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Application of ALINEA ramp control algorithm to freeway traffic flow on approaches to Bosphorus strait crossing bridges

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Abstract

Beginning from the 1960ies sustainability has been being pointed out as an important criterion in development which made many countries plan sustainability originated progressing policies. The decision makers, planning to construct a third roadway bridge to connect Asia and Europe continents on to the Bosphorus in Istanbul metropolitan area, first have to evaluate the exaggerated road traffic congestion phenomenon. Before making such a non-environmentally friend decision, advanced traffic managing strategies have to be incorporated to regularize the current pattern of traffic flows on the existing road network that prevails the road based urban transport.
Ramp control is an efficient strategy that has been employed to prevent recurrent traffic congestion since 1970ies. With the employment of ramp control applications, several benefits of ramp management, including i.e., the increase on the level of traffic safety, the increase on travelling speeds and consequently decrease on travelling times, the increase on the level-of-service, increase on energy consumption efficiency, decrease on environmental impacts, and increase on user satisfaction, have been experienced. The present paper aims to impose advanced traffic management schemes, specifically the ramp control, on the non-efficient utilisation of freeway approaches to existing Bosphorus bridges as an alternative to a third bridge crossing.

Keywords: sustainibility, traffic management, ramp control

1. Introduction

Ramp management is the application of control devices, such as traffic signals, signing, and gates to regulate the number of vehicles entering or leaving the freeway, in order to achieve operational objectives (Neudorff et al., 2003). Those objectives usually are stated similarly to the following: Balance freeway demand and capacity; maintain optimum freeway operation by reducing incidents that produce traffic delays, improve safety. Ramp management strategies can be classified as 'Ramp Closure', 'Ramp Metering', 'Special Use Treatments', 'Ramp Terminal Treatments' (Jacobson et al., 2006).

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Ramp closure has the greatest potential impact on existing traffic patterns and is rarely implemented as a long-term strategy. Closures may involve controlling automatic gates or manually moving barriers or gates at the ramp. More extreme methods such as physically removing the ramp are also options for permanent applications. Regardless of the method used to close the ramp, closures will have a significant impact on existing traffic flow patterns. Closures will result in traffic diverting to upstream and downstream ramps. As a result, traffic volumes and congestion will likely increase on nearby ramps and adjacent arterials (Jacobson et al., 2006). Benefits of the ramp closures are generally supported by an experiment of peak-period ramp closures conducted on a 5 km stretch of the John C. Lodge Freeway in Detroit which observed by Prevedouros (1999). This experiment produced the following findings: Freeway volumes increased 3.5 to 13.7 percent. Average freeway speed (averages over all periods and locations) increased from 43 to 60 km/h in the AM peak period and from 41 to 62 km/h in the PM peak period. *Ramp metering* involves the use of traffic signals at freeway on-ramps to regulate the volume rates at which vehicles enter the freeway. It will be discussed fallowing parts of the paper in detail. *Special use treatments* for ramp management focus on providing preferential treatment to a specific class or classes of vehicles and can be applied to either entrance or exit ramps. Special use treatments include exclusive access to ramps for a class of vehicle (e.g., high occupancy vehicle (HOV), emergency, freight, or construction) or special lanes on a ramp for the exclusive use by these vehicle classes (Jacobson et al., 2006). *Ramp terminal treatments* include signal timing improvements, ramp widening, additional storage or new turn lanes on arterials, and improved signing, and pavement markings on or adjacent to ramps. These treatments are geared to improving localized problems at either entrance or exit ramp terminals. Treatments focus on providing solutions to problems at the ramp/arterial intersection, on the freeway (e.g., exit ramp traffic queuing onto the freeway mainstream), or on freeway ramps. Ramp terminal treatments provide advantages as reduced delay, reduced queuing, improved safety (Jacobson et al., 2006).

2. Ramp Metering

Ramp meters are used to regulate the flow of traffic entering freeways according to current traffic conditions. They are intended to reduce congestion on the freeway in two aspects, (1) control the traffic volume entering the freeway, regulate freeway demand, and keep it under its capacity and (2) break up the platoons of vehicles released from an upstream traffic signal, to provide a safe merge (Mirchandani and Zou, 2006).

