Раздел VII. Моделирование сложных систем

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NEW LOCAL RAMP METERING CONTROL

As shown by many works and studies, the traffic flow control remains the best and the efficient solution of the congestion problems. The ramp metering is a means to reduce congestion effects, it has shown his effectiveness to improve the flow and consequently to reduce the Total Time Spent by the vehicles in the network (TTS). In this article, we have defined a new local ramp metering control in order to respect constraints on density and queue length at the vicinity of the on-ramp and at the on- ramp, respectively. The idea is to express the control variable (the metering rate) according to the output (density or queue length at the on-ramp). The aim of the control is to keep the density in the segment where the on-ramp is connected below a density (called the target density y_T) for which we have the lowest TTS with the constraint that the queue length at the on-ramp do not exceed a maximum value. In order to evaluate the controller's efficiency and applicability, a comparison is made with traditional ALINEA based controller. We illustrate this approach by comparing the cases 'no control' and 'ramp metering' for a simple network.

METANET model; Ramp Metering; Target density; maximum queue length.

1. **Introduction.** To tackle the problem of congestion or at least limit its effects, controlling the motorway traffic flow the best solution, rather than construction of new roads. However, this problem calls for design and implementation of efficient control strategies in such a way that congestion is solved, reduced, or at least postponed. The purpose of the control of traffic flow is to use the freeways at their capacity. Controlling the motorway traffic process can be assured by different control measures such as ramp metering, route guidance, variable speed limits, lane closure and lane control, mainline metering, and motorway-to-motorway control. These control measures may be applied either individually or collectively.

Intelligent transportation systems involves managing existing facilities more effectively, rather than building new facilities. Ramp metering is an example of intelligent transportation sys- tems. According to Hegyi et al. [2002], Papageorgiou et al. [1990, 1997], Bellemans et al. [2002, 2006], Scariza [2003], the ramp metering has shown his effectiveness to increase the flow and the speed by adjusting the metering rate such that the density remains below the critical density. Ramp metering is one of the most frequently used methods of freeway control intended to reduce congestion. The first use of ramp metering was on the Eisenhower Expressway (I-290) in Chicago, Illinois, in 1963, and today it become more popular in both the USA and in Europe, with applications including Amsterdam, Paris, and Glasgow. All ramp metering algorithms are divided into two categories: local or coordinated. Local ramp metering al gorithms only take into account traffic conditions near a single ramp, while coordinated algorithms try to optimize traffic over an area. ALINEA is a local ramp metering algorithm introduced by Papageorgiou et al. [1991]. In order to handle ramp queues in a more efficient manner, Smaragdis and Papageorgiou [2003] have proposed ALINEA / Q which is a local algorithm based on ALINEA. FLOW developed by Jacobson et al. [1989] is a co-ordinated algorithm that tries to keep the traffic at a predefined bottleneck below capacity. The Linked

Algorithm introduced by Taylor et al. [1998] is a coordinated algorithm that seeks to optimize a linear-quadratic objective function.

Ramp metering advantages: According to Roess et al. [1998], ramp metering has many potential advantages:

- Improvement of freeway mainline flow, due to access control and traffic diverting to other, less congested roads (such as parallel frontage roads).
- Metering smoothes out the traffic flow and breaks up platoons, allowing more efficient merging.
- Reduction of accidents, fuel consumption, emissions, and vehicle operating costs.
- Network routings may be altered to achieve greater balance and efficiency.

Ramp metering disadvantages

- The main disadvantage to ramp metering is that it can lead to long queues on the ramps, and lead to delays for on- ramp traffic.
- Network rerouting can possibly have negative effects on alternate routes.
- If no method of controlling ramp queues is used, then ramp traffic can back up onto surface streets.

It is argued in Kotsialos and Papageorgiou [2001] that in order to have efficient, generic, and systematic solutions to a wide range of traffic control problems, macroscopic motorway traffic flow models in state-space form are most appropriate. Such models allow the exploitation of available powerful, systematic, and theoretically supported automatic control concepts.

