Contextual Routing and Navigation Method in Road Networks

LI Yuan*
School of Architecture and Civil E ngineering
Xiamen University
Xiamen, China
yako79@gmail.com

ZHU Qing
LIESMARS
Wuhan University,
Wuhan,China
zhuq66@263.net

LI Xiaoming
LIESMARS
Wuhan University,
Wuhan,China
lxmingster@gmail.com

Abstract—**In this paper, a novel method, namely contextual routing and navigation, is proposed. This method is based on the author's proposed hierarchical, lane-oriented 3D road network. The key to implement contextual routing and navigation is to adopt cognition-based hierarchical routing strategy and the view-based multi-scale navigation strategy. The two strategies enable users routing on roadway centreline, carriageway or lane and provides 2D, 2.5D and 3D communicating based on user defined context. A prototype is also developed in the VGEGIS system and the experimental results have confirmed the effectiveness and efficiency of the method. The paper will provide a contribution to flexible location-based services by innovatively considering the hierarchical knowledge of the road network system and contextual visualization needs.**

Keywords- Navigation; 3D GIS; Road Network Model

I. INTRODUCTION

The routing and navigation functions on a roadmap are extremely fundamental for any location-based service (LBS), intelligent transportation system (ITS) and emergency response (ER) [1, 2]. As urban spaces continue to burgeon upward and downward, modern road network systems grow in multidimensionality and dynamism while the traffic control systems of many are executed at lane level [3]. Examples are flyovers, tunnels, ramps, viaducts, turning restrictions, speed limits, one-way instructions, limited width, emergency and movable lanes [4]. Those changes call for contextual or personalized or adaptive services which support routing on the road network with different levels of details and multi-scale navigation with various route instructions. For example, in a familiar environment, lane-level routing is required because users care more about which lane should run along the trip. However in an unfamiliar environment, users just care about which road segments are allowed to pass through and only expect for a rough route description to the destination. In this case, carriageway-level or street-level routing is desirable. Another example is emergency routing. In emergency situation, the police car can run in special lanes and context is totally different with that for a taxi driver. Paralleling to the special requirements for routing service, the map visualization services should be also contextual and user-oriented. That is to say, some users like detailed route description supported by 3D scenarios while other likes general route reporting in a 2D symbology map, still others hope the navigation service could be supported by multiple views in order to help them fully understanding the environment.

A key to provide such contextual routing and navigation service is to develop a kind of road network model which supports routing and navigating at different level of details. Over the past twenty years, road networks have been commonly modelled as roadway centrelines, simplifying the complicated transportation system to a network of single lines and treating flyovers as points. It is obvious that the visualization of 3D structures and 3D operations (such as 3D distance measurement) cannot be obtained from 2D models. Beside, 3D objects presented as 2D projections in GIS may lose some of their properties (texture, graphic, height, etc.) and their spatial relationships to other objects [5]. In the recent years, since there is a growing diversity of using non-planar network to represent the 3D structure of transportation system or using turn table to reflect the complex traffic rules at interchange or using linear reference method to model individual lane and connectivity among parallel lanes [6-15], the topological objects have still relied on simplified 2D roadway centreline for cartographic representation [4, 5]. As a result, some scholars start the research of true 3D road network model [15-17]. The research of 3D road network model depends much on the advanced road capture techniques, for example Terrestrial Laser Scanning and Differential GPS, as well as 3D data management, 3D representation and 3D analysis platform [4]. Comparing with the traditional 2D road network model, 3D model aims to resolve problems such as: (1) true distance measurement across hilly terrain; (2) representation of 3D structures, such as overpasses and on-ramps, and (3) assigning multiple routes over a single arc [18].

However, current 3D road networks can not directly support contextual routing and navigation because there is no hierarchical data structure inside the models. Hierarchical data structures, which consider both simplified aspects and detailed aspects of the objects, provide flexible, natural and rational means for modelling at different levels of detail (LODs). International organisations have also proposed hierarchical data structures for road network, for example GDF 4.0 [19]. Since GDF 4.0 aims at explaining the importance of simple feature (level-1) and complex feature (level-2) in the road network system, the hierarchical structure has still not answered the question of how to organize the hierarchical geometry and topology. Besides,

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GDF 4.0 is a concept model and the implementation issues are still vague.

