Urban Route Planning Considering Traffic Flows

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***Abstract*—Urban route planning is an important direction in the research of Intelligent Transportation Systems (ITS). As the development of sensor and information technology, we can recognise timely how crowded a street is. Route planning considering traffic congestion can further improve people's travel and effectively reduce the time-cost. In this paper, we use the traffic flow of a road to describe how crowded this road is, and construct a weighted network model based on a traffic-flow data of the main roads in the center of Beijing. By designing the network's weights, route planning considering traffic flows is transformed into searching for the shortest paths in the network. This route planning has been realized based on the real data in this paper. The results have shown that the routes recommended by the strategy considering traffic congestion save more time for travellers than the strategy not considering the traffic congestion.**

***Index Terms*—Intelligent Transportation Systems, route planning, road network, traffic flows.**

I. Introduction

Development of the satellite navigation and electronic technology makes all kinds of navigation instruments common, and electronic maps bring a big convenience for people's travel. Route planning of the electronic map is based on the principle that travel time from the start to the destination should be the shortest. The time passing through a road costs, which is called theoretic shortest time, is computed by dividing the permissive maximal speed of the road into the distance, and the traffic congestion is not considered. However, increase of the vehicles makes urban road traffic all the world over more crowded. The theoretic shortest time has been affected badly by the traffic congestion. Congestion in different roads are different, so the route recommended by the theoretic-shortest-time principle is always not the optimal one that cost the shortest time. To improve this, urban route planning should consider the traffic congestion. Besides, the inherence of the urban route planning considering traffic congestion that avoiding the most crowded road relieves the traffic a certain extent.

Nowadays, we have entered into a data-intensive era [1]. Supporting by the current technology and abundant data, the design of Intelligent Transportation Systems (ITS) [2] is continually improved to make people's travel more convenient. By different kinds of traffic surveillance methods, we can obtain each road's traffic flow in a whole city. According to the analysis of the traffic flows, the congestion degree of each road can be evaluated, and then route planning considering traffic congestion can be realized based on the traffic flows.

In this paper, we construct a weighted network model based on a traffic-flow data of the main roads in the center of Beijing. The weights in the network are the actual time passing through the roads cost, which are evaluated by the traffic flows. According to the design of the network model, route planning considering traffic flows is transformed into searching for the shortest paths in the network and has been realized based on the real data of Beijing. The remainder of this paper is organized as follows: in Section II, we introduce the related concepts about complex network, Dijkstra algorithm and the effects of the Traffic Performance Index on the travel time; in Section III, the construction of the road network model considering traffic flows is presented; in Section IV, we analyze and discuss the routes recommended by the strategy considering traffic flows; Section V gives the conclusions.

II. Basic Concepts and Methods

A. Concepts on Complex Network

A network consists of a set of vertices (nodes) and edges (lines) which connect the vertices (nodes), and can be represented as a graph. If the edges in a network have directions, the network is a directed network otherwise it is an undirected one. If the edges in a network are assigned with values which are called weights, the network is a weighted network otherwise it is an unweighted one.

A path from a node v_1 to another node v_n in a network is an alternate sequence of nodes and edges, $v_1, e_1, v_2, e_2, ..., v_n$, in which each edge e_i connects node v_i and node v_{i+1} and no edge and node are repeated. The length of a path in an unweighted network is defined as the number of edges the path contains, while in a weighted network it is the sum of weights assigned to edges. The shortest path from a node v_1 to another node v_n in a network is a path which links the two nodes and has the shortest length. The length of the shortest path is also called the distance between a pair of nodes.

B. Dijkstra Algorithm

Dijkstra algorithm, which is a classic algorithm to compute the shortest paths in a network, was proposed by a Netherlandish scientist E. W. Dijkstra in 1959 [3]. This algorithm can be used to obtain the shortest paths from a start point v_1 to the other points in the network and the length of these paths. In the algorithm, points in the network are divided into three categories: unsigned points, ready-signed points and signed points. In the beginning, all the points are initialized as unsigned points, the points between which the shortest paths and the start point v_1 have been obtained are called signed points, and the points which directly link with the signed points during the search are the ready-signed points. The shortest paths are obtained by a repeating method. During the searching process, the one between which the length and the start point v_1 is the shortest in the ready-signed points will be chosen to be a signed point. When all the unsigned points are signed, the repeating process ends.

