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Using structured systems analysis to design an integrated system for transport planning and environmental analysis

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Abstract——This paper applies Yourdon's (1989) structured systems analysis techniques to transport planning, and the environmental analysis of transport plans. It is usual for planners to treat these activities as separate processes or "systems". Six serious shortcomings are identified in prevailing approaches to accounting for the environmental impacts of transport plans. The application of systems analysis has elucidated opportunities for overcoming these problems by integrating the two processes. The paper highlights the benefits of using these methods to direct research into, and development of, an integrated transport planning- environmental analysis system. Techniques applied are data flow diagrams, a Venn diagram and an entity-relationship diagram. Significant potential exists for integration within a geographic information system(GIS), although adoption of integrated methods by transport planners is likely to be incremental. Research confirms the usefulness of systems analysis in guiding the development of a GIS application to accommodate integrated transport planning and environmental analysis. Systems analysis also facilitates more careful and effective design of the databases underlying GIS analysis.

Keywords: transport planning; travel demand modelling; GIS; environmental planning; systems analysis.

1 Introduction

The foundation of urban transport planning since the 1960s has been computer modelling of travel demands. The models utilize statistical relationships between travel patterns and underlying patterns of land use or economic activity to predict changes in these patterns and the resulting traffic flows (Hall, 1982). Mitchell and Rapkin(Mitchell, 1954) were the originators of the method whose most notable early applications were with the Detroit and Chicago area transportation studies of 1953 and 1956, respectively(Bruton, 1985). Specifically, the method results in an "assignment" of traffic to the road network following analyses of trip generation from " zones", trip distribution between zones and split between different transport modes. While these models predict traffic volumes and resulting congestion, they do not go further and predict the ramifications of traffic such as vehicle collisions, noise or air pollution. For some time, transport modelers have been trying to address satisfactorily another shortcoming of the models, namely, the land use-transport interaction where changing traffic density has a " feedback" effect on further land use changes (Roberts, 1983; Beimborn, 1979).

The emergence of popular concern for environmental quality during the 1960s caused transport planning to become increasingly controversial. Transport plans invariably led to road building with attendant environmental repercussions, the significance of which are now widely accepted. Responding to public pressure, governments began to adopt environmental protection as a policy priority. As public sector endeavors, controversial road proposals were catalytic to the introduction of environmental impact assessment (EIA). The environmental planning technique of EIA has its origins in the 1969 American federal legislation, the National Environmental Protection Act (NEPA). Of the 5500 impact statements prepared under NEPA before July 1974, 2162 of them (39%) concerned road projects(CEQ, 1974).

Other less influential techniques for analysing the environmental implications of roads were also developed. Planners attempted to augment the established project evaluation technique of cost-benefit analysis with environmental data (Walshe, 1990). Buchanan (Buchanan, 1963) promoted the idea of determining the " environmental capacities " of streets concurrently with their vehicular capacities. More recently, transport planners have begun to tailor the concept of environmental management systems to road networks(Hopkinson, 1994) and they are grappling with state of the environment (SoE) reporting and developing performance measures against multiple goals. Nevertheless, it remains the case that transport planning and environmental analysis tend to be conducted separate from each other-in effect, as isolated systems.

The typical approach has been to prepare transport plans and then scrutinise their transport infrastructure recommendations for environmental implications. This has several significant weaknesses:

(a) Sequence and Inertia: Aspects of transport plans become entrenced early in the planning process, thus reducing flexibility for modifying proposals within a subsequent environmental analysis process. Engineering factors such as predicted travel demands and the technical feasibility of adding new links to the road network currently have the greatest influence at early planning stages. Even if certain elements of transport plans could be ruled out altogether for especially significant environmental repercussions, this information would not come to light until a later stage in the process. Generally, transport planners package combinations of possible plan elements into a few broad alternatives before environmental factors are taken into consideration, and before the plan has been scrutinised by environmental professionals. Bureaucratic commitment to one or more of these broad alternatives increases with the time and effort invested, ultimately militating against the later creation of additional options during environmental analysis processes.

(b) Scale: Environmental analysis techniques can not be readily adapted to different scales of development. Developments to the road network occur at widely varying scales. Existing processes for assessing environmental impacts are inflexible in that they do not lend themselves equally to small scale and large scale developments. As a result, the transport planner has to use different methods for different scales. For example, the conventional approach to EIA is to follow a fairly comprehensive process prescribed by legislation. This ensures a high cost for EIA, making it impractical for small developments.

(c) Conflict: Dominant assessment methods can contribute to conflict and adversarial or strategic behavior on the part of participants in the process by polarising development and environmental objectives(i. e. they tend to pit proponents of transport plans against affected residents, community groups, organized environmental lobbies and in some cases government environmental agencies). This effect is most pronounced for environmental analyses that are reviewed by boards or courts established on a legalistic model.

(d) Resistance: Some transport planners resist undertaking environmental evaluation due to real or perceived costs, time delays and conflict.

(e) Clarity: Even good quality scientific analysis is sometimes presented in a manner that is essentially uninformative or inaccessible to planners.

(f) Policy testing limitations: Assessment techniques can not easily deal with combinations of possible alternatives (e. g. non- structural options such as travel demand management proposals).

