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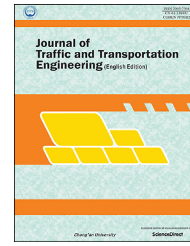


Original Research Paper

# An integrated approach for dynamic traffic routing and ramp metering using sliding mode control

*Hirsh Majid* [a,*], *Chao Lu* [b], *Hardy Karim* [a]

[a] *Department of Civil Engineering, College of Engineering, University of Sulaimani, Sulaymaniya, Iraq*
[b] *School of Mechanical Engineering, Beijing Institute of Technology, Beijing, 100081, China*

## HIGHLIGHTS

- Integrated traffic control strategy can optimize freeway traffic circulation.
- Ramp metering could be more active when it is combined with dynamic traffic routing.
- The proposed algorithm can manage traffic flow through alternate routes with different geometric designs and lengths.

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## ABSTRACT

The problem of designing integrated traffic control strategies for highway networks with the use of route guidance, ramp metering is considered. The highway network is simulated using a first order macroscopic model called LWR model which is a mathematical traffic flow model that formulates the relationships among traffic flow characteristics in terms of density, flow, and mean speed of the traffic stream. An integrated control algorithm is designed to solve the proposed problem, based on the inverse control technique and variable structure control (super twisting sliding mode). Three case studies have been tested in the presence of an on-ramp at each alternate route and where there is a capacity constraint in the network. In the first case study, there is no capacity constraint at either upstream or downstream of the alternate routes and the function of the proposed algorithm is only to balance the traffic flow on the alternate routes. In the second case study, there is capacity constraint at downstream of alternate routes. The proposed algorithm aims to avoid congestion on the main road and balance the traffic flow on the alternate routes. In the last case study, there is capacity constraint at upstream of alternate routes. The objective of proposed algorithm is to avoid congestion on the main road and to balance the traffic flow on the alternate routes. The obtained results show that the proposed algorithms can establish user equilibrium between two alternate routes even when the on-ramps, located at alternate routes, have different traffic demands.



* Corresponding author. Tel.: +964 7701939815.
E-mail addresses: hirsh.majid@univsul.edu.iq (H. Majid), chaolu@bit.edu.cn (C. Lu), hardy.karim@univsul.edu.iq (H. Karim).

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## 1. Introduction

Nowadays, improving the traffic conditions is a challenging problem as the highways in most of time are overused and the extension of the infrastructures and capacities is not always possible. Therefore, transportation researchers have focused on other ways to resolve congestion in highway networks. One of the solutions is to design and implement intelligent traffic control and management systems. Feedback control is among the freeway traffic control schemes proposed in the previous researches by Papageorgiou et al. (1991) and Papageorgiou and Kotsialos (2002) and it is mostly used for controlling traffic congestion at local on-ramps by keeping the density of vehicles equal or less than a critical level. But, in case of multiple on-ramps, a simple feedback control law would not be able to deal with the problem of reducing the overall travel time. Among the heuristic approaches for control of several on-ramps are the traffic responsive feedback control strategy heuristic ramp metering coordination (HERO) (Papamichail et al., 2010a) and the so-called CORDIN algorithm (Bhouri et al., 2013). Recently, the model predictive control (MPC) approach has been used in the transportation framework as a solution for coordination between multiple traffic measures (De Schutter et al., 2002). In Kotsialos et al. (2002b), an integrated control approach with the use of ramp metering, route guidance is considered, based on the generic problem formulation in the format of a discrete-time optimal control problem whose numerical solution is achieved by the use of a feasible-direction algorithm. In Hegyi (2004), an MPC scheme is proposed for the control of a small freeway network using an integrated control algorithm with the use of ramp metering and variable speed limits. However, the main issue with MPC and generally with optimal control is the computation time required to solve the optimization problems embedded in the MPC controller.

The computational complexity becomes a burden, especially, when we have a large network where there is a large number of control variables and real-time control is essential. Except for algorithms using the classic control theory, some other approaches from artificial intelligence (AI) such as machine learning and planning have also been used to develop traffic control strategies. Among these methods, reinforcement learning (RL) has gained great attention from researchers. A number of RL algorithms have been applied to solve traffic control problems, such as predictive Q-routing for traffic routing (Choi and Yeung, 1996), natural actor-critic for intersection control (Bernhard et al., 2007) and Dyna-Q for Q1 coordinated ramp metering (Lu et al., 2015). However, RL based algorithms often suffer from low convergence speed when a large-scale network and dynamic traffic flow are considered, and thus fail to deal with real-time control problems (Xie et al., 2012a). Under such circumstances, a decentralized control system using efficient scheduling algorithms is developed in Xie et al. (2012a, b). Although low computational demand of this system can support the real-time use, the optimal solution cannot be guaranteed. Most of the AI systems reviewed here are only focused on one control method, and the integration of different control methods (e.g. the integration of traffic routing and ramp metering) has not been solved properly using these algorithms. In the context of freeway traffic control and for coordination of a large number of on-ramps, there is not much related work in the literature. In Papamichail et al. (2010b), a hierarchical control approach is proposed for coordinated ramp metering in freeway networks. The optimization algorithm is solved for the whole network and in a centralized manner. The optimal control inputs are sent as reference trajectories to several local controllers at the lower level. In Frejo and Camacho (2012), a comparison between global and local MPC algorithms has been done. The problem of decentralized control and the sub-optimality of the obtained control inputs has been solved by establishing a communication scheme between the neighboring subsystems. In Frejo and Camacho (2011), a distributed cooperative algorithm was proposed. In this algorithm, each local MPC controller solves the global optimization problem with the overall objective function (in contrast to the decentralized MPC in which each agent deals with its own local objective function). From a practical point of view, fully distributed control schemes might not be feasible because they mostly require a high-level communication scheme between agents. In Majid et al. (2014b), a new distributed model predictive control (MPC) scheme for freeway traffic control has been proposed. It is aimed at reducing the communication efforts and the computation times in a large network.

In this paper we establish a new control system using the heuristic approach. We propose a new integrated control algorithm that combines the actions of dynamic traffic routing (DTR) with on-ramp metering to optimize the traffic flow in a highway network and exploit the capacity of the infrastructure to the maximum extent possibility without time consuming for calculation. The new algorithm will be tested using three different case studies. The algorithm can manage the system in the case where there is capacity constraint in the highway network. The rest of the paper is organized as follows. Section 2 reviews the macroscopic traffic flow model, LWR, which is used to predict the evolution of the states. Section 3 presents the main principles of the DTR problem and its mathematical formulation. Section 4 shows the design methodology using the concept of inverse control technique and high order super twisting sliding mode control. Section 5 presents three algorithms proposed for three different case studies. Simulation results for the implementation of three case studies are provided in Section 6. Finally, the conclusion and future works are presented in Section 7.

## 2. Macroscopic traffic flow modeling

LWR is a first order macroscopic model and it is the first macroscopic model in traffic domain (Lighthill and Whitham, 1955; Richards, 1956). This model takes into account control actions such as ramp metering and route guidance (Kotsialos et al., 2002a). The basic equations used to compute the traffic variables for every segment I of a motorway link are the following (Fig. 1).