TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol. 12, No. 10, October 2014, pp. 7242 ~ 7248
DOI: 10.11591/telkomnika.v12i8.5666

Study on Cooperation between Traffic Control and Route Guidance Based on Real-time Speed

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Abstract
Aiming at minimizing the total travel time of the road network, a cooperation model of traffic control and route guidance is built based on real-time speed obtained from cooperative vehicle infrastructure system. Genetic algorithm is used to solve the cooperation model to get the optimal green ratio and guidance rate of flow through transforming genetic algorithm with constraints into unconstrained genetic algorithm by penalty function. The simulation results of an experimental simulation on a small network show that this method can effectively balance the network flow, reduce total travel time and improve the efficiency of road network.

Keywords: *cooperative vehicle infrastructure system, traffic control, route guidance, genetic algorithm, penalty function*

1. Introduction

Traffic control and traffic flow guidance are important means to affect traffic flow. The former affects the induction strategy of traffic flow by changing time distribution of the traffic flow, while the latter affects the control strategy of traffic flow by changing arrival time and quantity of vehicle at intersections. Grasping the supplementary effect and space-time relationship between the traffic control and traffic guidance, combining the traffic control with traffic guidance has an important significance for safety, high efficiency and smoothness of traffic.

Allsop is the first British scholar who did integrated research on traffic signal processing and traffic flow equilibrium. After years of development, some collaborative model of traffic control and route guidance have emerged, for instance, a collaborative model in which route guidance predominates [1], a collaborative model in which control predominates [2], iterative optimization and allocation process model [3, 4] and global optimization model [5]. Although these models link the traffic control with route guidance, most of them do not put control and guidance in the equally important position. Some models avoid network OD needs [6] and fail to achieve the real coupling of the traffic control and route guidance.

Based on previous studies on the cooperation between traffic control and route guidance, this article will introduce collaborative vehicleinfrastructure system into the cooperation between traffic control and route guidance. A collaborative model of traffic control and route guidance is built on traffic volume, vehicle speed and other information which collected and transmitted by advanced data acquisition and communication technologies of collaborative vehicleinfrastructure system. The collaborative model is solved by genetic algorithm to get the best parameter of traffic control and route guidance to achieve reasonable optimization of traffic flow and reduction of traffic congestion.

2. The Establishment of Collaborative Model of Traffic Control and Route Guidance under the Environment of Collaborative Vehicle Infrastructure System

There are many indicators to evaluate the performance of road networks. For example, total travel time, total cost of driving, total delay time and so on. The model in this article will use

Received January 24, 2014; Revised June 28, 2014; Accepted July 20, 2014

total travel time (total travel time includes driving time and delay time) as objective function to evaluate the performance of road networks.

2.1. The Composition of Travel Time

A single road is shown in figure 1. In the graph, the box represents a vehicle. l_i is the vehicle's length. v_i is the vehicle's speed. L is the road's length. l is the queueing length. T_{a1} is the driving time which is runtime of the vehicle in the road's upstream area with low density. T_{a2} is the delay time which is runtime of vehicle in the road's downstream area with high density.

Travel time of the whole road is composed of driving time and delay time, therefore, the travel time of road A is:

$$T = T_{a1} + T_{a2} \tag{1}$$

2.1.1. Driving time T_{a1}

Most of the previous models solved driving time based on the relationship between the traffic volume and vehicle speed. One of the most commonly used models is the linear relation model proposed by Green Shields. Because of speed and travel time indirectly obtained by traffic volume, these models lack directness and precision. This article introduces collaborative vehicleinfrastructure system into the cooperation between traffic control and route guidance. Vehicle speed and length (include vehicle spacing) are obtained by the vehicle terminal. These information are collected by roadside terminal through wireless communication technology such as zigbee [7]. The average speed and queueing length got from the roadside terminal are acquired to get the driving time to improve the precision. In the model, the driving time T_{a1} is the road length divided by the average speed v. Its expression is as follows:

$$T_{a1} = \frac{L - l}{v} \tag{2}$$

In this expression, the road length is equal to the difference between the road actual length L and queueing length l. This paper does not take the assumption of point queueing for the queueing length. The collaborative vehicle infrastructure system lets v_0 be a velocity threshold, the vehicle would be in the queueing status when the vehicle speed is less than v_0 (assuming queueing vehicles are located in the downstream intersection). The queueing length L is equal to the sum of queueing vehicle length (length contains vehicle spacing) $l_1, l_2, l_3, \ldots l_n$ divided by the number of lanes a_r. Average speed v is the average of speed which is greater than v_0.