Research at Griffith University is focussing on overcoming the above shortcomings by integrating transport planning (specifically output from travel demand models) and environmental analysis. This work is an expansion of Brown and Patterson's (1989) research into integration traffic noise assessment with travel demand modeling (TDM). Application software is being developed for a commercial desk-top geographic information system(GIS) to achieve this integration. This paper describes the early design of a GIS application tentatively called "SMIRC", System for Modelling the Impacts of Roads on Communities.

2 Transport planning and environmental analysis as parallel systems

Fig. 1 gives an overview of the interaction between the two systems: transport planning, and environmental analysis. It is based on data flow diagram (DFD) concepts. Data flow diagramming is one of the main techniques for structured analysis and it is discussed in greater detail below. When describing complex transport or environmental planning systems, most authors resort to some form of diagram. Most frequently these are unstructured pseudo-flow charts that are contrived to suit the author's personal tastes and immediate communication intent (e. g. Bruton, 1985; Beimborn, 1979). In contrast, the established conventions for structured diagrams dramatically reduce ambiguity and clearly emphasise particular features of the system (such as data) necessary for effective analysis, design or redesign of systems.

Fig. 1 suggests that decision makers (normally governmental) call for the development of a transport plan. The resulting transport plan becomes a data store as a product of the

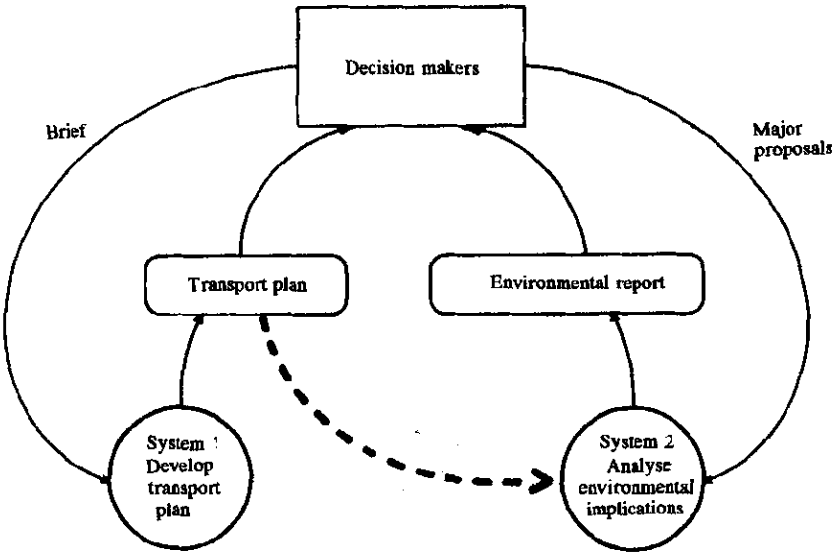

Fig. 1 Context diagram of two systems: transport planning (system 1) and environmental analysis (system 2). Based on data flow diagram (DFD) concepts

transport planning process. Individual data elements do find their way into the environmental analysis process, as represented in Fig. 1 by the dashed line between the transport plan and system 2, entitled "analyse environmental implications". A conceivable example of this might be the use of predicted traffic volumes from the transport planning process in a subsequent traffic noise analysis. Nevertheless, the main impetus for a process of environmental analysis occurs when the decision makers refer certain major components of a proposed transport plan to environmental analysis, producing an environmental report as a data store.

The following two sections of this paper apply structured analysis, particularly the data flow diagramming technique, to system 1 (transport planning) and system 2 (environmental analysis) in turn. In doing so, the paper will cover the questions of: (a) Are there opportunities for maintaining digital databases which both systems can access? (b) Are there common data elements or processes that might be a suitable starting point for integration ? and (c) How can structured systems analysis provide useful insight to complex engineering and scientific situation, given its methods were designed for business applications?

3 Data flows in the transport planning system

For the last thirty years, transport planning has relied heavily on computers and models which manipulate massive databases. Nevertheless, there remain important aspects of the overall planning process that have nothing to do with computers, such as selecting alternative future urban scenarios for testing. Structured analysis techniques were developed to improve the design of business related database, e.g. efficiently storing information about customers, orders, stock, employees, and so on. While systems analysis emphasise the need to design such systems without dwelling on issues of technical implementation (such as database software), business systems are now invariably implemented with computer software. Fortunately, it is original emphasis within structured analysis of viewing the system independently of the technology that permits the techniques to bridge the gap between the "higher" level, people-based elements of transport planning (e. g. goal setting exercises), and the detailed processing of travel demand models.

The following section does just this; it begins by examining the data flows through the transport planning system, and then "zooms-in " for two successive levels to uncover some details of transport planning(in particular travel demand modelling) that are relevant to integration with environmental analysis. The data flow diagramming technique uses a set of terms to differentiate these successive levels of the system. Zooming-in is called "decomposition". The highest level is called a " Top level" DFD; the next level is a "level Φ DFD; and all successively lower levels are referred to by a derivative of the level Φ process they decompose (e. g. a level 3. 3 diagram expands on the process labelled " 3. 3" in the level Φ DFD).

Recognizing that transport planning processes do vary between jurisdictions, the purpose of this analysis is to examine the process in a generic sense. Fig. 2 is a top level DFD derived from Bruton(Bruton, 1985). It combines elements of his unstructured diagram into the six processes included in the DFD. Transport planning processes of various types share certain key elements, such as determining baseline traffic conditions or travel demand modelling. This paper will show that it is in some of these key elements that one can expect to find much of the data necessary for environmental analysis.

