MODELLING TURNING RESTRICTIONS IN TRAFFIC NETWORK FOR VEHICLE NAVIGATION SYSTEM

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Commission IV, WG IV/1

KEY WORDS: ITS, in-car navigation, navigable database, data modeling, turning restriction

ABSTRACT:

Vehicle navigation is currently the most widespread and successful consumer application of GIS-T. It is based on positional accurate data and comprehensive transportation-related content. A specially-made navigable database is essential for the key functions of the vehicle navigation systems, for example, route finding and driver guiding. There are lots of research challenges in generating a satisfied navigable database. Among them the data modelling is the most important comparing with representation, data processing, etc., especially the modelling of the turn restrictions of the traffic network. There are three levels of data modelling for the vehicle navigation systems, i.e., conceptual modeling, logical modeling, and algorithmic modeling. The authors of this paper think that special consideration should be put onto the algorithmic model, because it represents not only the relationships between the transportation elements but also the real-time and dynamic traffic restrictions in the traffic network. This paper discussed firstly the properties of the turning restrictions in road networks. The model in conceptual model (GDF 4.0) and logical model (UNETRANS) are introduced. Concerning the algorithmic model, the authors analyzed the disadvantages of the commonly used data structure for representing the turning restrictions. And proposed a new link-based data structure, where a node-link table is used to represent the connectivity of the road network, and a link-link table is used to represent the turning restrictions. The algorithm for route finding was also modified accordingly. The results of the experiment show that the efficiency of route finding is obviously improved with the new method.

1. INTRODUCTION

GIS-T is the application of geographic information systems in transportation. It is now one of the most important application areas of GIS technology [Waters, 1999]. Vehicle navigation is currently the most widespread and successful consumer application of GIS-T, with huge profit already in the developed countries and huge market potential in the developing countries as China. For example, the market volume of in-vehicle navigation and information systems alone in China is expected to be over 2 billion Euro in the next 12 years, and the intelligent transport systems using digital road map as a basis will reach a market volume of 10 billion Euro in China for the same time horizon. Thus lots of studies in GIS field of China are now focusing on the methodologies and technologies related to in-car navigation system. One of them is the study of navigable database for vehicle navigation system, which need to modelling traffic related features and various traffic restrictions.

Two key functions of the vehicle navigation system are route finding and driver guiding. That is, when the driver defines two points on a given road network (one is the start point and the other is the destination point), the system should provide an optimum path connect these two points based on multiple impedances, such as the geometric distance, time (speed limit), cost of travel (where data is available) , as well as the traffic conditions. Then generate turn-by-turn guidance during the driving. And further, dynamically find a new route if the current route has some problem to go through (such as due to traffic accidents or jams) of if the driver has taken a wrong turn. A specially-made navigable database is essential for such functions. Within the navigable database three kinds of information need to be modelled, including geometric data that representing the road network and position of transportation-related features, attribute data that representing various address, traffic conditions and restrictions, and dynamic date describing real-time traffic information. Other Location-Based Services (LBS) fields in ITS (Intelligent Transportation System), such as fleet and asset management, emergency services, telematics, etc., are also depended on such specially-made navigable databases.

Although there already are some commercial navigable database being put into use all over the world, especially in North American, Europe and Japan, there are still lots of research challenges in generating a satisfied navigable database, concerning with data modelling, representation, data processing response to the requirement of ITS applications [Goodchild, 2000]. With the responsibility for providing the fundamental geographic information and related service, the National Geomatics Center of China (NGCC) is now undertaking some projects funded by the State Development Planning Commission of China, State Bureau of Surveying and Mapping of China, as well as some enterprises involved in ITS technology. One of these projects is related to study and establish a navigable database for vehicle navigation. During the implementation of this project, the authors of this paper

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found that data modelling is the most important comparing with representation, data processing, etc.

There are three levels of data modelling for the vehicle navigation systems, i.e., conceptual modelling, logical modelling, and algorithmic modelling. The conceptual model defines the potential contents of such databases (Features, Attributes and Relationships). The logical model specifies how to organize the objects in databases. In the algorithmic model, data structure (such as list or array) is defined according to the characteristics of conceptual and logical models to facilitate the searching, indexing and computing for various particular functions, such as optimum routes finding, turn-by-turn guiding, etc.