This first application of ramp metering was first implemented in 1963 in US and involved a police officer who would stop traffic on an entrance ramp and release vehicles one at a time at a predetermined rate, with the objectives of safer and smoother merging onto the freeway traffic, without disrupting the mainstream flows (McDermott et al, 1979; Piotrowicz et al., 1995). More than 2200 ramps have been metered in USA (Kachroo and Ozbay, 2003). Minnesota is the largest ramp metering application area in USA. The Minnesota Department of Transportation (Mn/DOT) uses ramp meters to manage freeway access on approximately 336 km of freeways in the Twin Cities metropolitan area. Mn/DOT first tested ramp meters in 1969 as a method to optimize freeway safety and efficiency in the metro area. Since then, approximately 430 ramp meters have been installed and used to help merge traffic onto freeways and to manage the flow of traffic through bottlenecks (Cambridge Systematics, 2001).

In Europe, the development is much more recent. In 1986, Great-Britain installed its first devices on the M6 freeway. After implementation bottleneck capacity increased about 3.2%. In 1970, 35 ramps on the Paris freeway network were equipped with traffic lights running on fixed time cycles that were set for morning peak periods during the week, and for the week-end returning periods (Kunkel, 1999). 20 ramps were metered at the end of the 1998 in Netherland (Taale and Middelham, 2000). After implementation bottleneck capacities increased by 3% and travel times decreased 13.8 min to 12 min. Germany, Belgium, Israel are the other countries, metering implementation is widely using (Papageorgiou and Papamichail, 2007).

With the employment of ramp metering applications, several benefits of ramp management, including i.e., the increase on the level of traffic safety, the increase on travelling speeds and consequently decrease on travelling times, the increase on the level-of-service, increase on energy consumption efficiency, decrease on environmental impacts, and increase on user satisfaction, have been experienced.

3. Ramp Metering Algorithms

Ramp metering, when properly applied, is a valuable tool for efficient traffic management on freeways and freeway networks. According to Papageorgiou and Kotsialos (2002), ramp metering algorithms may be classified into: (a) Reactive algorithms (tactical level) aiming at maintaining the freeway traffic conditions close to pre-specified set (desired) values by the use of real-time measurements and (b) Proactive algorithms (strategic level) aiming at specifying optimal traffic conditions for a whole freeway or a freeway network based on demand and model predictions over a sufficiently long time horizon (Smaragdis et al., 2004). Both kinds of metering algorithms may be combined within a hierarchical control structure, whereby a proactive network-wide strategy delivers optimal traffic conditions to be used as set (desired) values by sub-ordinate reactive algorithms (Smaragdis et al., 2004).

Reactive ramp metering strategies may be local or coordinated. Local strategies make use of traffic measurements in the vicinity of each ramp, to calculate the corresponding individual ramp metering values, while coordinated strategies may use available traffic measurements from greater portions of a freeway. Local strategies are far easier to design and implement; nevertheless, they have proved non-inferior to more sophisticated coordinated approaches under recurrent traffic congestion conditions (Papageorgiou et al., 1997). Demand – Capacity Algorithm, Occupancy – Capacity Algorithm and Gap Acceptance (Feed–forward); ALINEA (the acronym for 'Asservissement line´ aire d'entre´ e autoroutie') and derivatives, Neural Networks (Feedback); and Zone Algorithm are the examples of Local Reactive Algorithms. Helper, Linked (cooperative), Compass, Bottleneck, SWARM, FLOW (competitive), Coordinated ALINEA, Stratified Zone Algorithm are coordinated reactive algorithms (Zhang et. al, 2001).