As their name suggests, data flow diagrams emphasis the movement of data through a system. Processes represent the various individual functions that the systems carries out (Yourdon, 1989). Processes transform inputs into outputs. Data flows connect the individual processes and are labelled with either the input data required by a process, or the information a process generates as output (Fig. 2). Data stores show stored information-they will normally become computer databases, or tables in a database. Terminators show the external entities with which the system communicates (Yourdon, 1989).

In Fig. 2, the "transport planning authority" is a terminator, i. e, it is assumed to be outside the scope of systems analysis. Normally, such an authority would be a public sector agency responsible for road network planning. It should be noted that all data flows are labelled. For example, the data flow from the authority is labelled as a "brief". The brief essentially commissions a study to take place. It is likely to include a budget, time frame for study completion, designations of key persons responsible for the study and so on.

Process 1 in Fig. 2 (organize and scope the planning process) includes a goal setting exercise which normally draws upon government policies. For example, it may strive to translate policy objectives in the areas of employment, economic development and environmental protection into objectives specific to transport planning. The more specific objectives become the bacteria against which alternatives are evaluated(Bruton, 1985). Other organizational

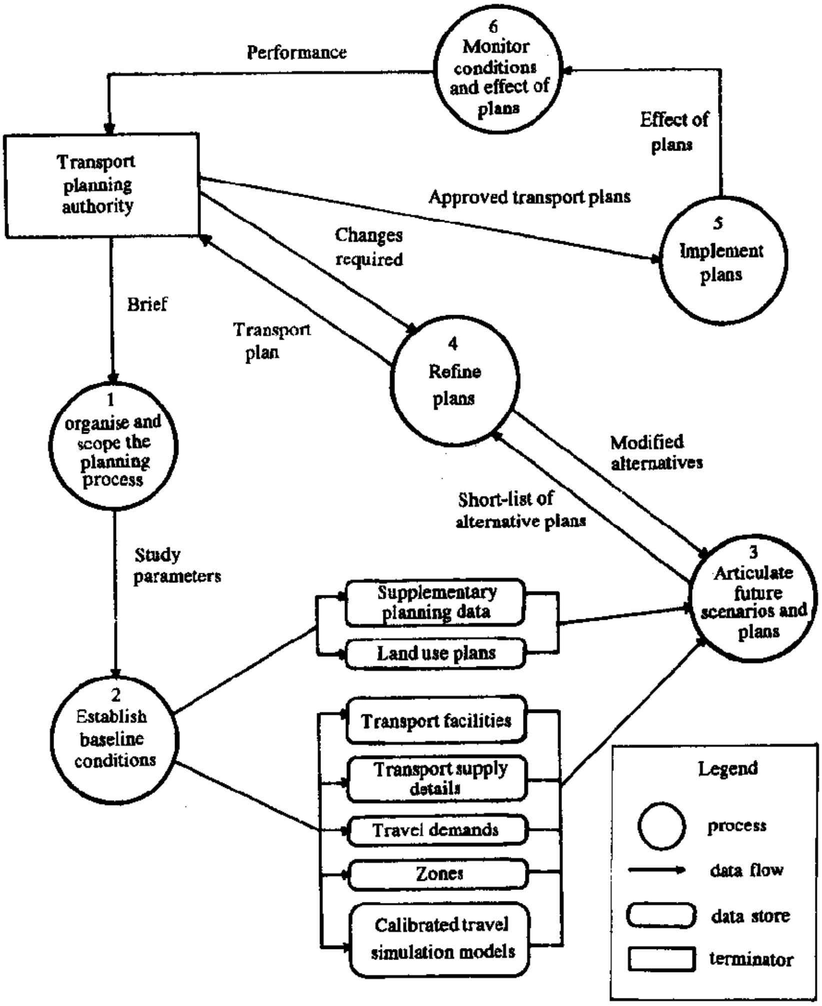

Fig. 2 The transport planning process(a top level DFD)

tasks include deciding the study area, setting the planning time horizons and designing the consultation program. Bruton (1985) includes five lower level processes within process 2, namely: divide area into zones; collect baseline data; check its accuracy; calibrate the travels demand model and develop an immediate action plan. Process 3 receives closer attention below through its decomposition into two successively lower levels (Fig. 3 and 4). The output from process 3 is a short-list of alternative plans. The activities described by the remaining processes(4—6) are relatively self-evident.

Fig. 3 is a decomposition of process 3 from Fig. 2. The central process is " apply models" (which itself will be decomposed to the next level in Fig. 4). Process 3. 1 involves forecasting future land-use demand and travel patters. A range of complex mathematical models and, in some cases, ad hoc estimates based on land use plans and " discussions with advisory committees" are employed (Beimborn, 1979; Bruton, 1985). Thus, the data flow from process 3. 1 comprises land use scenarios, plus estimates of future patterns of movement.