Now GDF4 (Geographical Data File) is under approving by ISO, which specifies the conceptual data model and data exchange format for the geographic databases for ITS applications. Some logical data models are also proposed, such as the UNETRANS (Unified Network for Transportation) Data Model by the UNETRANS Consortium in U.S. But for the algorithmic model, generally people think it is just an implementation of the conceptual and logical model. Actually for vehicle navigation systems special consideration should be put onto the algorithmic model, because it represents not only the relationships between the transportation elements but also the real-time and dynamic traffic restrictions in the traffic network. Fig.1 shows the components of a vehicle navigation system. There is a navigable database, which generally stored in a CDROM. A data structure should be established based on the tables in the database to facilitate the computing of the functional modules. When there is an real-time traffic message received, the lists or array in the data structure should be updated, and then a new route or instruction will be computed. So it is very important for the data structure to properly represent the relationships between the transportation elements, as well as the real-time and dynamic traffic restrictions in the traffic network.

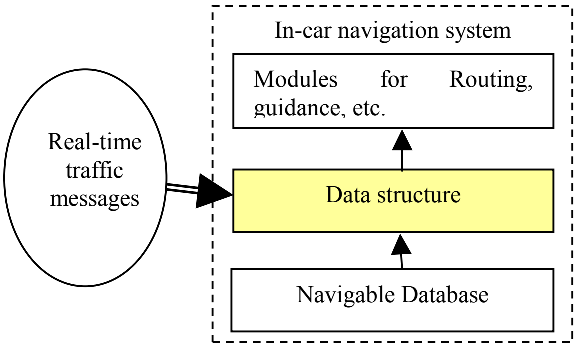


Figure 1 The components of the in-car navigation system

The authors of this paper studied how to model the turning restrictions in traffic network for vehicle navigation systems. The properties of the turning restrictions are discussed first. The model in conceptual model (GDF 4.0) and logical model (UNETRANS) are introduced. Concerning the algorithmic model, the authors analyzed the disadvantages of the commonly used data structure for representing the turning restrictions, which is based on the nodes relationship of "directed graph". A new link-based data structure was proposed, where a node-link table is used to represent the connectivity of the road network, and a link-link table is used to represent the turning restrictions. And the algorithm for route finding was also modified accordingly. The results of the experiment show that the efficiency of route finding is obviously improved with the new method.

2. TURNING RESTRICTIONS IN TRAFFIC NETWORKS

There are various traffic restrictions in traffic networks, including restricted period of time, vehicle type restriction, signal, turning restrictions, etc. (Fig.2). Among them the turning restrictions contributed significant to the total travel time [Dirch, 1977; Pallotinno, Scutella, 1997]. The magnitude of delays by them may even be comparable to the link travel time which account for 17~35% in the total time [Nielson, Frederiksen and Simonsen., 1998]. Ignoring the turning restrictions in the traffic network modeling may miss essential characteristics of the network and lead to sub-optimal or illogical paths.

In the GDF4 conceptual model a road network is modelled in 3 levels according to different grade of abstracting. Where level 0 describes the geometry of the road network, level 1 (Fig.2a) describes the network in terms of simple features (such as road element and junction), and level 2 (Fig.2b) describes the network with complex features (such as road and intersection). Generally turning restrictions are related to intersections or junctions (Fig.3). For a specific intersection, the turning restrictions are the generalization of the restrictions of related junctions. A kind of relationship called Prohibited Manoeuvre is used to represent the turning restrictions in GDF4.

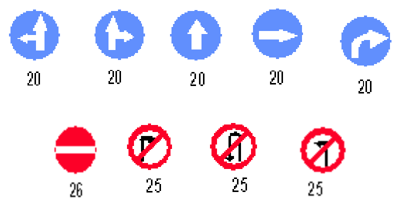
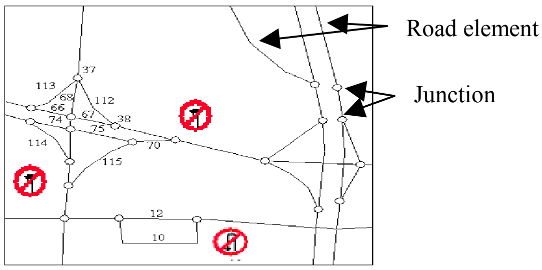
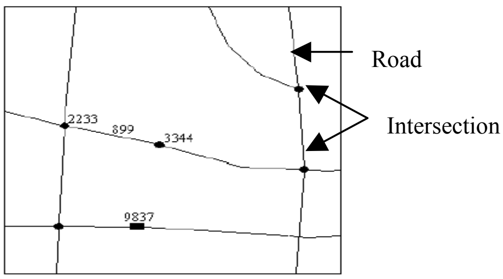


