Network Capacity, Traffic Instability, and Adaptive Driving: Findings from Simulated Network Experiments

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Introduction

The existence of a reproducible and well-defined relationship between network-wide average flow, average density, and average speed has been established in the literature (Herman and Prigogine, 1979; Mahmassani et al., 1984; Mahmassani et al., 1987; Williams et al., 1987; Mahmassani and Peeta, 1993; Williams et al., 1995; Geroliminis and Daganzo, 2008). Such network-wide relation has more recently been referred to as a "Macroscopic Fundamental Diagram" (MFD). Recent results from field experiments in Yokohama (Japan) (Geroliminis and Daganzo, 2008), Toulouse (France) (Buisson and Ladier, 2008), Twin Cities (MN, USA) (Geroliminis and Sun, 2011a, 2011b), Portland (OR, USA) (Saberi and Mahmassani, 2012), and simulated data for the San Francisco (CA, USA) (Geroliminis and Daganzo, 2008), Amsterdam (Netherlands) (Ji et al., 2010), and Nairobi (Kenya) (Gonzales et al., 2011) networks have revealed useful insights about the properties of such relationship for urban traffic. A comprehensive background can be found in Saberi and Mahmassani (2012).

Recent results from analysis of small idealized networks by Daganzo et al. (2011), Daganzo (2011), and Gayah and Daganzo (2011) suggest that networks are inherently unstable when density is sufficiently high. Therefore, the network-wide flow-density relation undergoes a bifurcation and becomes multi-valued. However, it is conjectured that if drivers choose routes adaptively based on real-time information of prevailing traffic condition, the bifurcation's critical density increases and a wider range of densities become stable. Adaptive driving may also reduce hysteresis and scatter (Daganzo, 2011). Daganzo et al. (2011) used a symmetric 2-bin model to answer this question that whether adaptive driving can eliminate or postpone the bifurcation. Using an idealized homogenous network where vehicles circulate indefinitely without exiting, they found that "the more adaptive drivers are, the greater the range of densities for which MFD is single-valued." However, this conjecture has not been tested in a real network consisting of asymmetric arterials and freeways with exit flows, various signal timings, ramp metering, stop signs, yield signs, etc. Other studies (Mahmassani and Jayakrishnan, 1991; Mahmassani and Peeta, 1993; Jayakrishnan et al., 1994; Srinivasan and Mahmassani, 2000; Dong et al., 2006; Fernandez et al., 2009) investigated the effects of traveler information on network performance mostly in terms of average trip time, total trip time, and social welfare.

The objective of this paper is to study the effects of adaptive driving on network capacity and traffic instability under heavily congested conditions in a large-scale urban street network with exit flows in the context of dynamic traffic assignment using simulated results intended to emulate real network experiments. Using a calibrated network model of the Chicago (IL, USA) metropolitan area (see Fig. 1), this study explores some of the limiting properties of network-wide traffic flow relationships in connection with real-time traveler information.