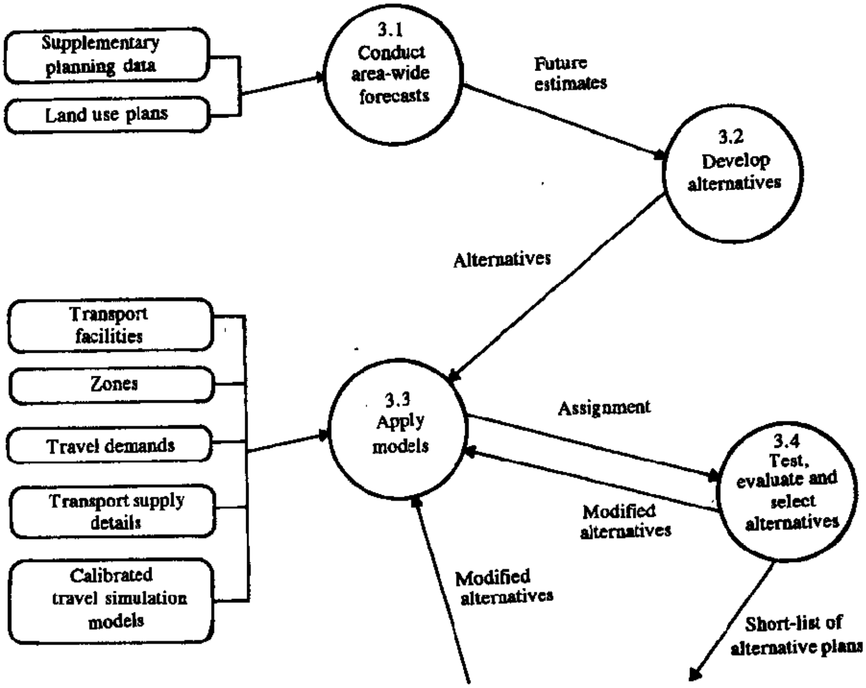

Fig. 3 Articulation of future scenarios and plans (DFD level Φ)

As indicated by the loop between processes 3. 3 and 3. 4, the development of alternatives is an interactive process. Process 3. 2 produces the first iteration of broad approaches to planning transport and land use. Alternative networks generally take the form of complete systems serving the whole of the area under examination(Bruton, 1985). Planners develop an array of alternatives which may range from maximising public transport and urban density, to coping with low density settlement with motorways.

Fig. 4 shows the next level of decomposition of process 3. 3. In doing so it provides a detailed and self-explanatory account of the classic TDM process used by transport planners. Note the specific input requirements of data from data stores described at the top level and level Φ DFDs.

4 Data flows in environmental analysis

One can apply exactly the same structure techniques to provide a data flow analysis of a conventional environmental analysis. Fig. 5 presents a DFD of a generic environmental analysis process and the following discussion of environmental analysis systems emphasizes the data stores emanating from such an analysis. Techniques for environmental analysis vary considerably between jurisdictions and while the individual steps or processes are relevant to all environmental analyses, they are applied to this example for a generic environmental im-

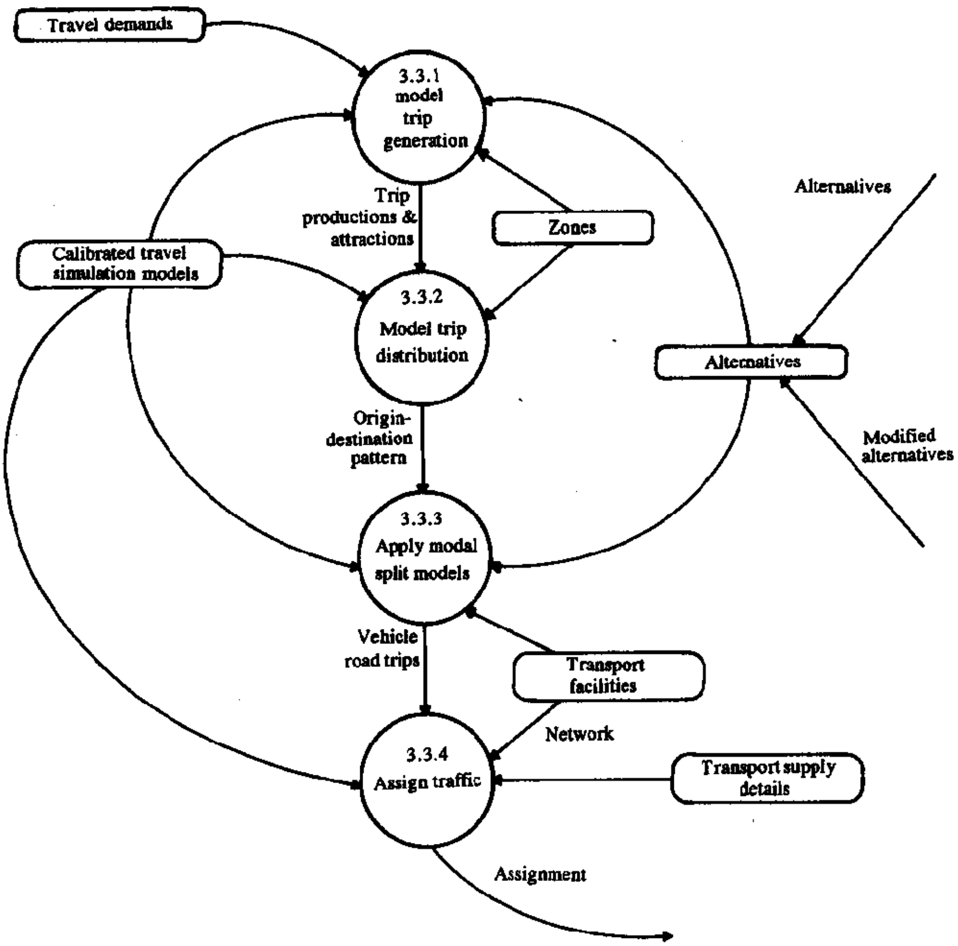

Fig. 4 Application of travel simulation models (DFD level 3. 3)

pact assessment (EIA). EIA processes are probably the most common, and consistent, across different jurisdictions. The input to the environmental analysis process assumed in this example is a proposed transport plan(i. e. , the output from the transport planning process)-probably in the form of a report.

