A fresh look at ramp metering control: ALINEA without any tedious calibration

Cédric Join, Hassane Abouaïssa, Michel Fliess

Rapport de recherche *Research Report*

LIX, École polytechnique, France

Février 2015 *February 2015*

A fresh look at ramp metering control: ALINEA without any tedious calibration

Cédric Join[1,4,5]**, Hassane Abouaïssa**[2]**, Michel Fliess**[3,4]

[1]CRAN (CNRS, UMR 7039), Université de Lorraine, BP 239, 54506 Vandœuvre-lès-Nancy, France.
cedric.join@univ-lorraine.fr

[2]LGI2A (EA 2926), Technoparc Futura, Université d'Artois, 62400 Béthune, France & Univ. Lille Nord, 59000 Lille, France.
hassane.abouaissa@univ-artois.fr

[3]LIX (CNRS, UMR 7161), École polytechnique, 91128 Palaiseau, France.
Michel.Fliess@polytechnique.edu

[4]AL.I.E.N. (Algèbre pour Identification & Estimation Numériques), 24-30 rue Lionnois, BP 60120, 54003 Nancy, France.
{cedric.join,michel.fliess}@alien-sas.com

[5]Projet Non-A, INRIA Lille – Nord-Europe, France

Abstract ALINEA is a well known ramp metering closed-loop control the aim of which is to improve highway traffic. This report shows that ALINEA may be slightly modified in order to be efficiently implemented without any need of crucial time-varying quantities, like the critical density and the free-flow speed, which are most difficult to estimate correctly online. Some convincing computer experiments, which employ real data, are displayed and discussed.

Keywords Highway, ramp metering, critical density, free-flow speed, closed-loop control, ALINEA, estimation, calibration.

---

1 Introduction

The goal of *ramp metering* is to improve the highway traffic conditions by an appropriate regulation of the inflow from the on-ramps to the highway mainstream (see, *e.g.*, [19]). This is depicted in Figure 1 where

- q_r, in veh/s, is the ramp flow related to the control variable r,
- w represents the queue length in vehicles,
- d, in veh/s, is the ramp demand,
- q_e, in veh/s, is the upstream segment flow,
- q_s, in veh/s, is the downstream segment flow,
- ρ_s, in veh/m, is the segment density,
- v_s, in m/s, is the segment speed.

Quite diverse approaches have been proposed. Among the various feedback control laws which may be found in the literature, *ALINEA*, which

- is an acronym of the French words *Asservissement LINéaire d'Entrée Autoroutière*,
- was introduced more than twenty five years ago ([8, 9, 20]),

