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THE RELATIONSHIP BETWEEN GEOGRAPHIC INFORMATION SYSTEMS AND DISAGGREGATE BEHAVIORAL TRAVEL MODELING

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This paper introduces the theme of the special issue and lays a foundation for arguments concerning the potential usefulness of Object-Oriented Geographic Information Systems (OOGIS) for the development and testing of disaggregate behavioral travel models It also states goals for Intelligent Transportation Systems (ITS) research and discusses the role of behavioral travel models in pursuing ITS goals and objectives

Keywords Object-oriented GIS, disaggregate models, travel behavior models, advanced traveler information systems (ATIS), spatial databases

1. INTRODUCTION

Transportation science is host to a variety of theories concerning (among others) network structure, routing algorithms, traveler activity patterns, mode choice, demand forecasting, vehicle or traffic assignment, trip allocation, and actual or simulated traveler behavior It has an express goal of increasing accessibility for all groups of people with regard to the environments in which they live and interact. A significant component of these goals is to further develop Intelligent Transportation Systems (ITS) through multi-level and multi-modal research and testing This includes contributing to research in transportation systems architecture, technology development, policy formation, and operational tests of various systems

Intelligent Transportation Systems (ITS) utilize advanced communication and transportation technologies to achieve traffic efficiency and safety There are different components of ITS, including Advanced Traveler Information Systems (ATIS), Automated Highway Systems (AHS), Advanced Traffic Management Systems (ATMS), Advanced Vehicle Control Systems (AVCS), and Advanced Public Transportation Systems (APTS) The development of a system for implementing ITS depends on an ability to deal with a vast amount of information about the locations of places and their attributes as well as dealing with the complex representation of the transportation network linking those places Today, this link is being achieved with increasing frequency using geocoded databases Such systems can be constructed based upon the foundation of an integrated and comprehensive Geographic Information System (GIS) To make an effective GIS both static and dynamic information processing is needed

2. BASIC COMPONENTS OF A LINKED SYSTEM

To develop a system such as that proposed above, the first essential component is a representation of the real world environment with all the street networks and information about locations of related objects Vehicle routing and navigation has to be based on this network representation

A second component consists of the dynamic traffic information updating available in real-time (i e , short discrete time intervals) so that accurate traffic forecasting can be undertaken Recent advances in computer technologies can now provide such fast location and temporal updating Global Positioning Systems (GPS) can accurately fix and trace the location of a vehicle even when moving Accuracies of around a hundred meters can be obtained using Selective Availability (i e , a GPS signal randomly perturbed by the Department of Defense), but with a system of partially overlapping base stations that provide differential correction factors (DGPS), vehicle accuracy can readily be obtained to less than ten meters For tracking vehicles in specific lanes, accuracies of less than three meters are required and this is still proving somewhat difficult for continuous real-time measurement purposes To complement these locational updating technologies, today's traffic counters can record numbers of vehicles and transmit directly to a central collecting station. On many freeways now, high occupancy vehicle (HOV) travel lanes and prepaid or specially billed fast-moving lanes are available for some traffic When added together, the very real question arises as to how this vast temporal stream of data can be handled efficiently.

For today's ITS, a variety of data types is needed, including

- Traveler characteristics (e g , socio-economic characteristics, individually stated attitudes and perceptions towards travel decisions and traffic information, flexibility in departure time, trip purpose, number of stops on route, stated or revealed preferences for routes, and preferred route selection criteria),
- Data on information system characteristics (e g , ATIS availability, type of information provided, access cost and cost per usage, reliability),
- Trip and transportation systems characteristics (usual trip times and overall network performance, trip-specific data such as travel times on each link and accident frequency)

Given the complexity of the data needs it is expected that the necessary data should be collected by means of a combination of sources such as surveys, demonstration projects, and travel simulators

Over the last decade there has been an increase in the functionality of Geographic Information Systems, and a contemporary user has greater control over the computer environment than ever before Unfortunately, the increased sophistication of GIS has not always been accompanied by an improvement in usability, because GIS make considerable demands on users (Medyckyj-Scott and Hernshaw, 1993) GIS can be complex to understand, the number of functions may be daunting, and interaction may be formulated in a non-intuitive way Where GIS are user-unfriendly this has the effect that users have to spend time and effort learning how to work a specific system before they are able to produce any effective output The consequence of this is that GIS are often only used for a small number of well-known tasks and consequently the potential benefits of the technology are not fully exploited (Medyckyj-Scott and Blades, 1990)

