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Literature Review of Advancements in Adaptive Ramp Metering

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Abstract

Over a period spanning more than 30 years, several ramp metering algorithms have been developed to improve the operation of freeways. Many of these algorithms were deployed in several regions of the world, and field evaluations have shown their significance to improve traffic conditions on freeways and ramps. Previous reviews of ramp metering algorithms focused more on the research outcomes and evaluations of traditional metering algorithms developed in the early stage of ramp metering research. The purpose of this paper is to cover the more recent developments in ramp metering in relation to the traditional metering strategies. Several local and coordinated ramp metering algorithms were reviewed. In summary, Asservissement Linéaire d'Entrée Autoroutière (ALINEA) was found to be the most widely deployed local ramp metering strategy. The algorithm is simple and implementation costs less than other strategies. It also guarantees the targeted performance goals provided that the on-ramp has sufficient storage. Several extensions were proposed in the literature to fine-tune its performance. Among the coordinated metering strategies, zone based metering is simple to implement and easy to re-configure. System-wide adaptive ramp metering (SWARM) algorithm is more sensitive to calibrate for accurate prediction of traffic states. Heuristic ramp-metering coordination (HERO) algorithm can be useful if both local and coordinated control are desired particularly if the local control is using ALINEA. Fuzzy logic based algorithms are gaining popularity because of the simplicity and the fast re-configuration capability. Advanced real time metering system (ARMS) seems theoretically promising because of its proactive nature to prevent congestion; however, its performance is highly dependent upon accurate predictions. Finally, some guidelines were proposed for future research to develop new proposals and to extend the existing algorithms for guaranteed performance solutions.

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Keywords: freeway operation; signal control; queue management; congestion management; algorithms; coordination strategy; traffic control

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1. Introduction

Ramp metering is a ramp management strategy to control the number of vehicles entering a freeway using a traffic signal. They are programmed with a much shorter cycle time to allow a single vehicle or a small platoon of vehicles (usually two or three) per green phase. The metering rate is based on the traffic volume and speed on the freeway. On freeways, the goal is to increase throughput, speed, and capacity to maintain the optimum operation of the freeway. Ramp meters are usually employed to control vehicles at the on-ramp to enter the freeway (mainline) to mitigate the impact of the ramp traffic on the mainline flow. However, ramp meters can also be used to control traffic flow from the freeway to freeway and arterial to ramp and freeway. The selection of appropriate ramp metering strategy is based on the needs and goals of the regional transportation agency.

The simplest form of ramp meters works based on pre-set metering rates. The metering rates are either fixed or variable rates that are assigned on a defined schedule based on some historical traffic data. Fixed time or pre-timed metering addresses the recurring congestion problem but fails in case of non-recurring congestion. A better approach to ramp metering is adaptive or traffic responsive ramp metering where variable metering rates are allocated to ramps in response to actual traffic conditions. Traffic responsive metering uses present traffic conditions to adjust its metering rate. Traffic data is collected using loop detectors or any other detection system in real time. The metering rate is either calculated based on some algorithms or selected from a pre-defined matrix. Traffic responsive control can be implemented in both local and coordinated fashion.

This paper is divided into two main sections. The first section presents a review of the adaptive ramp metering systems developed in the earlier stage and their evaluations. The second section provides a review of the recent developments in ramp metering strategies.

2. Traditional Ramp Metering Algorithms

This section describes the traffic responsive algorithms that were developed in the early stages. The working principles and control logics of these algorithms are explained and compared in several aspects in Table 1.

2.1. Asservissement Linéaire d'Entrée Autoroutière (ALINEA)

ALINEA is a local traffic responsive feedback control algorithm for ramp metering developed by Papageorgiou et.al[1]. The algorithm takes freeway occupancy as input and computes the metering rate as a control variable that varies in response to changes in occupancy. ALINEA uses a single detector per lane of the freeway installed downstream at a distance of 40 meters or 400 meters. The downstream detectors measure the occupancy rate and send to the controller at regular intervals usually 40 seconds. The controller computes the difference between desired occupancy threshold and measured occupancy and determines the metering rate for the next interval (40 seconds). The algorithm also considers the previous interval metering rate while computing the metering rate for the next interval to avoid major variations in the metering rates for smooth operation. The goal of ALINEA is to set the metering rate at which the flow will not exceed the freeway capacity.

ALINEA performs well in maintaining a desired flow at the freeway. However, it creates long queues at the on-ramp that causes bottlenecks. Zhang et al.[2] proposed an extension to basic ALINEA to avoid the ramp traffic to exceed the capacity. Smaragdis and Papageorgiou[3] proposed three more modifications FL-ALINEA, UP-ALINEA and X-ALINEA/Q to the standard version for improving the performance in various scenarios.

FL-ALINEA uses the mainline flow from the downstream detectors instead of occupancy while UP-ALINEA uses occupancy values from the upstream detectors when the downstream detectors are not available. X-ALINEA/Q addresses the problem of long queue formation on the ramp when the freeway is saturated that causes restricted metering rates. Smaragdis et al.[4] proposed another extension AD-ALINEA, which addresses the issue of constant desired occupancy value that might change in real time due to weather conditions or traffic compositions.

Several field studies evaluate the performance of ALINEA. Chu et al.[5] evaluated ALINEA in a simulation environment over a stretch of the I-405 freeway in California where ALINEA shows good performance under both recurrent and non-recurrent congestion scenarios. Caglar and Hilmi[6] used ALINEA on Bosphorus Strait crossing bridges on State Road D100 and Europe Route E80 between Europe and Turkey. Field results showed that ALINEA