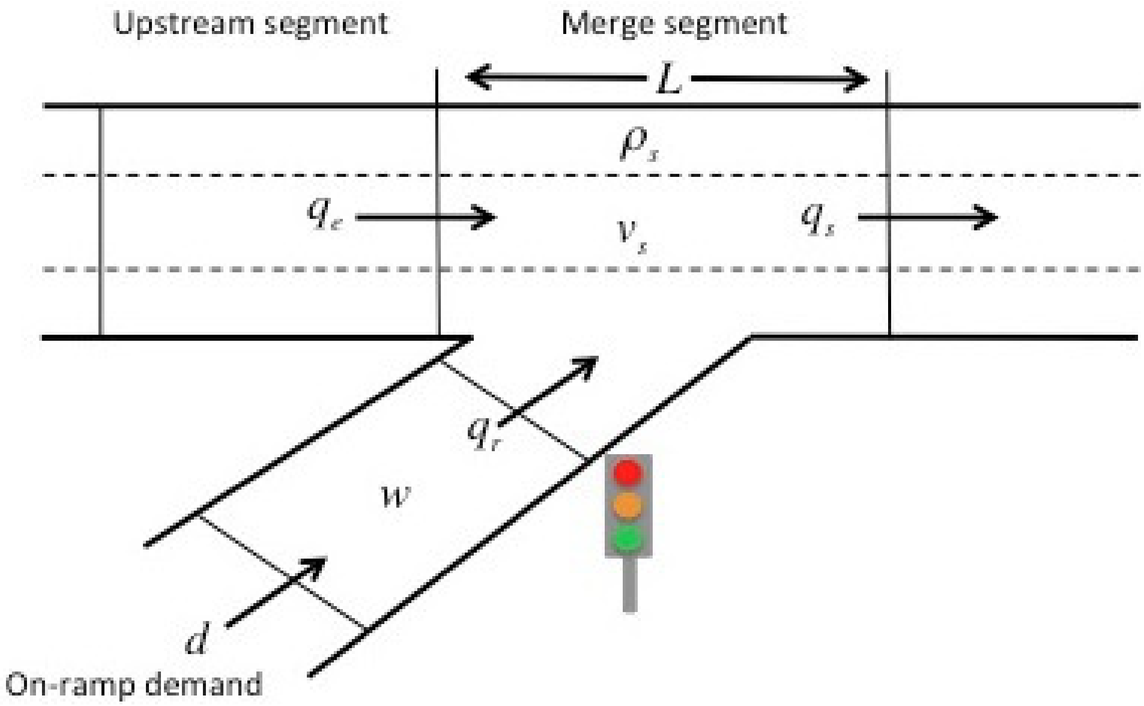


Figure 1. Highway ramp metering principle

certainly still is the most popular one, thanks to the numerous variants which have been published (see, *e.g*, [17, 21, 22], and the references therein). Moreover, ALINEA is, to the best of our knowledge, one on the very few closed-loop control synthesis which has been implemented in practice. Notice that some open-loop control strategies have also been used (see, *e.g*, [12, 15]).

The quality of any control law depends on a good knowledge of the highway characteristics, especially the *critical density* and the *free-flow speed*, which are unfortunately most difficult to estimate in real time. The purpose of this study is to show that a slight change of the ALINEA algorithm may be successfully implemented without the need of such a knowledge. This is an adaptation of a similar result [2] for an "intelligent" controller derived from *model-free* control [7].

Our paper is organized as follows. Short reviews on the traffic parameter estimation and on the usual ALINEA control algorithm are provided respectively in Sections 2 and 3.1. Section 3.2 displays our modified ALINEA algorithm. Computer experiments are discussed in Section 4. The conclusion in Section 5 explains why we are publishing this research report neither in a journal nor in the proceedings of a conference.

2 Fundamental diagram: a short overview

Most important parameters for obtaining a good traffic characterization may be obtained from May's *fundamental diagram* [14], depicted in Figure 2. This diagram is defined by

$$\boxed{V(\rho_i) = v_f \exp\left(-\frac{1}{a}\left(\frac{\rho_i}{\rho_c}\right)^a\right)} \qquad (1)$$

where

- ρ_i is the density of the segment i of the highway,
- V is the corresponding the mean speed,
- v_f is the free-flow speed,
- ρ_c the critical density,
- a is a model parameter.

Let us stress that Formula (1) is

- not derived from any law of pure physics,
- a rather rough heuristic approximation.

Offline techniques like, *e.g*, [3, 6, 11, 13] do not permit to take into account of the parameter variations. This explains the development of several online settings, like

1. extended Kalman filters (see, *e.g.*, [16, 24, 25]),
2. adaptive least square techniques (see, *e.g.*, [23]),
3. algebraic estimation techniques [1, 2],
4. various other viewpoints (see, *e.g.*, [4, 10, 26]).

Although the third approach yields often fair results, it should be stressed that the approximate nature of Equation (1) does not allow until today fully satisfactory estimates.

