Development of traffic analysis system using GIS

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This paper reports on our development of a GIS-based traffic network analysis system, named GIS-based Transport Decision Support System, which provides a graphical analysis platform to transportation planners and researchers for transportation network analysis. The system has the functions of designing traffic networks on digital maps and doing traffic equilibrium analysis, as well as a novel function to integrate local detailed structures of intersections into global networks. The latter is particularly useful for the analysis of large traffic network where the detailed local network structures of some intersections have to be taken into account. The system links great volumes of traffic data and geography information data accumulated for visualization traffic analysis. We added information data on the following: road structure data, zone geography information data and node geography information data. The system also enabled us to extract traffic data by road section and by specific condition.

GIS system; Traffic analysis;Ttraffic network

I. Introduction

A fundamental problem in transportation network planning and traffic engineering is the evaluation of the impacts of a design plan or some management policy on the distribution of traffic flow on the network, which is solved by the equilibrium network analysis method (4, 6). The essence of equilibrium network analysis is the consideration of the influence of traffic volumes on travel times, and consequently on route choices of travelers, which then reversely change traffic volumes (See Section II). There have been developed several software packages in which the equilibrium network analysis algorithms are implemented (10, 11).

Conventionally, for the purpose of transport network planning, detailed structures of intersections are usually omitted in equilibrium analysis. On the other hand, the geometric design and signal setting for intersections are conducted assuming that the crossing traffic flows are given. For a network with uniformly located intersections, a simple treatment of intersections by assuming "average" constant delays yields sufficiently good accuracy. However, this method may result in very poor forecast accuracy, for networks with heterogeneous structures where some intersections attract particularly large traffic volumes. A natural remedy for this is to include the accurate delay functions for intersection into the whole network (5). However, the inclusion of the detailed structures of all intersections into the network requires huge work on data preparation and computing time, and has not been adopted in practical large network application. A realistic method is to integrate a relatively small set of important intersections into the global network covering the study area, e.g., a city.

For this purpose, we have developed a GIS-based Transport Decision Support System (GIS-TDSS) (1), which not only have the basic functions of designing traffic networks on digital maps and traffic equilibrium analysis, but also can easily integrate local detailed structures of intersections into global networks.

In the following section, the composition of we developed GIS-TDSS system is described. And our method for integrating local and global networks database model is described. In Section III, a brief review of traffic network equilibrium analysis theory is provided. In Section IV, a numerical example that applies our system for equilibrium traffic flow analysis of an urban road network with one detailed intersections is provided.

II. Development of traffic analysis system

A. System Design

In order to provide a systematic and comprehensive platform for transportation network analysis to transportation planners and researchers, we have developed a GIS-based system, named GIS-based Transport Decision Support System, which has the functions of designing traffic networks on digital maps and doing traffic equilibrium analysis, as well as a novel function to integrate local detailed structures of intersections into global networks.

Based on a combination of MFC and XML schema, we were able to develop a first version of a real city Mapping applied for practical traffic analysis applications. It offers an extra-compact, efficient and inexpensive solution and flexible geospatial database access, this is no GIS software required on server while GIS Services capacity such as visualization, spatial querying and human computer conversation were retained.

B. *Achitecture and Functions*

In our development of GIS-TDSS for traffic road network mapping applications, objectives on geographic processing providing operations for processing or transforming data in a manner determined by user specified data. Through the system, we are able to integrate with other new traffic analysis model, this including road information, data management, and traffic model execution and management. Figure 1 shows the structure of our development of GIS-TDSS system.

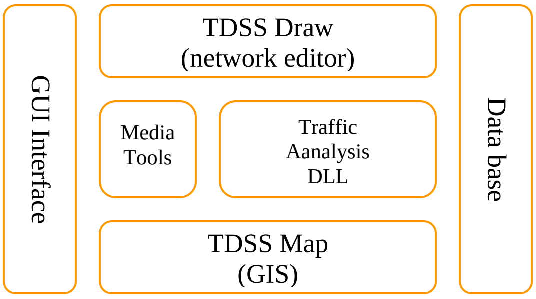

Figure 1. Structure of GIS-TDSS system

Similar to other GIS software, geographic information in our development is organized into 6 groups as follows:

GUI system, database system, TDSS Map, TDSS Draw, media information tool and traffic network analysis algorithm DLL (Dynamic link library) files. GUI is the basic function group in a graphic interface built using Microsoft GDI (Graphics Device Interface). TDSS Map is the core module for processing digital map.

TDSS Draw is the module for network drawing and editing. The media tools module provides tools for storing various kind of regional multimedia information, e.g., traffic video at important intersections. The traffic network analysis algorithm DLL is the dynamic link library of network analysis programs which are created based on the theory reviewed in Section III.