In this paper, a hierarchical, lane-oriented 3D road network model will be briefly introduced in Section 2. The new model will provide a foundation for contextual routing and navigation. Based on the model, Section 3 discusses two related methods, namely cognition-based hierarchical routing and view-based multi-scale navigation. Section 4 covers the implementation issues of contextual routing and navigation. Finally, concluding remarks at presented in Section 5.

II. HIERARCHICAL, LANE-ORIENTED 3D ROAD NETWORK MODEL

Referring to GDF 4.0 [19] and CRNM model [6], hierarchical, lane-oriented 3D road network model, shortly HL-3DRNM, is proposed [5]. A huge difference between GDF 4.0 and HL-3DRNM is that the new model considers three geometric and topological level of road network. HL-3DRNM also treats lane geometry and lane topology as the minimum modelling elements, which are not considered in CRNM model.

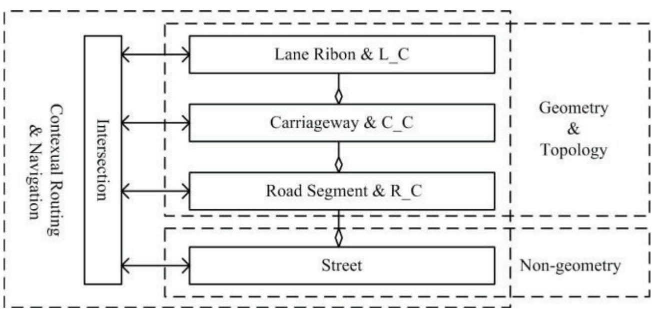

Figure 1. Conceptual model for hierarchical, lane-oriented 3D road network model

As shown in Fig. 1, there are three levels of topological structures to model the road network system, namely roadway centreline (R_C), carriageway (C_C) and lane centreline (L_C). Correspondingly, there are three levels of geometric structures, namely rod segment, carriageway and lane ribbon. The geometry and topology elements are linked by intersection, which are reflected as a zone for geometric representation and reflected as a node for topologic analysis. Jointed with the non-geometry object (Street), the hierarchical data structures can be used for contextual routing and navigation by providing the functions of hierarchical network analysis and multi-scale visualization.

III. CONTEXTUAL ROUTING AND NAVIGATION

Relying on the proposed hierarchical, lane-oriented 3D road network model, the contextual routing and navigation method will be introduced. Context is a widely used term in the fields of science and with many meanings [20, 21]. From the cartographic point of view, context is closely related to the purpose of a map [22]. In this paper, the term “context” is defined as “the psychological environment of users and the degree of familiarity with their surroundings”. The purpose of the contextual routing and navigation should be that user who works with context-aware map application should just describe his context instead of defining map content and symbology as it is common in a traditional approach to cartographic representation. Special types of context for routing and navigation are “A: Role”, “B: Situation” and “C: Needs” (Fig. 2). For example, “user is a taxi driver” and “user is a policeman” describe the same object, i.e. user role. “User is unfamiliar with the traffic situation” and “user is in crisis management” describe the same context type “Situation”. “Needs” describe the requirements for map visualization at different levels of details.

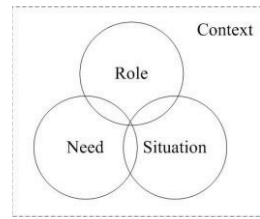

Figure 2. Types of context for routing and navigation.

In this paper, in order to support the different types of context, contextual routing and navigation will use the strategies of cognition-based routing method and the view-based multi-scale navigation method.