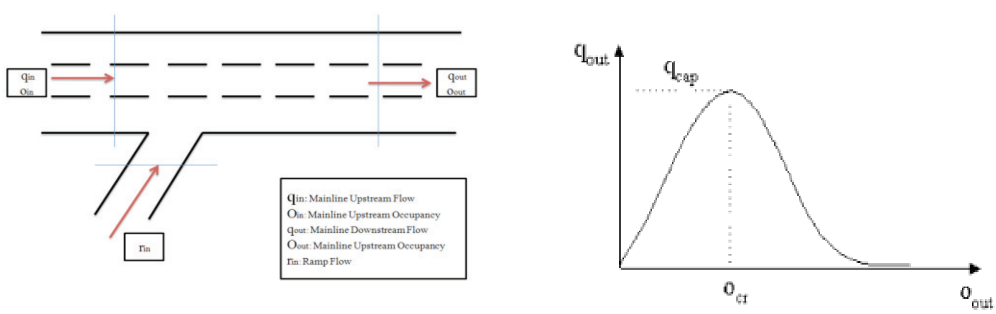
Proactive ramp metering algorithms are usually coordinated. Model Predictive Metering and Nonlinear Optimal Metering could be local or coordinated. Sperry Algorithm, Linear Programming Algorithm, METALINE, FHWA, ARMS are the examples of proactive metering algorithms.

3.1. Algorithm of ALINEA

ALINEA is a local traffic responsive feedback ramp metering strategy, attempts to maximize the mainstream throughput by maintaining a desired occupancy on the downstream mainstream freeway. ALINEA adjusts the metering rate to keep the occupancy downstream of the on-ramp at a pre-specified level, called the occupancy set-point (desired occupancy) $\hat{o}$, according to the formula given below (Papageorgiou et al., 1997):

$$r(k) = r(k\text{-}1) + K_R*[(\hat{o} - o_{out}(k\text{-}1)] \qquad (1)$$

where k = 1, 2, . . . discrete time index; $r(k)$: metering rate at cycle k; o out$(k - 1)$: last measured downstream freeway occupancy (%); K_R: regulator parameter; $\hat{o}$: set (desired) value for the downstream occupancy (Papageorgiou et al., 1997).



(a) (b)

Figure 1 (a) Simple Merging Ramp Figure (b) The fundamental diagram

The metering rate $r(k)$ that results from Eq. 1 is truncated if it is outside the range [$r$min, $r$max], where $r$max is the ramp's flow capacity (e.g., equal to 1600 veh/h or 1800 veh/h for single-lane ramps), and $r_{min} > 0$ is a minimum admissible ramp flow (typically 200–400 veh/h). A wide range of values for the update cycle of the ramp-metering rate have been used from 40 seconds to 5 minutes. Control results have been found to be insensitive for a wide range of values of the regulator KR, used for adjusting the constant disturbances of the feedback control. In real-world experiments, the algorithm has been determined to perform well for KR=70. The desired occupancy can be equal to or close to the occupancy value at capacity, which can be found in the volume-occupancy diagram. Various values ranging from 0.18 to 0.31 have been found in previous applications (Papageorgiou et al., 2008).

3.2. Some Evaluation Studies

Hernandez et al. (2004) evaluated the performance of local responsive and three coordinated ramp metering methods –Helper, Zone, Bottleneck algorithms- using WATSIM. Algorithms were adapted to the study site, a 10 mile section of I-15 north of Salt Lake City. Reductions in total travel time in freeway main flow for the entire simulated freeway section during AM and PM peak hour varied from 0% to 2% depending on the metering method, traffic volume and time of day (AM and PM peak hour). When only congested freeway links were analyzed for each 15 minute interval of the AM and PM peak hour reductions in travel time in freeway main flow ranged from 0% to 30%; however in some cases travel time increased. High reductions in travel time at congested links were offset by the increases and decreases in travel times in other links in the freeway when the entire simulated freeway system was analyzed for one peak hour. Also, all the tested metering methods increased on ramp travel time, offsetting 30% to almost 100% of the total travel time saved for the freeway main flow. The analysis resulted in mixed results indicating the benefits of these algorithms are not always guaranteed.

Chu et al. (2004) evaluated three well-known adaptive ramp-metering algorithms: ALINEA, BOTTLENECK, and ZONE using PARAMICS. The evaluation has been conducted in a simulation environment over a stretch of the I-405 freeway in California, under both recurrent congestion and incident scenarios. Simulation results show that adaptive ramp-metering algorithms can reduce freeway congestion effectively compared to the fixed-time control. ALINEA shows good performance under both recurrent and non recurrent congestion scenarios. BOTTLENECK and ZONE can be improved by replacing their native local occupancy control algorithms with ALINEA. Compared to ALINEA, the revised BOTTLENECK and ZONE algorithms using ALINEA as the local control algorithm are found to be more efficient in reducing traffic congestion than ALINEA alone. The revised BOTTLENECK algorithm performs robustly under all scenarios. The results also indicate that ramp metering becomes less effective when traffic experiences severe congestion under incident scenarios.