In this paper, we focus to reduce the congestion by controlling the metering rate such that the density keep below the target density y_T and we take into account the limitation of the queue length at the on-ramp. The paper is organized as follow. First, the macroscopic traffic flow model Metanet of our network is described. Then, the control approach is presented and its application to design an effective control algorithm for traffic flow. Finally, we present some simulation results obtained from the implementation of the control laws. The last part draws conclusions and presents some perspectives.

2. Network of experiments

2.1 Problem description. The ramp metering is useful when traffic is not too light and not too dense Hegyi et al. [2005]. Any control method that improves the flow will at best achieve an improvement of ap- proximately 5-10%. In this paper we consider a situation where the on-ramp is metered (see figure 1). The purpose is to define the outflow of the on-ramp for which the traffic density of the segment, in which the ramp in connected, do not exceed the desired density (desired behavior). In addition, we use a maximum queue length on the on-ramp as constraint. This constraint prevents too long queues on the on-ramp, which could block other traffic streams on the secondary road network.

2.2 Metanet model of our network. A mathematical model of the process, deduced from suitable laws or induced from experimental results is necessary for de- veloping a control system. Macroscopic models based on fluid dynamic equations consider the traffic flow as a continuum, i.e. a fluid with specific characteristics. The study of continuum models began with the LWR model developed independently by Lighthill and Whitham [1955] on kinematic waves and by Richards [1956] which is the first order model.

The LWR model has its deficiencies, the most fatal one is that the speed is solely determined by the equilibrium speed density relationship, no fluctuation of speed around the equilibrium values is allowed, thus, the model is not suitable for the de- scription of non-equilibrium situations like stop-and-go traffic etc. Many efforts were devoted to improving the LWR model through developing high order models.

In this paper we use, a second order model, a destination independent METANET model introduced by Kotsialos et al. [2002] and extended by Hegyi et al. [2005]. The reader can find the full description of the model in Papageorgiou et al. [1990], Kotsialos et al. [1999, 2002]. We present here the METANET model of our experiments network shown in figure 1 which is identical to the one used in Hegyi et al. [2005].

The network considered consists of two origins (the main- stream origin is denoted o1 and the on-ramp origin is denoted o2), two freeway links (indicated by the index m) corresponding to freeway stretches, with $m \in \{L1, L2\}$, and one destination (denoted d1). The links L1 and L2 have the same characteristics. The number of lanes of these links is denoted λ while the on-ramp is a single lane origin. The length of the links is four km for L1 and two km for L2. Each link is divided into segments (indicated by the index i) of $L = 1$ km long (four segments for L1 and two segments for L2). The capacities of each lane of the origins are denoted Q^{o1}_{cap} and Q^{o2}_{cap} and the des tination d1 has an unrestricted outflow. Each segment i of link m is characterized by the density $\rho_{m,i}(k)$ (veh/lane/km), the mean speed $v_{m,i}(k)$ (km/h), and the outflow $q_{m,i}(k)$ (veh/h), where k indicates the time instant $t = kT$, and T is the time step used for the simulation of the traffic flow.

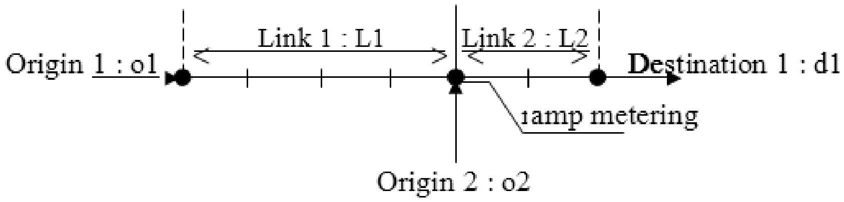

Fig. 1. Network includes two links and metered on-ramp

The evolution of the network over time is described by the following equations. The outflow of each segment is equal to the density multiplied by the mean speed and the number of lanes on that segment:

$$q_{m,i}(k) = \lambda \rho_{m,i}(k) v_{m,i}(k). \tag{1}$$

The density of a segment equals the previous density plus the inflow from the upstream segment, minus the outflow of the segment itself (conservation of vehicles law)

$$\rho_{m,i}(k+1) = \rho_{m,i}(k) + \frac{T}{L\lambda} \cdot \Big[q_{m,i-1}(k) - q_{m,i}(k) \Big], \tag{2}$$