A. Cognition-based Hierarchical Routing

According to the principle of human spatial cognitive [23] and the definition of the proposed HL-3DRNM, the road network system can be abstracted as three hierarchies, from macroscopic roadway centreline, to mesoscopic carriageway, and to microscopic lane. The natural rule also shows that the macroscopic level includes general information as well as minimum data volume, while the microscopic level contains more detail information and undoubtedly will require more computing resources. The knowledge about the road network hierarchy will be beneficial in both multi-scale routing applications and faster lane-oriented microscopic routing. That means that if we need a lane-based route, it does not need to compute on the huge lane-based topological network. Instead, it is possible to find a rough route on the macroscopic network first, and then narrow down to a local microscopic network in order to refine the lane-based topological network. The solutions will minimize the network searching space as well as providing hierarchical routing results. Based on these discoveries, a new kind of hierarchical routing method, namely cognition-based hierarchical routing, is defined. The most difference between the cognition-based hierarchical routing and other hierarchical routing method [24-29] (for example road class-based hierarchical routing and map scale-based hierarchical routing) is that the former considers the detailed road information at all level from roadway centreline, to carriageway, and to lane.

As shown in Fig. 3, the first strategy considers the hierarchical structure as different road classes, for example, primary road, secondary road and local road. The hierarchical route prefers primary roads, based on the assumption that such delays are less on primary roads. Creating a hierarchical route also takes less processing time than an exact route, especially over large urban networks. The second strategy considers the hierarchical structure as different map scales, for example, 1:10 000, 1:5000, and 1:2000. This strategy is mainly employed for large road networks (like at provincial level) because all the network data in a large-scale map would be quite huge but not necessary in route computing. Searching a hierarchical route from one place in a city to another city will also takes less processing time than on a local map. It is obvious that the two hierarchical routing strategies aim at different application domains: the road class-based hierarchical routing has reduced the search space in urban road networks by utilizing the road class information, while the map scale-based hierarchical routing has reduced the search space among urban road networks by utilizing the different scale maps, but both strategies could never provide routes at three levels of details.

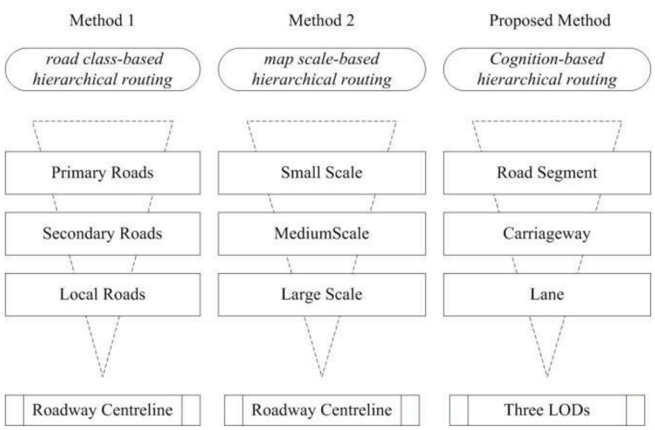

Figure 3. Comparison of the different hierarchical routing strategies

Cognition-based hierarchical routing strategy resolves the problem by three steps. First, it computes on the macroscopic structure of the road network. In this step, 1) the road network is made up with 2D roadway centrelines; 2) the complicated flyover is highly abstracted as a topologic node; 3) the road segment is bi-directional; 4) ignore the restriction at the interchange, use Euclidean distance as the weight for road segment; 5) global search, calculate the street-based routes. Second, it computes on the mesoscopic structure of the road network. In this step, 1) the road network is made up with 2.5D carriageways; 2) the flyover is abstracted as several links and nodes; 3) the road segment is directional; 4) turning restriction is enabled at interchanges, use average travel time as the link weight; 5) local search, calculate the carriageway-based route from the street-based routes. Third, it computes on the microscopic structure of the road network. In this step: 1) the road network consists of 3D lane ribbons; 2) the detail feature of the road surface, including texture and traffic signal, can be recognized; 3) the land ribbon is directional; 4) intersection zone is made up with several turning links, each link owns real travel time; 5) local search, calculate the lane-based route from the carriageway-based route.

However, as shown in Fig. 4 (a, b), since the routing operation adopts the same starting and ending point, the routing results for the roadway centreline-based network and the carriageway-based network are not exactly the same. This problem is mainly due to the complicated situation of the road network because urban road systems are almost one-directional but in the roadway-centreline network the assumption is that the road is bi-directional and the flyover is usually modelled as a single point. Thus, it is unable to build the relationship between the roadway centreline-based route and carriageway-based route. However, the relationship between the carriageway and lane can be maintained in a fixed way.

