Vehicle route optimization of Centrally Dynamic Route Guidance Systems

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Abstract

Because of severe traffic jams and congestion, nowadays every country applies modern science and technology to solve these problems. This paper will utilize the real-time traffic volume data, the relationship between traffic volume and travel time and the incremental-load short-distance optimization algorithm to research the vehicle route optimization technique of Centrally Dynamic Route Guidance Systems which is one branch of Urban Traffic Flow Guidance Systems (UTFGS, the core of Intelligent Transportation Systems).
Keywords: ITS, UTFGS, CDRGS, traffic flow information, incremental-load short-distance optimization.

1 Introduction

Nowadays, the ever-fast progress of the world's economy stimulates the traffic requirement. Because of the continued increase in traffic volume and the limited construction of highway facilities in urban, intercity and rural areas, transportation has become the 'bottleneck' of modern cities where severe traffic congestion occurs frequently. To some degree it restricts people from going out. For example, in the USA the loss caused by traffic congestion and delay is estimated to be more than 100 billions US dollars [1, 2, 12]. If these problems are not solved, they will continue to be an obstacle to the progress of the whole of society. In order to improve the management of urban traffic, many countries, including China, apply modern science and technologies, including network

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system control, Intelligent Transportation System (ITS) etc. ITS is known as an effective way of managing urban traffic. Consequently there are three typical systems of ITS in Europe, USA and Japan.

ITS includes electronic surveillance, communications, and traffic analysis and control technologies, which bring benefits to users and managers. So, ITS can improve safety, effectiveness and the environment of the transportation system. Urban Traffic Flow Guidance System (UTFGS) [3, 4, 8-10], as a major part of ITS, can solve existing traffic problems effectively. As a part of UTFGS, the Centrally Dynamic Route Guidance Systems (CDRGS) uses dynamic traffic flow information to provide route guidance to the vehicle's requirements. There are many short-distance optimization algorithms, such as Chaotic Neural Network algorithm, Ant algorithm, etc. So, in this paper we will introduce the incremental-load short-distance optimization algorithm which is based on the real-time traffic flow information. Although it is an equilibrium algorithm, this method does not yield an equilibrium solution [17].

2 Basic idea of the incremental-load short-distance optimization algorithm

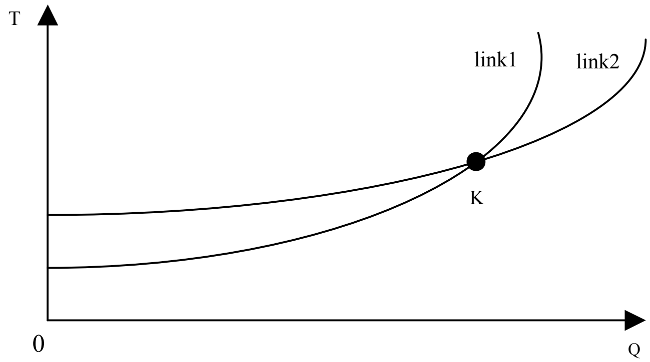
It is known that travel costs, which refer to travel time or travel distance, are an important criterion to judge whether the route guidance is optimized. In this paper the incremental-load short-distance optimization algorithm has the integrative feature of traffic guidance and control and chooses the optimized travel route for the customer.

According to traffic theory, there is biquadratic relationship between link travel time and link traffic volume [6]:

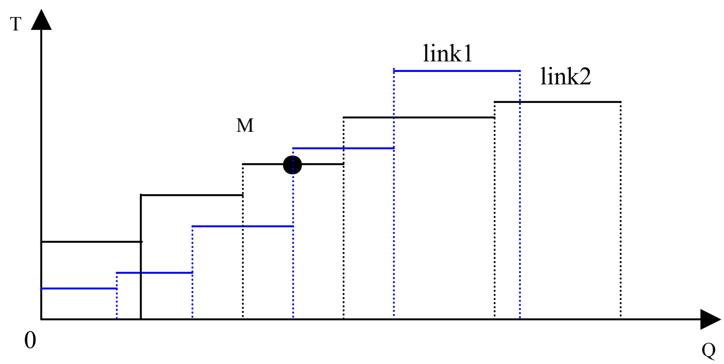
$$t = t_0\left[1 + 0.15\left(V/C\right)^4\right] \tag{1}$$

Then, considering a single link, link travel time increases as link traffic volume increases. As for several links, the link time-volume curve will possibly intercross, as shown in fig. 1(a), (b).

