Research on the Impact of Traffic Information Coverage Rate on Traffic Congestion

Zhuo Song\textsuperscript{1,\,a}, Fujun Wang\textsuperscript{2,\,b}

\textsuperscript{1}School of Economics and Management, Beijing Jiaotong University, Beijing 100044, China
\textsuperscript{2}School of Transportation, Beijing Jiaotong University, Beijing 100044, China

\textsuperscript{a}18120571@bjtu.edu.cn, \textsuperscript{b}18120894@bjtu.edu.cn

Abstract. With the vigorous development of technologies such as the Internet, Internet of Things, and cloud computing, terms such as “car networking” and “intelligent transport” have gradually appeared in people's field of vision. Traffic information has become more and more timely and comprehensive, which has gradually improved the transportation system. From the perspective of traffic participants' knowledge of information, this paper studies the impact of traffic information coverage on traffic congestion. First, the author established a mathematical model based on optimization theory. Then through simulation, the author simulates the traffic congestion situation in different scenarios (traffic participants have different information), and then obtains the following conclusions: Traffic participants who are completely random or choose their path according to their own preferences will affect road traffic efficiency and cause traffic congestion. In addition, the traffic information coverage rate is not as high as possible, but there is an optimal coverage rate. Finally, through the analysis of the Sancha Road network system, the author has obtained the following conclusion: It is a reasonable situation to set 73\% of traffic participants' information transparency, that is, the information coverage rate is 73\%.

1. Introduction

In recent years, with the continuous development of the national economy, the scale of the city has become larger and larger, and the subsequent urban traffic pressure has become more apparent. In recent years, with the continuous development of the national economy, the scale of the city has become larger and larger, and the subsequent urban traffic pressure has become more apparent. At the dawn of the development of technologies such as the Internet, the Internet of Things, and cloud computing, smart traffic has gradually emerged, which has eased the pressure on urban traffic, but the traffic congestion problem remains unresolved. And smart traffic makes traffic participants more and more dependent on information.

Smart transportation brings convenient real-time traffic information to people. Scholar Tanaka M & Uno N (2014) studied the influence of navigation system on the choice of traffic traveler's path, reflecting the convenience of real-time traffic information [1]. In addition, scholar Tian D & Yuan Y (2013) studied the influence of information sharing on the current situation of traffic congestion, and designed a vehicle routing algorithm based on real-time traffic information [2]. AHMED A &DONG
N (2016) used real-time information to analyze the route selection behavior of traffic participants, so that congested vehicles can be quickly evacuated [3]. In addition, scholars Ben-Elia & Erev I (2008) used the simulation method to obtain the conclusion that real-time traffic information can reduce the travel time of participants [4]. A.L.Kok & E.W.Hans (2012) studied the path selection algorithm based on real-time traffic information, and the research shows that the algorithm can reduce the probability of traffic congestion [5]. The research by Genders W & Razavi S N (2015) shows that planning roads based on real-time traffic information can reduce the probability of road congestion and improve driving safety [6]. In addition, some scholars have studied the carbon emission problem of vehicles based on real-time traffic information, and provided theoretical support for green transportation [7].

According to the research of scholars, the author finds that real-time traffic information can solve some traffic problems, but there is very little research on the road network system after adding real-time traffic information. The economy is constantly developing, cities are expanding, urban roads are becoming more complex, and vehicles are increasing. Although information technology has been introduced into transportation systems (such as traffic broadcasting, mobile navigation, etc.), if information technology isn't 100% full coverage, will it also affect the efficiency of transportation? Or how much information coverage can improve traffic conditions to alleviate traffic congestion? This is what this paper is about.

2. Model Hypothesis
As shown in Fig. 1, it is assumed that the departure place of the traffic participants is point A and the destination is point B.