3 ALINEA

3.1 Basic ALINEA

The feedback loop defining ALINEA reads

$$\boxed{r(k) = r(k-1) + K_I(\rho^\star - \rho_s)}$$

where

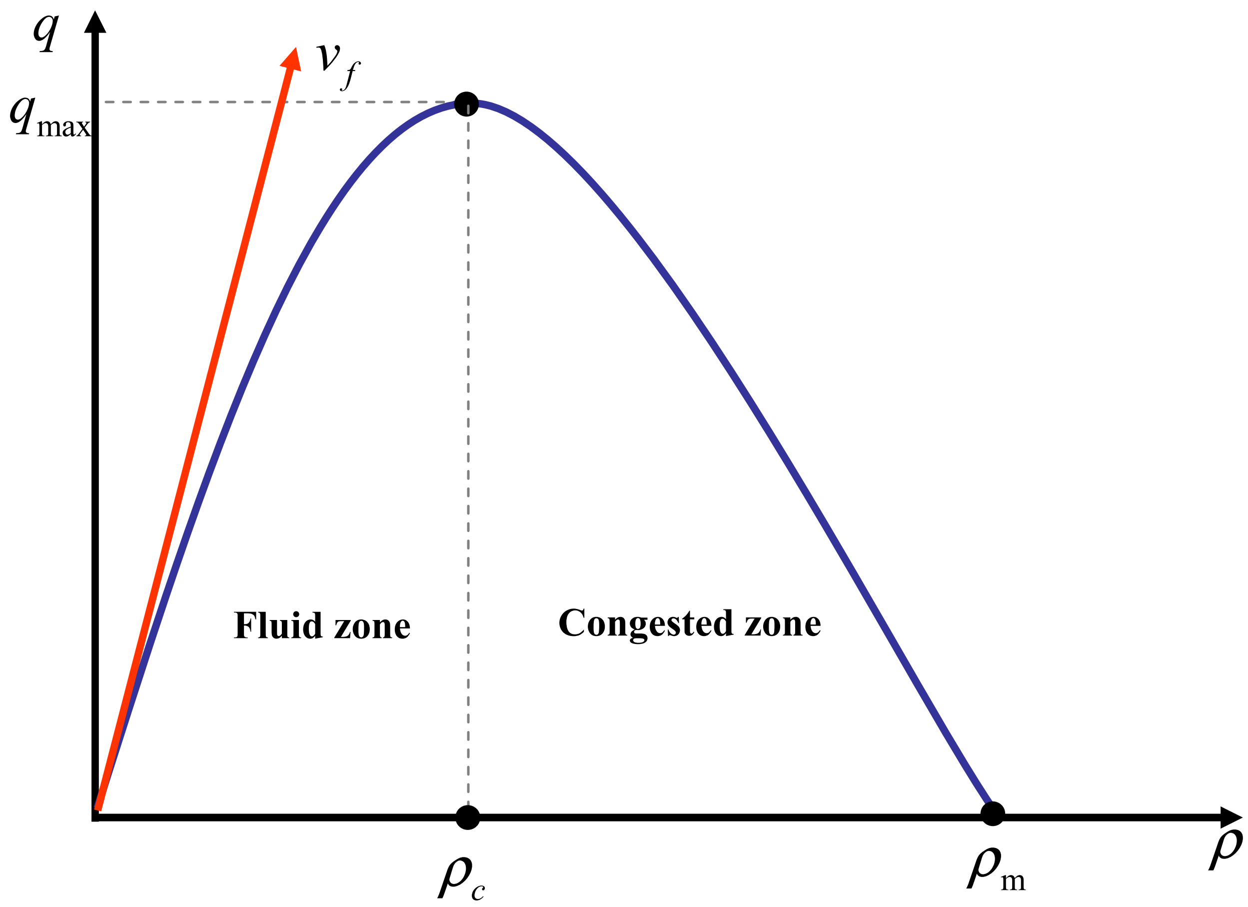


Figure 2. Fundamental diagram: an example

- $r(k)$, which is the rate of ramp inflow (see Figure 1), stands for the control variable,
- the *gain* K_I is the only adjustment parameter,
- the segment density ρ_s (see Figure 1) stands for the output variable,
- $\rho^\star$ is the reference trajectory,
- $e = \rho^\star - \rho_s$ is the tracking error.

ALINEA may be therefore viewed as

- a discrete-time analogue of a simple integrator,
- corresponding to the I in the classic PID controllers,

The reference $\rho^\star$ is usually close to the critical density ρ_c, *i.e.*, a quantity which is, as already stated, most difficult to estimate.

3.2 Modifying ALINEA

The following rules for choosing $\rho^\star$ permit to bypass the above calibration:

- Let V_{filtered} be the filtered mean speed and $V_{\text{threshold}}$ the speed threshold.[1]
- ρ_{d0}, ρ_{inc}, ρ_{dec} denote respectively the initial density, the increment and decrement of the desired density.
- If $V_{\text{filtered}} > V_{\text{threshold}}$, then $\rho^\star = \rho_{\text{d0}} + \rho_{\text{inc}}$.
- If $V_{\text{filtered}} < V_{\text{threshold}}$, then $\rho^\star = \rho_{\text{d0}} - \rho_{\text{dec}}$.

4 Computer experiments

Our computer simulations are based on numerical data which are collected from the French highway *A4Y* with one on-ramp: see Figures 3 and 4-(d). The macroscopic models (see, *e.g.*, [18]), which are employed for computer simulations, are

- heuristic,
- quite sensitive to parameter variations and uncertainties.