We assume that a network contain n points, the set of all the points is V, the start point is v_1. The detailed process that computing the shortest paths to other points v_i is described as below.

Algorithm 1 Dijkstra Algorithm

Initialize:

for each $v_i \in V$ **do**
    $d(v_i) \Leftarrow \infty$
end for
$d(v_1) \Leftarrow 0$
$S \Leftarrow [v_1]$
$u \Leftarrow v_1$

Search Process:

while $S \neq V$ **do**
    for each $v_i \in Q$ **do**
        if $d(v_i) > d(u) + \omega(u, v_i)$ **then**
            $d(v_i) \Leftarrow d(u) + \omega(u, v_i)$
            $f(v_i) \Leftarrow u$
        end if
        $v^* \Leftarrow \emptyset$
        $d(v^*) \Leftarrow \infty$
        if $d(v^*) > d(v_i)$ **then**
            $d(v^*) \Leftarrow d(v_i)$
            $v^* \Leftarrow v_i$
        end if
    end for
    $S \Leftarrow S \cup [v^*]$
    $u \Leftarrow v^*$
end while

In the algorithm description above, $d(v_i)$ represents the distance between the start point v_1 and v_i, S is the set of signed points, Q is the set of ready-signed points, u and v^* are both temporary variables, and $\omega(u, v_i)$ is the weight of edge from u to v_i.

C. Effects of Traffic Performance Index on Travel Time

In China, urban traffic congestion can be described by the Traffic Performance Index (TPI) [4]. The Traffic Performance Index is represented by a integer number between 0 to 10 and divided into 5 levels. Effect of each level of traffic congestion on the travel time is listed in TABLE I.

TABLE I
EFFECTS OF TRAFFIC PERFORMANCE INDEX ON TRAVEL TIME

TPI	Effects on travel time
0-2	no effects
2-4	an increase by 0.2-0.5 times
4-6	an increase by 0.5-0.8 times
6-8	an increase by 0.8-1.1 times
8-10	an increase by more than 1.1 times

Hence, we built a function to represent the relation between TPI and travel time, as shown in equation 1.

$$T' = \begin{cases} T & TPI < 2 \\ (1.2 + 0.3 \cdot \frac{TPI-2}{2} T) & 2 \leq TPI < 8 \\ 1.5T & 8 \leq TPI < 10 \end{cases} \quad (1)$$

where, T' is the actual travel time and T is the theoretic shortest time.

III. CONSTRUCTION OF THE WEIGHTED ROAD NETWORK

A. Introduction of the Real Main Road Map with Traffic Flows

In this paper, we achieved the GIS data of the Main Roads in Beijing center (Fig. 1). This data is composed of large numbers of main roads, as we can see from the figure, the GIS data supplies the detailed geographic locations of all the roads. Furthermore, the data contains the length, width, and hourly traffic flows in 6 weekdays and 3 weekends of each road. Connections among the roads can be abstracted as a network naturally, and the traffic flows can be used to evaluated the congestion degree of each road.

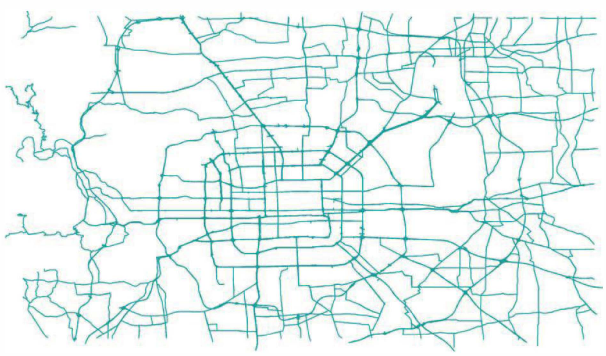


Fig. 1. Main Road Map of Beijing Center

B. Structure and Weights of the Network

There are three main road network modeling methods: primal graph approach [5], dual graph approach [6], and "Name Street" method [7]. In the primal graph approach, junctions are abstracted as nodes and roads are abstracted as edges. While in the dual graph approach, roads are abstracted as nodes and junctions are abstracted as edges. The "Name Street" method reflects a higher level of abstraction topological connections in a given street network, in which many roads with the same name are abstracted as one node and edges represent the connections among these roads with different names.