GIS-TDSS uses conventional layer models for storing and editing information. The topological relation between a global network and a local network is described in the data table for the local network data, detailed structure of this is described in the following section.

C. *Data Structure*

The characteristics of the geospatial data set are changing. First and foremost, in order to meet users demands effectively, the capacity for the real-time collection, synthesis and access must exist; data import and export is essential. The data should be seamless, without artificial boundaries, and linked to attributes table that has become critical to many applications, for example, traffic flow management, road of disaster, and flood and earthquake traffic.

The GIS-TDSS system project file consists of a workspaces file, multiple geometric files, multiple relational data tables and multiple attribute data tables. The map file is a direct access, variable-record-length file in which each record describes a shape with a list of its vertices. In the index file, each record contains the offset of the corresponding main file record from the beginning of the main file. The data table contains feature attributes with one record per feature. The one-to-one relationship between geometry and attributes is based on record number. Attribute records in the data file must be in the same order as records in the main file. Figure 2 shows the data file structure of GIS-TDSS system and data file flow.

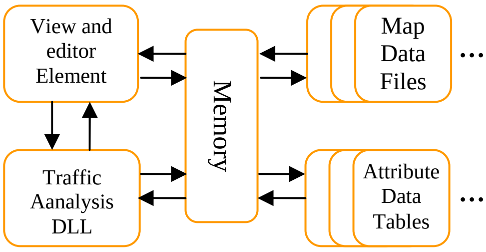

Figure 2. Data file structure of GIS-TDSS system

We propose new concepts for the GIS-DSS system: seamless operation of a detailed local network into a global network. As mentioned in the Introduction section, the integration of a detailed local network for an intersection into a global network is necessary to improve traffic analysis accuracy without involving too large a computational burden.

In the general structure of GIS (9), spatial data can be divided into three groups: geometric data – data for describing space characteristics of spatial data, also known as location data, positioning data; 2) attribute data – data for describing attributes of spatial data such as type, grade, name, status, and so on; 3) relational data – data for describing topological relationship between spatial data. These three data groups are stored in separate tables in conventional GIS. In this study, the geometric data and relational data are placed in a unified data management table. In the following an example is given to illustrate our method.

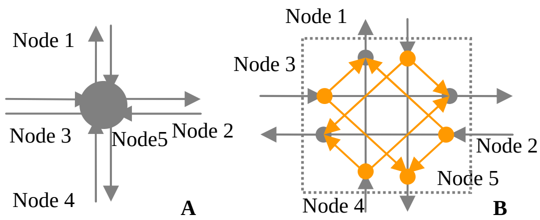

Figure 3. Local detailed network of an intersection.

In Figure 3 part A is shown a traffic network in which intersections are simple nodes, and part A in the Table A of Figure 4 is the data structure of the network. Key 1 is the primary key of data. Key 2 and Key 3 are the name keys of the start and end points of a link, Col1 and Col2 are their coordinates, respectively. Key 4 denotes the correspondence of node numbers between original and modified networks.

When Node 5 is expanded as a detailed network, twelve new links are created (enclosed by the dotted square in Figure3 part B), and at the same time eight existing links are modified by changing their end points to be compatible with the detailed network for the intersection, as shown in part B of Figure 4 Table. In the Table B of Figure 4 are shown the data for the created intersection network. Key4 is set to be the original number of Node 5 in the simple network. Values of Col1 and Col2 can be ignored.

When local detailed network is being created, attributes of the link can be defined and inserted into data attribute tables, which can be accessed in traffic equilibrium analysis by primary key. These functions are omitted due to space constraint, which can be found in (2).

The module for implementing the above data modification in the GIS-TDSS is shown in Figure 4. The layer manager extracts data from data file in accordance with the requirements of the system, forms a graphic layer with the data of the geometric table, and then loads the required layer attribute data, and loads them into memory to output the required layer.

The data manager controls the definition and value assignment of the structure and metadata in the layer-refining table, defines the geometric shapes in network, extracts data, etc.