So, the basic idea of the incremental-load short-distance optimization algorithm is [5–11, 16]: firstly, load the traffic volume of all links stepwise into the corresponding link based on a given proportion and utilize the link-block function to calculate link travel time. Then, judge whether the link time-volume curves intercross from fig. 1 to provide real-time optimized route guidance: if they are intercrossed, the optimized route must contain the links in which travel time is lower than the crossing-point M; if they do not intersect, the optimized route contains links which have the shortest travel time. Repeat the computing procedure described above to modify the optimized route, until the traffic volume data of all the links in the network are exhibited, then the final optimized route can be obtained.



(a)



(b)

Figure 1: The relation between link traffic volume and travel time.

3 Real-time traffic flow information prediction

In this paper we use three statistical methods [11–15] and make use of the data gained from 28 detectors at the different intersections in Chang Chun city. The 28 detectors are shown as follows:

1 PA—CQR: N 1001; 2 PA—CQR: S 1012; 3 PA—CQR: W 1013; 4 PA—CQR: E 1014; 5 LR—CS: W 3021; 6 LR—CS: E 3026; 7 LR—CS: S 3027; 8 LR—CS: N 3028; 9 PA—LR: S 3002; 10 PA—LR: N 3007; 11 PA—LR: W 3011; 12 PA—LR: E 3012; 13 XAR—GMR: E 2001; 14 XAR—GMR: W 2008; 15 LR—CS: W 3023; 16 LR—CS: E 3024; 17 LR—CS: S 3029; 18 LR—CS: N 3030; 19 PA—JSR: S 3001; 20 PA—JSR: N 3008; 21 PA—JSR: W 3009; 22 PA—JSR: E 3010; 23 LR—PYS: E 3015; 24 LR—DJR: E 3016; 25 LR—PYS:

W 3018; 26 LR—DJR: S 3019; 27 LR—XMS: E 3025; 28 LR—XMS: W 3022.
PA- People Avenue, CQR- Chong Qing Road, LR- Liberation Road, CR- Comrade Street, XAR- Xi An Road, GMR- Guang Ming Road, LR- Liberation Road, CS- Construction Street,JSR- Jin Shui Road, DJ- DaJing Road, XMS- Xin Min Street. E-east, S-south, W-west, N-north.

3.1 Cluster analysis method

The parameters of system clusters are shown in Table 1. The system cluster result is shown in fig. 2.

In this example, we use the traffic volume of the 6th detector to predict the traffic volume at the east entrance of the Liberation Road – PingYang Street intersection. The equation of regression is:

$$Q_y = 41.58 + 0.73Q_x \tag{2}$$

In this equation Q_y indicates the traffic volume that will be predicted and Q_x indicates the traffic volume that is detected by the detector.

3.2 Principal-factors analysis method

The linear regression is shown as follows:

$$\begin{aligned} y = (&-2.97 + 1.01Z_1 + 0.63Z_2 - 1.61Z_3 - 0.6Z_4 - 0.09Z_5 \\ &+ 0.55Z_6 - 0.35Z_7) \cdot 10^{-5} \end{aligned} \tag{3}$$

Table 1: The parameters of system clusters.

No.	Similarity Coefficient	Row	Column	No.	Similarity Coefficient	Row	Column
1	0.9910	24	23	2	0.9882	17	12
3	0.9875	16	12	4	0.9808	15	12
5	0.9772	18	12	6	0.9759	3	1
7	0.9743	4	1	8	0.9739	6	2
9	0.9706	8	1	10	0.9691	7	2
11	0.9683	11	10	12	0.9667	18	10
13	0.9606	18	9	14	0.9548	7	1
15	0.9527	18	1	16	0.9523	26	23
17	0.9497	25	23	18	0.9484	22	1
19	0.9389	19	1	20	0.9369	14	1
21	0.9007	5	1	22	0.8842	25	1
23	0.8168	25	13	24	0.7869	28	13
25	0.7463	27	13	26	0.6217	20	13
27	0.5140	21	13				