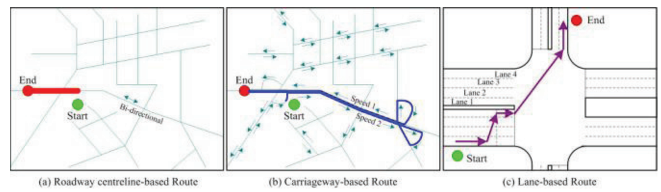

Figure 4. The comparison of roadway centreline-based route, carriageway-base route and lane-based route

As a result, a practical model of the cognition-based hierarchical routing is adjusted as two steps: Step 1 on a carriageway-based topological network and Step 2 on a lane-based topological network. The first step considers the average travel time of each directional carriageway. The topologic network is derived from the carriageway centreline. The relationship of the topology and geometry of a carriageway is one-to-one. In this step, a carriageway-based route will be generated first with the support of the traditional Dijkstra routing algorithm. The second step considers the travel time of each lane on a single carriageway. The lane-based topological network is also derived from the carriageway centreline but the relationship of the topology and geometry is many-to-one. It is obvious that the purpose of step 2 is to refine the route at lane level and minimize the search spaces to a great extent.

B. *View-based Multi-scale Navigation*

In most cases, the user enters an origin and destination, and the navigation system responds by providing driving directions/instructions to get from the specified origin to the specified destination [30]. However, there is a trade-off between the speed and accuracy of navigation information. For example, if the system provides the user with a rough description of the route, the system will spend less time organizing and visualizing the lower dimensional navigation environment. On the other hand, if a 3D navigation environment is required, the system will spend more time on the processing of huge volumes of data. Another trade-off between clarity and completion is also very common. That means, the users would like to get full information about the navigation environment but at the same time, they also need a simple, concise and contextual visualization for the environment.

A solution is to provide contextual navigation supported by multi views and multi-scale visualization. “View-based” refers to Goodchild’s three views of navigation. “Multi-scale” means the information management method, corresponding to the levels of details. View-based multi-scale contextual navigation is therefore, a process of adapting map applications to a particular user’s context by highlighting context-relevant spatial information in different scale and different level of details. The first step for implementing view-based multi-scale navigation is to build the multi-scale dataset, linking with three kinds of sub-data: multi-scale landmark data, multi-granularity attribute data and hierarchical network data. The multi-scale landmark data are divided into 2D, 2.5D and 3D, which consist of different levels of detail (LOD). For example, a hospital has been modelled as three types, one is 3D model with texture, one is 2.5D box with colour, and one is 2D footprint. Multi-granularity attributes describes the characters of the objects at different level of details. For example, “left lane speed” and “average lane speed” shows different granularity, and the relationship among different granularity can be constructed through “Foreign Key”, for example “CarriagewayID”. The multi-granularity attribute data is mainly used for map visualization at different scale. When the semantic relationships are predefined, it can be also used for attribute derivation. For example, the left lane speed is 1.2 times of average lane speed. Hierarchical network data play a key role in the view-based multi-scale navigation service for the multi-scale landmark and multi-granularity data are all related to hierarchical network.

As shown in Fig. 5, the three modes of views are created, namely map view, navigation view and behaviour view: In the map view: the global navigation scenarios are provided; it is a static view and characterized by: 1) showing the integrated street name and related street information; 2) relating to 2D landmarks. In the navigation view: 1) the road network is 2.5D carriageways and a flyover is visually one point; 2) the traffic flows are one-directional; 3) the landmarks along the route are extended to 2.5D and related information such as building attributes are attached by a single colour. For example, the red colour represents business buildings and yellow means residential. In the behaviour view: 1) the road network is made up with elongated regions with texture; 2) lane-related traffic information and road attributes, such as turning restrictions at interchanges, and speed restrictions are dynamically visualized.