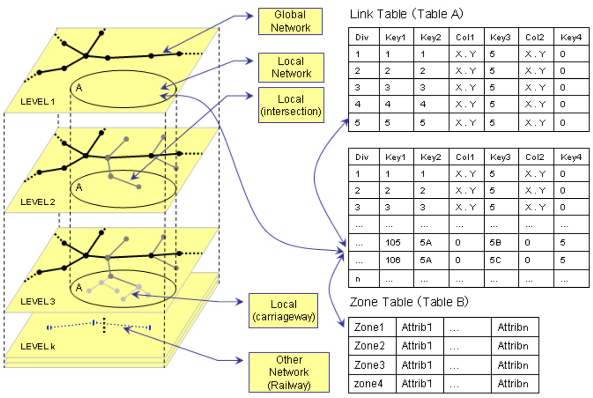

Figure 4. Network data modification

D. *Data Converter and Import*

Building a GIS application is usually inherited from GIS desktop services and based on existing geographic information available in common GIS format. GIS-TDSS provides both vector and raster import/export functions for a nice range of formats. Our system development also includes a Data Converter, which is used to convert GIS data from various sources (e.g., ESRI shape files, MapInfo tables, DRM data of Japan, raster TIFF images or data from GPS survey, etc.) to prepare maps and associated data for the GIS-TDSS. The Data Converter module is presented in Figure 5.

For specific applications and depending on map data type features complexity, optimal design of structure layers is conducted, then, layers are organized and converted into appropriate schema. For spatial features, the Data Converter can convert to 3 groups of layers.

Geometric data layer: convert geometric data directly into Geometry and relational file. Attribute data layer: converter will retrieve spatial data from database – when a layer is requested, the conversion controller will query database and create corresponded attribute table. For attribute data, the format is database format and as XML files schema.

And we developed the GIS-TDSS system can output results data into the SVG (Scalable Vector Graphics) format. The SVG file is a family of specifications of an XML-based file format for describing two-dimensional vector graphics data and it support to internet browser.

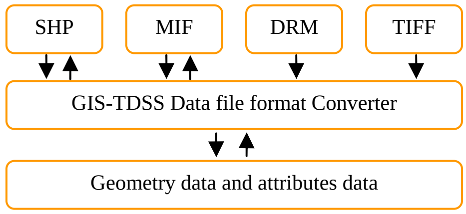

Figure 5. Data converter format of GIS-TDSS

E. *Controller and View Method*

In this system, the most important problem is to improve the speed of vector graphic showing while performing operations, such as graphic regeneration, network editing and scaling after calculation. In order to resolve this problem, the bucket method (12) is developed for data division management to achieve the speeding-up vector graphic showing, which has also been proved effective for mass vector graphic processing. Especially for the case of the processing of advanced local network in the global network, the developed bucket method can avoid the processing of the data of whole network to improve process speed.

To minimize the time of map showing or editing, the following problems has to be resolved. Firstly, do not process the portion out of the showing range or editing range. Then catch the data related to showing or processing range from map large-scale data.

To resolve the problem mentioned above, this system uses bucket-based method, which separates the data as rectangular unit (bucket) to index and describes by layer. At first, assign the map data to bucket of the same dimension. Then draw up the map data index of bucket-interacted graphic factors (segment or some other object).

While processing the graphic of showing range, processing special position retrieves the referring unit, from the unit graphic object index, the necessary map data can be found out from the memory. These functions are omitted due to space constraint, which can be found in (2).

III. Analysis Capabilities And results Of The Traffic Analysis System

There are several definitions of equilibrium for traffic analysis. In this paper we briefly review the “stochastic” equilibrium model (6) which has a simple system of equation formulation. Assume that the traffic network is represented by a directed graph which consists of a set of links $A = \{\cdots, ij, \cdots\}$, where i and j are network nodes. Let $t = (t_{ij})_{ij \in A}$ denote the travel time costs incurred in the network links. Let

$$C_k^{rs} = \sum_{ij} t_{ij} \delta_{k,ij}^{rs} \qquad [1]$$

be the travel cost of route k from origin r to destination s, where $\delta_{k,ij}^{rs} = 1$ if ij is a link in the path k, $\delta_{k,ij}^{rs} = 0$ otherwise. In a stochastic equilibrium model, the probability that the k-th path is chosen is

$$P_k^{rs} = \frac{\exp(-\theta C_k^{rs}(t))}{\sum_p \exp(-\theta C_p^{rs}(t))} \qquad [2]$$

Where θ is a constant parameter. Let x_{ij} denote the traffic flow on link ij, $x = (x_{ij})_{ij \in A}$. In general, link cost is a function of this flow vector and some control vector λ (e.g., traffic signal parameters) $t = t(x, \lambda)$. Let q_{rs} be the travel demand from origin r to destination s, the stochastic user equilibrium on the network can be formulated as

$$x_{ij} - \sum_{rs} q_{rs} \frac{\exp(-\theta C_k^{rs}(t))\delta_{k,ij}^{rs}}{\sum_p \exp(-\theta C_p^{rs}(t))} = 0, \; ij \in A \qquad [3]$$

There has been developed efficient algorithm for solving this system of equations for x_{ij} (4, 6).

