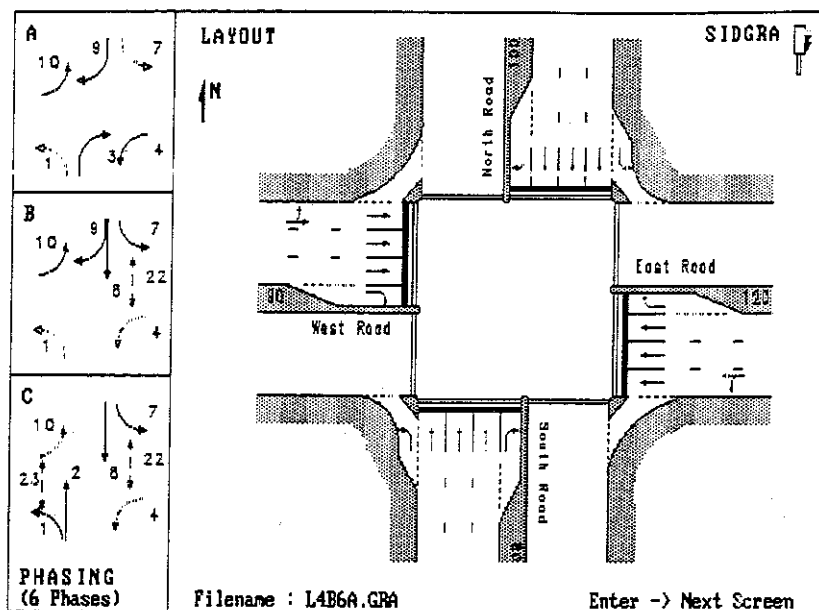


Figure 8: Interactive display of intersection geometry and traffic signal phasings, from SIDGRA

TRAFFIC AND ENVIRONMENTAL IMPACTS

Transport planners now have considerable scope for data analysis on their desk tops, due to the advent of the PC and its rapid dissemination into professional practice. Besides the enhanced opportunities for modelling, there are also new opportunities for the analysis of transport data - either observed data or that generated by models such as those introduced above. Analysis involves the 'straight' application of statistical methods, the interpretation of data through exploratory data analysis (EDA) methods, and the estimation of transport impacts. Statistical analysis may be done using a general statistical package (e.g. STATGRAPHICS), special transport statistical analysis packages, such as TRANSTAT (Thompson, Taylor and Young, 1988), or within a modelling package, as a post-modelling process. Each of these alternatives has its own area of application. MULATM provides for several types of exploratory and statistical analysis of its data, and generates output files that may be taken for use as input to other analysis packages.

A further application of MULATM data is in environmental impact analysis, using the POLDIF model. This model and its linkages to MULATM are described by Taylor and Anderson (1988). POLDIF takes network and traffic data from MULATM and produces area-wide air and noise pollution levels for the study area. It disperses the pollutants emitted on each link, and aggregates the pollution levels occurring at any point in the area. It presents its output in tables, as contour maps, perspective drawings, or as cross-sections on selected screen lines.

CONCLUSIONS

This paper has outlined the development of a connected hierarchy of traffic models, set under the umbrella of the 'Traffic Microscope', that provides transport engineers and planners with new and powerful means to investigate travel demand and transport systems performance. It provides an insight into the current developments in information technology that are reshaping the methodology of transport planning.

A common thread in all of these developments is the expansion of the computer package beyond the bounds of the model that provides the engine for the study. The model

becomes the kernel of a larger database system that the engineer may use to achieve a better understanding of the system under investigation. The computer is the means by which the engineer gains greater insight into the features and problems of the study area. GIS, for example, provide a powerful integrated database systems that can merge separate databases (e.g. physical, land use, demographic and transport), whilst keeping the essential spatial dimensions of each data set in train. Land use and transport modelling packages can then operate from the integrated database, providing physical and traffic inventories, environmental impact analysis, and diagnostic appraisal of the existing state of the system. Full modelling and simulation capability is always available, but it is but one element in the tool kit available to the planner. Further, communications between the researcher and the practitioner are enhanced, as the practitioner may now take up the most recent developments in a short space of time, and can quickly inform the model developer of the needs for new or alternative output forms, or analysis capabilities. An emphasis on graphics capability provides the means for the rapid dissemination of findings, ideas and proposals to the engineer, other interested professional groups, and the community.

REFERENCES

- Akcelik, R (1984). SIDRA-2 does it lane by lane. *Proc. 12th ARRB Conf.* 12 (4), pp.137-149.
- Atkin, R H (1974). *Mathematical Structure in Human Affairs*. (Heinemann Educational Books: London).
- Brownlee, A, Millican, R, Stephenson, B, Schnablegger, J and Repley, S (1988). Large scale integration of computer programs. *Proc. Third Int. Conf. on Computing in Civil Engineering*, Vancouver, BC, August, Canadian Society for Civil Engineering, pp.660-666.
- Chung, E C S, (1989). SIDGRA (SIDRA Graphics) development. ARRB Restricted Report DN1643. Australian Road Research Board.
- Florian, M (1977). A traffic equilibrium model of travel by car and public transit modes. *Transportation Science* 11 (2), pp.166-179.
- Horowitz, A J (1987). Quick Response System II reference manual version 2.1. (AJH Associates : Milwaukee).
- Kurt, C E and Connolly, T J (1989). Integrating databases and graphics in transportation engineering. *Proc. First Int. Conf. on Applications of Advanced Technologies in Transportation Engineering*, San Diego, February. (ASCE: New York), pp.305-310.

TAYLOR

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

Shaw, M G H (1980). *On Becoming a Personal Scientist*. (Academic Books: London).

Taylor, M A P (1987). Applying interactive colour graphics in traffic planning. *Computers and Graphics* 11 (3), pp.241-248.

Taylor, M A P (1988). Computer models for traffic systems applications. In Newton, P W, Taylor, M A P and Sharpe, R (eds.), *Desktop Planning; Microcomputer Applications for Infrastructure and Services Planning and Management*. (Hargreen Publishing: Melbourne), pp.264-275.

Taylor, M A P and Anderson, M (1988). Modelling the environmental impacts of urban road traffic with MULATM-POLDIF: a PC-based system with interactive graphics. *Environment and Planning B* 15 (4), pp.413-431.

Taylor, M A P, Young, W and Newton, P W (1988). PC-based sketch planning methods for transport and urban applications. *Transportation* 14 (4), pp.361-375.

Thompson, R G, Taylor, M A P and Young, W (1988). FRANSTAT: a microcomputer program for fitting distributions to traffic data. *Proc. 14th ARRB Conf.* 14 (2), pp.206-221.

Wigan, M R and Kenyon, J A (1988). Integrated graphics and database systems: a prototype visual pavement management systems database. In Newton, P W, Taylor, M A P and Sharpe, R (eds.), *Desktop Planning; Microcomputer Applications for Infrastructure and Services Planning and Management*. (Hargreen Publishing: Melbourne), pp.317-331.

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

Zwart, P R and Williamson, I P (1988). Parcel-based land information systems in planning. In Newton, P W, Taylor, M A P and Sharpe, R (eds.), *Desktop Planning; Microcomputer Applications for Infrastructure and Services Planning and Management*. (Hargreen Publishing: Melbourne), pp.44-53.