Are there really inefficient links in a real transportation network?

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1. Introduction

The well-known Braess paradox (Braess, 1968) occurs in cases that the addition of network capacity increases overall system time. This paradox might come into effect under certain conditions that are set by the link congestion function and the total demand for travels in the network (Pas and Principio, 1997). The link congestion function of the different links must follow a certain structure for the paradox to take place.

Several strategies have already been suggested in order to avoid the paradox if it does occur. For example, Korilis et al. (1999) showed that the paradox is avoided when resources are added across the network, rather than on a local scale, and when upgrades are focused on direct connections between the sources and destinations. Yang and Bell (1998) calculated the so called "reserve capacity" of the network with respect to the new project. That is, evaluating the capacity of the network with respect to the given demand with and without the proposed project. A decrease in this capacity may suggest that by implementing the new project, the overall system time in the network is expected to increase. Abrams and Hagstrom (2011) proposed a method for detecting problematic links that is based on linear programming, while Park (2009) focused on finding the same links using stable dynamics model.

The strategies indicated above might not be suitable for large-scale networks, due to their computational complexity. Bagloee et al. (2014) and Sun et al. (2015) developed heuristic methods based on a two-stage approach. At first, links whose inclusion in the network increased the overall system time were identified. Then, using a meta-heuristic algorithm, the system time was minimized by removing links of the network, out of the links previously found.

The present paper follows the above recent line of research: for a real transportation network, try to identify inefficient links, defined as the links that, once removing them, the overall system time decreases. In contrast to the previous papers, this paper focus first on three issues related to the network and assignment parameters. The first issue is the assignment precision, the second issue is the volume-delay function and the third issue is the origin-destination matrix.

2. Inefficient links and assignment precision

In order to find the inefficient links, several traffic assignment runs must be performed, and therefore the convergence criteria should be carefully investigated. In Bagloee et al. (2014) indicate the use of

EMME software, but it is not indicated the precision. Sun et al. (2015) indicate that the Frank-Wolfe algorithm was used, which is known to have poor precision (Bar-Gera et al., 2013).

Our hypothesis is that with increasing assignment precision, there will be less inefficient links. Note that when increasing the assignment precision, the overall system time should decrease. For a large network (that is, a network with a large number of links), the decrease in travel time may be sufficient to avoid the occurrence of the Braess paradox in certain links. Note that still may be links that will exhibit the paradox in random places, as demonstrated by Valiant and Roughgarden (2010), but we claim that these links are scattered around the network and not concentrated in certain places.

The paper presents results for two networks: the well-known Winnipeg network (2,200 links) and the planning network of the Tel Aviv metropolitan area (14,000 links). For both networks, the path-based method included in the EMME software was used. The assignment was performed for different precisions, ranging from 10^{-2} to 10^{-5}. The results confirm our hypothesis: for 10^{-2} precision, there are hundreds of links that may be inefficient, where the 10^{-5} precision there are very few links that exhibit the paradox.

3. Inefficient links and volume-delay function

The parameters of the volume-delay function are discussed in Pas and Principio (1999), who showed that the paradox occurs for a certain range of the parameters. For a large network, it is not possible to find this range in a reasonable amount of time. The approach of the present paper is simply to change the volume-delay parameters by a uniform weight.

Since both Winnipeg and Tel-Aviv network uses a BPR-type function, we artificially changed the alpha and beta parameters by factors of 0.5, 0.75, 1.5, and 2.0 and performed similar tests as in the previous section. The results indicate that for higher parameter values, there may be additional inefficient links, but not at a significant extent.

4. Inefficient links and demand matrix

The origin-destination matrix in planning networks generally is derived from different transportation models, and there are certainly discrepancies with respect to a real matrix. As with the previous section, for small networks it can be shown that the paradox occurs for a specific demand range (Prashker and Bekhor, 1999).

The approach of the present paper is to randomly change the demand from a cell in the matrix to a geographically contiguous cell. This is performed just for cells with low demand (less than 2 units of flow). The idea is to see if the specific location of the scattered flows has an influence in finding inefficient links. The results indicate that the spatial distribution does not have a significant effect.

5. Conclusions

The several tests performed in this paper indicate that there may be inefficient links in the network, but they are not significant and removing them will not decrease dramatically the system time.

References

Abrams, R.A. and Hagstrom, J.N. (2006). Improving traffic flows at no cost. In: Lawphongpanich, S., Hearn, D.W., Smith, M.J. (Eds.), Mathematical and Computational Models for Congestion Charging. Springer, New York, NY, pp. 1–22.

Bagloee, S.A., Ceder, A., Tavana, M. and Bozic, C. (2014) A heuristic methodology to tackle the Braess Paradox detecting problem tailored for real road networks. Transportmetrica A, Vol. 10, No. 5, pp. 437-456.

Bar-Gera, H., Hellman, F., & Patriksson, M. (2013). Computational precision of traffic equilibria sensitivities in automatic network design and road pricing. Procedia-Social and Behavioral Sciences, 80, 41-60.

Braess, D. (1968). Über ein Paradoxen aus der Verkehrsplannung. Unternehmensforschung, Vol. 12, pp. 258-268.

Park, K. (2011). Detecting Braess Paradox based on stable dynamics in general congested transportation networks. Networks and Spatial Economics, Vol. 11, No. 2, pp. 207-232.

Korilis, Y. A., Lazar, A. A., & Orda, A. (1999). Avoiding the Braess paradox in non-cooperative networks. Journal of Applied Probability, 36(01), 211-222.

Sun, L., Liu, L., Xu, Z., Jie, Y., Wei, D. and Wang, P. (2015). Locating inefficient links in a large-scale transportation network. Physica A, Vol. 419, pp. 537-545.

Valiant, G and Roughgarden, T (2010). Braess's Paradox in Large Random Graphs. Random Structures and Algorithms 37 (4): 495–515.

Yang, H. and Bell, M.G.H. (1998). A capacity paradox in network design and how to avoid it. Transportation Research Part A: Policy and Practice, Vol. 32, pp. 539-545.