It is useful to imagine conventional reports as data stores. Paper reports do subsume a great deal of data which may be far more accessible for future use it were kept in a digital format. Typed into tables, maps or graphs in a conventional manner, the data can become effectively unusable, since the effort required to re-enter it into a GIS or spreadsheet (for example) may exceed its value. Perhaps an appropriate analogy is to describe the " entropy" of the data. When the data is placed in paper reports without accompanying disks(or the like), the entropy of the data is significantly increased, rendering it much less accessible.

Most environmental analyses undergo some form of scoping process(process 1), possibly resulting in a preliminary environmental report to define the parameters of the study and establish a basis for initial consultation. Fig. 5 shows data inputs which would come from

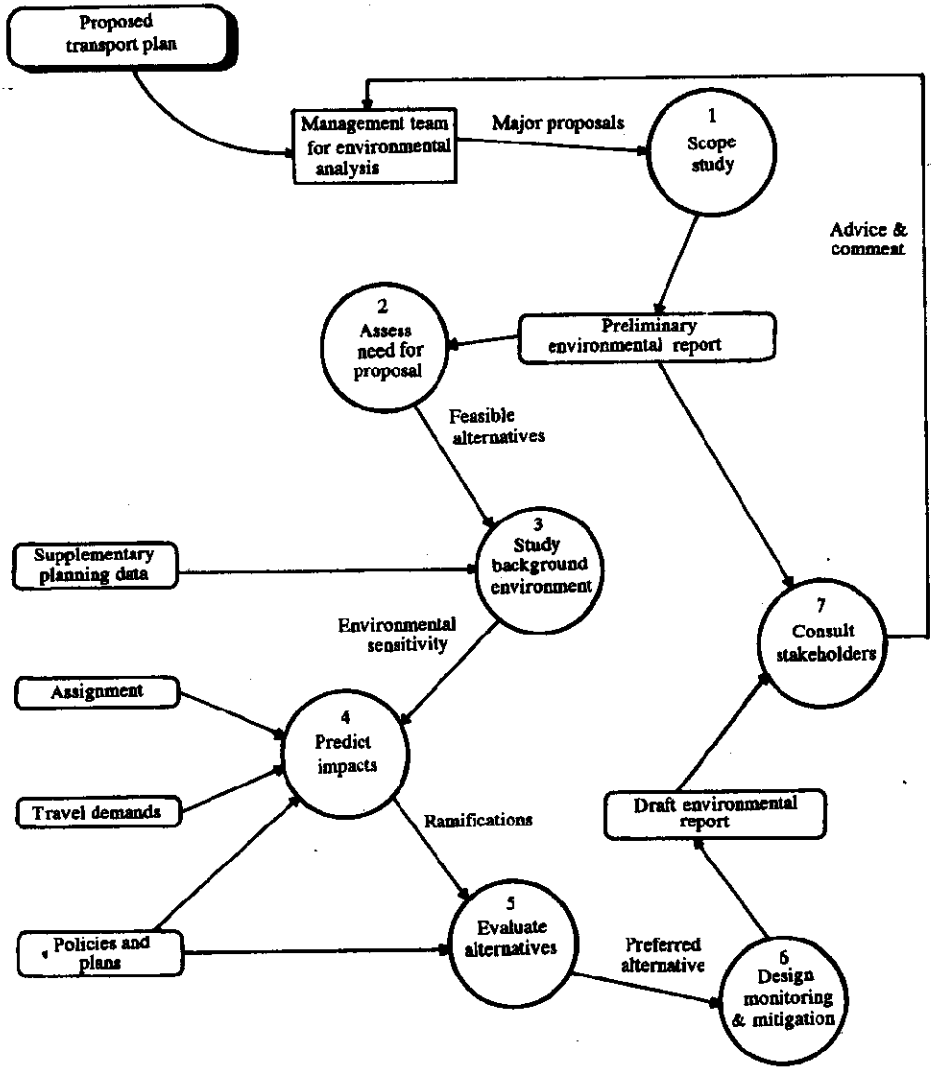

Fig. 5 An environmental analysis process (a top level DFD)

various stages in the transport planning process. The draft environmental report is a document to be distributed for a final round of consultation. In contemporary practice, this is invariably a weighty written report that can intimidate lay readers and coast a great deal to the reproduce.

The advent of the internet may contribute to greater emphasis being placed on digitally formatted EIA "reports", since it can allow for expanded, less-costly consultation, or on-line multi-media consultation exercises (Schiffer, 1995).

5 Towards integrating the transport planning and environmental analysis systems

The foregoing sections have hinted at possible integration between the transport planning and environmental analysis systems. It is already technically possible to manage the bulk of the data involved in transport planning (including travel forecasting) within a GIS. However, it is unlikely that transport planners will immediately abandon established travel demand models for the sake of developing new GIS applications to undertake the same functions. Initially, GIS is tending to be used more for presentation than modelling, i. e. , displaying modelling results as thematic map layers over geographically accurate representations of transport infrastructure (which means at least the software will become increasingly familiar and available to transport planners). For this reason, an incremental shift towards integrating transport planning and environmental analysis within the GIS is suggested in favor of wholesale abandonment of current systems.

