A Data Model for Guide Sign System and Its Application in Guide Sign Placement

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Abstract—Guide signs are recognized to be one of the most important elements in road facilities. The frequent changes of road network structure and traffic control strategies in urban area promote the need of updating guide sign dynamically and designing a placement solution rapidly. In order to accomplish those requirements, a data model is introduced to describe the guide sign system and the extracting data will be stored in the guide sign database. The data model is composed of five core components: junction, road segment, guide sign location, guide sign panel, and guide sign item. A Point of Interest Oriented Placement Method (POIOPM) is proposed to accomplish the need of designing a placement solution for POI rapidly. Finally, the placement solution to the proposed data model is built on the platform of ArcGIS and C#. It has shown the solution matches the practical guide signs. This indicates the correctness and reliability of the proposed data model.

Keywords—guide sign; road network; data model; guide sign placement; point of interest

I. INTRODUCTION

Guide signs are facilities to indicate road user to travel along the route and inform them of destinations and intersecting routes. Due to its outstanding function in directing road and way-finding, guide sign is taken as a main approach to alleviating traffic congestion by indicating traffic to an alternate route. The complicated urban road network and widely distributed Point of Interest (POI) make it difficult for engineer to work out a rational and feasible guide sign placement solution. What makes matter worse is that several new building roads may change the structure of original road network and alter the best path between two traffic generators. In these complicated condition, it is approximately impossible for engineers to work out a program to check out all the unreasonable and incorrect guide signs. Poor guide paths mean dissipating much more time and fuel and might cause congestion. And if engineers want to check whether a serial of guide signs, which indicate the same destination, collaborate with each other and form a consistent guiding path, they have to drive along the route directed by those guide signs and check it one by one.

Due to the complex management tasks, the demand for a data model to abstract road guide sign into structure data which support engineers to handle, analyze and edit guide signs is increasing rapidly. Thanks to the highly developed image processing and locating technique, we can acquire guide signs data easily. Numerous scholars have thrown themselves into the research of extracting indicating information which contains name or number of indicating object (route or destination), guiding direction (single head arrow), cardinal direction and guiding distance from road guide sign sheets. Maldonado et al. [1] provides a road guide sign detection and recognition system based on support vector machines. Benallal and Meunier [2] implement a color segmentation strategy to recognize guide signs in various sunshine. Fang et al. [3] introduces an approach which utilizes two neural networks to extract color and shape to detecting and tracking guide signs. Reference [4] proposes a road sign classification utilizing new Laplace kernel rule. The largest number of these methods are oriented for the driver support systems or computer vision systems of intelligent vehicles. Most of them put the emphasis on guide sign recognition and data extract, rarely referring to how to store these extracted information in structured database.

Reference [5] and [6] provide general guidelines in designing and mounting the guide sign, but doesn’t give any detail information for which destinations or streets should be indicated or which junctions should place guide signs indicating a specific destination. Some scholars go into the research of optimizing the existing signage on one route or in a particular area. Lan [7] finds the more lanes and higher speed the road is designed, the greater advance placement distance of guide sign are required. Toi [8] defines the Straying Index and proposes a mathematical model and its algorithm to build the optimum road sign system whose optimization goal is to minimize the Straying Index. These scholars’ research supplements the deficiency of national standards.

In general, previous studies mainly focus on the extraction of indicating information; the effect of signage features on legibility, such as retroreflectivity, alphabets, font, and capitalization [9][10][11]; influence of human psychological and physiological factors and other outside environment on drivers’ reaction time [12][13]; layout rules and optimization model [7][14]. But, from the point of traffic management and planning, these researches are far insufficient to support traffic engineer to analyze, modify and update guide signs, not to mention establishing a placement solution according to specified deployment rules.

The objective of the paper is to develop a data model for guide sign system and a placement method for Point of Interest (POI) and utilize the placement method to create a placement
solution. The placement solution is stored in the guide sign database generated from the conceptual model. Firstly, our research begins with analysis of guide sign national standard and features, then focuses on the guide sign data model and a road network data model for guide sign. Secondly, we have tried to transform our guide sign system data model to a guide sign database whose data came from the placement method. Finally, our placement method has been tested on the Guangzhou High Education Mega Center (GHEMC). By comparing our placement solution with the current one and analyzing the consistency, we have tried to figure out the gap between the solution and the current scheme.