While (1) and (2) are based on physical principles and are exact, the equations that describe the speed dynamics and the relation between density and the desired speed are heuristic. The mean speed at time instant $k + 1$ equals the mean speed at time instant k plus a relaxation term that expresses that the drivers try to achieve a desired speed $V(\rho)$, a convection term that expresses the speed increase (or decrease) caused by the inflow of vehicles, and an anticipation term that expresses the speed decrease (increase) as drivers experience a density increase (decrease) downstream

$$v_{m,i}(k+1) = v_{m,i}(k) + \frac{T}{\tau}\left(V(\rho_{m,i}(k)) - v_{m,i}(k)\right) +$$
$$\frac{T}{L} v_{m,i}(k)\left(v_{m,i-1}(k) - v_{m,i}(k)\right) - \frac{\nu T}{\tau L} \frac{\rho_{m,i+1}(k) - \rho_{m,i}(k)}{\rho_{m,i}(k) + \kappa}, \tag{3}$$

where τ, ν, et κ are model parameters, with:

$$V(\rho_{m,i}(k)) = v_f \cdot \exp\left[-\frac{1}{a}\left(\frac{\rho_{m,i}(k)}{\rho_{crit}}\right)^a\right], \tag{4}$$

where a is a model parameter, v_f is the free speed, and ρ_{crit} is the critical density at which the traffic flow is maximal.

In order to account for the speed drop caused by merging phenomena due to the on-ramp, the term

$$-\frac{\delta T q_{o2}(k) v_{L2,1}(k)}{L\lambda\left(\rho_{L2,1}(k)+\kappa\right)} \tag{5}$$

is added to (3) for $m = L2$, $i = 1$, where δ is a model parameter and $q_{o2}(k)$ is the outflow of the origin o2.

Origins are modeled with a simple queue model. The length of the queue of the origin o (denoted ω_o) equals the previous queue length plus the demand $d_o(k)$, minus the outflow $q_o(k)$

$$\forall o \in \{o1, o2\}, \omega_o(k+1) = \omega_o(k) + T\left(d_o(k) - q_o(k)\right). \tag{6}$$

The outflow of the origin $q_{o2}(k)$ (on-ramp) depends on the traffic conditions on the main-stream and on the ramp metering rate $r(k)$, where $r(k) \in [0, 1]$. More specifically, $q_{o2}(k)$ is the minimum of three quantities: the available traffic in time period k (queue plus demand), the maximal flow that could enter the freeway because of the main-stream conditions, and the maximal flow allowed by the metering rate

$$q_{o2}(k) = \min\left[d_{o2}(k) + \frac{\omega_{o2}(k)}{T}, \; Q^{o2}_{cap} \min\left(r(k), \frac{\rho_{max} - \rho_{L2,1}(k)}{\rho_{max} - \rho_{crit}}\right)\right] \tag{7}$$

where ρ_{max} is the maximum density of link L2.

In addition assumptions are made regarding the boundary con- ditions for the up-stream speed and downstream density for (3). We assume that the speed of the (virtual) entering link $v_{L1,0}$ equals the speed of the first segment, and the speed of the (virtual) entering link $v_{L2,0}$ equals the speed of the last segment of link L1

$$\begin{aligned} v_{L1,0}(k) &= v_{L1,1}(k), \\ v_{L2,0}(k) &= v_{L1,4}(k). \end{aligned} \tag{8}$$

Also, We assume that the density of the (virtual) leaving link equals the density of the last segment of the second link in free flow, and equals the critical density in congested flow

$$\rho_{L2,3}(k) = \min\left(\rho_{L2,2}(k), \rho_{crit}\right) \tag{9}$$

In addition :

$$\begin{aligned} q_{L2,0}(k) &= q_{o2}(k) + q_{L1,4}(k) \\ q_{L1,0}(k) &= q_{o1}(k), \end{aligned} \tag{10}$$

where $q_{o1}(k)$ is the outflow of the origin o1.