![Multipath selection diagram](image)

This paper further makes the following assumptions:
(1) There are a total of m traffic participants from A to B (note: traffic participants refer to vehicles in this paper), which constitute the set Q.
(2) There are a total of n paths from A to B, forming a set L. And there is no mutual influence between the paths.
(3) The travel time of the i-th car entering the path j is completely determined by the number of vehicles on the road in front of it, and the travel time of the car from A to B is recorded as $T_{ij}$.
(4) Assume that the maximum capacity of each road is $D_j$.
(5) The total number of vehicles passing on path j is counted as $S_j$.

3. Model Establishment
From the perspective of the overall operational efficiency of the road network, the Ministry of Communications and the traffic participants will hope that the time from the A to the B is the least, that is:
\[ \text{Min} \sum_{i=1}^{m} \sum_{j=1}^{n} CT_{ij} \]

\[ c = \begin{cases} 
1 & \text{choose the path} \\
0 & \text{others} 
\end{cases} \]

\[ m = \sum_{i=1}^{n} S_{ij} \]

\[ S_{ij} \leq D_{ij} \]

\[ (l_1, l_2, l_3, \ldots, l_m) \in L \]

\[ (q_1, q_2, q_3, \ldots, q_m) \in Q \]

If the driving time of all vehicles from point A to point B is within an acceptable range, the system time can be optimized to achieve the optimal goal.

4. Model Solving

4.1. Scene Simulation

(1) Scene I

First, we discuss the simplest path selection method. It is assumed that all people are completely irrational when selecting paths, that is, completely randomly selecting paths.

To facilitate the simulation, the author chose a simple Sanza Road and assume that there are \( m = 100 \) drivers from A to B. The three paths are recorded as: \( L_1, L_2, L_3 \). Assuming that the road traffic flow is \( q \in (0, D) \), and the maximum traffic flow is \( D \), the time functions are equal and the size is:

\[ T_{ij} = \frac{D}{D - q}, \quad (i = 1, 2, ..., 100; \ j = 1, 2, 3) \]  

Equation 1 has the following characteristics: When \( q \) is 0, the time function results in 1; when \( q \) reaches the maximum traffic volume \( D \), that is, the vehicle passing time is infinite, and the road is in a "self-locking" state. Here we take \( D = \frac{2m}{3} ||, (j = 1, 2, 3) \), and use python to program to simulate Scene I.

Since Scene I is simulated based on the driver's random selection behavior, the results of each simulation are different. Table 1 is a random simulation result in the experiment.

| path | \( L_1 \) | \( L_2 \) | \( L_3 \) |
|------|--------|--------|--------|
| Number of vehicles | 40 | 34 | 26 |

As can be seen from the results, the paths \( L_1, L_2, L_3 \) were selected: 40 cars, 34 cars and 26 cars. There is a certain difference in this result. Obviously, there are too many vehicles with the path \( L_1 \), and
traffic congestion will occur. Path $L_3$ is the least number of vehicles on the three roads, but may not have the ability to perform.

In view of the above phenomenon, the author further analyzes the time spent by the vehicle on each road. As shown in Fig. 2, Fig. 3 and Fig. 4, the travel time of the traffic participants on the route $L_1$, $L_2$, $L_3$ are respectively shown.

Assuming no other vehicle intervention on the road, the time from $A$ to $B$ is 1 unit. According to Figures 2 and 4, it is clear that nearly half of the traffic participants spend more than 1.6 units of the path $L_3$. That is to say, for the congestion condition of the path $L_1$, $L_3$ has a complete chance to alleviate, but the driver has an irrational choice due to the closedness of the information in the process of selecting path, which leads to the occasional traffic congestion.

(2) Scene II

In real life, traffic participants often do not simply choose the path randomly, but have certain preferences. For example, from $A$ to $B$, everyone will choose a route based on historical experience, or choose a road with less travel time, or choose a road with good road conditions. In this scenario, assume that the ratio of the lengths of the paths $L_1$, $L_2$ and $L_3$ is 1: 1.2: 1.4, many traffic participants will prefer to choose a shorter path $L_1$. At the same time, it is assumed that the choice of traffic participants is inversely proportional to the length of the road, that is, the preference ratio is 1: 0.833: 0.714. It should be specially noted that in this scenario, the time functions of the paths $L_2$ and $L_3$ will change due to the difference in road length. The time functions of the three roads at this time are:

Fig. 2 Time of travel on the route $L_1$

Fig 3 Time of travel on the route $L_2$

Fig. 4 Time of travel on the route $L_3$
\[ T_{i1} = \frac{D}{D - q} \]  
\[ T_{i2} = \frac{D}{D - q} + 0.2 \]  
\[ T_{i3} = \frac{D}{D - q} + 0.4 \]

Again, \( q \in (0, D); \ i = 1, 2, ..., 100 \).