Fig. 6 demonstrates this incremental approach. The diagram bends the data flow diagram rules to give an impression of the processes described in the first diagram (Fig. 1) as system 1 and system 2, merging into a single process.

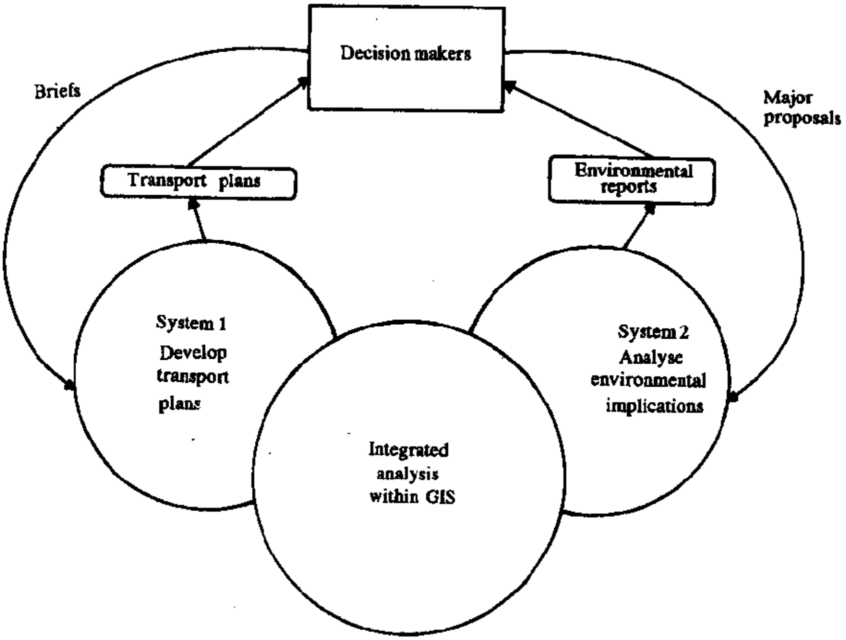

Fig. 6 Merging the transport planning and environmental analysis systems within a GIS

What might lie beneath the large circle in Fig. 6 labelled "integrated analysis within GIS" is hinted at by Fig. 7. The Venn diagram shown in Fig. 7 renders an instant picture of some common data elements produced by or required for the modelling of travel demand, traffic noise and air pollution. In reality, the data required or produced for these types of analyses does depend on the specific types of models employed. The critical aim must be to tailor the environmental models (such as noise and air pollution) to minimise the data required over and above the TDM process without sacrificing their usefulness for planning purposes.

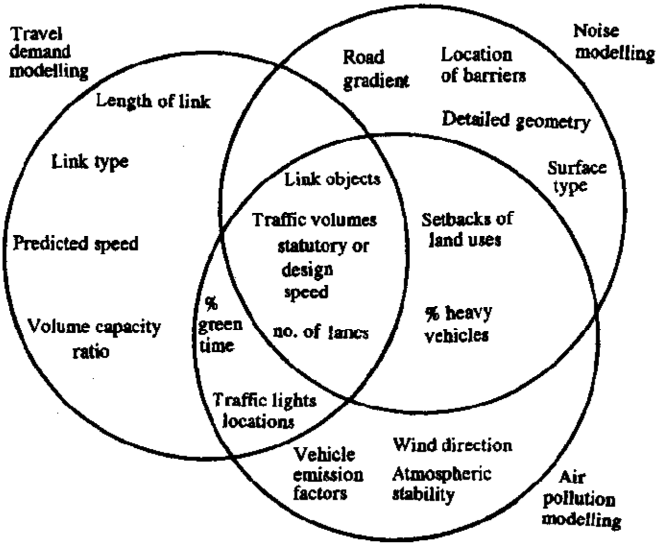

Fig. 7 Venn diagram showing common data between modelling for travel demand, noise and air pollution

Although the Venn diagram is very good at conveying an instant picture of the potential for integration, it is too simplistic to act as a model to design a more integrated system. For example, there are more environmental effects associated with transport plans than just noise and air pollution. The addition of further dimensions to the Venn diagram would most likely confuse the picture. Systems analysis provides a suite of tools for making the transition between analysis and design. Most useful to the development of a GIS application is the entity-relationship (E-R) diagramming technique (Yourdon, 1989).

Fig. 8 is a diagram of the entities and relationships involved in modelling the impacts of the road network on urban communities. This E-R diagram is somewhat different from the most common examples. Rumble and Smith(Rumble, 1990) observe:

In a business database, the E-R diagram is used to provide a data model of an organization or part of an organization. In science and engineering it is used to provide a model for part of the physical world covered by the database.

While data flow diagrams give a good representation of a system's function, they give little detail on the content of data stores or their relationship to other data store. The E-R diagram describes the stored data layout of a system at high level of abstraction (Yourdon, 1989). Entities represent collections of tangible objects whose individual members (or " instances") can be identified uniquely, play an essential role in the system, and can be described by one or more attributes (Yourdon, 1989).