Yasar et al. (2006) proposed two new feedback – based coordinated ramp metering strategies C – MIXCROS and D – MIXCROS and evaluated them in microscopic and macroscopic simulation models under different demand scenarios. METALINE, ALINEA, New control (Kachroo and Ozbay, 2003) and MIXCROS (Kachroo and Ozbay, 2003) are also implemented using the same network and results are compared. D – MIXCROS and C – MIXCROS both perform better than all other control strategies for all demand scenarios.

3.3. Other Studies

Zheng et al. (2009), proposed an extension of the feedback local ramp metering strategy ALINEA for urban expressways, Shangai Urban Expressway, allowing the urban expressway ramp to have three control models, including no control, ramp metering, and ramp closure. The ramp control model was changed according to the comparison of the control threshold and the real-time detecting traffic data. During the ramp-metering cycles, the queue length subsection constraint model was proposed to avoid the ramp queue length exceeding the ramp's capacity for queue length. Therefore this local metering strategy for an urban expressway may be constituted with three parts: a ramp-model control threshold, an ALINEA algorithm and the queue length subsection constraint model. The off-line simulation results show that the ramp metering strategy can both increase the main line speed and relieve the urban expressway main line downstream congestion. This queue length subsection constraint model also avoids an on-ramp queue's interference with surface street traffic.

An efficient ramp control strategy may not be politically attractive due to its negative impacts on equity. Zhang and Levinson (2005) addressed this issue and presented a new objective for ramp metering—minimizing weighted travel time—which is able to balance efficiency and equity. A simulation approach is used to achieve the new objective. BEEX, a new family of control strategies with various degrees of equity consideration, are developed and used to demonstrate this approach.

According to Smaradgis and Papageorgiou (2003), ALINEA is occupancy based—both the set value $\hat{o}$ and the real-time measurements $o(k)$ relate to traffic occupancies. A basic reason for using occupancies instead of flows, is that, as evidenced by Figure 1b, traffic volumes do not uniquely characterize the traffic state. More specifically, the same traffic volume may appear for noncongested and for congested traffic conditions because of the inverse U-shape of the fundamental diagram (Figure 1*b*). On the other hand, occupancy measurements may not be readily related to the classic traffic flow variables (density, traffic volume, mean speed) because of the uncertainty in the *g*-factor, which is known to depend on traffic composition (e.g., cars versus trucks), measurement device sensitivity, and different installation conditions. Moreover, in the case of a central network wide specification of set values (strategic level) for local ramp metering (*1*), it may be easier to specify set values for flows than for occupancies. For these reasons, it may be useful under certain conditions to apply the flow-based version of ALINEA (FL-ALINEA)

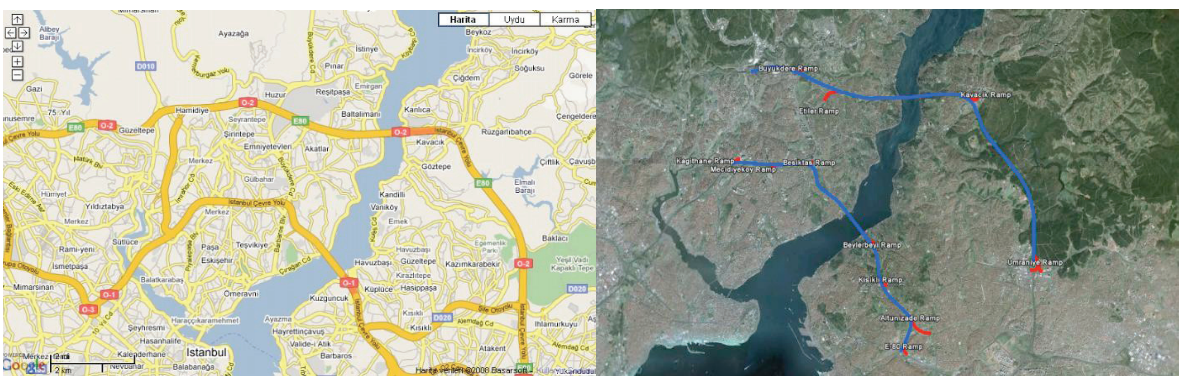
There are also several other extensions of ALINEA as UP-ALINEA (upstream-occupancy-based version), UF-ALINEA is an (upstream-flow-based strategy), AD-ALINEA (Adaptive – with estimation algortihm to o_{cr}), *X*-ALINEA/Q combination of any of the preceding strategies with efficient ramp queue control) (Smaragdis et al., 2004).

