

Road Network Optimization for Increasing Traffic Flow

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Abstract

In the traffic flow on the city road network, it is observed that a new additional road, which is constructed for overcoming the traffic jam, causes more terrible traffic jam. This is well known as Braess's paradox. Recently, it is pointed out that Braess's paradox depends on the traffic density and the paradox disappears at high traffic density.

The aim of this study is to describe the algorithm for increasing traffic amount by changing road network. The algorithm is applied for simple numerical example. The road networks are determined at different traffic density. The results show that the road network for increasing traffic flow depends on the traffic density and, at high traffic density, the Braess's paradox may disappear.

Keywords – Traffic capacity, Braess's paradox, Road network, Optimization.

1 Introduction

Traffic jam occurs the financial loss on the transportation system and the environmental pollution problems. Many researchers are studying the traffic flow control, the traffic signal control, the road network design and so on in order to overcome the traffic jam. For improving the traffic amount of the city road network, new roads are constructed if the capacity is not sufficient. It is pointed out that the new additional road causes the traffic jam at the other road and then, the total road capacity is reduced. One of the most popular studies in this field is reported by Braess [1]. Braess explains that, when two roads exist between two points, a newly added road causes the reduction of the traffic capacity between two points. Recently, Nagurney [2] points out that Braess's paradox disappear at the high traffic density.

The aim of this study is to describe the algorithm for increasing the traffic capacity of the road network by deleting some road links. The problem is formulated so as to maximize the traffic capacity between two points. The existence of the road link is taken as the design variable. The traffic flow is estimated by traffic simulator. The simulator is based on the cellular automata model and the optimal velocity model [3,4]. Simple road network is considered as the example. The road network connecting two points is considered as the example. More than one road paths exist between the points. The road network is optimized at the different traffic density in order to discuss Braess's paradox.

The remaining part of this paper is as follows. In section 2, the algorithm is explained. Numerical example is shown in section 4. The results are summarized again in section 4.

2 Algorithm

2.1 Traffic Amount

The road network is composed of some road links. One entrance and one exit points exist on the road network. Assuming the number of the vehicles as N over the time t (s), the traffic amount is represented as follows.

$$q = \frac{N}{t} \quad (1)$$

2.2 Optimization Problem

The optimization problem is defined so as to maximize the traffic capacity. The objective function is defined as follows.

$$f = q \rightarrow \text{Max} \quad (2)$$

Assuming the total number of road links is n and the design variable for the road link i is given as z_i , the design variable vector is given as follows.

$$z = \{z_1, z_2, \dots, z_n\}^T \quad (3)$$

where

$$z_i = \begin{cases} 0 & \text{Road link } i \text{ is available.} \\ 1 & \text{Road link } i \text{ is not available.} \end{cases} \quad (4)$$

The above problem is so-called 0-1 integer program problem. The relaxation problem is defined as follows.

$$f = q \rightarrow \text{Max} \\ z = \{z_1, z_2, \dots, z_n\}^T, 0 \leq z_i \leq 1 \quad (5)$$

The relaxation problem is solved by the gradient-type optimization algorithm.

3 Numerical Example

The object under consideration is shown in Fig.1(a). The road links are numbered as shown in Fig.1(b). Each vehicle can take one of the routes shown in Fig.1(c). Maximum velocity at each road link is shown in Table.1. Simulations are performed 10 times and the average traffic flow at different traffic density is shown in Fig.2. Traffic flow increases from traffic density = 12 to 84 vehicles and then, decreases from 156 to 300 vehicles.

The road network is optimized at the traffic density = 60, 240 and 300 vehicles. The results are shown in Fig.3. In case of traffic density = 60 and 240 vehicles, the link 5 or the link 5 and 6 are absent, respectively. In case of traffic density = 300 vehicles, all links are necessary.

In case of traffic density = 300 vehicles, the traffic capacity of the road network is almost saturated. Therefore, the absence of the road length makes the traffic jam terrible.