At first glance, Fig. 8 may appear to belabor the obvious (Yourdon, 1989). However, it provides excellent guidance in structuring the relational database used within a GIS and developing models that rely on this data structure. For example, the entity " nodes" may be-

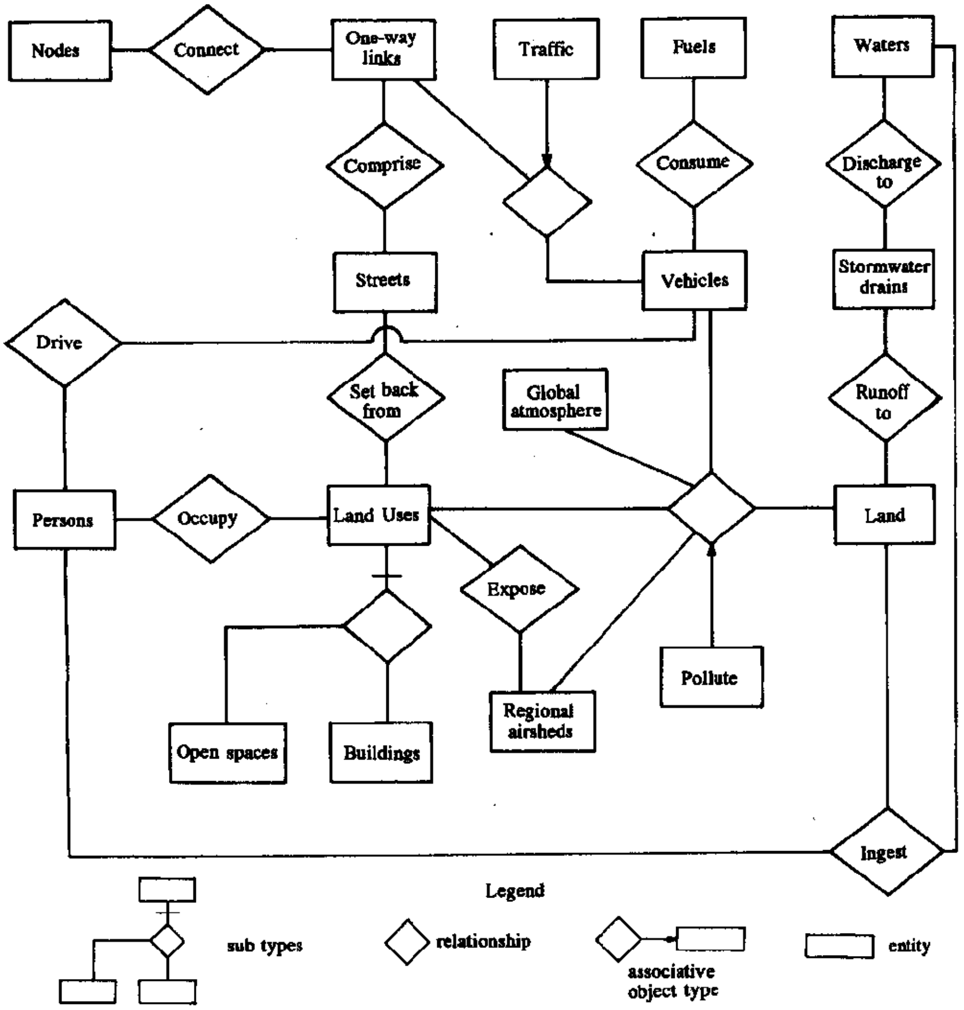

Fig. 8 Entity-relationship diagram of road-community interaction

come a database table. Each instance of a node would have the attributes: node number; x co-ordinate; and y co-ordinate. The one-way links "connect" nodes in what database designers refer to as a one-to-many relationship. The same concepts apply throughout the diagram, e. g. one instance of a building would include the attributes of type (dwelling or school for example); setback; and adjacent link.

The diagram includes two special notations. "Traffic" and "pollute" (as nouns or verbs) are associative object types. This means they act both as objects and relationship. Another way to think of this is that data will be maintained about traffic and pollution (Yourdon, 1989). This makes sense as a principal objective of this research is to maintain and analyse data about pollution, but it is hard to imagine pollution as simply an object or a relationship. The other special notation shows that "buildings" and "open spaces" are subtypes of " land uses". The development of SMIRC will break Fig. 8 into stages, taking the exposure of buildings (especially dwellings) to pollution as the first priority.

6 GIS as the cornerstone of integration

6.1 The potential of a GIS application to achieve integration

There is some danger in seizing on GIS as a panacea (it is after all a chisel, not a sculpture). However, in cases where the data needed for analysis and its associated geographical features are readily available in a digitised format; where analysis techniques require computer processing; where the spatial dimensions of data as critical to the analysis; and where presentation of results may benefit from on-screen interactive features or flexible output; then GIS technology may well have much to offer. All of these circumstances apply to the case of integrating transport and environmental modelling.

The core components of GIS software include: graphics processing functions, basic cartographic and geographic analysis utilities, and a database management system. Conceptually resting on top of the core GIS software are special application packages that are integrated with the GIS to carry out specific operations (Antenucci, 1991). GIS software permits the display of information contained in a database as maps, that are easier for people to relate to and comprehend. It also allows interaction with the database from the map display, i. e., "geographic queries" such as defining the boundaries of a study area by drawing a shape on the computer screen. What is the potential, then, for the development of GIS application software to begin and to overcome the aforementioned "significant weaknesses" in contemporary approaches to environmental analysis of transport plans?