This paper is organized as follows: after the introduction, Section 2 introduces a guide sign data model and a road network data model for signs. In Section 3, an overview of guide sign placement method is described. And Section 4 gives some results to support our theories. Some conclusion and discussion of future research are drawn in Section 5.

II. DATA MODEL FOR GUIDE SIGN SYSTEM

Due to the fact that guide signs are closely associated to road network, the guide sign system can be divided into two parts: road network and guide sign. Signs are located in the road network, and we assume that signs are placed only at the approaches towards junctions. Furthermore, the indicating route and destination are part of road network. Therefore, there is a need to establish a road network data model to match the demand of guide sign. Thus, the road network must be satisfied these characteristics as follows:

- There are two essential components including geometry and topology. More specifically, geometry represents real roads’ general configuration and topology describes the connectivity among road segments;
- Junction and road segment cloud be the modeled as the primary elements of road network;
- The data model should support to describe the different traffic flow directions within a road segment, no matter whether it is one-way or bi-directional;
- Traffic rules are able to attached to junction and road segment;
- Non-planar intersection could be described by the model.

A road network is generally represented as a node-arc model by a set of nodes and links. The designed conceptual data model on the base of the classical node-arc model is constituted upon the above criteria list. Geometry of the data model is subdivided into two categories: point geometry and linear geometry. Point geometry is the abstract shape of junction, and linear geometry represent the linear shape of road segment. Topology is modeled as a logical abstraction of Geometry. It represents the physical and logical connection among geometry. The physical connection describes the connection in spatial, while the logical connection represents the connection in traffic rules.

Topology of the data model can be specified by the directed graph. We denote a directed graph as \( G = (V, A) \), where \( V = \{ v_i \} \) is a set of nodes and \( A = \{ a_{ij} | a_{ij}=(v_i, v_j), v_i, v_j \in V \} \) is a set of links. As mentioned above, \( v_i \) is the abstraction of junction point and road segment polyline is extracted as \( a_{ij} \). We define that there exists only one link between two nodes, but may be two traffic flow directions. That is to say, \( a_{ij} \) and \( a_{ji} \) represent the same road segment and opposite traffic flow directions.

We define a pair of links that are connected in a node as Connected Links, and if the turn between the Connected Links is allowed, the pair of links is called Accessible Links. In road network, traffic rules always make themselves way out by regulating the accessibility among links. Thus, to a certain extent, traffic rules regulate logical connection of topology. The adjacent link set is a collection of all the links starting or ending with the same node from the north in clockwise order, and it is denoted as \( v_a.\text{AdjLinks} = \{ a_j | \forall i = k \text{ or } j = k, a_k \in A \} \). \( v_a.\text{ConnState} \) is an \( n \times n \) logical connectivity matrix among adjacent links, and it is defined as (1). \( n \) in (1) is the count of adjacent link set of \( v_a \). If \( a_k \) and \( a_i \) are Accessible Links, \( c_{ij} \) is equal to “1”; otherwise, “0” is assigned to \( c_{ij} \).

\[
v_a.\text{ConnState} = \begin{bmatrix}
    c_{11} & \cdots & c_{1n} \\
    \vdots & \ddots & \vdots \\
    c_{n1} & \cdots & c_{nn}
\end{bmatrix}
\]  (1)

North angle set, a collection of angle from North towards adjacent links in node \( v_a \), is introduced to record the geographic orientation of adjacent links. We denote the set as \( v_a.\text{NorAngles} = \{ \theta_k | \text{ angle from North towards } a_k, a_k \in v_a.\text{AdjLinks} \} \). Thus, by processing the information of north angle set, adjacent links set and logical connectivity matrix implicitly, we can figure out the accessibility and turning direction of any pair of Connected Links. Other attributes of node and link are highlighted in Fig 1.

In order to fulfil the most common requirements of guide sign administration, such as guide sign placement, analysis, accessibility optimization and plate visualization, a reasonable and practical guide sign data model should ensure:

- **Multilevel model.** The data model is able to respectively describe the spatial and traffic information of the installed place, the style of panel ruled by national standards, the spatial and traffic information of indicating object;
- **Way-finding and path guidance.** The data model should support for drivers’ way-finding in the traffic network, that is, guide sign data model must establish the association between signs and road network;
- **Plate visualization.** The visual sign panel is the most intuitionistic way to show the features of signs. The guide sign data model should support to assemble indicating object on the panel dynamically. Furthermore, the indicating information on panel ought to be updated with the change of guide sign database.

