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The Revelation of Traffic Congestion Drift and Induction Mechanism under Information Modification

Abstract。 *It is shown in this paper that for the group of travelers, the individual's rational decision-making is not best, in some cases, still far away from the global peak. This conclusion has been proved by two common models --Greenshields and Underwood. Meanwhile, when the travelers know all the data of systems, congestion drift which can reduce the system throughput often occurs due to the conflict between individual rationality and global optimization. In this paper, we propose an induction mechanism which can greatly reduce the congestion drift by modifying some path information. The simulation experiments verify that the efficiency of the traffic system based on different network structure.*

Streszczenie. *W artykule opisano schemat postępowania przy wyborze optymalnego rozwiązania, w przypadku grupy podróżnych. Wstępną analizę przypadku wykonano na bazie modelu Greenshield i Undrwood, co wykazało, że rozwiązanie najlepsze indywidualnie, nie musi być optymalne dla grupy. Zaproponowane rozwiązanie redukuje pojawiający się zator uliczny. Badania symulacyjne potwierdzają skuteczność metody. (**Zagadnienie napływu korku ulicznego oraz działania mechanizmu indukcyjnego przy zmienności danych**).*

Keywords: congestion drift; induction mechanism; minority game; traffic simulation.
Słowa kluczowe: zator uliczny, mechanizm indukcyjny, gra mniejszościowa, symulacja ruchu ulicznego.

Introduction

In modern society, an efficient road traffic system is one of the most fundamental means of supporting both industry and urban life. Therefore, to establish a smooth traffic flow and solve the traffic congestion problem, finding a more intelligent and efficient traffic information system is a current hot topic. For different road network and traffic conditions, it requires different guide strategies. Existing traffic guidance systems provide drivers the optimal paths, or quasi-optimal paths. There are many algorithms related to path optimization, such as Dijkstra, A*, Bellman-Ford-Moore, Floyd and etc[1]. To provide the road user with optimal travel routes, J. Wahle propose a procedure in two steps. First on-line simulations supplemented by real traffic data are performed to calculate actual travel times and traffic loads. Afterwards these data are processed in a route guidance system which allows the road user an optimization with regard to individual preferences[2]. S. Maniccam studied the effects of back step movement and update rule on the traffic congestion properties of mobile objects, and verified that sequential update without back step has the highest traffic flow capacity of about 50% and parallel update with back step has the least traffic flow capacity of about 20%[3].

However, guiding drivers basing the real road network information may lead to drivers' concentration of reaction, and as a consequence brings new congestion drifts. To prevent from congestion shift, Jiang Guiyan presented three methods: escalating the guidance proportion of induction, adding disturbance to link cost data and providing K alternative routes[4]. The most important key for solving this kind of problem is to maintain a balanced distribution of vehicles on the road.

Modelling

Some information will be got from the primary traffic information system. Therefore, drivers always choose the same road when they are in the same intersection. We supposed that there are two roads r1 and r2 in front of the drivers in this intersection, and r2 is more crowded now. If a majority of drivers choose r1 following the guidance information, r2 will become unimpeded, instead, sequent congestion will emerge on r1. Therefore, everyone who wants to be the minority (to choose the r2) spends less transit time and gets more benefit. In fact, path choice problem is a process of minority game. If the number N of people who choose r1 is less than a preset threshold m, r1 is free-flowing and everyone on r1 can gain much benefit.

A. Basic path choice model

In this paper, we will work on this issue: help drivers, excluded public transport drivers, choose one path alternatively from one particular place to another. The simplified traffic path network model is shown in Fig.1. Drivers want to reach point D from point A.

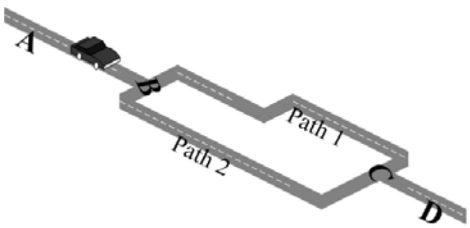

Fig. 1.Simplified traffic path network model

Greenshields was the first one to develop a single-regime model based on speed–density measurements (Greenshields, Bibbins, Channing, & Miller, 1935). He postulated a linear relationship between speed and density as expressed in equation (1)[9]. This model is simple and several researchers have found good correlation between model and field data.

(1) $$V = V_f \times (1 - N/N_m)$$

Where N and N_m are the density and jam density, V and V_f are the speed and free-flow speed. Thus we get the transit time t as follows:

(2) $$t = L/(1 - N \times b))$$

Here, L is the simulated length of the path. Particularly when N = 0, t =L, users go through the path used the minimum transit time. In fact they are in the ideal speed. b is the saturation capacity parameter of path. When b is very large, we can consider the path is near to its saturation capacity. We took into account the possibility of drivers who choose path1 is x. Thus, there are $n\times x$ and $n \times (1-x)$ drivers choosing path1 and path2 respectively, the system transit time from B to C is,

(3) $t(x)=x\times t_{path1}(N\times x)+(1-x)\times t_{path2}(N\times(1-x))\, x\in[0,1]$

Let denotes the value of x when system is optimal (That is min *t(x)*), and it can be obtained by and the transcendental equation is as follows,

(4) $$\frac{L_1}{(1-N\times b_1\times x^{\#})^2}-\frac{L_2}{(1-N\times b_2\times(1-x^{\#}))^2}=0$$

However, caring about personal interests only, drivers will select paths through they can travel in the shortest time.