All current GIS have one model of the user More effective interaction between system and user can occur if a user model exists within the GIS for each use of that system In this way the GIS could take account of individual difference between users A user model would allow the GIS to decide how to ask for input from the user, to interpret the user's input, to provide the most suitable help and advice for the user, and to give appropriate output

Where improvements have been made in the level of usability, this has opened the way for misuse of GIS Lack of an appreciation of the complexities involved in working with spatial data, in conjunction with the increase in ease of use, has led to users collecting the wrong data for problems, using data (locational and attribute) at the wrong scale and/or resolution, and performing invalid analytical operations, with the result that erroneous conclusions are drawn It has been argued that avoidance of such errors and misunderstandings require the education of the user in GIS concepts, data structures, and operation algorithms, and that GIS should only be used by spatially aware experts Used in this way, however, GIS would become the domain of the well-trained and professional user, and would limit the potential of the system because access to the technology would be restricted

At the same time, consideration must be given to how the users can be educated so as to raise their level of understanding of the nature of spatial data, and the analytical concepts that are specifically oriented towards handling spatial data This would involve the design of user interfaces which make the consequence of data usage and operations on that data visible to the user in ways that they can understand (Medyckyj-Scott and Blades, 1992) This may be through the use of analogies to situations in everyday life with which the users are familiar and through scientific visualization techniques (Buttenfield and Ganter, 1990)

3. GIS AND ACTIVITY SCHEDULING

An analysis of data provided by Kitamura, Nilles, Conroy and Fleming (1991) on a state telecommuting study based in Sacramento, California, indicated that telecommuting reduces a household's propensity to use specified network segments by as much as 50% on telecommuting days Total trips undertaken in the city by telecommuters were also reduced, and the total patterns of movement in the system both reduced and altered In addition the total time spent traveling by telecommuters changed for both persons in a two member household For example, the telecommuter travel time dropped from 337 to 308 minutes over the three sample days, while the non-telecommuting household member increased from 153 to 206 minutes over the same time period It is possible to examine the individual movement patterns and trip purposes in relation to the urban environment by relating these flows to an underlying land use and population attribute surface This can be done using a number of different GIS systems (e g , *ARC/Info*, *Map Info*). In using GIS functionalities to help examine the changing behavior pattern of telecommuters such as those in the Sacramento study, first a limited number of business places and home locations throughout the city must be defined, together with the duration of business hours of each activity and its location Location is defined by x–y or other types of coordinates They can then be projected into a geo-referenced system using the built-in projection function of a standard GIS

Each activity defined for a household can be described as a set of productions. But these productions need to be implemented in a network context reflecting the idiosyncrasies of a real environment A GIS can facilitate the construction of such an environment for activity scheduling by providing an approximation of the street network on which the individuals travel either through local digitizing or by importing existing digital networks The ability to modify (either add or delete) arcs to the network enables the input of finite network elements essential for the disaggregate modeling If the location of the activity is given an address form, that location can be placed in the network using the address matching capability available in most standard GIS

Location of activities represented as points, street networks specified as a list of nodes and a list of arcs between pairs of nodes, and census tracts represented as polygons are the geographical components of the GIS. Non-spatial data such as the business hours of an activity, availability of transportation nodes on a network segment, speed over specific distances by a mode of travel, purpose of the trip, and so on, can be stored as attributes and linked to the environment through a relational join in a GIS For example, it should be possible to select a trip purpose and identify the set of locations at which that purpose can be satisfied A set of numerical and statistical operations can be performed on these points, arcs and polygons, and their attributes (for example, distance between pairs of locations) can be calculated either using a Euclidean distance or network distance measure

Using buffer operations we can define the feasible opportunity set within a user-defined interval (e g., distance or time from a point, an arc or a polygon). For example, a circle defined by a certain radius (representing time, distance, or cost of travel) can be generated around the home Relevant locations at which a specific activity could be undertaken within that circle could be selected as possible destinations for a given trip purpose Or a road could be buffered (i e , reconstructed as a corridor or sector of a defined width) to represent a region which is accessible from the road within a certain time or distance Again sets of feasible activity locations within that corridor can be defined

The brief example given above shows that GIS are able to display the individual aggregate data of the environment in tables, graphs, or via a map A combination of the various presentation media is also feasible For example, color or bar charts can be used to show the individual's schedule of activities and the respective locations of those activities In terms of aggregate levels, the traffic flow of each link, the flow to each region via trip purpose, and so on can all be shown by using a map with different network elements