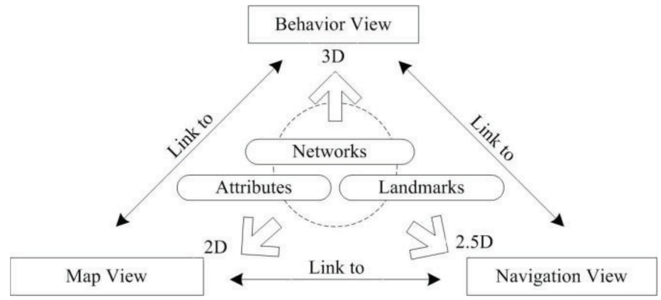

Figure 5. Conceptual model for View-based Multi-scale Navigation

The purpose of the view-based multi-scale navigation has many benefits: first of all, navigation-related information has been classified in order to satisfy different scales of applications. Such classification also facilitates the better management of the navigation knowledge according to the users needs. Secondly, the optimum is to pass the user the most actual data in an understandable, uncomplicated and clear way, meeting the user’s needs by filtering out the unhelpful information. The user can choose which kinds of view and navigation content are best suited for their environment, and it is flexible enough for the user to switch between the different views.

IV. PROTOTYPE AND IMPLEMENTATION ISSUE

The prototype was built on a 3D GIS software — VGEGIS6.0 — developed by Wuhan University in China. The development environments are Visual C++6.0 and OpenGL. The sample data are a series of main roads, including roadway centreline, carriageway, lane ribbon, and intersection zone.

The first step is to derive carriageway from the basic roadway centreline network. Given the number of carriageway, it is possible to create the related carriageway centreline by offsetting the pre-defined distance. Take Fig. 6 as an example, each main road contains two directional carriageway and the offset distance is determined by the road width, however, the ramps are one-directional and each only contain one carriageway. There are two methods to create the connectivity among the carriageways: using buffering zone and using available intersection zone. Using intersection zone is a direct way to organize the network connectivity but it needs special field works. Buffering zone is an interactive way by defining the centre point of the circle and its radius. After the intersection zone or buffering zone are created, each carriageway has been assigned a unique ID, including In_CarriagwayID, Out_CarriagwayID, Bi_CarriagwayID in order to explain their roles in the network connectivity. The connectivity inside the intersection zone or buffering zone can be automatically created by defining special rules such as: the node of In_CarriagwayID (the one which locates close to intersection zone or buffering zone) can link to each nodes of Out_CarriawayID or Bi_CarriagwayID (the one which locates close to intersection zone or buffering zone).

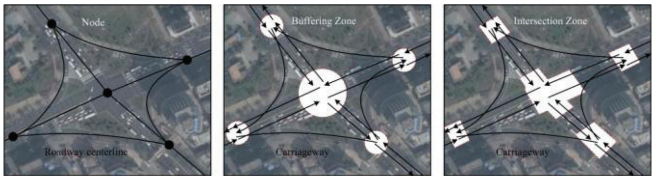

Figure 6. An example of deriving carriageway from roadway centreline

The second step is to derive the lanes from carriageway. Given the number of lanes on a carriageway, lanes (physical lane) can be reproduced from the carriageway link, while the relationship between the lane link and carriageway link is simultaneously established. The lane-to-lane relationship should be maintained by gathering the turning information among lanes with the support of aerial images or on-site surveys. For example, inputting how many left lane and right lane, the allowed travel speed for each lane, etc. The lane-to-lane connectivity is created by adding virtual lanes to the lane-based network. Taking Fig. 7 as an example, each right lane (derived from In_Carriageway) only links to its neighbour right lane (derived from Out_Carriageway) in order to take right turn, each left lane links to its two neighbour left lanes (derived from Out_Carriageway) in order to take left turn and U-turn. The traffic rules can be also flexibly changed by real traffic situation.