Hegyi and his co-workers in Hegyi et al. [2005] have extended the original METANET model: the main-stream origin o1 is different compared to a regular on-ramp (the queue at a main- stream origin is in fact an abstraction of the sections upstream of the origin of part of freeway network that we are modeling). Like Hegyi, we use a modified version of (7).

$$q_{o1}(k) = \min\left[d_{o1}(k) + \frac{\omega_{o1}(k)}{T}, q_{lim,L1,1}(k)\right]. \tag{11}$$

$$q_{lim,L1,1} = \begin{cases} \lambda v_{L1,1}(k)\rho_{crit}\left[-a\ln\left(\frac{v_{L1,1}(k)}{v_f}\right)\right]^{\frac{1}{a}} & \text{if } v_{L1,1}(k) < V(\rho_{crit}) \\ \lambda Q_{cap}^{o1}, & \text{if } v_{L1,1}(k) \geqslant V(\rho_{crit}) \end{cases}. \tag{12}$$

3. New local ramp metering control. The objective of the control approach presented here is to keep the density in the first segment of L2 below the target density y_T. The target density must be chosen near ρ_{crit} to have a great flow. This control will limit the flow that accesses the mainstream. With a high on-ramp demand, this causes an increase in the queue length on the on-ramp which may have negative effects on the upstream roads. To avoid these negative effects, the flow which accesses the mainstream from the on- ramp is controlled such that the queue length on the on-ramp does not exceed a maximum value denoted ω_{o2}^{*}

So this control method commutates between three control laws:

- The first one consists to opening the on-ramp ($r(k) = 1$), this is applied when $\rho_{L2,1} < y_T$.
- The second law consists to metering the on-ramp such that $\rho_{L2,1}$ be equals y_T, this law is applied when $\rho_{L2,1}$ exceeds y_T and $\omega_{o2} < \omega_{o2}^{*}$.

The third law is $r(k) =$ $r(k) = \frac{d_{o2}(k)}{Q_{cap}^{o2}}$: according to (6), it avoids the growth of the queue length when the demand is below the on-ramp's saturation flow, this law is applied when $\omega_{o2} > \omega_{o2}^{*}$.

Since the first and the third laws are trivial, we will focus on the second law.

In the second law, the metering rate $r(k)$ is such that the density $\rho_{L2,1}(k+1)$ equals the target density y_T. The advantage of this approach is that it can be used directly to build a controller. The desired behavior (here the target density) is treated as an input variable in the model, and the action (here the metering rate $r(k)$) is treated as an output variable. When a new desired behavior is given, the controller just asks the model to predict the action needed.

Equations (2) and (10) of the model give:

$$\frac{\rho_{L2,1}(k+1) - \rho_{L2,1}(k)}{T} = \frac{1}{L\lambda}\left(q_{L1,4}(k) - q_{L2,1}(k) + q_{o2}(k)\right), \tag{13}$$

We search a metering rate for which $\rho_{L2,1}(k+1) = y_T$. This is possible only if $q_{o2}(k) = Q_{cap}^{o2}\, r(k)$ in (7): if this is not the case, the control does not affect the system and consequently $\rho_{L2,1}(k+1) = y_T$. Under this consideration and under the constraint $r(k) \in [0, 1]$, the value of the metering rate is deduced from (13):

$$r(k) = \max\left(0, \min\left(1, \frac{1}{Q_{cap}^{o2}} \cdot \left(L\lambda \frac{y_T - \rho_{L2,1}(k)}{T} - q_{L1,4}(k) + q_{L2,1}(k)\right)\right)\right) . \quad (14)$$

Fig. 2 represents graphically the control algorithm.

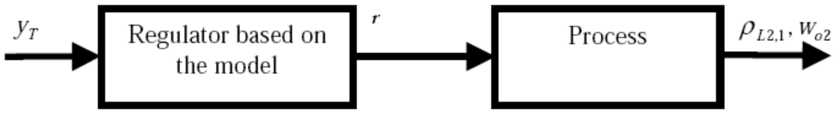

Fig. 2. Control principle

4. Simulation results. As mentioned above, we consider the section of Fig. 1. For the various tests carried out, the model parameters are chosen from the literature and are given by Kotsialos et al. [1999]: T = 10 s, τ = 18 s, κ = 40 veh/lane/km, ν = 60 km^2/h, $\rho_{\max}$ = 180 veh/lane/km, δ = 0.0122, a = 1.867, ρ_{crit} = 33.5 veh/lane/km and v_f = 102 km/h. The capacity of each origin is $Q_{\text{cap}}^{\text{o1}}$ = 2 000 veh/h and $Q_{\text{cap}}^{\text{o2}}$ = 2 000 veh/h. The demand scenario is considered (Fig. 3): the main-stream demand increases from 1 000 veh/h to the 3 500 veh/h and remains constant for about 1 hour. Finally it drops to 1 000 veh/h. The demand on the on-ramp has a constant value of 500 veh/h at the beginning and then raises to the 1 500 veh/h. Then it remains constant for about 15 minutes. Finally it drops to the 500 veh/h again.