Among the three methods, primal graph approach is the most simple and links among the points are more comprehensive. Furthermore, each road is represented as a segment in the GIS data and the nodes on the both sides of the segment can be endowed with an unique ID separately by ArcGIS. Hence, structure of the road network is constructed by the primal graph approach naturally, namely the nodes on the both sides of the line which represents a road are abstracted as points and the lines are abstracted as edges.

The network structure abstracted from the real map supplies correct connection of the roads. However, it is still not enough for the route planning. Each edge should be endowed with a suitable weight. As in the traditional route planning without considering the traffic congestion, the weight of each edge is the theoretic shortest time passing through the corresponding road costs. To evaluate how crowded a road is, we assume that traffic flows of all the roads are stay in the non-saturation state [8], namely that traffic flows do not exceed the roads' transportation power. In other words, the traffic flows can directly reflect the congestion degree of roads and the heavier the traffic flow in a road is the more crowded this road is.

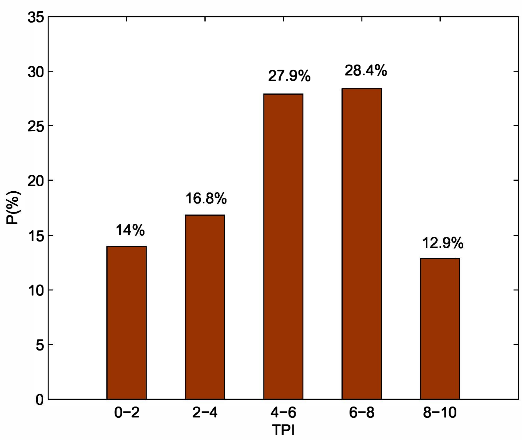


Fig. 2. Distance Distribution of TPIs during the Morning Peak of Weekday in Beijing's Main Roads

One always has the similar behavior pattern in the weekdays and another different behavior pattern in weekends [9]. Therefore, we assume that one would have the same travel pattern in each day of the weekdays, and use the average hourly traffic flows of the 6 weekdays to represent the hourly traffic congestion in each weekday. The same data processing was also applied to the weekends' traffic flows.

According to 2010 Traffic Reports of Bejing City, the distance distribution of main roads with different congestion degree during the morning peak (7:00 to 9:00) in weekdays are shown in Fig. 2. To build the relationship between traffic flows and TPIs, we choose the period 8:00 to 9:00, in which the maximal traffic flow appears, to be weekday's morning peak. Then all the roads are sorted by the increasing order of traffic flows in them and the traffic flows are distributed into five intervals according to the distance distribution in Fig. 2. The five traffic-flow intervals are corresponding to the five TPI levels, and the relation between traffic flows and TPIs are listed in TABLE. II.

TABLE II
RELATION BETWEEN TRAFFIC FLOWS AND TPIS

TPI	0-2	2-4	4-6	6-8	8-10
Taffic Flows (pcu/lane/hour)	0-24	24-33	33-46	46-63	63-145

We assume that there exists a linear relation between TPIs and traffic flows in each traffic-flow interval, a function was designed as shown in equation 2.

$$TPI = \begin{cases} \frac{f}{12} & 0 \leq f < 24 \\ 2 + \frac{2(f-24)}{9} & 24 \leq f < 33 \\ 4 + \frac{2(f-33)}{13} & 33 \leq f < 46 \\ 6 + \frac{2(f-46)}{17} & 46 \leq f < 63 \\ 8 + \frac{2(f-63)}{82} & 63 \leq f < 145 \end{cases} \quad (2)$$

where f represents the traffic flow.

We assume that if there is no any impact from other vehicles the average velocity of a vehicle is 42 km/h. According to equation 1, equation 2 and traffic flows of the roads in different temporal intervals, we can evaluate the actual time passing trough the roads costs. The actual time passing trough each road costs can be regarded as the weight of the edge which represent the road. Thus, route planning considering traffic congestion is realized by searching the shortest paths from the start to the destination using Dijkstra algorithm.