4. Case study

4.1. Istanbul

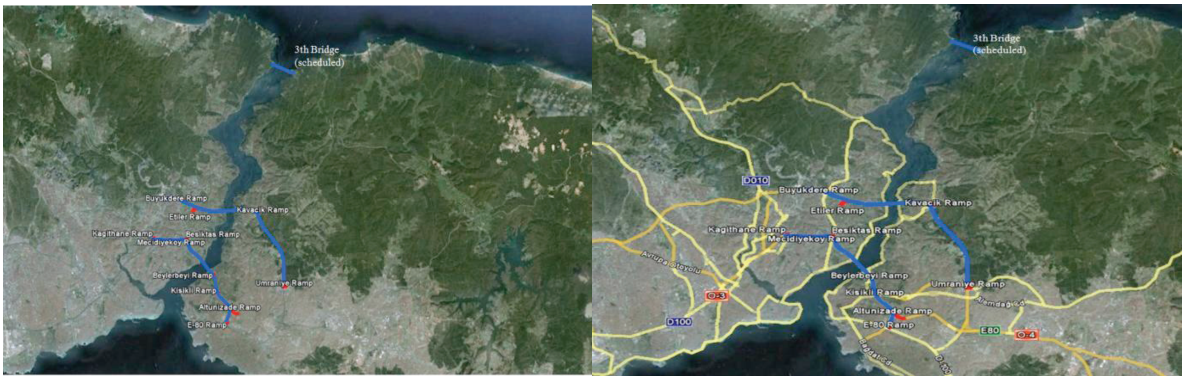
Istanbul freeways have an important status as a connection between Europe and Asia. The State Road D.100 and the European route E80 are two the main freeway connections between Europe and Turkey. Freeways lead east to Ankara and west to Edirne. There are also two expressways circling the city. The older one, the O-1, is mostly used for inner city traffic, and at the same route with Bogazici Bridge; while the more recent one, the O-2 which is at the same route with FSM Bridge, is mostly used by intercity or intercontinental traffic (see Figure 2a).

The decision makers planning to construct a third roadway bridge (see Figure 2c) to connect Asia and Europe continents on to the Bosphorus in Istanbul metropolitan area first have to evaluate the exaggerated road traffic congestion phenomenon. Before making such a non-environmentally friend decision, advanced traffic managing strategies have to be incorporated to regularize the current pattern of traffic flows on the existing road network that prevails the road based urban transport. E – 80 Ramp, Altunizade Ramp, Kisikli Ramp, and Beylerbeyi Ramp merge into O-1 expressway at Asia site of Istanbul. Umraniye and Kavacik Ramps merge into O-2 expressway at Asia site of Istanbul. At European site of Istanbul Besiktas, Mecidiyekoy and Kagithane ramps merge into O-1 and Buyukdere, Etiler ramps merge into O-2 expressway (see Figure 2b). Figure 2d also illustrates the freeway network in Istanbul.



(a) (b)

Figure 2 (a) Freeways in Istanbul / (b) O-1 and O-2 Freeways and the ramps merging into



(c) (d)

Figure 2 (c) Planning 3th bridge , (d) Planning 3th bridge and freeway network in the city.

4.2. Numeric Analysis

Numeric analysis has been carried out to investigate ramp metering usability. Four demand scenarios have been implemented to simple merging ramp figure (Figure 1a) for an hour and ALINEA algorithm is adapted to study site. As seen Figure 1a, study section consists of three lanes of mainstream and single ramp lane. Mainstream and ramp demands are loaded as constant in scenario 1; time-varying loading has been enforced in scenario 2; a sine curve is loaded in scenario 3; and real flow measurements on approaches to Bosphorus strait crossing bridges are utilized in scenario 4 (Figure 3a-3b-3c-3d).