The only available accurate physical law is the conservation equation. All other equations, which for instance are connected to the speed and the fundamental diagram, are based on empirical observations which yield coarse approximations. The main parameters such as the critical density and the free-flow speed are moreover subject to variations.

Two cases are studied:

1. ALINEA control by setting, as in Section 3.1, $\rho^\star = \rho_c$, which is assumed to be well estimated and constant: see Figures 4 and 5,

[1] Concrete studies (see, *e.g.*, [5]) have demonstrated that the level of service is highly damaged and that the congestion phenomenon is reaching its maximum, when the mean speed of individual vehicle is about 5 m/s. The threshold of discomfort is reached, when this speed is equal to 20 m/s.

Figure 3. Aerial view of the site (Source: DiRIF (*Direction des Routes Île-de-France*))

2. ALINEA control by selecting $\rho^\star$ as in Section 3.2: see Figures 6 and 7.

The control is relaxed if the queue length w (see Figure 1) is greater than 500. Some numerical results for important quantities are reported in Tables 1 and 2. The differences between those results for the two cases is rather small. It confirms that the tedious estimation of the critical density may be avoided without any harm.

5 Conclusion

Due the difficulties related to the online estimation, only real data with a constant critical density were available. Although computer simulations with an artificial time-varying critical density were achieved, which show a great superiority of our modified ALINEA, we decided not to show them here. We hope that some future work will confirm this fact via real data and concrete experiments.

References

[1] H. Abouaïssa, M. Fliess, V. Iordanova, C. Join, Vers une caractérisation non linéaire d'un réseau autoroutier, 3^{es} J. Identif. Modél. Expériment., Douai, 2011. Online available at
`http://hal.archives-ouvertes.fr/hal-00572818/en/`

[2] H. Abouaïssa, M. Fliess, V. Iordanova, C. Join, Freeway ramp metering control made easy and efficient, 13th IFAC Symp. Control Transportation Systems, Sofia, 2012. Online available at
`http://hal.archives-ouvertes.fr/hal-00711847/en/`

[3] A. Alessandri, A. Febbraro, A. Ferrara, E. Punta, Nonlinear optimization for freeway control using variable-speed signaling, IEEE Trans. Vehic. Techno., vol. 48, 2042-2052, 1999.

[4] T. Bellemans T, B. De Schutter, B. De Moor, Model predictive control with repeated model fitting for ramp metering, 5th IEEE Int. Conf. Intellig. Transport. Syst., Singapore, 2002.

[5] CETE Méditerranée, Niveaux de service des réseaux routiers en PACA : Etat en 2004, Evolution estimée à l'horizon 2020, Rapport d'Études, 2006.

[6] C. Chien, Y. Zhang, P. Ioannou, Traffic density control for automated highway systems, Automatica, vol. 33, 1273-1285, 1997.

[7] M. Fliess, C. Join, Model-free control, Int. J. Control, vol. 86, 2228–2252, 2013.

[8] H. Haj-Salem, J.-M. Blosseville, M.M. Davée, M. Papageorgiou, ALINEA: Un outil de régulation d'accès isolé sur autoroute – Étude comparative sur site réel', Rapport INRETS n° 80, Arcueil, 1988.

[9] H. Haj-Salem, J.-M. Blosseville, M. Papageorgiou, ALINEA - a local feedback control law for on-ramp metering: a real life study, 3rd IEE Intern. Conf. Road Traffic Control, London, 1990, pp. 194–198.

[10] J.-C. Herrera, A.M. Bayen, Incorporation of Lagrangian measurements in freeway traffic state estimation, Transport. Res. B, vol. 44, 460-481, 2010.

[11] U. Karaaslan, P. Varaiya, J. Walrand, Two proposals to improve freeway traffic flow, Tech. Rep. California PATH Research Report UCB-ITS-PRR-90-6, 1990.