The results of the no-control case are shown in Fig. 4. When the demand increases on the on-ramp, the density on the main- stream on-ramp section (segment 1 of link 2) also increases

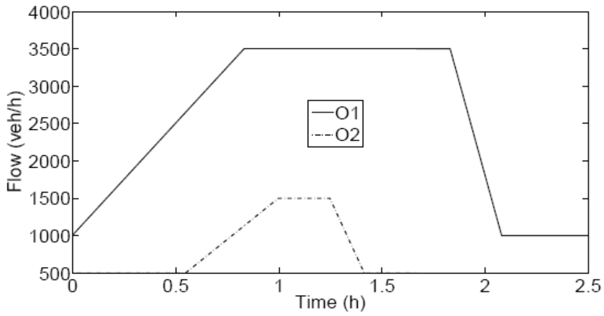

Fig. 3. The demand scenario

and creates a congestion that propagates through the upstream segments. This causes a queue at the upstream of segment 1 of link 1 of approximatively 250 vehicles. As the demand on the on-ramp drops to 500 veh/h the densities of segment 1 of link 2 up to segment 1 of link 1 decrease, the density of segment 1 of link 2 remain constant at a relatively value (approximatively 45 veh/lane/km). At the end, when the mainstream demand drops, the congestion dissolves and the network reaches state. The TTS is 1 015.3 veh-h.

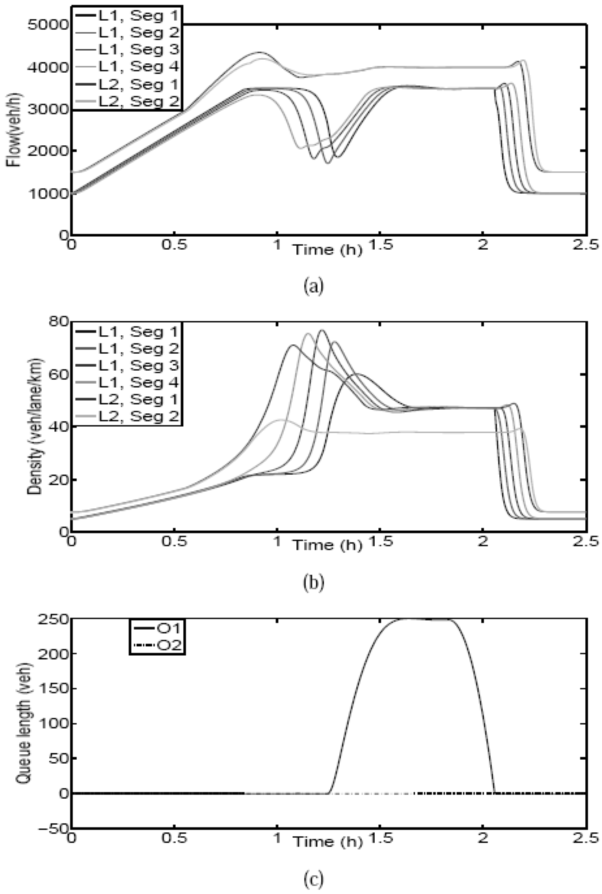

Fig. 4. The simulation of the no-control case

In Fig.5 the results of ALINEA ramp metering controller are presented. ALINEA, Papageorgiou et al. [1991] is a local, closed loop ramp metering algorithm. A fairly simple equation is used to calculate the metering rate:

$$r(k) = r(k-1) + K_R[O_{crit} - O_{out}(k-1)]. \tag{15}$$

Note that, $r(k) = Q_{cap} \cdot r_o(k)$, with $r_o(k)$ is the metering rate, O_{crit} is the target set point occupancy and $O_{out}(k-1)$ is the measured occupancy. K_R is a regulator parameter. In this paper we choose $K_R = 70$ veh/h. Since during ramp metering the queue cannot be allowed to grow larger than 150 veh. The TTS in the ALINEA controller case is 966.9 veh-h with an improvement of 4.77% with respect to the 'no-control' case (see Table 1).

