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Q1 An extended signal control strategy for urban network traffic flow

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HIGHLIGHTS

- A novel iterative learning control strategy for traffic signals of urban networks was proposed.
- The convergence of the proposed control strategy was proved by rigorous theoretical analysis.
- The impacts of the ILC-based strategy on the macroscopic fundamental diagram were analyzed.
- The ILC-based control strategy can balance the accumulation and improve the network mobility.

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ABSTRACT

Traffic flow patterns are in general repeated on a daily or weekly basis. To improve the traffic conditions by using the inherent repeatability of traffic flow, a novel signal control strategy for urban networks was developed via iterative learning control (ILC) approach. Rigorous analysis shows that the proposed learning control method can guarantee the asymptotic convergence. The impacts of the ILC-based signal control strategy on the macroscopic fundamental diagram (MFD) were analyzed by simulations on a test road network. The results show that the proposed ILC strategy can evenly distribute the accumulation in the network and improve the network mobility.

1. Introduction

With the rapid development of urbanization and increasing demand on automobile, traffic congestion increasingly grows in most cities. In general, traffic signal control is considered as a fundamental and effective measure to alleviate the traffic congestion and improve the network mobility. Over the past few decades, a number of traffic signal control approaches for urban networks have been developed, and the model-based control strategies make up the majority of them [1]. However, a limitation of the model-based control methods is the sensitivity to or the dependence on the modeling accuracy. At present, realistic modeling traffic flow dynamics in urban networks remains a big challenge for both traffic researchers and practitioners, due to various uncertain factors, such as the mode choices, route choices, driving behaviors, and unexpected incidents, etc. Instead of the micromodeling method, the notion of macroscopic fundamental diagram (MFD) aims at simplifying the complex micromodeling task of urban traffic and describes the characteristic of traffic movement in cities at an aggregate level.

The MFD provides a relationship between the number of vehicles and network performance for urban networks. This concept was first proposed by Godfrey [2], and its existence for urban traffic networks was verified by Geroliminis et al.

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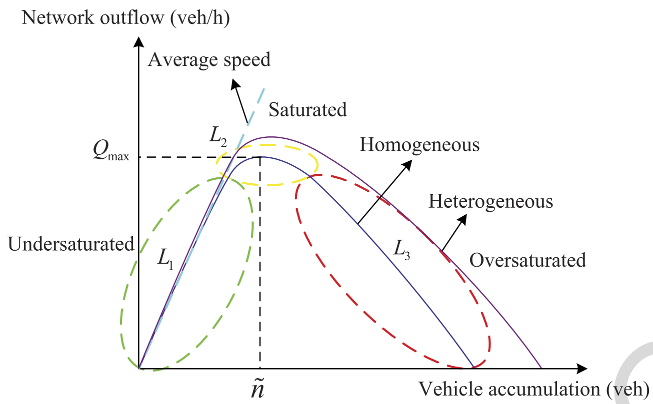

Fig. 1. MFD for urban networks.

through real traffic statistic data from Yokohama, Japan [3]. In 2009, Helbing developed analytical theories for explaining the existence of an MFD, which match the empirical results quite well [4]. The factors that affect the scatter and the shape of MFDs were discussed in Ref. [5], and Buisson et al. gave a conclusion that heterogeneity of traffic networks has a strong impact on the scatter and the shape of an MFD [6]. This indicates that a well-defined MFD only exists for a traffic network Q3 when the traffic flows are homogeneously distributed in the network. In addition, according to the work in Ref. [3], the well-defined MFD exists independently of the network traffic demands. This important property of MFD can be used to predict the effect of traffic management measures and applied to design elegant control strategies without detailed origin–destination information. In Ref. [7], the MFD has been used for evaluating the performance of the traffic networks under different control methods. Additionally, many control strategies have been proposed to improve the network mobility by adjusting the accumulation in the network based on the MFD. Geroliminis et al. proposed a model predictive control method for two urban regions with the MFD representation [8], and Haddad et al. analyzed the stability of the control approach for the two-region traffic network [9]. In Ref. [10], a model predictive control method has been introduced to solve the optimal traffic control problems. In Ref. [11], an easy-to-implement feedback control approach has been proposed to ameliorate the traffic mobility within the network. The investigation of routing strategy based on MFD can be found in Ref. [12].

So far the dynamics of urban traffic flow has been studied from many aspects [13–16]. The impacts of heterogeneity and road structure on traffic flow have been studied by Tang et al. [17–22]. Moreover, the traffic flow motion in the signalized urban networks largely depends on the traffic signals' characteristics and vehicle density [23–25]. The result that network with more homogeneous distribution of vehicle density exhibits higher network capacity suggests that it is possible to improve the network mobility by adaptively adjusting traffic signals. On the other hand, the macroscopic traffic flow patterns exhibit obvious repeated behavior on a daily or weekly basis, although they change at different time of the day. For instance, the daily traffic flow always starts from a very low level at midnight and gradually reaches the first peak during the morning rush hour from 7 to 9 AM, and then the second peak from 5 to 7 PM [26]. This inherent repeatability feature of traffic flow makes it possible to apply iterative learning control (ILC) theory to solve the urban traffic control problem. ILC was initially proposed by Arimoto et al. [27], which is specially fit for applying to a system that executes the same task repeatedly in a finite interval. The major advantage of such a control approach is that it has a very simple structure and needs very little system knowledge. This is a very desirable property for urban traffic control as the accurate traffic model and the exogenous disturbance information are almost impossible to obtain in practice.

The goal of this paper is to design an ILC-based signal controller for urban networks by using the repeated traffic patterns. Based on the aforementioned MFD model, the ILC-based signal controller manages to evenly distribute the accumulation in the network so that a well-defined MFD holds for the network with high capacity and mobility. The designed controller consists of two parts: a feedforward learning part used to learn the experience from previous task executions to meet the performance requirement, and a feedback stabilizing part designed to restrain the disturbances such that the output tracking error is bounded within a reasonable range. Both the theoretical analysis and the simulation results are given to verify the effectiveness of the proposed control method.

This paper is organized as follows. In Section 2, the MFD of urban traffic networks is provided. Section 3 describes the traffic flow model and gives the problem formulation. Section 4 presents the ILC-based signal control strategy and analyzes the convergence. Section 5 analyzes the impacts of the ILC strategy on the MFDs. Finally, a conclusion is given in Section 6.

2. MFD for urban networks

It has been shown that a well-defined MFD exists for a traffic network when the traffic flows homogeneously scatter in the network. Based on this property of the MFD, the control strategy investigated in this paper exactly attempts to distribute the accumulation homogeneously in the network so that a well-defined MFD holds for the network with high outflow and mobility. The MFD curves for both homogeneous and heterogeneous networks are shown in Fig. 1, where $\tilde{n}$ is the critical

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