[12] F. Middelham, H. Taale, Ramp metering in the Netherlands: An overview, 11th IFAC Symp. Contr. Transport. Syst., Delft, 2006

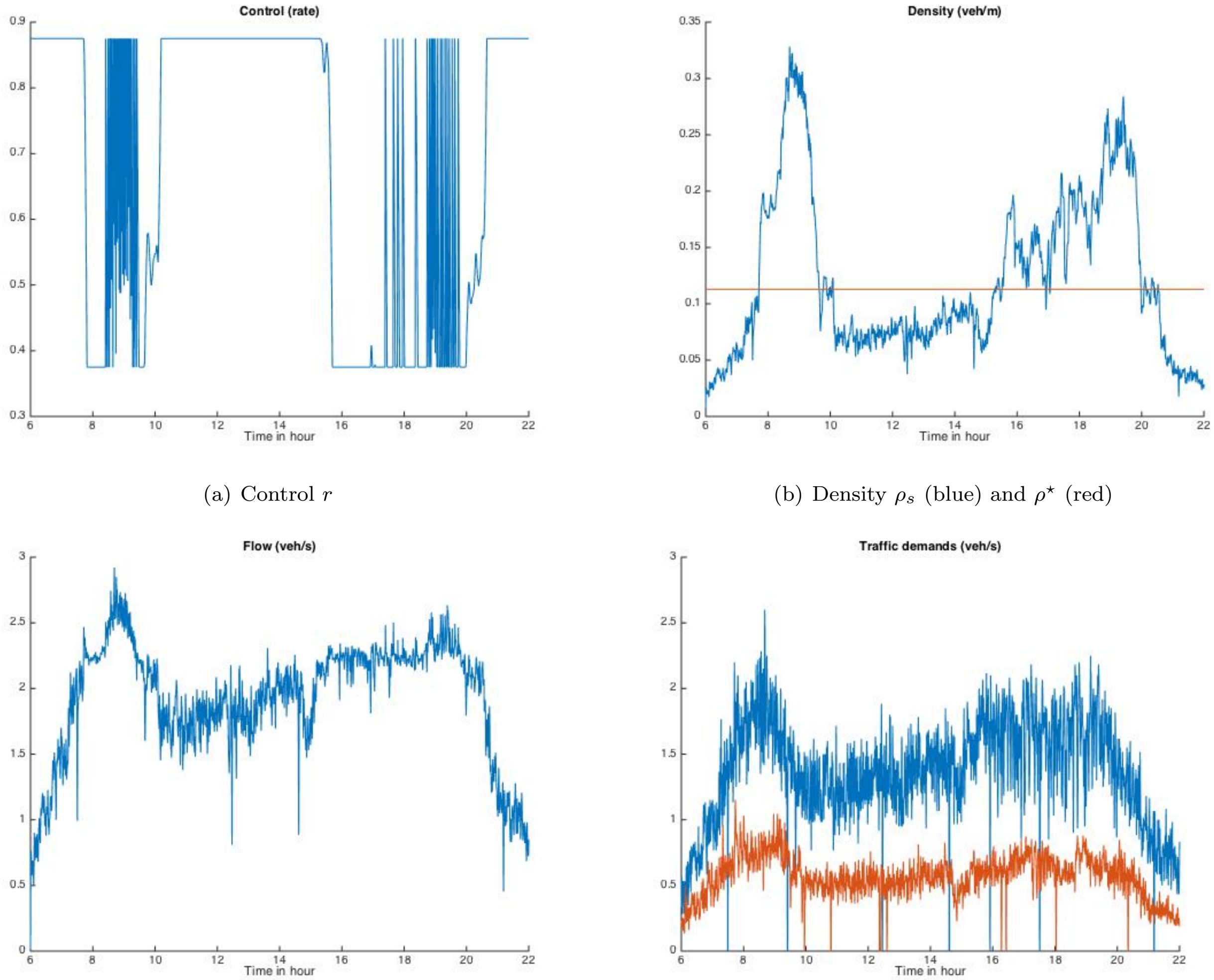
[13] C. Nanthawichit, T. Nakatsuji, Parameter estimation of macroscopic traffic simulation model, Infrastructure Planning Rev., vol. 18, 935-942, 2001.