To sum up, the driving time is as follows:

$$T_{a1} = \frac{L - l}{v} = \frac{L - \dfrac{l_1 + l_2 + \cdots + l_{n1}}{a_r}}{\dfrac{v_1 + v_2 + \cdots v_{n-n1}}{n - n1}} \tag{3}$$

In the expression, n_1 is the number of queueing vehicles; n is the total number of vehicles.

In the actual travel, vehicle congestion and delays often occur at intersection, therefore, to a large extent, the level of intersection smoothness determines the length of travel time. Signal intersection delay calculation is an important part of the study on traffic flow theory in traffic engineering. The delay time is not merely an important index of intersection service level evaluation, but also a key part of the urban road travel time calculation[8]. In this article, the delay time calculation uses the HCM (1985 edition) delay calculation formula[9]. Its computation formula is as follows:

$$T_{a2} = 0.38c\frac{(1-\lambda)^2}{1-\lambda X} + 173X^2\left[(X-1)+\sqrt{(X-1)^2+\frac{16X}{s}}\right] \tag{4}$$

In the formula, *c* refers to signal intersection cycle; λ refers to green ratio; *X* refers to the degree of saturation; *s* refers to saturated traffic volume of signal intersection.

2.2. The Establishment of the Collaborative Model

The article will take time as the cost function of road and evaluation index, and take the frequently-used total travel time of the road network as modeling objective function. The objective function will express traffic control strategy through green ratio of intersection, and express route guidance strategy through rate of traffic inflow. Constraint condition 1 and 2 are used to limit the distribution of the traffic on the network by setting threshold of the mean and variance of saturation. Constraint condition 3 is the constraint for network flow balance. Constraint condition 4 restricts the relationship between the rate of traffic outflow and traffic volume. Constraint condition 5 and 6 are the threshold range of green ratio and traffic volume. In summary, collaborative model is established as follows:

$$f = \min\sum_{a=1}^{n} T_{a1} + T_{a2}$$

$$s.t.\begin{cases} \overline{X} = \frac{1}{N}\sum_{1}^{n} X_i < \psi \\ S^2 = \frac{1}{N}\sum_{1}^{N}(X_i - \overline{X})^2 < \sigma \\ \sum_{a\in A(k)} u_a^n(t) = OD_k^n + \sum_{a\in B(n)} v_a^n(t) \\ v_a^n(t) = x_a^n(t)/T_{a1} \\ 0 < \lambda_a < 1 \\ 0 \le u_a^n, x_a \le \tau \end{cases} \tag{5}$$

3. Solving the Collaborative Model on the Basis of Genetic Algorithm

Genetic algorithm is a new random search and optimization algorithm developed rapidly in recent years. Its basic idea is based on Darwin's evolutionary theory and Mendel's heredity theory. The genetic algorithm provides a general framework for solving problems of complex system optimization. It is independent of specific fields of problem and has a strong robustness for the types of problems, hence this article uses the genetic algorithm to solve the model.

Genetic algorithm only searches by using the fitness of individuals in the population on the basis of fitness function. The objective function is the network travel time in this paper, and its value is positive. For the minimum point problem, the objective function can be directly transformed into fitness function.

$$fitness = \min\sum_{a=1}^{n} T_{a1} + T_{a2} \tag{6}$$

For the optimization problem with constraints, the penalty function method is a commonly used technique. Essentially, it is that by punishing infeasible solution to convert constrained problems into unconstrained problems. In genetic algorithm, penalty function is used to keep parts of infeasible solution in each generation population. The genetic searching, therefore, can achieve the optimal solution from both sides of the infeasible region and the feasible region. Using the penalty function, the fitness function becomes:

$$fitness = \min \sum_{a=1}^{n} (T_{a1} + T_{a2}) + M\left(\sum (\max(0, -g_i(x)))^2 + (h_j(x))^2\right) \quad (7)$$

In the formula, $g_i(x)$ is inequality constraints, $h_j(x)$ is equality constraints, M is a large positive number. When the x is feasible, the penalty is 0; when x is not feasible, the penalty is a number greater than 0. M is 1000 in this paper.

4. Small Road Network Test

In order to validate the collaborative model and its algorithm, a small road network will be built to experiment in the VISSIM microscopic traffic simulation software. Figure 2 shows the small road network. The network contains four intersection and four two-way roads with two lanes. Every intersection is two phase intersection. The initial green ratio is 0.47. Cycle is fixed.