The guide sign conceptual data model is designed with three level: guide sign location, guide sign panel and guide sign item. Guide sign location depicts the position of guide signs in traffic road network, and it can be look on as the abstraction of installed point of signs. Guide sign panel describes the entire guide sign sheet designated on the installed point. As we know, there may be more than one panels on one installed point, that
is, the relationship between guide sign location and panel is one to many. In the third level, Guide sign item is the description of guide sign objects such as destination, route, cities, towns and other points of interest. Similar to guide sign location and panel, the relationship between guide sign panel and guide sign item is one to many, and it can be verified by the fact that the largest number of destinations regulated by MUTCD on Advance Guide and Supplemental Guide is three.

Unlike other facilities, guide signs are associated closely to road network topology for their specific usage such as way-finding, route guidance. Therefore, setting the association between guide sign and topology is the critical component in the process of establishing guide sign data model. The association is mainly embodied in guide sign location and item. A valid guide sign location is the integration of geometry and topology attributes. Geometry highlights the installed point in road network and topology attributes state the association with traffic network. The combination of indicating information and associating topology make up an integral guide sign item. Indicating topology is made up of the locating link of sign indicating intersection and the first arrival link through the indicating intersection. As mentioned above, the indicating information contains indicating object name, distance from the installed point to the destination and turning direction from locating road segment to the first arrival road segment in the indicating junction.

POI, road and indicating object are proposed to describe detail attributes of associated entities in guide sign system. POI depicts destination in road network, and entrances of a POI record the association between destinations and road network. Road is the modeling element to describe an entire highway owning the same name or number, and a road is divided into a serial of road segments by junctions. Indicating object is the element to integrate all kinds of guiding items, and an indicating object can be a POI or road. The detail attributes and relationships of road network, guide sign and associated entities are presented in Fig. 3.

III. PLACEMENT METHOD

The Destination Sign is one of the most important component in guide sign classification system. A destination usually is a (POI). A large amount of traffic generating from POI affluxes into the mainstream of urban traffic. Destination Sign is the most commonly used facility to lead them back to or out of these places. Thus, Destination Sign stresses the consistency and convenience of guiding path much more than other signs. From this perspective, way-finding and path planning are the key to working out a guide sign placement for POI. We propose the POI Oriented Placement Method (POIOPM) to design a placement solution.

First of all, the road network must support way-finding and POI locating. As described above, the road network data model for guide sign has taken logical and physical connection relationship into account. By calculating $v_i$AdjLinks and $v_i$ConnState, we can figure out the connecting state and shortest path (if connected) of any couple of nodes $v_i$ and $v_j$. In order to locate the POI in road network and provide way-finding for destination signs, establishing the association between POIs with the road network is a necessary step. The work we need to do is to associate the POI with the entrance road segment if the POI owns an entrance, otherwise we take the nearest road segment as its entrance.

The placement method could be elaborated as follow:

- **Step 1: generate road network.** Collect physical road data, logical connection data in junction and POI information in reality, then establish road network database under the guidance of road network data model.
- **Step 2: designate a placement region.** Divide a region for guide sign placement in the road network established in Step 1, and the placement region is denoted as $R$;
- **Step 3: create installed point.** Utilize linear reference method to create guide sign installed point beside of all the approaches to the intersection under the guidance of national standards.
- **Step 4: select guide sign style.** Follow the guideline ruled in national standard to select panel style according to the shape of intersection and traffic rules.
- **Step 5: choose a POI as the indicating destination.** Our method only supports to design a placement solution for a single POI at present.
- **Step 6: get directing path for the required approaches.** In this step, we will define a placement road network for the POIOPM, and way-finding algorithm will be utilized to search the placement path in the placement road network.
- **Step 7: assemble indicating objects on the panels.** Filter out the installed points for the guiding destination, acquire the indicating information from the shortest path and assemble the indicating information on the signs.

A POI usually owns its sphere of influence which is used to describe the space distributing the most traffic from the POI, and we assume that the sphere of influence is a circle whose
center is the POI itself and radius is \( r_c \). We regard the sphere of influence as the placement region of the destination sign and it is denoted as \( R \). China National Standard requires that all the approaches of junction must install Intersection Sign in urban areas. That’s to say, every approach to intersection owns at least one installed point for guide sign. Standards have regulated the distance between a junction and a guide sign as well. That gives a possibility and guideline to create the installed points of guide signs with the assist of the linear reference method. In the process of creating installed point, the association between the installed point and topology is established.