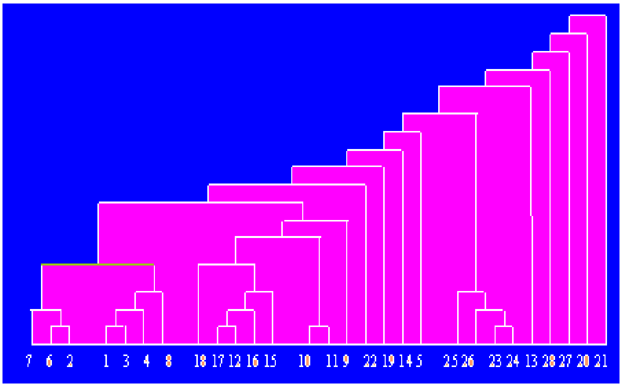


Figure 2: The pedigree chart of a system cluster.

In this example we adopt the ***F*** test method to judge the reliability of this model. The value of ***F*** is 27.9974, and its theoretical value is 2.13, and the multiple relative coefficient is 0.9535.

Here we make use of the data gained from 25 detectors at the different intersections in Chang Chun city, and assume No. 1014 detector (the PA-CQR intersection east entrance) to be a non-detector intersection.

In this example, we obtained seven main-factors by calculation. The coefficients of these seven main-factors are as shown in Table 2.

3.3 Stepwise regression method

In this example, the number of samples is 26, the number of variables is 24, and only two variables were exhibited in the equation: No. 3019 and No. 1001. The linear regression equation is shown as follows:

$$y = -3.78 \cdot 10^{-20} - 0.11x_1 + 0.32x_2 \tag{4}$$

The F test value is 7.7006, its theoretical value is 2.13, and the multiple relative coefficient is 0.9535.

4 Calculation of link-weight

Based on the real-time traffic flow information, in CDRGS we must calculate the link-weight. The link-weight (which refers to the travel time between two intersections) is given by [5–11, 17]:

$$T(i,j) = t(i,j) + d(i,j) \tag{5}$$

where: $T[i,j]$=link-weight;

$t[i,j]$=link travel time;

$d[i,j]$=average delay between intersection No. i and intersection No. j.

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Table 2: Main-factors.

Main-factors / n	z_1	z_2	z_3	z_4	z_5	z_6	z_7
1	0.2134	0.0778	-0.3162	-0.0610	0.1048	-0.0548	0.0465
2	0.2131	0.0803	-0.2948	0.0658	0.1234	0.1423	-0.0725
3	0.2145	0.0912	-0.2875	0.0555	0.0783	0.0945	-0.0132
4	0.2159	0.1166	-0.0190	0.1090	-0.0225	-0.0463	-0.3068
5	0.2223	0.0851	-0.0956	0.0557	0.0374	0.0927	-0.2399
6	0.2095	0.1140	-0.1587	-0.1319	0.0391	-0.2697	-0.2283
7	0.1998	-0.3103	-0.0156	0.0075	-0.1724	0.0527	-0.0472
8	0.2031	-0.2986	0.0469	0.0128	-0.1037	-0.0254	0.0513
9	0.1995	-0.3096	0.0515	0.0772	-0.1202	0.0594	0.0403
10	0.2061	-0.2945	0.0061	0.0330	-0.1123	0.0077	0.0458
11	0.1762	0.2020	-0.1030	0.5522	-0.1343	0.1420	0.2156
12	0.1945	0.1925	-0.2585	0.2146	0.0715	0.1478	0.4383
13	0.2079	-0.2731	-0.0153	0.0014	-0.1055	-0.0752	-0.0360
14	0.1230	-0.2006	0.3175	0.3640	0.8145	-0.1384	-0.0994
15	0.2060	-0.2967	-0.0053	-0.0178	-0.0710	-0.0177	-0.0004
16	0.2053	-0.2777	0.0154	-0.0621	-0.0828	-0.0508	0.1391
17	0.2095	0.1518	0.0071	-0.2759	0.0500	-0.0509	-0.2092
18	0.1574	0.1511	0.5091	-0.1126	-0.0442	0.6311	-0.0505
19	0.1858	0.0307	0.0837	-0.4024	0.2673	0.1176	0.5210
20	0.2099	0.1075	-0.0636	-0.3512	0.1103	-0.1883	0.0268
21	0.2136	0.1155	0.0160	-0.0800	0.0309	0.2300	-0.3303
22	0.1853	0.2178	0.2680	-0.0714	-0.0518	-0.4269	0.2323
23	0.2208	0.1253	0.1035	-0.0476	-0.0550	0.0540	-0.0946
24	0.2064	0.1532	0.2321	0.0160	-0.1202	-0.0672	0.1391
25	0.1710	0.2475	0.3239	0.2710	-0.2792	-0.3390	-0.0334

