EFFECTS OF ON-RAMP AND OFF-RAMP METERING ON QUEUE FORMING IN URBAN TRAFFIC NETWORKS

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AbstractTo control the traffic flows near on-ramps and off-ramps, ramp metering installations can be used. We compare on-ramp metering and off-ramp metering, with respect to queue forming and total time spent. Both control measures are used to improve traffic flow on freeways, and both have influence on the route choice of the drivers. Although the two measures are very similar, there are some major differences. The use of ramp metering installations can change the traffic assignment in the network because the inflows or outflows of the freeways are limited. This will result in a change in travel times in the network. And since drivers make a route choice based on these travel times, the route choice (and thus the traffic assignment) can change as well. This can lead to a relocation of queues in the network. With a case study we illustrate the differences between on-ramp and off-ramp metering, with three different control methods: fixed time control, ALINEA and a model predictive control-based method.

Keywords: Traffic control, Model predictive control, Ramp metering

1. INTRODUCTION

The amount of traffic on the roads has increased during the last years. This has led to an increase of congestion, mainly located on the freeways. This congestion leads to longer travel times, and as a result it has become more attractive for drivers to leave the freeway, use a shorter route through the urban network, and then enter the freeway again downstream of the congestion (rat-running). This causes an increase of long distance traffic on the urban network. The long distance vehicles in the urban network slow down the local traffic, decrease the safety due to higher speeds and less knowledge of the local situation, and generate more pollution and noise. This change in route choice can be prevented with static measures, e.g. lower speed limits on the urban network, closing lanes during peak hours, placing route guidance signs, etc. Also some dynamic measures are available, e.g. creating 'red waves', providing information on variable message signs, or using ramp metering installations. These measures influence the route choice of the drivers by increasing the travel times in the urban network, or by guiding unfamiliar drivers only along the freeway. In this paper we will focus on the effect of ramp metering on the route choice of the drivers.

Originally, on-ramp metering installations were used to prevent congestion on freeways (Papageorgiou and Kotsialos, 2002; Cassidy and Rudjanakanoknad, 2005; Chen *et al.*, 1990; Zhang *et al.*, 2001). When the on-ramp metering installations were actually implemented, it became clear that they also influenced the route choice of the drivers (Taale and Middelham, 2000; Haj-Salem and Papageorgiou, 1995). The explanation for this phenomenon is that ramp meter-

ing changes the travel times of the routes, and since route choice is mainly based on these travel times, some drivers will select another route when a ramp metering installation is placed. These ideas lead to research on corridor control where on-ramp metering installations are used to influence route choice (Bellemans, 2003; Karimi *et al.*, 2004; Yang and Yagar, 1994).

A problem with the use of on-ramp metering installations is that on-ramp metering creates longer queues on the on-ramps, which can spill-back in the urban network. This results in more noise and pollution in the urban network, causing problems for the inhabitants of the cities. To solve these problems, off-ramp metering can be used. This method limits the flow that can leave the freeway, and so decreases the number of vehicles in the urban network. This improves the traffic condition in the urban network, but since the vehicles stay on the freeway, it has a negative impact on the situation on the freeway.

This paper is organized as follows. We first describe on-ramp and off-ramp metering, and give some theoretical (dis-)advantages. Next, we present some control methods that can be used to determine the settings of the ramp metering installations. At last, to investigate the differences between on-ramp and off-ramp metering, we perform a case study in which we simulate traffic in a small network with two possible routes. We use the Metanet model developed by Papageorgiou (Messmer and Papageorgiou, 1990) to describe the evolution of the traffic flows. This model is a discrete time discrete space model that divides the freeway network into links m, which are again divided into segments i. For each segment three state variables (density $\rho_{m,i}(k)$, velocity $v_{m,i}(k)$, and flow $q_{m,i}(k)$) are computed every time step k. As a route choice model we use the model we described in (van den Berg *et al.*, 2005). We compare different methods to control the ramp metering installations: fixed time control, ALINEA (Papageorgiou *et al.*, 1991), and a model predictive control based method (Bellemans, 2003).

2. RAMP METERING

Ramp metering is a control method that limits the flow on ramps connected to a freeway. On-ramp metering limits the flow that enters the freeway, off-ramp metering limits the flow that leaves the freeway. Ramp metering is implemented with traffic signals, which allow only one vehicle to drive on during each green period.

The ramp metering rate gives the percentage of the capacity flow that is allowed to drive on. The ramp metering rate can vary between a maximum and a minimum value: $r_{\min} \leq r(k) \leq r_{\max}$.

2.1 On-ramp metering

On-ramp metering limits the flow that can enter the freeway via the metering rate:

$$q_{o,f}^{\text{real}}(k) = \min\left(r(k)Q_{\text{cap},f}, q_{o,f}^{\text{int}}(k)\right)$$

where $q_{o,f}^{\text{int}}(k)$ is the flow that intends to enter freeway f via on-ramp o, $r(k)$ is the ramp metering rate, $Q_{\text{cap},f}$ is the capacity flow, and $q_{o,f}^{\text{real}}(k)$ is the flow that really enters the freeway.

On-ramp metering can influence the route choice of drivers, but only when queues are formed that become long enough to influence the travel time significantly. When drivers have experienced a long queue on the urban network during previous trips, they will select the freeway route during a next trip. But the long queue that is required to obtain this change in route choice spills back through the total urban network. As a result the urban traffic is totally blocked, and the local traffic is also delayed.

2.2 Off-ramp metering

Off-ramp metering limits the flow that can leave the freeway:

$$q_{f,o}^{\text{real}}(k) = \min\left(r(k)Q_{\text{cap},f}, q_{f,o}^{\text{int}}(k)\right)$$

where $q_{f,o}^{\text{real}}(k)$ is the flow that really leaves freeway f toward off-ramp o, and $q_{f,o}^{\text{int}}(k)$ the flow that intends to leave the freeway. The part of the flow that intends to leave the freeway but that is not allowed to is given by

$$q_{f,o}^{\text{over}}(k) = q_{f,o}^{\text{int}}(k) - q_{f,o}^{\text{real}}(k)\ .$$

This flow will result in an increase of the density on the segment upstream of the off-ramp:

$$\rho_{f,N_m}^{\text{tot}}(k) = \rho_{f,N_m}(k) + \frac{T}{l\lambda}q_{f,o}^{\text{over}}(k) - \frac{T\gamma}{l\lambda}q_{f,o}^{\text{over}}(k-1)$$

where $\rho_{f,N_m}^{\text{tot}}(k)$ is the total density (including the vehicles that want to leave toward the off-ramp) on the last segment N_m of freeway f, $\rho_{f,N_m}(k)$ is the density on this segment as computed with the Metanet model (without the extra waiting vehicles), T the simulation time step, l the length of a segment, λ the number of lanes, and γ a parameter explained below. The waiting vehicles of the previous time step are used to compute the vehicles that intend to leave the freeway during the current time step:

$$q_{f,o}^{\text{int}}(k) = \gamma q_{f,o}^{\text{over}}(k-1) + q_{f,o}(k)$$

where $q_{f,o}(k)$ is the flow that wants to leave the freeway according to the Metanet model. When the number of vehicles that waits to enter the off-ramp becomes too high, some of these vehicles will change their route and stay on the freeway. The percentage of drivers that keeps waiting is given by γ.

Off-ramp metering can be used to prevent rat running by creating visible queues at the off-ramp, which