The style of guide sign panel is determined partially by the features and attributes of the indicating junction and guiding items. Firstly, the type of guiding objects determine the type of guide signs, for example, reference [6] regulates that all numbered highway routes shall be identified by Route Signs and Auxiliary Signs, and the Destination sign shall be a horizontal rectangle displaying the name of destination and directional arrow. We assume that guide signs are installed mainly on the approaches to the indicating intersection; that is, if there are traffic rules regulating turning directions in the junction such as prohibited left turn or U-turn, sign must hint the rules on the panel. The turn rules are embodied in the logical connection attribute of intersection. If the indicating junction is \( v_k \) with four legs \( a_{j1}, a_{j2}, a_{j3}, a_{j4} \) and \( a_{i1} \) is the road segment where guide sign is installed and we name it as locating link. Supposing that the turn from \( a_{j2} \) to \( a_{j3} \) is left and it is forbidden, the sign on \( a_{j2} \) has no need to indicate the destinations and routes on the left turn. Therefore, the attributes of junctions absolutely determine all the guiding directions which are needed to be displayed on the panels. In brief, by analyzing and calculating the characteristic of indicating junction and guiding object, we can figure out the panel style in a given installed point. So far, we have gained all the attributes of the guide sign location and panel. Thus, the first two levels of the conceptual data model are translated into database scheme.

It is widely accepted that drivers prefer to steering on the higher hierarchy street than the lower one, for instance, express way and arterial road in preference to collector road and branch road. But convenience play a much more critical role in the process of road choice when drivers are approaching their destination in the vicinity of POI. To cater to the need of driving habits, on one hand, we lead drivers to steer on the express ways or arterial roads (higher hierarchy road) as much as possible when they are far away from the POI; on the other hand, we provide the possibility for drivers to choose more convenient road to drive no matter what the hierarchy of roads are. Thus, we define a placement road network for POI. The placement road network is made up of two parts: core placement scope (denoted as \( G_p \)) and the peripheral placement scope (denoted as \( G_p' \)). \( G_p \) is composed of all the four hierarchy highway, and the scope is a circle whose center is POI and radius is \( r_c \). The corresponding peripheral guidance scope consists of higher hierarchy highway, and the scope is an annulus whose center is POI and inner radius is \( r_c \) and outer radius is equal to radius of the placement region. Thus, the core scope links up seamlessly with the peripheral scope via join road segments. The placement road network for \( D \) could be denoted as \( G_{pD} = G_p \cup G_p' \). Fig 2 presents the process of extracting guidance road work.

At present, our placement method is aimed at a single POI. Since the requirement of running time of the guide sign placement processing is not demanding and our objective is to find one-to-many paths, Dijkstra’s algorithm is able to satisfy our demand to search placement path perfectly and efficiently. Denote the shortest path from \( v_k \) to POI’s associated link \( a_{mn} \) as \( P(v_k) = \langle v_k, v_{k1}, a_{j1}, v_{j1}, a_{j2}, v_{j2}, a_{j3}, v_{j3}, a_{j4}, a_{mn} \rangle \). It should be noted that the logical connectivity matrix must be taken into account in the process of finding shortest path.

The rules listed below must be taken into consideration when filtering out the installed points for the guiding destination.

- The distance between two neighboring guide signs within a road in the \( G_p \) must be more than 500 meters. If not, the installed point locating on the road segment intersecting a higher hierarchy street is preferred and the further point is in preference to the nearer one if the intersecting roads are the same hierarchy;
- The approaches away from the POI have no need to place a sign guiding to POI unless there exists a need to place an U-turn sign;
- It is not allowed that two carriageways of a road segment own the signs indicating the same POI except that one’s indicating direction is U-turn.

The indicating information placed on Destination Sign...
contains the name of destination, the cardinal direction, distance (if needed) and the arrow pointing at appropriate angles to the left, right and ahead. The attribute of $v_i.\text{AdjLinks}$ and $v_i.\text{NorAngles}$ provide the possibility to calculate the turning angle from the locating link ($a_h$) to the link ($a_j$) towards POI on the shortest path. Because the $v_i.\text{NorAngles}$ record the angle from the north towards $a_h$, it is not hard to figure out the cardinal direction. The guiding distance to POI is able to be got by calculating the length of shortest path. Thus, we have got the indicating information for every installed point which is require to mount a sign guiding to the destination. The final step we need to do is to assemble the indicating information on the panels. Since every installed point owns at least a panel associated to it, the final step is to choose the right panel whose style suits for destination and store the indicating information in the Guide sign item data table.