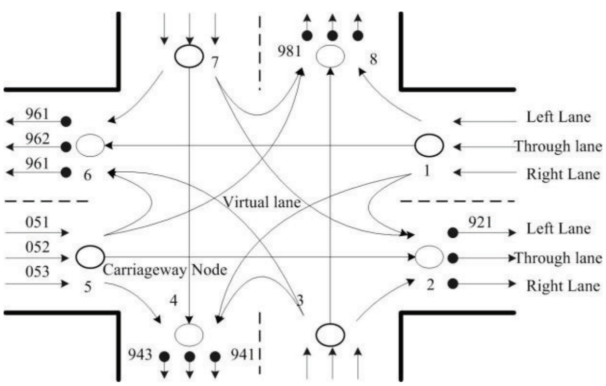

Figure 7. an example of deriving lane-to-lane connectivity from carriageway

In this paper, the effect of hierarchical routing is also testified. Taking an interchange as an example, if each carriageway is defined as containing three lanes (Left-turn/U-turn, Go-through, and Right-turn), the number of virtual lanes for a lane-based routing is 48. However, in hierarchical networks the number of virtual lanes is only three because the use of hierarchical knowledge of road network has minimizing the lane-level search space. For a small sample network with three interchanges, the numbers of nodes and links at carriageway level are 26 and 27, and the numbers of nodes and links dynamically created at the lane-level are only 33 and 42. The computational times of both routing algorithms include the time for deriving the physical lane, building the virtual lane and discretizing lanes among parallel lanes; for the hierarchical routing algorithm the total computational time is 11 ms. For a complicated urban road network, the advantages of using hierarchical routing will be more obvious.

The next implementation is to expand the traditional single-view navigation model to a multi-view navigation model. This expansion facilitates the maximum transmission of the navigation-related information as well as eliminating the contradiction between an abundance of information and the simplicity of navigation views. In Fig. 8, multi-scale navigation views provide different levels of detail, including geometry, attributes and traffic information. In the map view, the global navigation scene is presented as a 2D orthographic projection, where the names of main streets and buildings along the street have been figured out. In the navigation view, the local navigation scene is presented as a 2.5D axis projection, where the location of the moving objects is visualized in a more detailed manner. The landmarks along the designed route are coloured in order to reveal their building type, such as administrative buildings. The relationship of the two parallel carriageways of one street has been discerned and traffic control information at each interchange is attached to the scene. In the behaviour view, the 3D models and virtual instructions are taken into consideration. From this view, the feeling of immersion can be strengthened and navigation parameters such as travel speed can be added. Some extra strategies, such as using buffer 1 and buffer 2 to select special objects can be also achieved in the view-based multi-scale navigation.

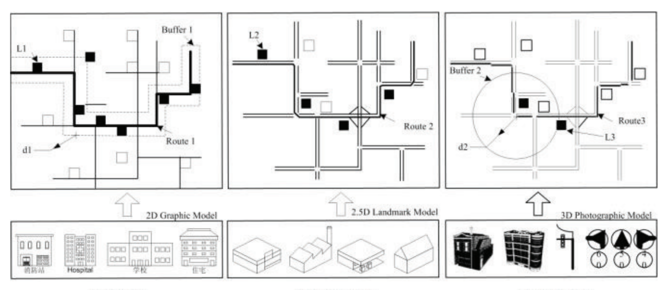

Figure 8. an example of organizing objects into view-based multi-scale navigation

V. Conclusion

This paper discusses the importance, method and implementation of developing a contextual routing and navigation method in a large-scale road network system. The character of contextual routing and navigation has been summarized from two aspects in this paper: on the one hand, it provides routing on the road network with different levels of details, from roadway centreline to carriageway and to lane. On the other hand, it provides multi-scale navigation supported by different route instructions. The needs for contextual routing and navigation have challenged the traditional routing and navigation method from all aspects:

1) The method of cognition-based hierarchical routing is quite new. Traditional hierarchical routing methods have two types: one is Road class-based hierarchical routing and

another is Map scale-based hierarchical routing, but both have not yet considered the detailed road information at lane level. Instead, cognition-based hierarchical routing method bases on the principle of human spatial cognitive, the road network system have been abstracted as cognitive hierarchies, from macroscopic roadway centreline, to mesoscopic carriageway, and to microscopic lane. Thus, it enables routing on different topological network. Besides, the new cognition-based method will speed up lane-level routing efficiency by minimizing the lane-level searching space. The implementation results have testified the advantages of hierarchical routing over normal lane-based routing by comparing the number of virtual lanes at an interchange and computational efficiency between a lane-based routing and hierarchical routing.