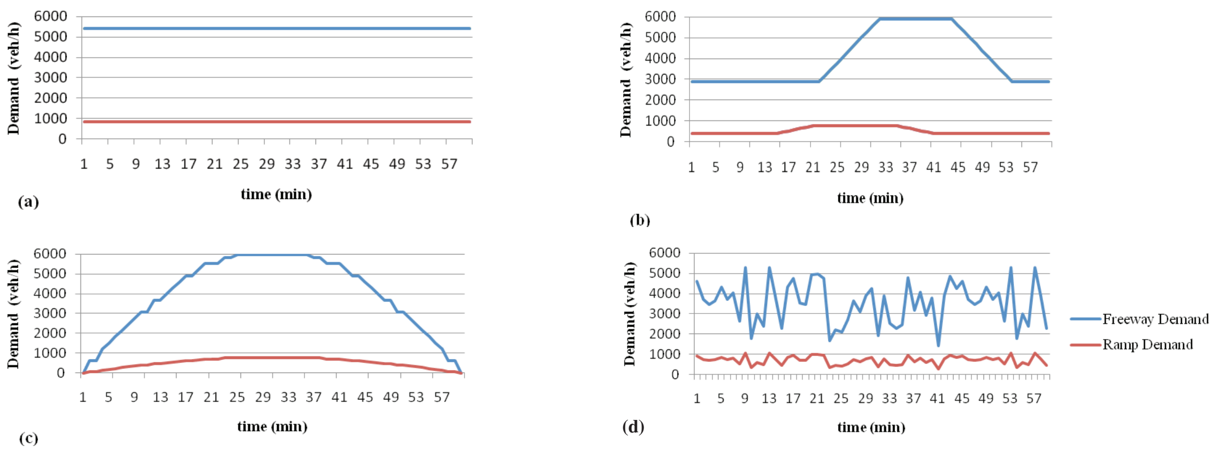


Figure 3 The utilized demand scenarios: (a) scenario 1(b) scenario 2 (c) scenario 3 (d) scenario 4

Mainstream capacity 6510 veh/h; minimum admissible ramp flow, r_{min} = 400 veh/h; ramp flow capacity, r_{max} = 1600 veh/h; K_R = 70; set (desired) value, $\hat{o}$ = 20% and o_{cr} = 21,7% are the assumed values in numerical analyses. When these values substitute in (1), the results have been computed in figure 4a, 4b, 4c and 4f.

No-metering case in figure 4 illustrates the total number of mainstream vehicles (q_{in}) and ramp vehicles (r_{in}) without metering for each time intervals. It does not denote the real flow behavior because the value of flow has to be under the capacity value. When the total number of vehicles are computed over capacity, the flow is unstable and congestion occurs. Figure 4d and 4e present the peak flow time intervals of Figure 4b and 4c specifically. In the numerical example that is based on dynamic detection, no-metering profile line is certainly under capacity and moreover is under the ALINEA profile as seen in Figure 4b, 4c and 4f.

