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Mitigating freeway off-ramp congestion: A surface streets coordinated approach

Germán Günther, Juan E. Coeymans, Juan C. Muñoz *, Juan C. Herrera

Department of Transport Engineering and Logistics, Pontificia Universidad Católica de Chile, Vicuña Mackenna 4860, Postal Code: 7820436, Santiago, Chile

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ABSTRACT

Congested conditions downstream from off-ramps often propagate upstream blocking all freeway lanes and affecting traffic that does not cause the bottleneck. Most efforts to understand this phenomenon have focused on how the queues form and propagate in the freeway, while scant attention has been paid to the causes of the formation of this type of queue. Exiting traffic often compete with traffic from surface streets for a limited capacity so that if part of this *competing traffic* is detoured to other streets the off-ramp will see its capacity increased. This paper studies this alternative by modeling what we consider fairly common conditions for the surrounding network. We propose a methodology to determine the flow of competing vehicles to be detoured to underutilized roads in the local network in order to improve the system's capacity and reduce total delays under stationary conditions. We also study the conditions under which this strategy may be beneficial during a rush hour period. The methodology aims at keeping the off-ramp flowing uncongested, eliminating the queue in the freeway and leaving the remaining capacity for the competing traffic. An experiment to test the mechanism was conducted on an urban freeway in Santiago, Chile confirming the opportunity for improvements in the system as a whole. It also showed that when the off-ramp ends in a weaving section, the capacity of this section drops significantly when both approaches reach congestion, emphasizing the importance of preventing these queues from appearing.

1. Introduction

Consider a fairly typical street network around an urban freeway surrounding an off-ramp as depicted in Fig. 1. In the network, vehicles leaving the freeway through the off-ramp join at node *M* those coming from a surface local service or side road. Physically, this node can represent a merge or an intersection (signalized or priority). In the first case, the capacity of node *M* may be affected by lane changing maneuvers, as occurs in freeway merges (Cassidy and Rudjanakanoknad, 2005) and weaving sections (Bertini and Malik, 2004). In case node *M* is an intersection, the capacity depends on the timings of the signal or the flow on the priority road. The figure also shows a selected subset of surface streets nearby in the local network representing the local grid that will be relevant for our purposes.

Inflows from the side road and from the ramp compete for the limited capacity of node *M* which, if exceeded, may trigger a queue in both approaches. Given the high flows observed during peak periods in urban freeways, an off-ramp queue would easily reach the freeway affecting through traffic that is not causing the bottleneck (since this traffic will not take the ramp in question) and propagate very fast triggering significant delays for the system (Kerner and Rehborn, 1997; Daganzo, 1999;

* Corresponding author. Tel.: +56 2 354 4270; fax: +56 2 553 0281.
E-mail address: jcm@ing.puc.cl (J.C. Muñoz).

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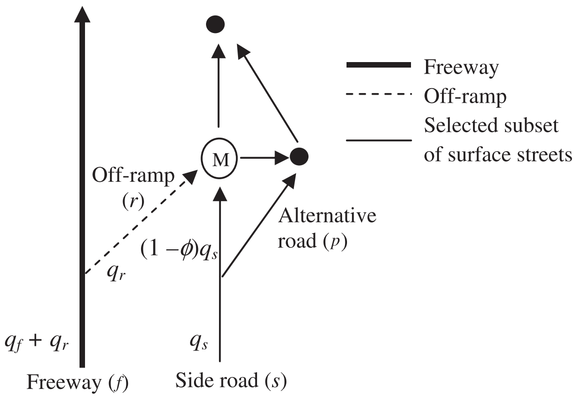

Fig. 1. Network around off-ramp.

Daganzo et al., 1999; Newell, 1999; Muñoz and Daganzo, 2002; Cassidy et al., 2002). Furthermore, if node *M* is a merge or a weaving section, a capacity drop may be expected when queues are observed in both approaches (Cassidy and Rudjanakanoknad, 2005).

In most cases the impacts of the queues are severe. There is a need to explore the circumstances under which they develop as well as management measures to mitigate them. Mitigation strategies available in the literature can be divided into two groups. The first group of strategies directly affect vehicles travelling on the freeway, such as lane assignment according to traveler's destinations (Daganzo et al., 2002) or dynamic closing of congested off-ramps to detour vehicles to less congested ramps (Daganzo et al., 2002; Van Den Berg et al., 2006). The latter may represent a too high penalty for detoured vehicles if nearby off-ramps are too far away.

The second group of strategies directly affects traffic conditions on the surface streets, mainly by controlling the traffic lights on nearby intersections. As discussed in Tian et al. (2002), most efforts to coordinate traffic from freeways and surface streets have focused on harmonizing ramp metering rates and traffic signals upstream (USDOT, 1996; Pooran and Lieu, 1994). The authors also comment that current practice on off-ramp coordination with surface traffic consists mainly in installing queue detectors at the upstream end of the off-ramp to prevent queue spillback onto the freeway. Once a queue is detected, the traffic signal gives the ramp extra priority and discharges the queue. The authors recognize that although the action eliminates queue spillback onto the freeway, it often disrupts normal signal operations on the surface street. Li et al. (2009) move this idea one step further proposing to minimize total delays by coordinating nearby traffic lights with traffic states observed at the off-ramp, the freeway and the surface streets. Hagen et al. (2006) found that common measures to deal with off-ramp queues include signal timing and geometric improvements. For urban areas, they also propose measures that require advanced technology such as TDM[1] (to reduce freeway demand), ATIS[2] (to inform travelers of traffic congestion), and ATMS[3] (to deploy ramp metering systems or to detect and respond promptly to incidents). Note that most of these strategies assume that the downstream intersection from the off-ramp is controlled by a traffic light, and also that this traffic light is the main bottleneck that causes the queue to form, which is not always the case.

In this paper we propose an alternative to avoid oversaturated off-ramps due to congestion downstream from it. The measure does not assume the presence of a traffic light at the end of the off-ramp, and it makes use of surface streets nearby the freeway. Therefore, it is more appropriate for off-ramps embedded in an urban environment. The approach consists of detouring a certain fraction of the side road flow through underutilized and nearby parallel roads in order to allocate more capacity of node *M* to the off-ramp flow. The detoured flow should be as low as possible, but high enough to avoid queues from arising on the side road and the off-ramp. Thus, all delays in the freeway caused by this off-ramp should disappear.

The rest of the article is organized as follows. Section 2 presents the proposed strategy in detail, while Section 3 discusses how to determine the magnitude of the detoured flow. Since the benefits of this strategy come at the expenses of detoured vehicles, in Section 4 we present a model to determine when this strategy would be convenient to implement for the given network. Section 5 presents our case study in an urban freeway in Santiago, Chile, and in Section 6 we conclude.

2. Description of the strategy

Node *M* in Fig. 1 represents the location where the flows coming from the off-ramp (q_r) and from the side road (q_s) merge. If the flows for both approaches are high, the capacity of node *M* may not be sufficient to serve both without generating queues at one or both approaches.

[1] Traffic Demand Management.
[2] Advanced Traveler Information Systems.
[3] Advanced Traffic Management Systems.