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Real-time route diversion control at congested freeway off-ramp areas

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ABSTRACT

This paper develops, investigates and demonstrates real-time route diversion policies in cases where recurrent freeway traffic congestion is created due to a saturated off-ramp. In particular, the proposed route diversion policies attempt to avoid the off-ramp queue spill-over onto the freeway mainstream and the resulting freeway congestion by appropriately re-routing the freeway vehicles through nearby off-ramps towards the same destination. The proposed route diversion concepts are based on feedback control laws and are tested for a hypothetical, but quite typical, network infrastructure and three different traffic scenarios by use of macroscopic simulation. In the first traffic scenario, the user-optimal conditions may be achieved without off-ramp queue spill-over and creation of mainstream congestion; thus the route guidance system may propose an alternative route without any disbenefit for the compliant drivers. In the second case, the user-optimal conditions may be achieved only after the off-ramp queue spills back to the mainstream freeway; thus the route diversion system will have to assume sufficient compliance to the proposed route choice; or be based on mandatory actions, such as temporary off-ramp closures. Finally, in the third examined case, the user-optimal conditions cannot be achieved, due to the traffic conditions on the alternative route, thus the route diversion system should decide for the temporary off-ramp closure, when and to the extent needed, in order to prevent formation of mainstream congestion. The obtained simulation results are compared to the case where no route guidance is applied to the network and reveal interesting features and the potential for significant improvements.

1. Introduction

During the last decades, freeway congestion has been a major problem especially at urban freeways and peri-urban ring-roads. Recurrent traffic congestion is usually encountered at freeway on-ramp areas or freeway-to-freeway merging areas, but, quite frequently, also close to freeway off-ramp areas, leading to infrastructure underutilization, long delays, increased fuel consumption and reduced safety. Since expanding the existing infrastructure is not always a feasible option, for economic and environmental reasons, traffic control has been proposed and employed as an efficient way to mitigate the problem of freeway congestion (Kotsialos and Papageorgiou, 2004).

Although various traffic control measures have been proposed for cases of congested freeway merging areas or other types of recurrent active bottlenecks, there is very limited technical literature (and, to the best of our knowledge, no practical systems) addressing specific control measures for cases where recurrent freeway congestion originates from off-ramp areas. The main reason

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for this lack is probably the fact that there is no direct way, from the freeway side, to control the freeway exit flow, so as to avoid the resulting strong reduction of the freeway capacity and related deterioration of the mainstream traffic conditions. The methodologies proposed so far either focus on affecting the behavior of the freeway drivers, e.g. by eliminating the lane changing maneuvers near the off-ramps; or suggest the increase of the off-ramps' exit flow; or propose a combination of the above. In Cassidy et al. (2002), the problem of freeway congestion due to an off-ramp bottleneck is studied, using field data, and it is observed that, whenever the off-ramp queues are prevented from spilling-over, the bottleneck does not arise. In Daganzo et al. (2002), some thoughts are expressed on how to increase the capacity at congested freeway off-ramp areas via fixed-time or dynamic lane assignment on the freeway mainstream, according to the drivers' destinations, by use of Variable Message Signs (VMS). The potential closure of a congested off-ramp and drivers' rerouting through nearby off-ramps is also proposed. In Rudjanakanoknad (2012) and Di et al. (2013), it is suggested to ban the lane-changing maneuvers near off-ramp areas, e.g. via pavement markings, combined with increasing the off-ramp exit flow when needed, though without considering the effects to the surface street network. As noted in Rudjanakanoknad (2012), sometimes banning lane-changing maneuvers merely results in shifting the bottleneck to another upstream location where lane-changing maneuvers are allowed. In Tian et al. (2002), it is also suggested to abruptly increase the off-ramp exit flow when the queue on the off-ramp is about to spill back to the freeway, admitting that this action may cause problems to the surface street traffic. In Günther et al. (2012), the detouring of a part of the vehicles moving on the surface street network is proposed, in order to enable the increase of the off-ramp's exit flow, thus benefiting the freeway users at the expense of surface street users. In Pei and Zhou (2013) and Yang et al. (2014, 2015), different approaches are proposed to optimize the signal plans on the surface street network to prevent the off-ramp queue spillback into the freeway. Finally, in Spiliopoulou et al. (2016), a merging traffic control algorithm is presented which aims at maximizing the surface street merge area outflow and at the same time prevent the off-ramp queue spillover into the freeway mainstream. Note that all the above proposed control measures were demonstrated using specific case studies and real or hypothetical traffic networks. This fact indicates that this is a particular type of congestion, and different freeway sites may call for different traffic control measures, depending on the network layout, the prevailing traffic conditions, the expected drivers compliance, the available traffic control equipment, etc.

This study examines specific cases where freeway congestion is created due to an over-spilling off-ramp queue. In particular, it is considered that there is no possibility to change the off-ramp's capacity, which is limited, e.g., due to its layout or due to a traffic light located at the downstream end of the off-ramp, at its intersection with a surface street. Moreover, there exists an alternative route, through an upstream off-ramp, which leads to the same destination and may accommodate the potential diverted traffic without major problems. Considering this situation, various local route diversion policies are proposed which aim to prevent the off-ramp queue spill-over and the resulting mainstream congestion by rerouting the exiting vehicles through the alternative route, when and to the extent needed. In the past, route guidance has been mainly proposed for bigger networks parts under more general assumptions. This study investigates the application of route diversion measures specifically for the case of recurrent mainstream freeway congestion stemming from an over-spilling off-ramp. Therefore, the proposed local rerouting policies are easy to implement, in contrast to network-level approaches (see Pavlis and Papageorgiou, 1999) which imply much higher implementation effort. Furthermore, although only one alternative route is considered in the current investigations, the proposed control concept could be extended to account for multiple downstream or upstream alternative routes; such cases may be investigated in future research. The proposed route diversion policies are tested under reasonable assumptions for a hypothetical test infrastructure and several traffic scenarios, which are simulated by use of a validated macroscopic traffic flow model.

The paper is organized as follows. Section 2 presents the proposed route diversion concepts and the control strategies employed to enable the rerouting decisions. Section 3 describes the hypothetical network and the traffic conditions considered for the simulation investigations. Section 4 presents the simulation results for all investigated traffic scenarios and, finally, Section 5 concludes with the main remarks on the study's results.

2. Dynamic route diversion concept

Route guidance systems aim to provide the drivers with information or guidance related to their route choice decisions. Route guidance has been mainly used in cases of non-recurrent events; for example, the system may guide, in real-time, the drivers through alternative routes during maintenance works, as proposed in Heutink et al. (2006), or in case of incidents, as suggested in Wang et al. (2006). This study investigates the application of route diversion measures specifically for the case of recurrent mainstream freeway congestion stemming from an over-spilling off-ramp.

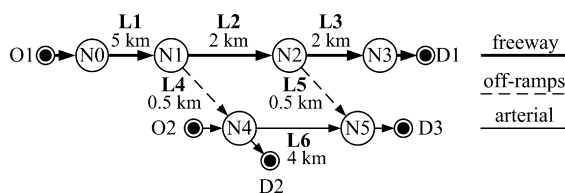


Fig. 1. Test network.

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