(5) $$t_{path1}(N\times x)=t_{path2}(N\times(1-x))$$

In terms of equation (5), we can obtain x^*

(6) $$x^*=\frac{1}{N}\times\frac{L_2-L_1+N\times b_2\times L_1}{b_2\times L_1+b_1\times L_2}$$

And, the dynamic replication function *v(x)*[14] is

(7) $$v(x)=x\times(1-x)\times(t_{path_2}(N\times(1-x))-t_{path1}(N\times x))$$
$$=x\times(1-x)\times(\frac{L_2}{1-N\times b_2\times(1-x)}-\frac{L_1}{1-N\times b_1\times x})$$

According to Lyapunov theorem, when $\left(\frac{dv}{dx}\right)\Big|_{x=0}<0$, x^* is the stable point. Verify that x^* can be converged by

(8) $$\frac{dv}{dx}\Big|_{x=x^*}=x\times(1-x)\times(-\frac{L_2\times N\times b_2}{(1-N\times b_2\times(1-x))^2}-\frac{L_1\times N\times b_1}{(1-N\times b_1\times x)^2})<0$$

Which is less than 0, and then is the stable point. At this point, the system reaches Nash equilibrium. In Greenshields model, within a given range of *N*, $t(x^*)>t(x^{\#})$ set up.

(9) $$V=V_f\times\exp(-N/N_m)$$

Thus we get the transit time t as follows:

(10) $$t=L\times e^{b\times N}$$

The system transit time from B to C is t(x),

(11) $$t(x)=x\times L_1\times e^{b_1\times N\times x}+(1-x)\times L_2\times e^{b_2\times N\times(1-x)}$$

$x^{\#}$ denotes the value of *x* when system is optimal, and it can be obtained by $d(t(x))/d(x)=0$ and the transcendental equation,

(12) $$L_1\times e^{b_1\times N\times x^{\#}}\times(1+b_1\times N\times x^{\#})-L_2\times e^{b_2\times N\times(1-x^{\#})}\times\left(1+b_2\times N\times(1-x^{\#})\right)=0$$

x^* denotes the value of *x* when users are optimal. So the passing time on each path1 and path2 is the same.

(13) $$L_1\times e^{b_1\times N\times x}=L_2\times e^{b_2\times N\times(1-x)}$$

In terms of equation (13), we can obtain x^*,

(14) $$x^*=\frac{1}{N}\times\frac{b_2\times N+\ln(L_2/L_1)}{b_2+b_1}$$

And, the dynamic replication function *v(x)* is

(15) $$v(x)=x\times(1-x)\times(t_{path_2}(N\times(1-x))-t_{path1}(N\times x))$$
$$=x\times(1-x)\times(L_2\times e^{b_2\times N\times(1-x)}-L_1\times e^{b_1\times N\times x})$$

Verify that x^* can be obtained and converged by,

(16) $$\frac{dv}{dx}\Big|_{x=x^*}=x\times(1-x)\times(-L_2\times b_2\times N\times e^{b_2\times N\times(1-x)}-L_1\times b_1\times N\times e^{b_1\times N\times x})<0$$

B. Analysis of congestion drift

The Fig.2 shows the simplified road network model. It is composed by 4 intersections and 5 roads -- 4 one-way roads and one two-way road path3. Every road has two important performance parameters mainly -- length parameter and saturation capacity parameter.

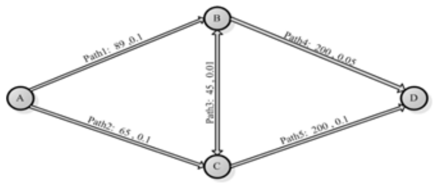

Fig. 2 Simplified road network model

In the experiment, we use the proposed simulation algorithm behind, *p*=6.85. And gain the data information from 1000th step and 1500th step showed in Fig.3.

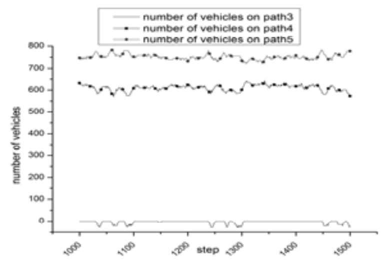

Fig.3 Data in simplified road network model before modification

C. Induction mechanism

Saturation capacity parameter is modified as,

(17) $$b'=\frac{b\times\beta}{1+\exp(\frac{\alpha}{b}-\mathrm{N})}$$

The parameter *N* is the total number of drivers in the road. And α is crowded parameter, β is predefined parameter. b' is the revised value of b in equation (10). Once the number of vehicles reaches the threshold associated with the crowded parameter α once, b' will increase largely compared with *b*, so that it will affect the travel time. We get the comparison figure of vehicles amount on three paths before and after modified as Fig.4 shows.