Fig2. Control signs in traffic network



(a)



(b)

Fig 2 Road network model in GDF4 [GDF4]

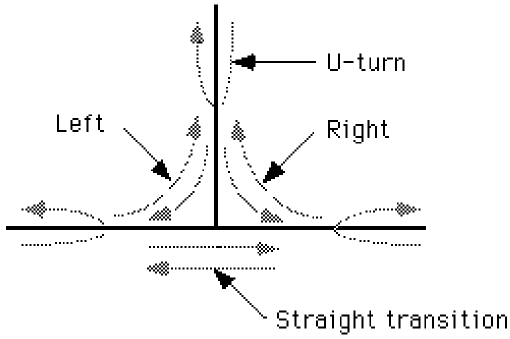


Fig.3 Turn restrictions in a junction/intersection

In the ArcInfo Network model or UNETRANS model, the turn restriction in each node (junction/intersection) is represented with turntables, where every possible turns are listed and maintained. Fig.4 is a example of turntable from ArcInfo.

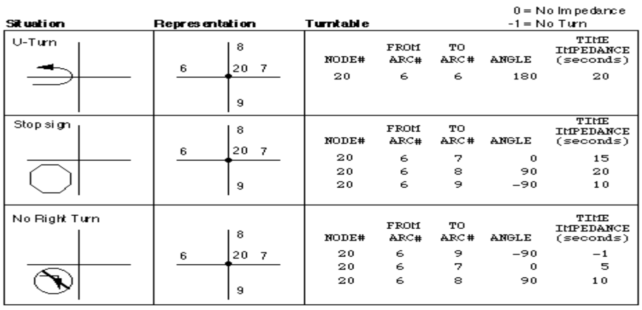
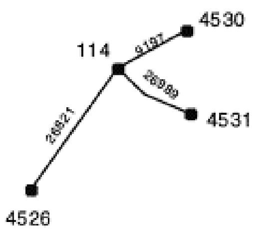


Fig.4 An example of turn table [ESRI]

3. ALGORITHMIC MODEL OF TURNING RESTRICTIONS

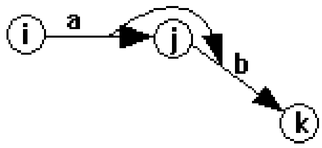
People usually use "directed graphs" to describe general networks, where only the connections between nodes and links are taken into consideration. Thus the route finding algorithms assume that there are no costs or prohibitions associated with nodes. A node-link table like the one in Fig.5 is enough to represent the connectivity between the nodes.



Link-ID	Node1-ID	Node2-ID
26821	114	4526
26989	114	4531
9197	114	4530

Fig.5 node-link table for connectivity describing

A turn represents a transition from one link to another link at a node. It represents relationships between links rather than nodes. Thus the node-link table in Fig.5 is not enough to describe such relationship between links. For example, to describe the relation between link a and link b in Fig.6, two tables are used, one for the turn and the other for the connectivity. At this moment, the classical route finding algorithms based on the nodes has to be modified to adapt to such change.



JUNCTION	From-Edge	To-Edge	Turn Value
j	a	B	TRUE

Turntable

Edge	From-Node	To-Node
A	i	j
B	j	k

node-link table

Fig.6 A node with turn between two links

Some people tried to solve the turning problem by expanding the network, that is to highlight each movement in the intersections, where the costs of the dummy arcs are the banned costs or penalties costs [Kirby and Potts, 1969]. So an intersection is split into many dummy nodes and dummy links that restructure a sub-network, as shown in Fig 7. The advantages of this approach are no turning delays and prohibitions are included in the large network, and the problem can be solved with any general data structure and route finding algorithm. But the shortage of the approach is evident, i.e. the resulting network is considerably larger than the original one. More computational time and computer memory are required and moreover, more time-consuming network updating is involved.

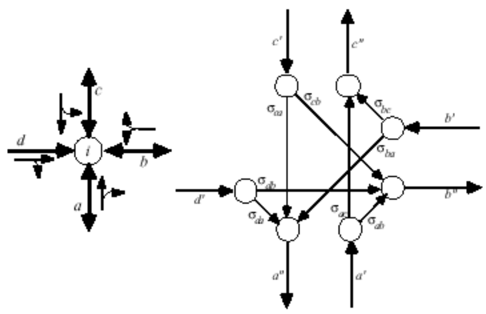


Fig. 7 An expended intersection with turns [Kirby and Potts]

To overcome the disadvantage of the network expending approach, some people tried to solve the turning problem without changing the topology of the network. For example, Ziliaskopoulos and Mahmassani proposed an extended forward star structure (EFSS) to describe the network [Ziliaskopoulos and Mahmassani , 1996], as Fig.8 shows. But when describing the turn with EFSS, the storage space expends rapidly and the efficiency of route finding will be reduced [Han and Jiang, 2001].