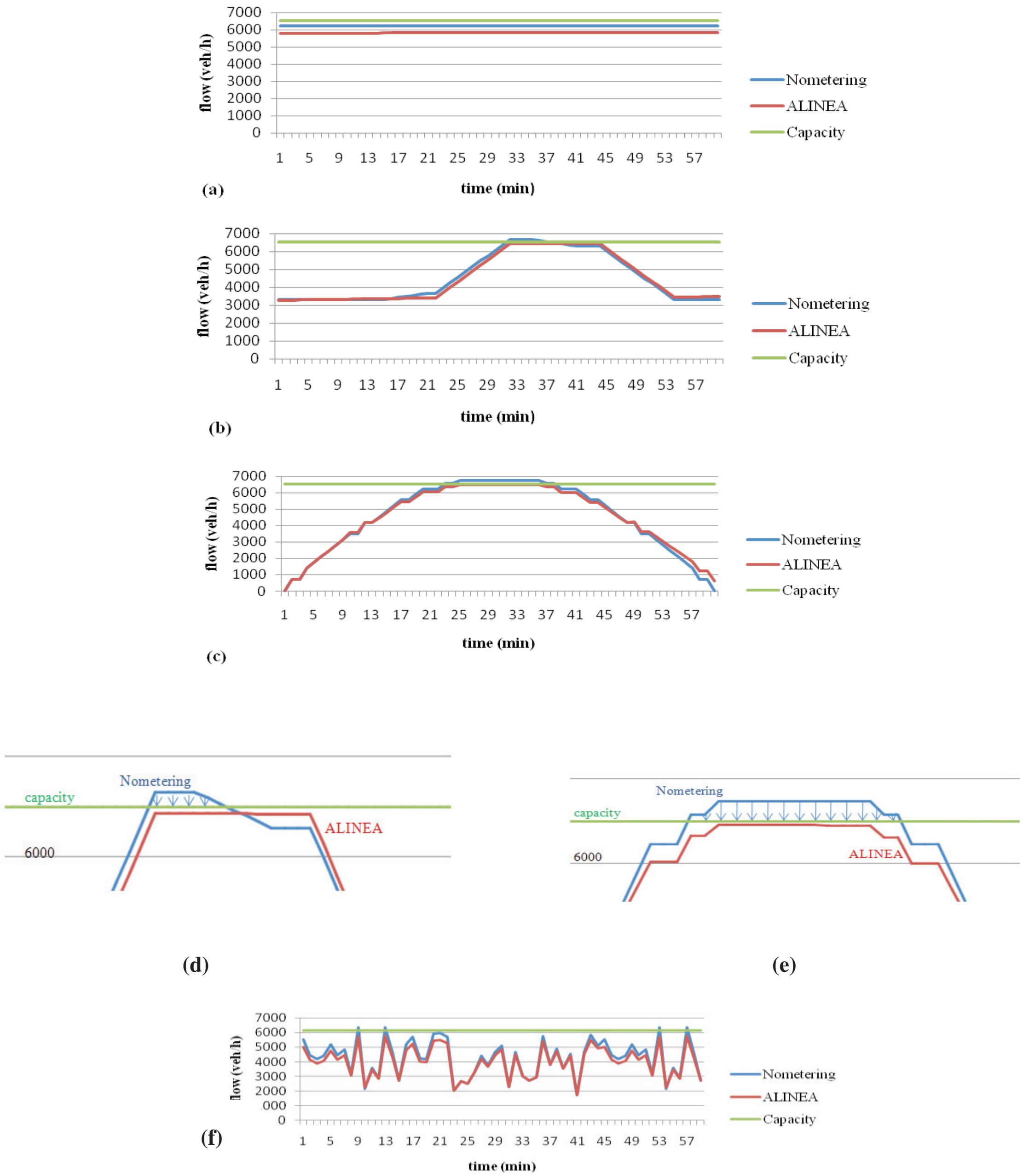


Figure 4 (a) outputs of scenario 1(b) outputs of scenario 2 (c) outputs of scenario 3 (d) outputs of scenario 2 in details (e) outputs of scenario 3 in details (f) outputs of scenario 4

As seen in Figure 4, not only in the theoretical traffic loadings but also in real flow measurements ALINEA algorithm regulates the ramp flow and keeps mainstream flow under the capacity. ALINEA prevents the congestion and keeps flow in stable mode (Figure 4b-4c-4f). Figure 4a illustrates that ALINEA fails in terms of under capacity flow conditions.

5. Conclusion and Remarks

The decision makers planning to construct a third roadway bridge to connect Asia and Europe continents on to the Bosphorus in Istanbul metropolitan area first have to evaluate the exaggerated road traffic congestion phenomenon. Before making such a non-environmentally friend decision, advanced traffic managing strategies have to be incorporated to regularize the current pattern of traffic flows on the existing road network that prevails the road based urban transport.

The objective of this paper is to demonstrate the benefits of ramp management strategies especially ramp metering. Istanbul freeway networks available to implement ramp metering strategies not only the local traffic responsive ones but also the coordinated ones. Throughout the numerical examples, four different demand scenarios are employed to process ALINEA. In first case, congestion is not occurred but ALINEA restricted the ramp flow and decreased the level of service. Except the first case, ALINEA presents successful results in all scenarios.

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