	Total Time Spent	Mean Speed	Mean Speed (with queue)
Case 1	9.2270e+06	15.1810	7.5590
Case 2	9.1320e+06	15.3388	7.2552

Table 1. Summary of a single day

	Total Time Spent	Mean Speed	Mean Speed (with queue)
Case 1	6.3191e+06	11.4727	5.0550
Case 2	6.2654e+06	11.5734	5.0309

Table 2. Congestion times between 7.30am and 9.30am, and between 3pm and 8pm



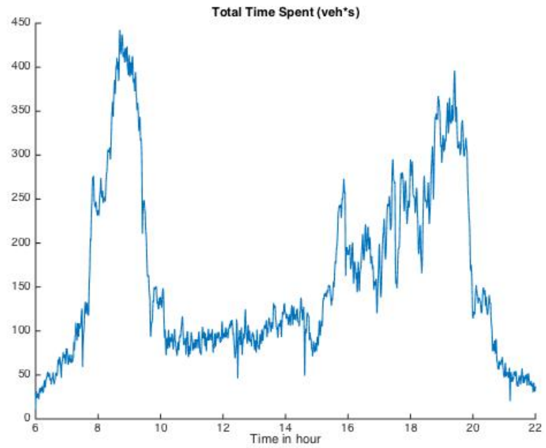
(a) Control r

(b) Density ρ_s (blue) and $\rho^\star$ (red)

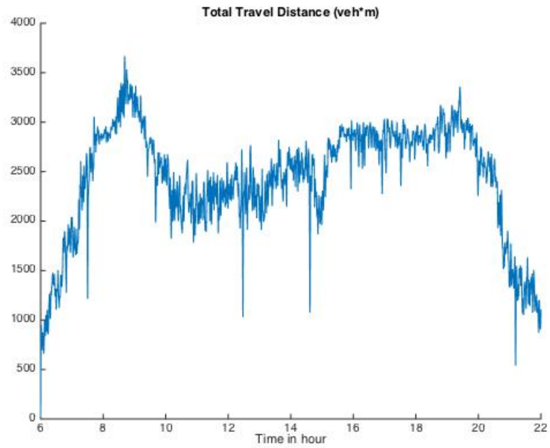
(c) Flow q_s

(d) Demands d (red) and q_e (blue)

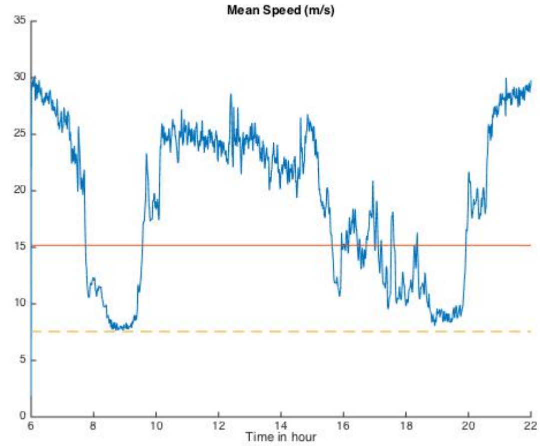
Figure 4. Case 1: simulation results



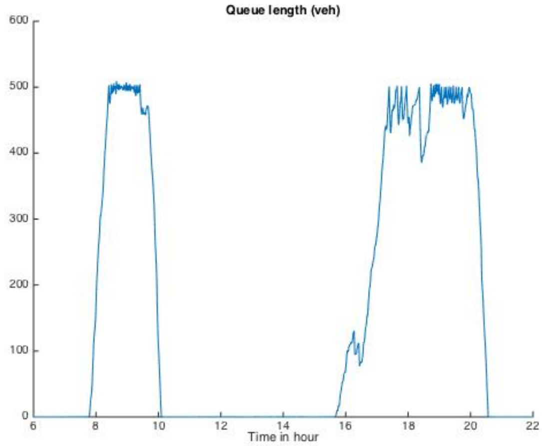
(a) Total time spent



(b) Total travel distance

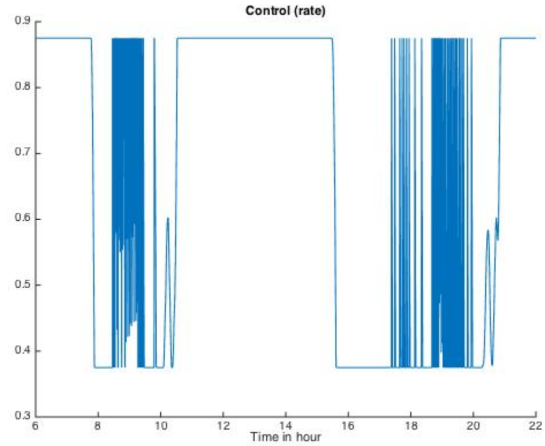


(c) Mean speed (bleue), day mean speed (without queue) (red) and day mean speed (with queue) (yellow - -)