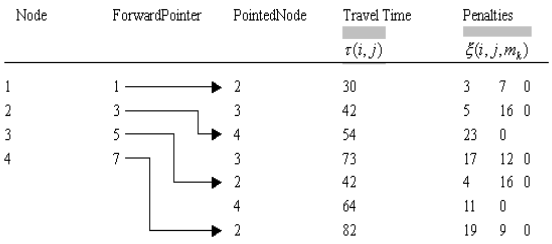


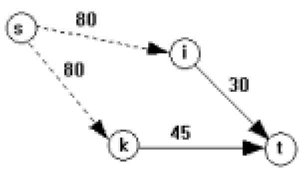
Fig.8 The EFSS including turn representation [Ziliaskopoulos and Mahmassani]

The authors of this paper proposed a new data structure for turning representation. In the data structure, the node-link table is used for connectivity representation and link-link table is used for turn describing, as defined below:

```
   Struct  NodeLink
{
    double m_dF_NodeID;
    double m_dT_NodeID;
    double m_dLinkID;
    double m_dLength;
};

   Struct LinkLink
{
    double m_dF_LinkID;
    double m_dT_LinkID;
    BOOL m_bTurn;
};
```

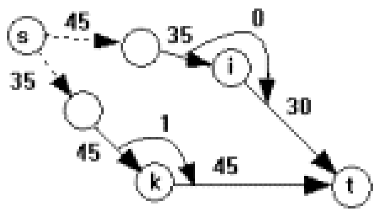
In classical node-based Dijkstra algorithm for route finding, the selecting of subsequent node depends only on the current node itself, as shown in Fig.9a. With turning restrictions, the subsequent node selecting is related to the parent node of the current node (Fig.9b).



Current node: t

Parent Node: i

(a) Only distance between node is considered



Current node: t

Parent Node: k

(b) Turning restriction is considered

Fig.9 Selecting of the subsequent node

To solve this problem, the authors modified the classical node-based Dijkstra algorithm to be link-based Dijkstra algorithm. According to analysis, the time consumption of the new data structure and algorithm is O(nlogn) compared with the classical O().

4. EXPERIMENTS AND CONCLUSIONS

The proposed method is tested in a large-scale road network of Hong Kong ,with 5351 nodes, 7117 links and 43575 turn restrictions. To find the longest route (which consists of 174 links) in the network, 4323 links are searched within no more than 0.2 seconds (Fig.10). Whereas more than 2 minutes are used with the classical method. The approach will be more efficient if some strategies of data organizing, such as dividing data sections according to geographic coverage, defining data layers according to road classes, and setting searching range according to the positions of the start node and destination node.

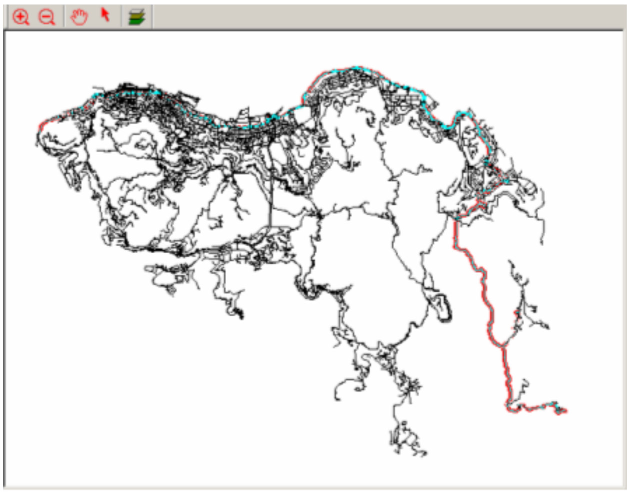


Fig.10 The longest route in the experiment network

Further study will focus on some other problems related to data modelling for vehicle navigation, such as 3D road network modelling, dynamic traffic condition modelling, as well as the efficient data organization methods.

5. ACKNOWLEDGEMENTS

This research was supported by the National Natural Science Foundation of China (grant No. 40171076) and the Surveying and Mapping Foundation (year 2000) from the State Surveying and Mapping Bureau. The study is also support by Brilliant Technology Development Limited.

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