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Local ramp metering with distant downstream bottlenecks: A comparative study

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ABSTRACT

The well-known feedback ramp metering algorithm ALINEA can be applied for local ramp metering or included as a key component in a coordinated ramp metering system. ALINEA uses real-time occupancy measurements from the ramp flow merging area that may be at most a few hundred meters downstream of the metered on-ramp nose. In many practical cases, however, bottlenecks with smaller capacities than the merging area may exist further downstream, which suggests using measurements from those downstream bottlenecks. Recent theoretical and simulation studies indicate that ALINEA may lead to poorly damped closed-loop behavior in this case, but PI-ALINEA, a suitable Proportional-Integral (PI) extension of ALINEA, can lead to satisfactory control performance. This paper addresses the same local ramp-metering problem in the presence of far-downstream bottlenecks, with a particular focus on the employment of PI-ALINEA to tackle three distinct cases of bottleneck that may often be encountered in practice: (1) an uphill case; (2) a lane-drop case; and (3) an un-controlled downstream on-ramp case. Extensive simulation studies are conducted on the basis of a macroscopic traffic flow model to show that ALINEA is not capable of carrying out ramp metering in these bottleneck cases, while PI-ALINEA operates satisfactorily in all cases. A field application example of PI-ALINEA is also reported with regard to a real case of far downstream bottlenecks. With its control parameters appropriately tuned beforehand, PI-ALINEA is found to be universally applicable, with little fine-tuning required for field applications.

1. Introduction

Ramp metering is a major means for freeway traffic control (Papageorgiou and Kotsialos, 2002; Bhouri et al., 2013; Frejo and Camacho, 2012; Geroliminis et al., 2011; Gomes and Horowitz, 2006; Hegyi et al., 2005; Li et al., 2014a,b; Lu et al., 2011; Meng and Khoo, 2010). The significance of ramp metering has been demonstrated in many field applications in the past three decades (Papageorgiou and Kotsialos, 2002; Bhouri et al., 2013). ALINEA is a popular and efficient local ramp metering strategy, developed on the basis of feedback control theory (Papageorgiou and Kotsialos, 2002; Papageorgiou et al., 1991; Wang et al., 2014). Since its design philosophy was developed in the late 1980s (Papageorgiou et al., 1991), ALINEA has been successfully applied to hundreds of freeway sites worldwide (Papageorgiou and Kotsialos, 2002). Despite its local operation

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nature, it may also be combined with coordinated ramp metering strategies (Papamichail and Papageorgiou, 2008). In principle, ALINEA aims to maximize freeway throughput in the ramp merging area (e.g. area *A* in Fig. 1) and, to this end, it is required that occupancy measurements fed to ALINEA be collected from this area. In some cases, however, a bottleneck with lower capacity than the merging area may be present further downstream (e.g. area *B* in Fig. 1), due to the existence of, e.g., an uphill or curved road section, tunnel, bridge, lane drop, or a downstream un-controlled on-ramp. In such cases, a concern arises in the design of ramp metering controllers due to the presence of a non-negligible time delay between the ramp metering action and its impact on traffic flow dynamics at the bottleneck location. Recent work (Wang et al., 2014) addressed the concern and demonstrated through in-depth theoretical investigations that occupancy measurements in this case have to be obtained from the bottleneck (Fig. 1), and moreover, that ALINEA is not sufficient any more to perform appropriately damped ramp metering (even with the bottleneck measurements) while PI-ALINEA, an extended version of ALINEA, can instead serve the need satisfactorily. The work (Wang et al., 2014) was also focused on some important properties of PI-ALINEA, e.g. the stability of the ramp metering system in the presence of distant downstream bottlenecks.

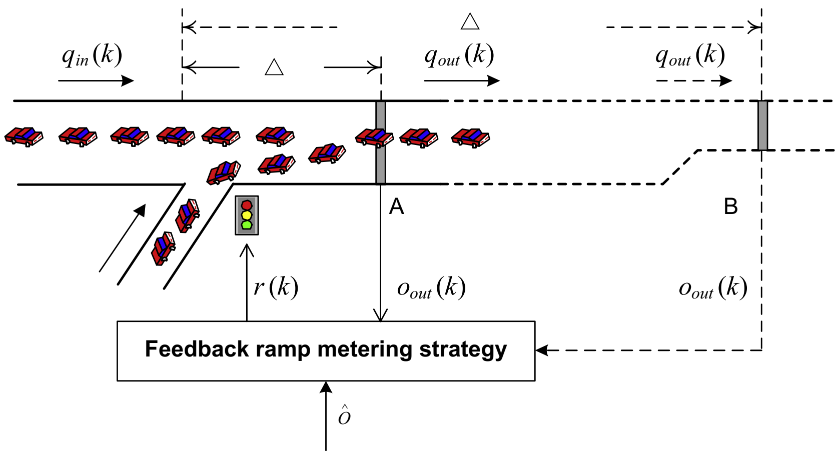

Fig. 1. Local ramp metering with a feedback control strategy.

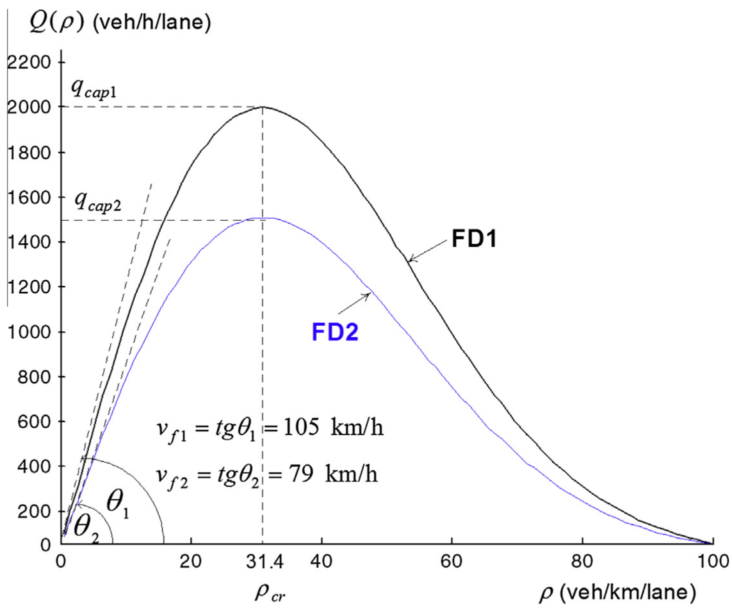

Fig. 2. The utilized fundamental diagrams: with FD1 resp. FD2 for non-bottleneck resp. bottleneck road sections.