IV. CASE STUDY

The design of the experiment includes the preparation of the road network data and designing a guide sign placement solution. Road network with turn controls from Guangzhou High Education Mega Center is used to test our guide sign placement method. Guangzhou High Education Mega Center is an isolated island with two entrances and exits: Guanzhou Tunnel and Nansha Port Express. The network is a typical radial and circular pattern with three circle main roads and a serial of radial streets. There are several universities, tourist attractions and public services in the mega center. The Sun Yet-sen University which is made up of Living Area (SYSULA) and Teaching Area (SYSUTA) is taken as our indicating object. We set the whole island as our test area, that is, the placement scope is the entire island, and the radius of the core scope as 1.5 times of the radius of circumscribed circle of the POI’s envelope.

Fig 3(a) presents the current guide sign placement for SYSU and Fig 3(b) depicts the placement road network and the designed placement solution for SYSU. Obviously, our placement for POI covers the most installed points in reality. But it tends to be redundant in some areas, such Area 1, 2, 3. But, considering the special function of Road 1 (Nansha Port Expressway) which is the one of most important entrances of the island, the guide signs installed in Area 1 and Area 2 are needed. The difference of placement solution create by POIOM and the current one reflects in the way to lead driving route. The current placement enhances the convenience of driving route, in another world, the guide signs lead the motorists to driving on the different segments within a road as much as possible and the same or higher hierarchy roads are chosen as the indicating direction rather than the direction of the shortest path. So, the installed Point 2, 3, 4 of our placement (in Fig 3(b)) indicate to left which is the direction of the shortest path to SYSU. Because we haven’t taken the U-turn into account, for example, we do not assemble a sign on Point 1 where exists a guide sign indicating U-turn for SYSU in reality. However, our placement solution may give some suggestion for the current one. We can see there are additional installed points in Area 4 and Point 5. These guide signs are essential for the consistency of destination guide signs.

Finally, we have analyzed the consistency of our placement solution. The darker lines in Fig 3(b) represent the continual routes guiding from the first signs directing the SYSU. The result of consistency analysis is obvious because of the route searching method we use. We utilize the Dijkstra’s algorithm to search the shortest path from every node to the guiding POI. Thus, the shortest path itself is continual.
V. CONCLUSION

We have proposed a data model for guide sign system and placement method for POI. The road network is based on the traditional node-arc data model and added the traffic rules in the intersection. Then we introduce a placement method for POI. Finally, we test our model on the GHEMC. The road network for guide signs is built to support the placement and analysis of guide signs. The placement method is applied on the test area and a corresponding placement solution is created. In order to test the practicability and rationality of placement solution, we compare the placement solution with the current and analyze the consistency of guiding message.

The experimental results show that road network associated with traffic rules in junction and the three level guide sign data model is a novel approach and is flexible to handle the guide sign data in real world. The guide sign data model provides a potential data model suiting for all the guide sign administration. The placement method presents a practical way to establishing a guide sign placement solution. Though our data model and placement method have tested its correctness and reliability in the experiment, there are still many issues worthy of our further research.

We have applied the guide sign system data model in the guide sign placement, consistency analysis and sign panel visualization. However, our tested applications haven’t covered all the common administrations in engineering. In addition, no more indices are available for guide sign evaluation and analysis apart from the consistency. That makes it difficult for us to evaluate the advance and drawback of the placement solution. Furthermore, limited by the data source of guide signs, the comparison between designed placement and the real world is limited to the scope of several intersections and hardly involving the area comparison. At present, our placement method concentrates on a single POI, but the placement solution in reality usually requires to integrate multiple POIs guidance.

Thus, we will test our data model on other guide sign administration fields, and improve it to realize the data sharing and interaction among different application fields. Then we will focus on guide signs data extracting and establish the guide sign database to support evaluation and analysis. Our long-term goals is to develop a guide sign placement model for Multiple POIs and establish a complete evaluation and analysis system for guide sign placement solutions.

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