As a result of changes in episodic movement, one can develop projections of traffic density and volumes on particular road segments in both the main traffic corridors and in local areas This information should also prove useful for local government decision makers and land use planners and may be required to estimate changing needs for different types of urban functions in local communities as a result of changing behavior patterns

4. SYSTEM TASKS

In order to overlay an activity scheduler on a GIS of a particular environment, the first task is to create point coverage for all possible origins and destinations This involves geocoding the specific land use systems as well as ensuring that they are compatible with the geocoding system used in say, the TIGER files for the underlying network structure—or whatever basic network system is being used Once this point coverage is obtained, it is possible to analyze destination choice by a single household on either single-purpose or multiple-purpose trips. or single-stop or multiple-stop trips Comparisons can be made with a simple gravity-type model (or discrete choice model) in terms of the ability to reproduce such trip patterns If individual households are aggregated into traffic zones, it may be feasible to use a standard gravity or entropy model (Wilson, 1970) as a base against which to compare the success of the GIS-generated activity patterns.

To date GIS T have limited capabilities to support the kind of network analysis and flow density analysis required in much transportation planning One significant problem for further research consists of being able to handle the pseudo-nodes for the development of spatial information in three-dimensional space A second major problem involves developing an ability to handle matrix information and to perform linear algebraic operations on large matrices with origin destination or mode-purpose combinations There is a need to integrate GIS with other forms of transportation modeling activities, such as discrete choice modeling or highly disaggregate activity based modeling in order to handle these things This involves more flexible data models and the development of an ability to convert data structures among different forms.

Given this broader set of needs, a GIS database with a wide variety of information and network elements becomes highly desirable The question of how much network analysis capability is fundamental immediately arises It also raises the question of what additional needs can be supplied by other programs or algorithms and how easy these will be to interface with the fundamental GIS

Yet another task in using GIS in a transportation context is to explore ways to link existing network-based software (e g , NETWORK-TRANSCAD, TRANPLAN, TMODEL and T-2MODEL) to help solve traffic assignment problems These software packages contain a variety of path selection algorithms ranging from linear programming and traveling salesman methods to various solutions to algorithms that optimize connectivity or minimize some travel characteristics (e.g , Dijkstra-based shortest path routines) Once such linkages have been developed, it will be possible to collect actual path data from diary or other longitudinal sources, and compare movement patterns from those diaries with paths or routes selected between specific origin and destination pairs within a GIS using a selection of criteria such as shortest paths Actual selection of routes could then be predicted depending on traveler preference for scheduling activities or constraints imposed on movement by the need to perform necessary or obligatory household functions

There is a need to integrate perception of the environment into GIS structures Presently the perceived time required to travel can be represented in a cost table in most GIS The higher the cost associated with an arc, the more friction there is for route designation that includes that arc

Apart from transforming physical into cognitive reality for each household, other components that are part and parcel of travel behavior modeling and planning include activity preferences and priorities, criteria for selecting feasible alternatives for destination choice, and weighting of activities by length of cycle, needed to be addressed This latter feature is important to ensure that necessary activities (e g , biweekly shopping) are carried out in a timely manner, by increasing the priority for the activity as the temporal window of opportunity contracts

Little has been done to incorporate the temporal aspects into GIS (but see Golledge and Egenhofer, 1998) How to extend the temporal aspects and make the retrieval, analysis and display of temporal data effective still remains an area of future research One objective of such future work could be to develop and implement an object-oriented GIS data model for transportation planning that can handle a multi-dimensional network, multi-level spatial modeling and multi-mode analysis in transportation planning Also, the model would need to handle fast-changing values in location and temporal updates for dynamic data, if a successful ITS implementation was being planned

5. CONCLUSION

The successful development of Intelligent Transportation Systems depends on the capability of incorporating a vast amount of information about the location of facilities which generate travel as well as a realistic representation of elements of a transportation network in which travel takes place Such a system can be based on an innovative and comprehensive Geographic Information System Whereas current

ITS primarily use simplified transportation networks as their basis, using an object-oriented data model, for example, would allow the provision of a more realistic representation of elements of the network and the ways that people perceive them This would assume that people conceive the environment as consisting of sets of objects A network could then be represented by defining roads or street hierarchies and by storing environmental data as layers which can be aggregated, or decomposed at will Storing the transportation network as a hierarchy facilitates the calculation of different paths through the network and allows the introduction of different path selection criteria A long-run aim of ITS is to develop a real-time multi-strategy travel decision support system over a multi-modal network It seems obvious that GIS have significant capability to facilitate this development

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