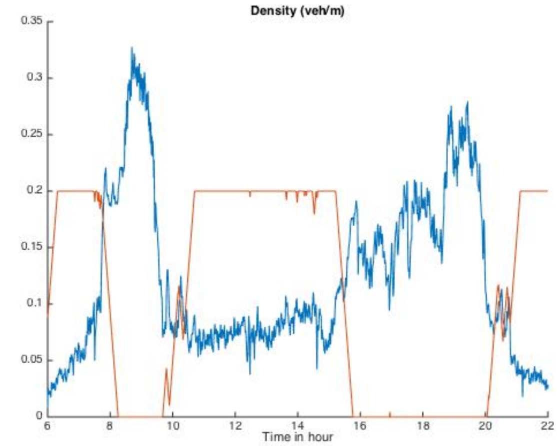


(d) Queue length w

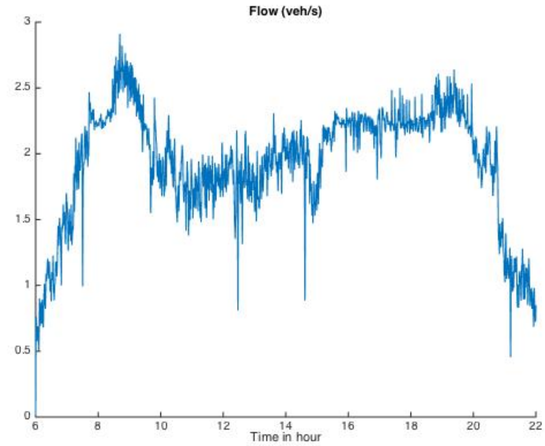
Figure 5. Case 1: Evalutions



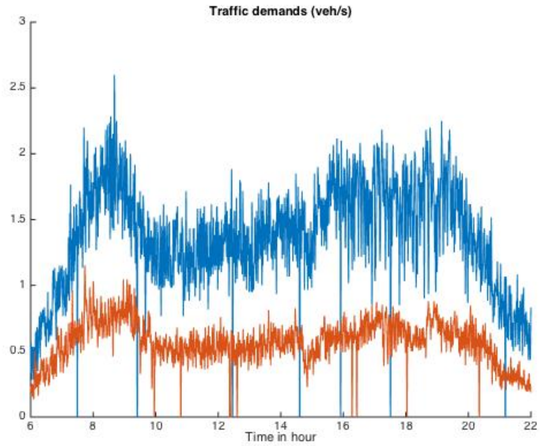
(a) Control r



(b) Density ρ_s (blue) and $\rho^\star$ (red)

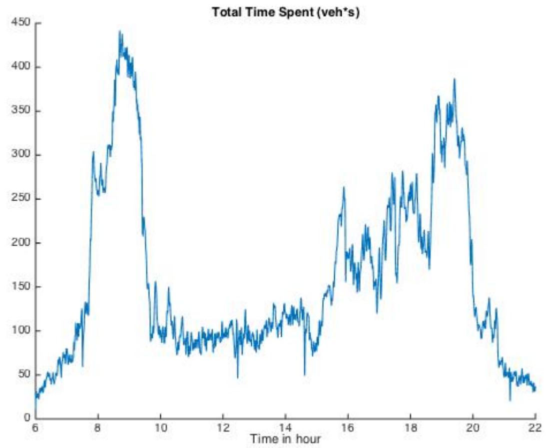


(c) Flow q_s

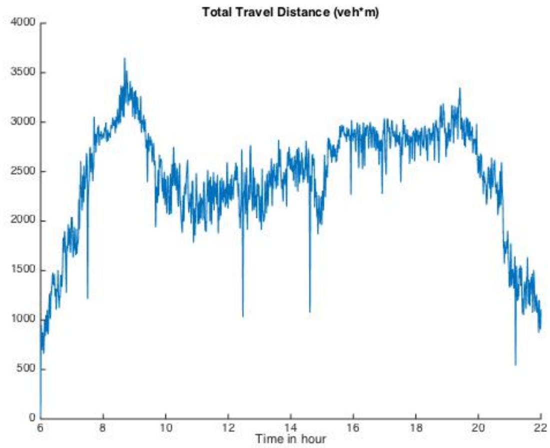


(d) Demands d (red) and q_e (blue)