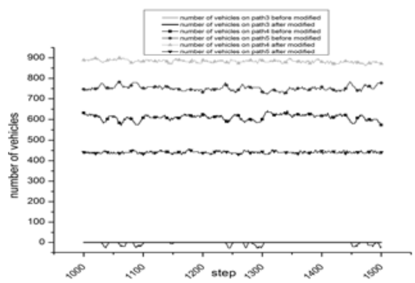

Fig. 4 Comparison of data in simplified road network model

We can see from Fig.4 that the amplitude of path4 and path5 curves both, fluctuation is weakened. The path3 curve is very smooth, and the fluctuation nearly disappears. The statistical results indicate that, in this simplified road network model, the modified induction strategy can take full advantage of limited traffic capacity resources and reduce congestion drift.

Simulation Experiments And Results Analysis

To test the practicability of the induction mechanism presented above, simulation experiments are necessary. We need to simulate the traffic condition closer to the real in experiments, and use simulation algorithm to calculate relevant data. Simulation algorithm is:

1. Initialize the road network graph with n intersections.

2. Generate vehicles randomly according to a preset ratio *p*, the starting and ending point of every vehicle distribute in different city.

3. The traffic information system calculates the new transit time information.

For every road *i→j,* use the equation (10) and equation (17) to calculate $time_{ij}$ which is the transit time from linked intersection *i* to *j*. Set $\alpha = 2.0, \beta = 1.6$. It is important to modify the data.

4. Publish all the transit time of all roads to drivers in the road network.

5. According the information, every driver chooses the next road spending the shortest time. If the vehicle arrives at the destination, statistics the total travel time.

6. If (step<NUM), go to 2; else print the statistical data. NUM is the predefined total value of operating steps.

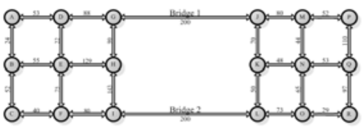

Fig.5 The two bridges model

Road network model is shown in Fig. 5. In this simulation experiment, we choose the two bridges road network model. It is composed by two cities connected by two bridges, 26 two-way roads and 18 intersections. As what we stated before, every road has two important performance parameters -- length parameter and saturation capacity parameter. The model is showed in Fig.5. Same as above, the generation ratio *p*=6.85. We get the data from 1500th step to 3000th step, as showed in Fig.6.

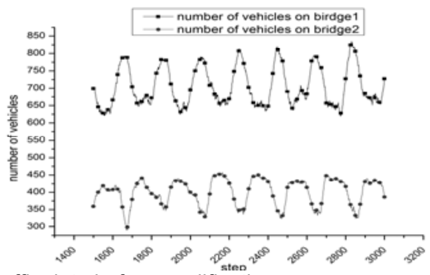

Fig.6 The traffic data before modification

In the Fig.6, the above two curves stand for the changed tendency of vehicles' account on the bridge1 and bridge2 separately varying with time. We can see the two curves appear cyclic variation, and the difference of their phase position is half of cycle exactly. Trends of the statistic data presented in Fig.8.

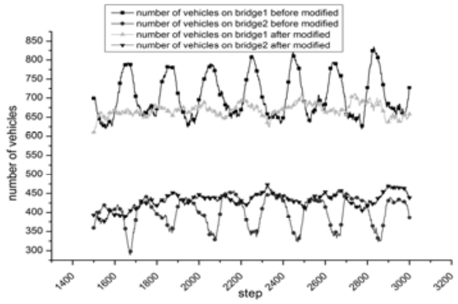

Fig.7 Comparison of data before and after modification

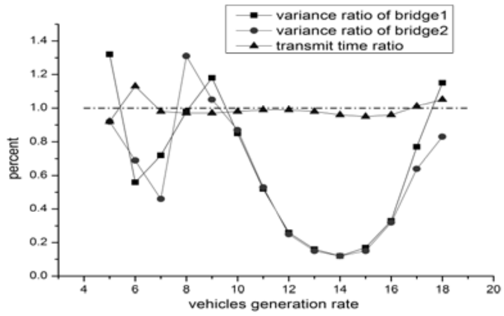

Fig.8 Data analysis of different traffic density

Conclusions

A traffic induction mechanism was presented based on minority game in this paper. It shows that the system time spent by rational drivers is more than the system optimal time, and the guide information reflecting the real traffic condition will lead up to the congestion drift. It is verified that the induction strategy proposed in this paper avoids the wasting of limited resources caused by uneven distribution of resources. While preventing the congestion drift, the induction mechanism improves the efficiency of whole traffic system, and reduces the average traffic time meanwhile. Moreover, the induction mechanism proposed in the paper can be also applied to internet information traffic and others.

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