Table 2. shows the results of a simulation.

| path   | \( L_1 \) | \( L_2 \) | \( L_3 \) |
|--------|-----------|-----------|-----------|
| Number of vehicles | 42 | 34 | 24 |

According to Table 2, in the case of Scene II, the traffic participants will have an intuitive perception of the path length based on experience, so that the number of people selecting path \( L_1 \) is significantly better than \( L_2 \) and \( L_3 \). At this point, the author further analyzes the time spent by the traffic participants on different routes. The simulation results are shown in Figure 5.

According to Fig. 5, from the overall point of view, in the early stage, due to the advantage of distance, the path \( L_1 \) is obviously superior to \( L_2 \) and \( L_3 \) in terms of time. However, as the number of vehicles on path \( L_1 \) increases, the time spent by the traffic participants on path \( L_1 \) loses its advantage in the later stages. Similarly, paths \( L_2 \) and \( L_3 \) are also the same.

For the traffic participants on each road, the specific reasons for the above behavior are shown in Figure 6.
In order to clarify the cause of traffic congestion more clearly, the author analyzes a specific vehicle. As shown in the 80th vehicle in Fig. 6, when the traveler participates in the path selection, path $L_1$ has actually accumulated 33 vehicles, at this time, path $L_2$ has only 20 vehicles, and the participant can completely select path $L_3$ to avoid the traffic congestion. However, due to the inherent experience and thinking of traffic participants, traffic congestion has occurred. Although the 80th vehicle departed earlier than the 81st vehicle, it arrived at point $B$ later than the 81st vehicle which selected the correct route. The author carefully observed the results of each simulation of the experiment, the above situation is not uncommon, that is, the road with the shortest distance is the most likely to cause traffic congestion.

4.2. Simulation of relationship between information coverage and average transit time

Through the discussion of Section 4.1, the author finds that traffic participants are prone to traffic congestion when they choose the path without being affected by external information and completely “irrational”. Obviously, the assumption that “traffic participants are completely unknown to the state information of the road network during the path selection process” is flawed. With the rapid development of electronic communication, traffic participants can always obtain a part of the current road congestion through broadcasting and mobile navigation software. JIANG Guiyan & ZHENG Zutuo (2006) found in his research that providing Variable Message Signs (VMS) can generate large traffic information induction [8]. In her research, ZHANG Xiaoning (2011) found that the release of traffic-induced information can have a beneficial impact on the transportation system [9]. In addition, there are many studies on traffic guidance information. Therefore, according to the traffic guidance information, the traffic participants have a clear understanding of the current status of the road network in the process of path selection, that is, the corresponding traffic management department can eliminate the “irrational choice” (problem in Section 4.1) by issuing traffic guidance information. However, when issuing traffic guidance information, how many traffic participants should be able to get accurate road network information? What is the relationship between information coverage and road network efficiency? What percentage of information coverage can ensure the maximum efficiency of vehicles passing through the entire road network? At present, there are few studies on the above issues, so this paper will focus on the above issues.

Suppose that among the $m$ traffic participants who make the path selection, there are $m^*$ traffic travelers (constituting the set $Q^*$) relying on the road information broadcast or the route navigation system for path selection, which has a certain sense of “God perspective”, that is, before the path selection, these $Q^*$ traffic participants have a clear understanding of the time-consuming situation of the three paths, and they can choose the path with the least time in the first time. And:
\[
\frac{m^*}{m} = \theta
\]  

And, \((q_1^*, q_2^*, q_3^* \ldots q_m^*) \in Q^\prime\). By comparing the use time of the traffic participants who choose the preference, the author simulates the change of the average transit time with the increase of \(\theta\) in the case of 100 path selections. The simulation results are shown in Figure 7.