2) The method of view-based multi-scale navigation method makes the contextual navigation service operational. Comparing with the traditional navigation method which usually adopts 2D GIS system, the proposed new method decomposes the complicated routing instruction into 2D, 2.5D and 3D view as well as highlights context-relevant spatial information in different scale and different level of details. The prototype has illustrated the concept of multi-scale navigation views which expands traditional 2D single navigation views into Goodchild’s map view, navigation view and behaviour view.

The implementation results show the efficiency of the proposed methods; however, in real practice, the tasks of gathering all the information on the three levels of network are huge. Besides, real transportation system is far more complicated than the sample data, for example, 3D flyover and cloverleaf, the proposed method just provide an initial solution for real 3D routing and navigation. In the next step, the methods of automatically generating hierarchical network topology and attributes from the lane-based network are also to be discussed. Other further research areas can be started to automatically generalize the 3D geographic features in order to reduce the redundancy of the multi-scale dataset. Also, depending on the context of the navigation, different types of objects should be defined as landmarks. The procedure to detect the potential landmarks in the 2.5D navigation view is by analysing the dataset with data mining techniques to discover unique objects. The criteria for landmark selection can be based on information about semantics (use, function) and geometry of the object itself (area, form, edges), but also information about topology (e.g. neighbourhood relations to other buildings and other object groups) and orientation of the buildings (towards north, next road, neighbour) [31]. The behaviour view requires landmarks in more detailed formats and mainly focuses on “road furniture”, such as traffic lights and pedestrian crossings.

ACKNOWLEDGMENT

The work described in this paper is supported by 863 project (2008AA121601), the National Natural Science Foundation of China (40801158) and Open Research Fund of State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing (WKL(07)0301).

REFERENCES

[1] G. Ghiani, F. Guerriero, G. Laporte, and R. Musmanno, "Real-Time vehicle routing: solution concepts, algorithms and parallel computing strategies," European Journal of Operational Research, vol. 151(1), 2003, pp. 1-11.

[2] T.J. Cova and J.P. Johnson, "A Network Flow Model for Lane-based Evacuation Routing," Transportation Research Part A: Policy and Practice, vol. 37(7), 2003, pp. 579-604.

[3] Q. Zhou and W. Zhang, "A Preliminary Review on 3-dimensional City Model," Proc. Asia GIS 2003 Conference, 2003, Wuhan.

[4] Y. Li, "3D Hierarchical Road Network," GIM International, vol. 22(8), 2008, pp. 49.

[5] Q. Zhu and Y. Li, "Hierarchical, lane-oriented 3D Road Network Model," International Journal of Geographical Information Science, vol. 22(5), 2008, pp. 479-505.

[6] X. Li and H. Lin, "A Trajectory-Oriented Carriageway-Based Road Network Data Model, Part 1: Background," Geo-spatiaI Information Science, vol. 9(1), 2006, pp. 65-70.

[7] Y. Liu, Y. Xu, Z. Gui, J. Zheng, and S. Qin, "Feature-based Two Level Structure Road Network Model for Navigation," Proc. IEEE 2005 International Geoscience and Remote Sensing Symposium (IGARSS'05), 2005, Seoul.

[8] P. Fohl, K.M. Curtin, M.F. Goodchild, and R.L. Church, "A Non-Planar, Lane-Based Navigable Data Model for ITS," Proc. 7th International Symposium on Spatial Data Handling, 1996, Delft, Netherlands.

[9] S. Malaikrisanachalee and T.M. Adams, "Lane-based Network for Transportation Network Flow Analysis and Inventory Management," TRR Journal of the Transportation Research Board, (1935), 2005, pp. 101-110.

[10] S.J. Bespalko, J. Sutton, M.M. Wyman, J.A. Van Der Veer, and A.D. Sindt, "Linear referencing systems and three dimensional GIS," Proc. Annual meeting of the transporation research board, 1998.

[11] H. Demirel, "A Generic Data Model Proposal For Multi-Dimensional Road Object," International Achives of Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. 35(4), 2004, pp. 1312-1317.

[12] N. Koncz and T.M. Adams, "A Data Model for Multi-dimensional Transportation Location Referencing Systems," URISURISA, vol. 14(2), 2002, pp. 27-41.