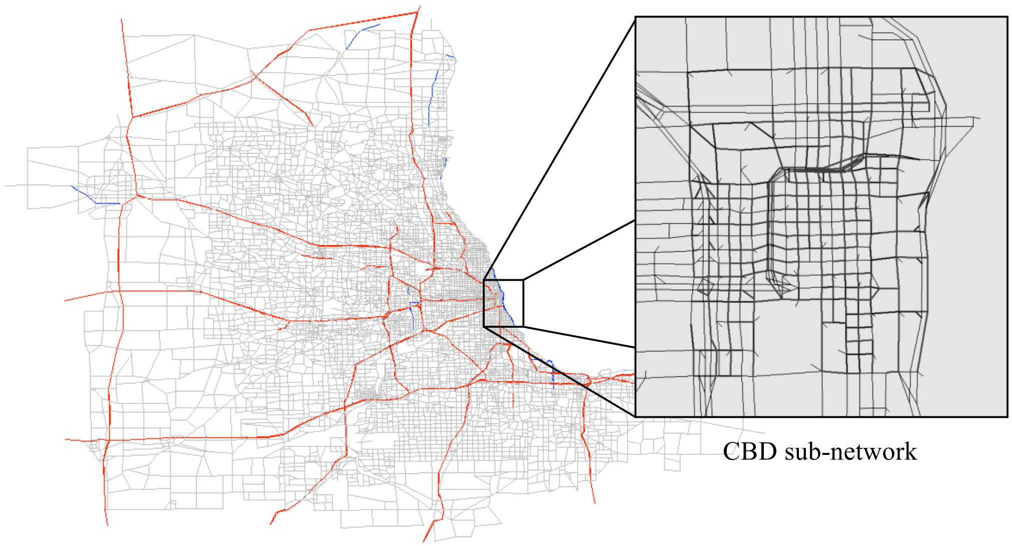

Fig. 1 Chicago metropolitan area network

Simulation of Adaptive Driving in the context of the Dynamic Traffic Assignment

In order to simulate adaptive driving behavior in the context of the dynamic traffic assignment (DTA), a specific class of users is defined. This class of users updates its paths at each intersection based on the prevailing shortest path tree. It is designed to reflect real-time information of prevailing traffic condition, and is based on "boundedly rational behavior." Two criteria are used for route choice, namely the indifference band and the threshold bound for switching decisions. The indifference band reflects a fraction of travel time improvement below which the user will not switch routes. The threshold bound reflects a time improvement below which the user will not switch routes. Should any of these two criteria be exceeded, the user will switch routes at the next intersection.

Preliminary Results

In this study, we use two definitions of network capacity as: i) the maximum trip completion rate, and ii) the maximum average network flow. Fig. 2(a) shows the relationship between vehicle accumulation in the network and trip completion rate for different percentages of adaptive drivers in the entire Chicago metropolitan area network. Results indicate that when the number of adaptive drivers increases, network capacity increases. However, the change from 30% of drivers being adaptive to 100% only slightly improves the network capacity. Also, it is worth mentioning that the maximum capacity was achieved when only 70% of drivers were adaptive. See Fig. 2(b). Network capacity seems to be very sensitive to route choice. Therefore, when a large population of drivers is adaptive, existence of some overlapping routes due to frequent route switching by adaptive drivers may discontinue the network capacity to improve continually. Results suggest that if the cost of providing real-time information of prevailing traffic condition is considered, an optimum percentage of adaptive drivers should exist that can maximize the associated benefit/cost ratio. Fig. 2(a) also shows that as the number of adaptive drivers in the network increases, hysteresis reduces. Therefore, the network traffic becomes more stable (or less unstable).

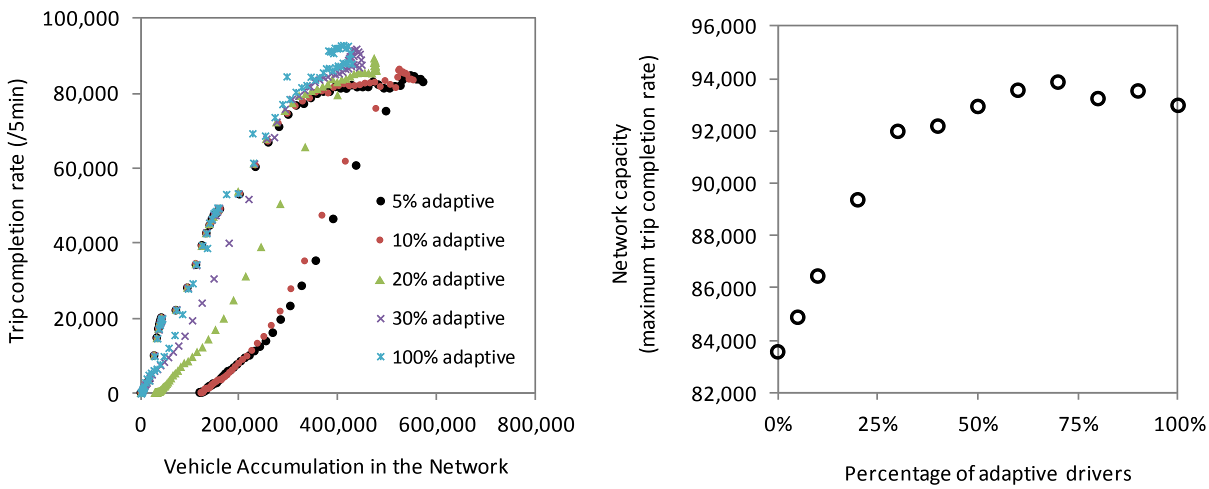

Fig. 2 (a) Network-wide relationship between vehicle accumulation in the network and number of completed trips for the entire Chicago metropolitan area network with different levels of adaptive drivers; (b) Relationship between percentage of adaptive drivers and network capacity (maximum trip completion rate) for the entire Chicago metropolitan area network