**Fig. 7** Comparison of average vehicle transit time

Obviously, the traveler who considers the traffic condition information has a significantly better traffic efficiency than the traveler who does not consider the traffic condition information. According to Fig. 7, as \(\theta\) increases, there is no significant increase or decrease in the average passing time, but a random fluctuation trend is presented. In this case, the author believes that traffic guidance information only serves as a guiding role, and that traffic participants do not communicate with each other in the process of path selection. Because the road network system lacks this part of the constraint information, the system can not automatically reach the optimal state, but shows a certain randomness. In order to establish a more developed road network system, it is necessary to further study the interaction between the traffic participants. This problem is beyond the scope of this paper, so this paper does not make in-depth interpretation and research.

At the same time, according to Figure 7, when the \(\theta\) value is about 0.73, the system takes the least time, which means that 73% of the traffic participants' information is transparent when there is no information exchange and negotiation decision between the traffic participants. It is a reasonable situation.

5. **Conclusion**

Through the analysis of the route selection behavior of traffic participants, this paper draws the following conclusions:

Under normal circumstances, the behavior of traffic participants completely randomly selecting paths is highly likely to cause traffic congestion.

In real life, due to the different road path resistance functions, the traffic participants have different path selection preferences, which will affect the road traffic efficiency and cause traffic congestion.

The effective use of information from broadcast and navigation software by traffic participants can alleviate road congestion.

Providing real-time information of road network for traffic participants, so that a certain proportion of traffic participants can accurately judge road condition information before selecting a route, which can reduce accidental traffic congestion and improve road network traffic efficiency.

When the road network traffic information is released, the information coverage rate is not as high
as possible, but there is an optimal coverage rate. For example, in the context of the Sancha Road network system, it is reasonable to ensure that 73% of the traffic participants' information is transparent, that is, the information coverage rate is 73%.

In addition, this paper does not discuss the information interaction between traffic participants, and whether it has a certain relationship with traffic congestion. In the future, this problem can be further explored to build a more perfect transportation system.

References

[1] Tanaka M, Uno N, Shiomi Y, Ahn Y, Experimental study of effects of travel time distribution information on dynamic route choice behavior, Journal of Intelligent Transportation Systems, 2014, 18 (2):215-226.

[2] Tian D, Yuan Y, Zhou J, et al. Real-time vehicle route guidance based on connected vehicles/Proceedings of the International Conference on Green Computing and Communications. Beijing, China, 2013:1512-1517.

[3] AHMED A, DONG N, WATLING D. Prediction of traveler information and route choice based on real-time estimated traffic state [J]. Transportmetric B: Transport Dynamics, 2016, 4 (1):23-47.

[4] Ben-Elia E, Erev I, Shiftan Y. The combined effect of information and experience on drivers route-choice behavior [J]. Transportation, 2008, 35:165-277.

[5] Kok A L, Hans E W, Schutten J M. Vehicle routing under time-dependent travel times: The impact of congestion avoidance. Computers & Operations Research, 2012,39 (5):910-918.

[6] Genders W, Razavi S N. Impact of connected vehicle on work zone network safety through dynamic route guidance. Journal of Computing in Civil Engineering, 2015,30 (2):04015020.

[7] Qian J, Eglese R. Fuel emissions optimization in vehicle routing problems with time-varying speeds. European Journal of Operational Research, 2016,248 (3):840-848.

[8] JIANG Guiyian, ZHENG Zutuo, BAI Zhu, et al. Simulation-based assessment of variable message signs route guidance information under congestion condition [J]. Journal of Jilin University(Engineering and Technology Edition), 2006,36 (2):183-187.

[9] ZHANG Xiaoning. Traffic pattern under the guidance of real time traffic information and traffic information benefit evaluation [J]. Journal of Management Sciences in China, 2011,14 (9):13-20.