The sequence and inertia weakness may be mitigated if environmental analysis can be conveniently brought forward temporally in the planning process. GIS is a medium where planners can conduct transport and environmental analyses simultaneously and integrally, given sufficient input data. If the effort required to obtain the necessary data is not onerous and the software exists to conduct environmental analyses, then there is some chance transport planners would invest the effort in simultaneous environmental analysis. An integrated analysis should be able to report on the environmental implications of a possible network configuration at the same time as its technical performance. Such an analysis would temper the initial dominance of technical considerations with an ability to consider environmental ramifications. Not only would it be possible to rule out environmentally deficient options early on, but eventually it should be possible to optimise the network plan to minimise environmental effects. An integrated analysis would allow environmental factors to influence the make-up of the package of broad alternatives presented in the transport plan.

Integrated, GIS-based analysis may allow environmental evaluation of small projects or "what if" testing of small sections of the network where full scale environmental assessment would be impractical. If the integrated technique becomes one of routine, then planners will always present environmental information alongside transport predictions. Data is normally maintained following a large scale transport planning exercise; subsets of this data could be conveniently re-examined at a later date. Similarly , the GIS can ease policy testing. If planners can determine the transport effects of a policy on the network, then the environmental implications are automatically known. Consider the case of traffic calming initiatives (Grava, 1993). An integrated GIS system should be able to predict the implications of traffic displaced by traffic calming devices on nearby neighborhoods.

It is conceivable that conflict associated with transport planning can be reduced if citizens can see that their concerns with the ramifications of the network for their immediate environment are part of the analysis. The interactive features of GIS can also allow them to become involved in the planning and decision making process. It follows that planners' resistance to environmental analysis would be reduced if efficient GIS-based planning can cut costs and time delays and take the heat out of some conflict situations.

It is the capacity of GIS software to prepare thematic maps and graphs quickly and interactively that offers the potential to improve clarify. Once the database and modelling are complete, the GIS can produce and costomise sophisticated outputs such as thematic map layers with little effort. Well-designed application software should translate the results of environmental modelling into meaningful displays that can be readily comprehended.

6.2 Effective database and application design

While there is general enthusiasm about the potential for GISs to contribute to better planning, one can easily misapply the technology, yielding misleading results or inefficient analysis. The most frequently cited trap with GISs is their tendency to obscure the source of data, hindering critical assessment of data quality. Another trap is when users pay insufficient attention to the design of the underlying database.

Typically, the database management systems included with the GIS ("proprietary" database) are based on the relationship model. It is only recently that databases and GISs have been accessible to end-users, including planners, environmental scientists and managers. A combination of the revolution in microprocessor capabilities and better "user-friendliness" of software means that professionals can now construct their own sophisticated databases with commercial software and their personal computers. Previously, databases were designed by specialists and several bodies of literature developed in the areas of systems analysis and design, database design, normalization theory, and so on (Hawryszkiewycz, 1991). While sound database design principles are increasingly intrinsic to commercial database management systems, it is still possible for non-specialists to create inefficient databases or databases that do not take full advantage of relational design.

An inefficient database structure may not be a significant problem of itself, but application software must rest upon its structure and frequently interrogate the database to conduct modelling. Structured analysis assists in designing an effective application, especially relating to those components of the software where the user is required to organize the database in a particular way. The user interface to the application must establish from the user where it can find the requisite data for modelling. Ineffective database design may force the application software to account for too wide a range of possible data locations, or result in frequent run-time due to circumstances that were unpredictable during programming.

7 Conclusion

The dominant approach to transport planning, which generally relegates environmental analysis to a late stage in the planning process, gives rise to problems and inefficiencies. The focus of this research is to test how these weaknesses might be overcome by integrating the transport planning and environmental analysis "systems". GIS technology is well suited as a medium to integrate the two systems due to the relevance of computer modelling and spatial analysis to each. While integration is attractive theoretically, it is more realistic to anticipate an incremental shift towards integrated modelling and analysis within GISs.

This paper has described how structured analysis (in particular structured diagramming) has guided thinking about the design of an integrated transport planning-environmental analysis system. The use of structured diagrams dramatically reduces ambiguity. Data flow diagrams facilitate scrutiny of a system's essential processes, and can assist in identifying similarities in data or processes between systems. Systems analysis has revealed opportunities to transfer digital information to environmental, analysis from several points in the transport planning process. The application of data flow diagramming techniques to these systems highlights how a paper report (The usual end product of transport planning or environmental analysis) is just as much as a data store as is a computer database. However, the " entropy" of the stored in reports is higher.

The paper has argued that the willingness of transport planners to engage in integrated analysis will depend in part on the availability of suitable software and the effort required for the acquisition of addition data. If an integrated system succeeds in bringing forward environmental analysis in transport planning, environmental considerations will have a better chance of influencing the resultant plans. In addition, the flexibility of GIS-based analysis should help improve the attractiveness and usefulness of environmental analysis to transport planners.

Systems analysis also serves to emphasis the importance of database design. It will be necessary to pay closer attention to this issue as user-designed databases permeate professional workplaces. To this end, entity-relationship diagramming can be a very helpful guide to structuring a GIS or other database. Finally, it is suggested that systems analysis has aided the Griffith University research-guiding the design of a GIS application and the structure of the underlying database.

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