Fig. 3(a) illustrates the relationship between average network density and average network flow for the selected sub-network (Chicago CBD). Similarly, results show that when the number of adaptive drivers increases, network capacity increases. Fig. 3(b) illustrates the associated relationship between percentage of adaptive drivers in the network and capacity which implies somewhat similar results as of Fig. 2. Network capacity, defined as the maximum average network flow, seems to be more sensitive to route choice compared to the previous definition of capacity. Although Fig. 3(b) shows a general increasing trend but several cases have been observed in which increasing the number of adaptive drivers did not improve network capacity. When 100% of drivers were adaptive, the network capacity increased about 40% compared to the no adaptive driver case. Results also suggest that with larger population of adaptive drivers, hysteresis and gridlock are less likely to form.

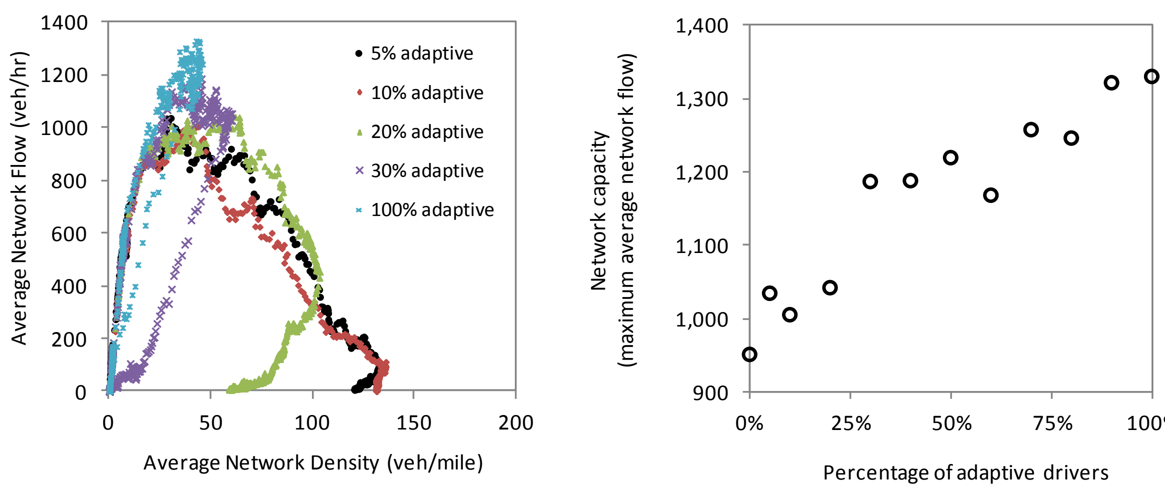

Fig. 3 (a) Network-wide flow-density relationship for the Chicago CBD sub-network with different levels of adaptive drivers; (b) Relationship between percentage of adaptive drivers and network capacity (maximum average network flow) for the Chicago CBD sub-network

Daganzo et al. (2011) conjectured that if drivers choose routes adaptively, the bifurcation's critical density increases and a wider range of densities become stable. Here we provide instances that suggest that this proposition does not always hold in a real network with exit flows. The results show that bifurcation and multivaluedness can still occur even when the entire population is adaptive. In this case, a small hysteresis can form and the network-wide flow-density relation undergoes a bifurcation at an average network density as low as 10 veh/mile and becomes highly multi-valued at capacity. The observed hysteresis and bifurcation at very low densities are mostly due to the existence of exit flows and rapid changes in demand which can add up to the heterogeneity of traffic distribution, especially during the recovery period.

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