[13] K.J. Dueker and J.A. Butler, "GIS-T Enterprise Data Model with Suggested Implementation Choices," Journal of the Urban and Regional Information Systems Association, vol. 10(1), 1998, pp. 12-36.

[14] J. Gottsegen, M. Goodchild and R. Church, "A conceptual navigable database model for intelligent vehicle highway systems," Proc. GIS/LIS Conference, 1994, Phoenix, pp.371-380.

[15] X.-q. Zuo, Q.-q. Li and B.-s. Yang, "3D Data Model of Transportation Network in City," Proc. MIPPR 2005: Geospatial Information, Data Mining, and Applications, 2005, Wuhan, China.

[16] S.J. Bespalko, M.M. Wyman and J.C. Sutton, "The Need for a Formal GIS-T Model," Proc. 4th Annual NCGIA Symposium on Interoperable Geographic Information Systems, 1997, Santa Barbara.

[17] F. Lu, C. Zhou and Q. Wan, "Implementation of a Feature-based Non-planar Database for Urban Traffic Networks," Acta Geodaetica et Cartograhica Sinica, vol. 31(2), 2002, pp. 182-186.

[18] H.J. Miller and S.L. Shaw, GIS-T Data Models, Oxford: Oxford University Press, 2001.

[19] R. Essena and V. Hiestermann, ""X-GDF"- the ISO model of Geographic information for ITS," Proc. ISPRS Workshop on Service and Application of Spatial Data Infrastructure, XXXVI(4/W6), 2005, Hangzhou.

[20] T. Reichenbacher, "Adaptive methods for mobile cartography," Proc. the 21 st International Cartographic Conference, 2003, Durban, South Africa, pp.1311-1323.

[21] L. Friedmannová, M. Konecny and K. Stanek, "An adaptive cartographic visualisation for support of the crisis management," Proc. Auto-Carto Conference proceedings, 2006, Vancouver, Canada.

[22] J. Kozel, "Open Contextual Cartographic Visualization," Proc. GI-Days 2007 – Young Researchers Forum, IfGI prints, 2007, Münster, Germany.

[23] M. Tomko, S. Winter and C. Claramunt, "Experiential hierarchies of streets," Computers, Environment and Urban Systems, vol. 32(1), 2008, pp. 41-52.

[24] F. Lu, D. Lu and W. Cui, "Time Shortest Path Algorithm for Restricted Searching Area in Transportation Networks," Journal of Image and Graphics, vol. 4(A)(10), 1999, pp. 849-853.

[25] K.H. Quek and T. Srikanthan, "A hierarchical representation of roadway networks " Proc. 7th World Congress on Intelligent Transportation Systems, 2000, Turin, Italy.

[26] G.R. Jagadeesh, T. Srikanthan and K.H. Quek, "Heuristic Techniques for Accelerating Hierarchical Routing on Road Networks," IEEE Transactions on intelligent transportation system vol. 3(4), 2002, pp. 301-309.

[27] B. Liu, "Route Finding by Using Knowledge about the Road Network," IEEE Transactions on Systems, Man, and Cybernetics Part A: Systems and Humans, vol. 27(4), 1997, pp. 436-448.

[28] M.A. Anwar and T. Yoshida, "Integrating OO road network database, cases and knowledge for route finding," Proc. the 2001 ACM symposium on Applied Computing, 2001, Las Vegas, NV, USA, pp.215-219.

[29] J. Wang, W. Zhang and H. Mao, "Study of Graph Simplifying Method in GIS Network Analysis," Acta Geodaetica et Cartographica Sinica, vol. 30(3), 2001, pp. 263-268.

[30] K.F. Richter, M. Tomko and S. Winter, "A dialog-driven process of generating route directions," Computers, Environment and Urban Systems, vol. 32, 2008, pp. 233-245.

[31] M. Hampe and B. Elias, "Integrating topographic information and landmarks for mobile navigation," in Location Based Services and Telecartography, G. Gartner, Eds. Wien: Geowissenschaftliche Mitteilungen, 2003, pp.147-157.