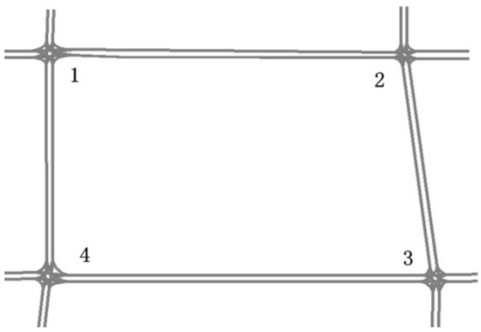


Figure 2. Diagram of Small Network

In VISSIM, the data detecting point and queueing counter are set to simulate the data acquisition device of collaborative vehicle infrastructure system. There are three data detecting points in each road to collect average speed. The queueing counter is set in the downstream of the road to collect queueing length. Its configuration is shown in Figure 3.

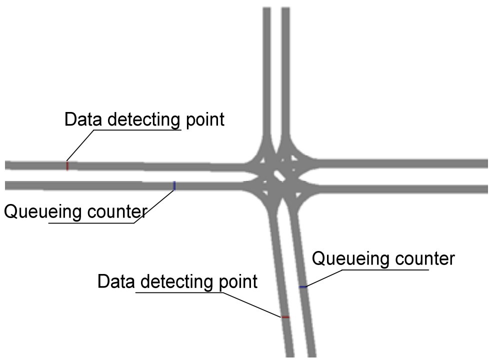


Figure 3. Diagram of Data Detection Point

In this article, the small road network has four OD demands, namely, 1-3, 2-4, 3-1 and 4-2. The paths of 1-3 are 1-2-3 and 1-4-3, its OD demand is 1.2 *vehicle/s*. The paths of 2-4 are

2-3-4 and 2-1-4, its OD demand is 1.4 *vehicle/s*. The paths of 3-1 are 3-2-1 and 3-4-1, its OD demand is 1.3 *vehicle/s*. The paths of 4-2 are 4-3-2 and 4-1-2, its OD demand is 1.1vehicle/s. The OD demand can be simulated by setting the path in VISSIM. As shown in Figure 4, there are 4 paths from the left road of intersection 1 to intersection 3. The proportion of a vehicle's choice of path can be simulated by setting these path flow distributions respectively.

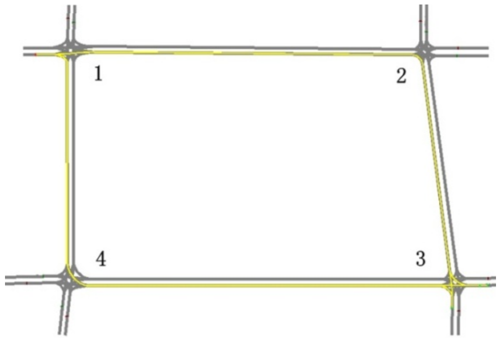


Figure 4. Diagram of the Path 1-3

In VISSIM simulation, the time is 5 minutes. Through setting the corresponding evaluation parameters, the data record files will be obtained by the end of simulation. The initial data of speed and road network obtained by sorting data are shown in the following table.

Table 1. Network Initial Data

Road	Length (m)	Queueing length(m)	Traffic volume (vehicle/s)	Inflow rate (vehicle/s)	Cycle (s)
1-2	480	37	0.57	0.24	120
2-1	480	158	0.42	0.33	100
2-3	310	36	0.31	0.40	90
3-2	310	33	0.35	0.48	120
3-4	530	22	0.40	0.37	100
4-3	530	58	0.19	0.45	90
4-1	300	36	0.17	0.45	100
1-4	300	191	0.45	0.36	100

Table 2. Speed of every Road

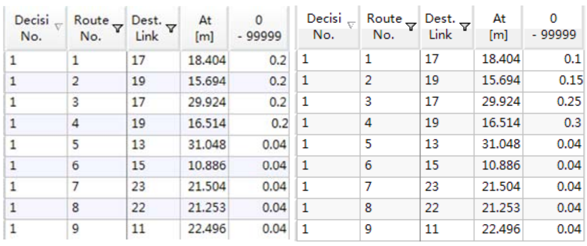
Road	Detecting point 1 (km/h)	Detecting point 2 (km/h)	Detecting point 3 (km/h)	Average (km/h)
1-2	50.8	48.8	41.9	47.2
2-1	50.9	43.9	32.2	42.3
2-3	50.5	46.1	37.1	44.6
3-2	51.5	45.8	38.8	45.4
3-4	52.2	48.6	41.0	47.3
4-3	52.1	51.5	48.1	50.6
4-1	49.9	43.7	39.6	44.4
1-4	41.9	35.6	30.6	36.0

In simulation software MATLAB, objective function is programmed with average speed and queueing length data. The value of ψ, σ and τ are ψ=0.4, σ=0.05, τ=3. The constrained problem is transformed into the unconstrained problem through penalty function. In the genetic algorithm toolbox, the population size is 30, the crossover probability is 0.6, mutation probability is 0.09, the termination of algebra is 1000, and other parameters are default. New inflow rate, traffic volume and the green ratio are got through 571 times of iterations simulation, and the value is shown in Table 3.