In the function, $t[i, j]$ is given by the link-block function and $d[i,j]$ is given by the modified Webster function.

4.1 Calculation of link-block function [5, 6, 11, 17]

$$U = \begin{cases} U_0\left(1-0.94\cdot V/C\right), & V/C \le 0.9; \\ U_0/\left(7.4\cdot V/C\right), & V/C > 0.9. \end{cases} \tag{6}$$

where: U_0 - travel speed when traffic volume is zero (km/h)

$$U_0 = rS\eta V_0$$

where: r = discount coefficient of bicycle;

η = coefficient of lane width;

S = influencing coefficient of intersection;

V_0= lane design speed

4.2 Analysis of intersection delay

If the saturation of the entry lane is less, the average delay of each entry lane is given by the modified Webster function [6,17]:

$$d(i,j) = 0.9 \times \left[\frac{T(1-\lambda)^2}{2(1-\lambda X)} + \frac{X^2}{2Q(1-X)} \right]. \tag{7}$$

where: $d(i,j)$ = average delay of the adjacent lane between intersection No.i and intersection No.j

T = cycle length;

λ= effective green time / cycle length on entry of lane;

Q=traffic volume of lane;

X=ratio of saturation $X = Q/(\lambda C)$.

If saturation of the inlet is large, the result gained by the Webster function is on the high side. The function below is proposed by the Handbook of Highway Capacity of America to estimate the delay on the entry lane:

$$d = d_1 + d_2 \tag{8}$$

where:

$$d_1 = 0.38T \frac{(1-\lambda)^2}{(1-\lambda X)},$$

$$d_2 = 173X^2 \left[(X-1) + \sqrt{(X-1)^2 + 16X/S} \right].$$

where: d_1 = uniform delay;

d_2 = super-saturation delay (i.e., incremental delay caused by stochastic approach and additional delay caused by cycle invalidation); the meanings of other symbols are as described above.

In general, the Webster function is applied when the ratio of saturation is X=0 – 0.66; the function proposed by Handbook of Highway Capacity of America is applied when ratio of saturation is X=0 – 1.20.

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5 Application

This paper makes use of the data obtained from 25 detectors at the different intersections in Chang Chun city to perform travel route optimization and obtain satisfactory results. The final optimization route of CDRGS, which is selected by the incremental-load short-distance optimization algorithm, is shown in fig. 3.

6 Conclusion

In this paper, we adopt the Cluster Analysis Method, the Principal-component Analysis Method and the Stepwise Regression Method to predict traffic volume at non-detector intersections. Then, we make use of detected traffic volume data and predicted traffic volume data to perform network traffic flow guidance. So, we can achieve centrally dynamic route guidance and macro management of the whole urban network.

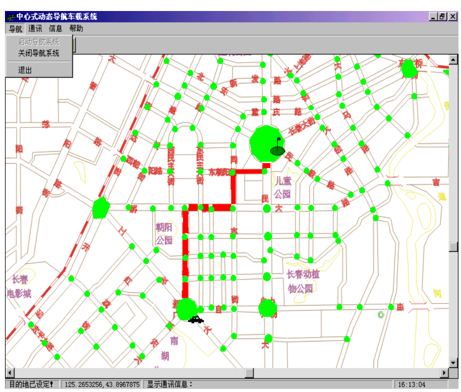

Figure 3: Travel route optimization.

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