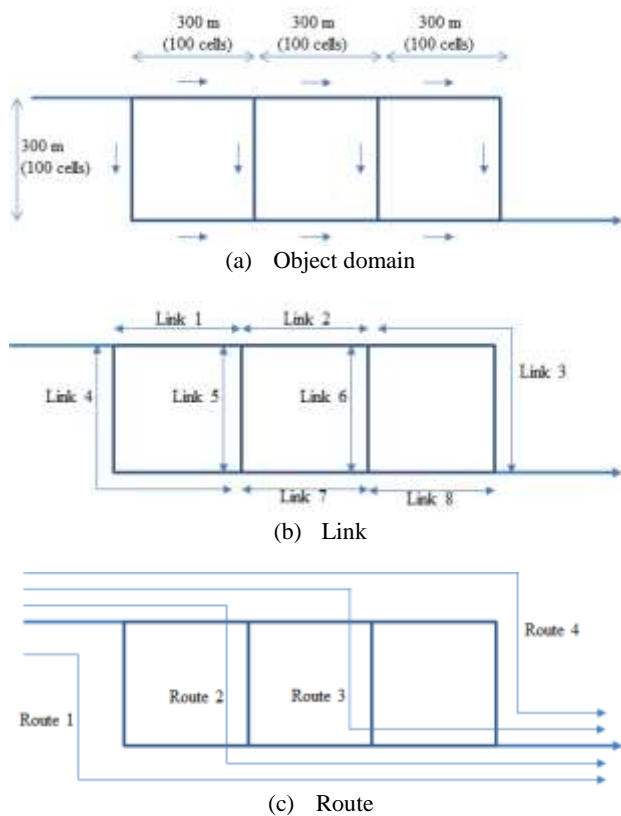


Figure 1: Object under consideration

Table 1: Maximum velocity at road link

Link No.	1	2	3	4	5	6	7	8
Max. Velocity	12	12	12	12	30	30	12	12

When the traffic density is smaller than 300, Braess's paradox is observed. The absence of the road link can increase the traffic capacity of the whole road network if some conditions are satisfied. Therefore, in case of the traffic density = 60 and 240, the road link 5 or the link 5 and 6 are absent.

Conclusion

In the city road network, it is reported that the newly constructed road causes the traffic jam at the other part of the network and then, the traffic capacity of whole road network is reduced. One of the most popular studies in this field is so-called Braess's paradox.

The aim of this study is to describe the algorithm for increasing the traffic capacity of the road network by deleting some unnecessary road links. The problem is formulated so as to maximize the traffic capacity. The existence of the road link is taken as the design variable. The traffic amount is estimated by traffic simulator based on the cellular automata and optimal velocity models.

The present algorithm was applied to the traffic capacity maximization problem in a simple road network. The results show that the algorithm can identify the unnecessary road link at low traffic density and that, at high traffic density, the absence of any road link reduces the traffic capacity. It is concluded that Braess's paradox disappears at the high traffic density

Acknowledgements

This work was supported by Grant-in-Aid for Scientific Research (C) Number 24560157.

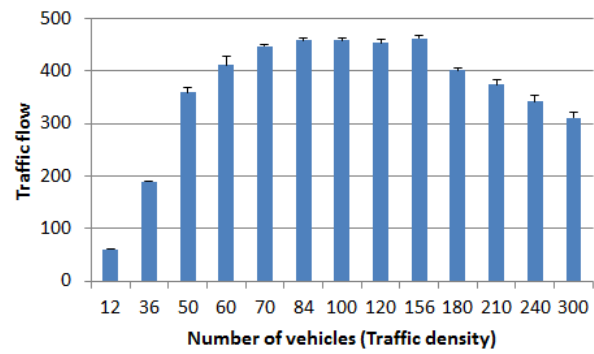


Figure 2: Simulation traffic flow

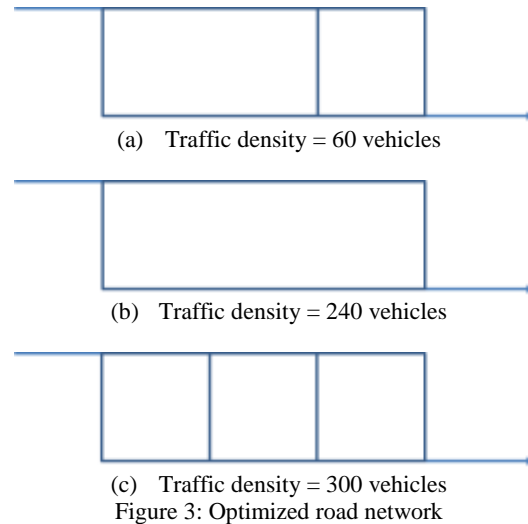


Figure 3: Optimized road network

References

- [1] D. Braess. Über ein paradoxon aus der verkehrsplanung. *Unternehmensforschung*, Vol.12, pp.258-268, 1969.
- [2] A. Nagurney. The negation of the Braess paradox as demand increases: The wisdom of crowds in transportation networks. *EuroPhysics Letter*, Vol.91, No.4, p.48002, 2010.
- [3] T. Tamaki, S. Yasue, and E. Kita. Traffic flow simulation using cellular automata. In *Proceedings of Civil and Structural Engineering Computing*. Civil-Comp Press, 2003. CD-ROM.
- [4] T. Tamaki and E. Kita. Urban city traffic simulation based on stochastic velocity model. In *Proceedings of The Tenth International Conference on Civil, Structural and Environmental Engineering Computing*, pp.215-216. Civil-Comp Press, 2005.
- [5] M. Bando, K. Hasebe, A. Nakayama, A. Shibata, and Y. Sugiyama. Dynamical model of traffic congestion and numerical simulation. *Physical Review E*, Vol.51, No.2, pp.1035-1042, 1995.