Table 3. Optimized Network Data

Road	Traffic volume (vehicle/s)	Inflow rate (vehicle/s)	green ratio
1-2	0.53	0.13	0.20
2-1	0.26	0.47	0.67
2-3	0.59	0.66	0.75
3-2	0.71	0.63	0.74
3-4	0.29	0.52	0.52
4-3	0.37	0.15	0.19
4-1	0.31	0.16	0.27
1-4	0.77	0.25	0.42

The optimized inflow rate is input into the VISSIM through the path inflow. The redistributed inflow rate of path 1-3 is shown in Figure 5.



Decisi No.	Route No.	Dest. Link	At [m]	0 - 99999
1	1	17	18.404	0.2
1	2	19	15.694	0.2
1	3	17	29.924	0.2
1	4	19	16.514	0.2
1	5	13	31.048	0.04
1	6	15	10.886	0.04
1	7	23	21.504	0.04
1	8	22	21.253	0.04
1	9	11	22.496	0.04

Decisi No.	Route No.	Dest. Link	At [m]	0 - 99999
1	1	17	18.404	0.1
1	2	19	15.694	0.15
1	3	17	29.924	0.25
1	4	19	16.514	0.3
1	5	13	31.048	0.04
1	6	15	10.886	0.04
1	7	23	21.504	0.04
1	8	22	21.253	0.04
1	9	11	22.496	0.04

The original traffic flow distribution The optimized traffic flow distribution

Figure 5. Traffic Flow Distribution Comparison of Path 1-3

According to the new value of green ratio, the intersection signal timing is reset. The setting of intersection 1 is shown in Figure 6.

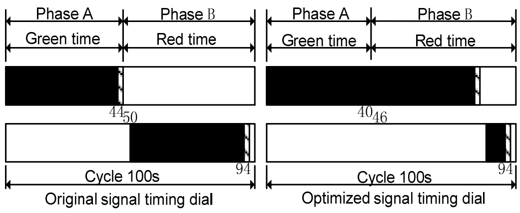


Figure 6. Signal Timing of Intersection 1

Simulating in VISSIM for 5 minutes, the travel time of every section of the road network is shown in Figure 7. From the figure, the road travel time is relatively balanced. The total network travel time decreased from 895.1s to 740.9s, a decrease of 17.2%. The traffic of each road is redistributed, therefore the total network travel time is reduced, and the efficiency of the network is improved.

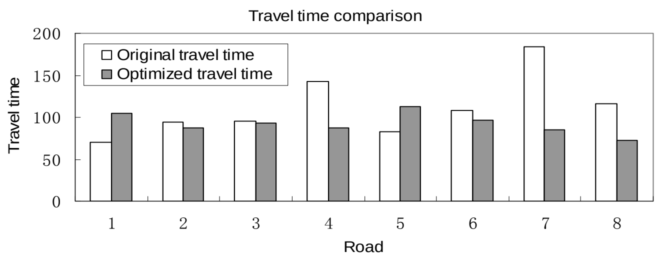


Figure 7. Travel Time

5. Conclusion

Collaborative vehicle infrastructure system is an intelligent system integrating with all kinds of high and new-technology. It can instantaneously obtain speed queueing length required by the cooperation system of traffic control and route guidance through wireless communication technology such as Zigbee, thus it is an important part of intelligent transportation system. In the article, the real-time speed and vehicle information of cooperative vehicle infrastructure system are used to reestablish the travel time model, and the OD information of all sections is applied in the collaborative model. The article solves the collaborative model with genetic algorithm to optimize traffic parameters, adjust travel time of each road and vehicle distribution of network. The network total travel time is 17.2% less than before, and the efficiency of the network is improved. In view of the complexity of traffic system, the impact of bus and other vehicles on traffic flow in modeling and simulation are not fully considered, and advanced technology and real-time data provided by collaborative vehicle infrastructure system are not fully used, these problems need further study.

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