The time cost of common road links is usually calculated by the following function: $t_{ij} = a + b x_{ij}^4$, where a and b are parameters (6). However, the time cost functions at intersections are rather complicated, due to the fact that flows for different directions interference each other, and are usually simplified as an average constant value in conventional network equilibrium analysis.

In order to improve traffic analysis accuracy, an intersection can be expanded as a detailed network composed of virtual links in accordance with traffic rules set for the intersection, as shown in Figure 6.

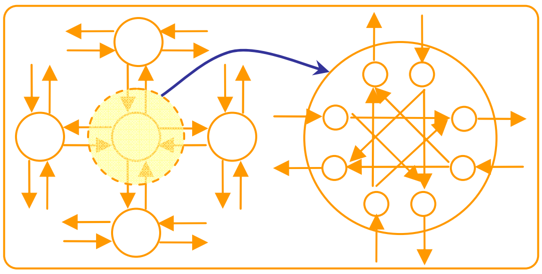

Figure 6. Detailed intersection structure.

The time delays at an intersection are functions in all the flow variables associated with the intersection. These functions are omitted due to space constraint, which can be found in (7, 8).

IV. Analysis Of Traffic And Examination Of Forecasting Function

In Figure 7 is shown a main road network map for the central part of Gifu city, Japan. Suppose that we are interested in the traffic flow crossing a special intersection (Intersection 181) indicated in the map. For this the detailed network for the intersection is integrated into the global city road network. Due to space restriction, the detailed data for the parameters of the network are omitted here.

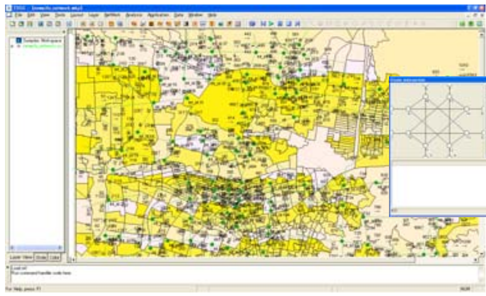

Figure 7. Traffic network of Gifu City Japan.

Step1: The Conventional equilibrium analysis result of the common transport network is shown in Figure 7, and the part surrounded by the dotted line is shown in Figure 8 (left). We can find out the traffic volume of the four links (two-way) connected to node intersection 181.

Step 2: The node intersection 181 shown in Figure 7 (right) is set to be a common intersection (local detailed network), so that new twelve links at the intersection can be inserted into data table and the start point or the end point of four links connected to the node intersection 181 can be revised.

Step 3: A further calculation on the new network obtained in Step 2 is taken to get the new equilibrium analysis results. As shown in Figure 8 (right), the traffic volume change on links connected to node 181 happened.

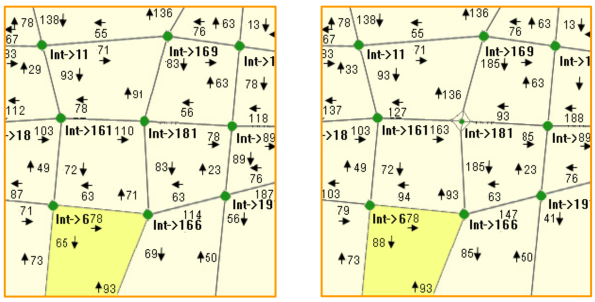

Figure 8. Flows without/with intersection delays.

For detailed analysis of the intersection denoted as node Intersection 181 in the network, Intersection 181 is expanded as a local detailed network with twelve new links. The equilibrium traffic flows for the new integrated network are shown in Figure 8. It can be seen that some of the traffic volumes have turned onto other links due to the delay impact of the intersection.

V. CONCLUSION

We have developed a GIS-based Transport Decision Support System for traffic network equilibrium analysis, with a novel function of integrating the detailed structures of intersections into global networks. Since traffic phenomenon involves both global network equilibrium mechanism as well as local detailed behavior, our system provides a method for realistic traffic network analysis.

The GIS software provides effective management of the detailed spatial data and the ability to query and visualize model results. A sophisticated spatiotemporal database design links the GIS with the dynamic flow module and enhances their capabilities by providing efficient data storage and retrieval of model results.

Advanced information technologies provide us with powerful tools for collecting and processing complex and detailed traffic information. By combining these technologies with network analysis, it is possible to do better transportation planning and management. For this purpose, an important work is to extend our system to establish a comprehensive platform for integrating local detailed and global information in a compatible way for network analysis.

We developing software are a prototype system. We are continuing software development along several avenues. Our first priority is new traffic analysis model system with the dynamic congestion module, GIS and decision support system. We are also developing a more sophisticated dynamic congestion module based on this tool which can handle dynamic flow. This will allow the user to trade-off computation speed for accuracy when modeling dynamic flows.

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