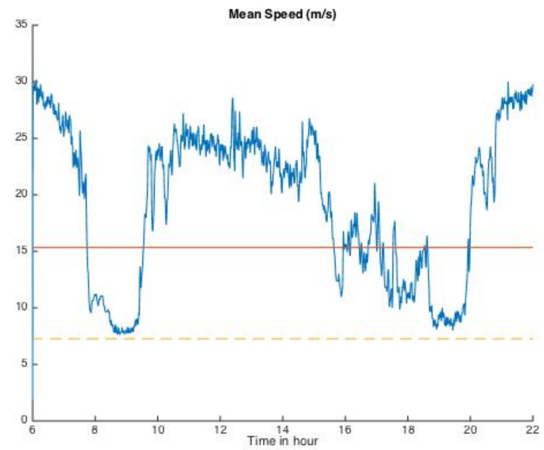
Figure 6. Case 2: simulation results



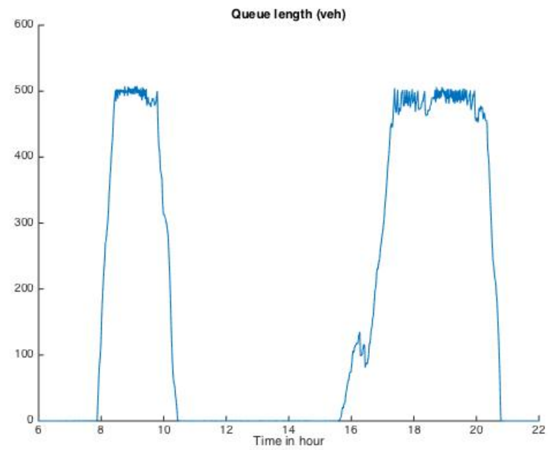
(a) Total time spent



(b) Total travel distance



(c) Mean speed (bleue), day mean speed (without queue) (red) and day mean speed (with queue) (yellow - -)



(d) Queue length w

Figure 7. Case 2: Evalutions

[14] A.D. May, Traffic Flow Fundamentals, Prentice-Hall, 1990.

[15] D. Owens, M. J. Schonfield, Access control on the M6 motorway : evaluation of Britain's first ramp metering scheme, Traffic Engin. Contr., vol. 29, 616-623, 1988.

[16] K. Ozbay, I. Yasar, P. Kachroo, Improved online estimation methods for feedback-based freeway ramp metering strategy, IEEE Conf. Intel. Transport. Syst., Toronto, 2006.

[17] I. Papamichail, M. Papageorgiou, Traffic-responsive linked ramp-metering control, IEEE Trans. Intel. Transport. Syst., vol. 9, 111-121, 2008.

[18] M. Papageorgiou, Some remarks on macroscopic traffic flow modelling, Transport. Res., vol. 32, 323-329, 1998.

[19] M. Papageorgiou, C. Diakaki, D. Dinopoulou, A. Kostialos, Y. Wang. Review of road traffic control strategies, IEEE Trans. Intelligent Transport. Syst., vol. 91, 2043-2067, 2003.

[20] M. Papageorgiou, H. Hadj-Salem, J.-M. Blosseville, ALINEA: A local feedback control law for on-ramp metering, Transp. Res. Record, n° 1320, 58-64, 1991.

[21] E. Smaragdis, M. Papageorgiou. A series of new local ramp metering strategies, Transport. Res. Record: J. Transport. Res. Board, vol. 1856, 74-86, 2003.

[22] E. Smaragdis, M. Papageorgiou, E. Kosmatopoulos, A flow-maximizing adaptive local ramp metering strategy, Transport. Res. B, vol. 38, 251-270, 2004.

[23] Y. Wang, P.A. Ioannou, Real-time parallel estimators for a second-order macroscopic traffic flow model, IEEE Conf. Intel. Transport. Systems, Toronto, 2006.

[24] Y. Wang, M. Papageorgiou, Real-time freeway traffic state estimation based on extended Kalman filters: general approach, Transport. Res. B, vol. 39, 141-167, 2005.

[25] Y. Wang, M. Papageorgiou, A. Messmer, Real-time freeway traffic state estimation based on extended Kalman filter: Adaptive capabilities and real data testing, Transport. Res. A, vol. 42, 1340-1358, 2008.

[26] D.B. Work, S. Blandin, O.-P. Tossavainen, B. Piccoli, A.M. Bayen, A traffic model for velocity data assimilation, Appl. Math. Res. Express, vol. 2010, 1-35, 2010.