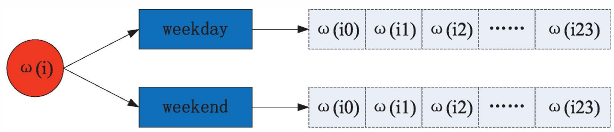


Fig. 3. A Edge's Weight

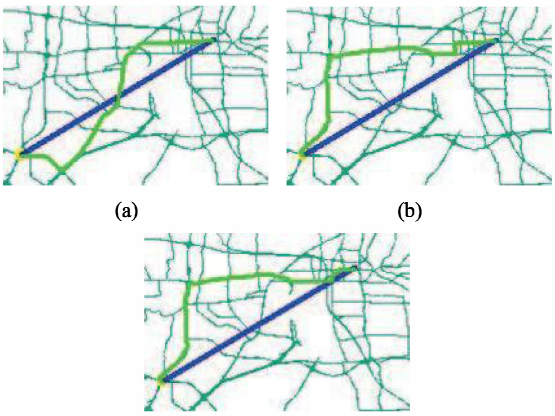
Since the traffic flows change over time and traffic flows has two different pattern: weekday pattern and weekend pattern, weights of edges in the network also need to change in the route planning process from the start to the destination. Therefore, weight of each edge in the network is composed of hourly time passing through the road costs in the weekday pattern and weekend pattern. The weight of a edge is shown in Fig. 3.

The detailed route planning process from the start to the destination is as follows:

- Deciding the pattern of the weights (weekday pattern or weekend pattern) by the date.
- Updating the weights of the whole network according to the start time.
- Searching the shortest path using Dijkstra algorithm. When a new point would be signed, we will judge whether it is the destination point. If it is, then the search stops. If it is not, the time reaching this point costs will be recorded. Then, the pattern and temporal interval will be updated according to recorded time and the weights will be updated along with them. The search will not stop until the destination point is found.

IV. Results and Discussion

Based on the mapping between the network model and GIS data, we developed a tool to realize the route planning considering traffic congestion in the main roads of Beijing center. We randomly chose a pair of points to be the start and the destination. The start time was set at 8:00. Then we obtained the optimal routes under the weekday and weekend pattern. Comparison between the strategy considering traffic congestion and not considering traffic congestion is shown in Fig. 4.



(a) (b)

(c)

Fig. 4. Results of Route Planning under the strategy considering traffic congestion and not considering traffic congestion

In Fig. 4, the bold green lines represent the recommended routes. Fig. 4(a) shows the route recommended by the strategy not considering traffic congestion; Fig. 4(b) shows the route in weekday pattern recommended by the strategy considering traffic congestion; Fig. 4(c) shows the route in weekend pattern recommended by the strategy considering traffic congestion. Since the strategy not considering traffic congestion do not distinguish the weekday pattern and weekend pattern, routes recommended by it are the same in both weekdays and weekend. From the results we can clearly see the impacts from the traffic congestion on the route planning. The different traffic congestions in weekdays and weekend have made the routes under the two pattern different, which are recommended by the strategy considering traffic congestion. Moreover, the two routes are different from the one recommended by the strategy not considering traffic congestion. We have recorded the distances of the routes and time passing through the routes recommended by the two different route planning strategies in the two different pattern (TABLE III and TABLE IV).

TABLE III
COMPARISON OF ACTUAL TIME PASSING THROUGH THE RECOMMENDED ROUTES

	Weekday Pattern (min)	Weekend Pattern (min)
Not Considering Traffic Congestion	57.39	52.12
Considering Traffic Congestion	49.08	43.97

TABLE IV
COMPARISON OF DISTANCES OF THE RECOMMENDED ROUTES

	Weekday Pattern (km)	Weekend Pattern (km)
Not Considering Traffic Congestion	27.07	27.07
Considering Traffic Congestion	28.91	28.61

From the tables, we can see that though it has a shorter distance, the route recommended by the strategy not considering traffic congestions costs more time to reach the destination than the routes recommended by the strategy considering traffic congestions. Moreover, since traffic is usually more smooth during the period 8:00 to 9:00 in weekends, we can see that reaching the destination costs less time in weekends than weekdays.

V. Conclusion

In this paper, we have constructed a weighted network model, in which the weights are designed by the traffic flows in the roads. According to Dijkstra algorithm, the shortest paths between a pair of points in the network can be found and the route planning considering traffic congestion is realized by this. Furthermore, we developed a tool to compute the optimal routes based on the main-road map of Beijing center. Using this tool, the least-time-cost routes from a start to its destination can be obtained easily. Then we compared the routes recommended by the strategy considering traffic congestion and not considering traffic congestion. The results have shown the importance to consider the traffic congestions. Though it has a shorter distance, the route recommended by the strategy not considering traffic congestion costs more time to reach the destination than the route recommended by the strategy considering traffic congestion.

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