In Fig. 6, and for the approach of control used in this article we can see that ramp metering can resolves the congestion problem and keeps the flow high (capacity) until the maximum queue length is reached. Moreover, the density of all the segments decreased, and yet the ramp metering removes the queue at the upstream of segment 1 of link 1 until approximatively 1.5 hours, and creates a queue at the on-ramp which remain constant of 150 vehicles. When the demand on the on-ramp drops to 500 veh/h the queue length decrease until her disappearance.

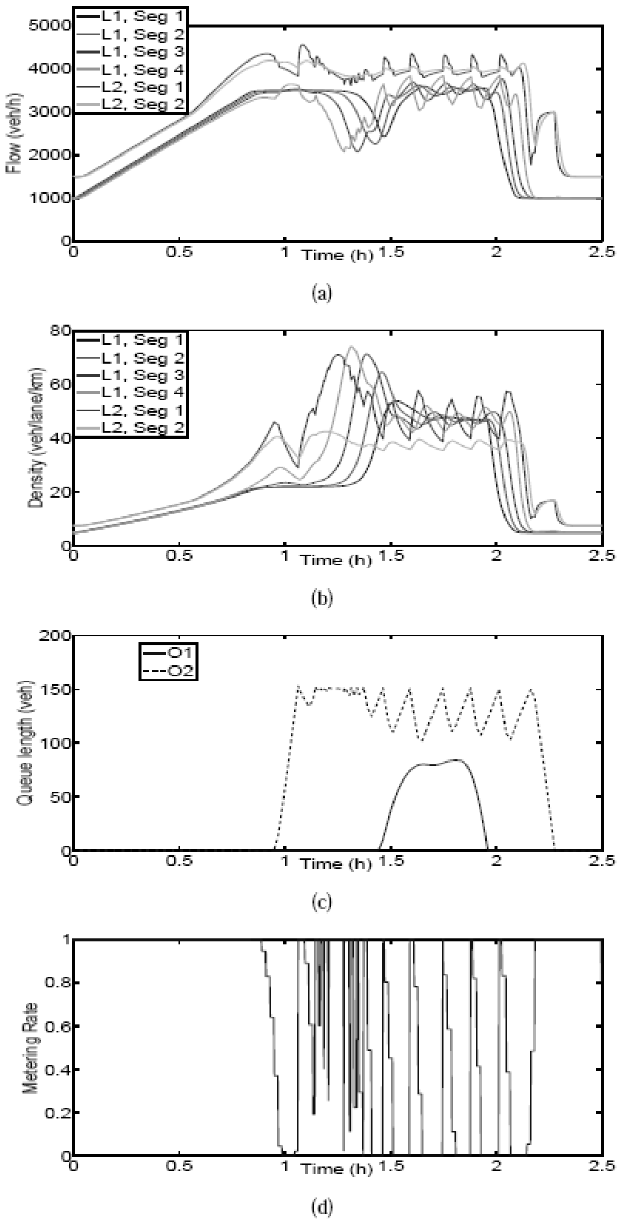

Fig. 5. The simulation results for ALINEA controller case

Table 1

TTS (veh-h) correspond of each value y_T

y_T (veh/lane/km)	30	ρ_{crit}	36	41	42
Our approach	993.8	968.2	953.1	944.9	945.4
Alinea	974.9	973.2	966.9	978.5	976.2

Table 1 presents the value of the TTS for the different values of the target density y_T: the best TTS is obtained for $y_T = 41$ veh/lane/km.

The TTS in the 'ramp metering case' is compared to the 'no- control' case and to the ALINEA controller case in the next Table 2 for y_T =41 veh/lane/km. This table presents the time spent in different parts of the network (the link L1, the link L2, the queue at the origin o_1, the queue at the on-ramp).

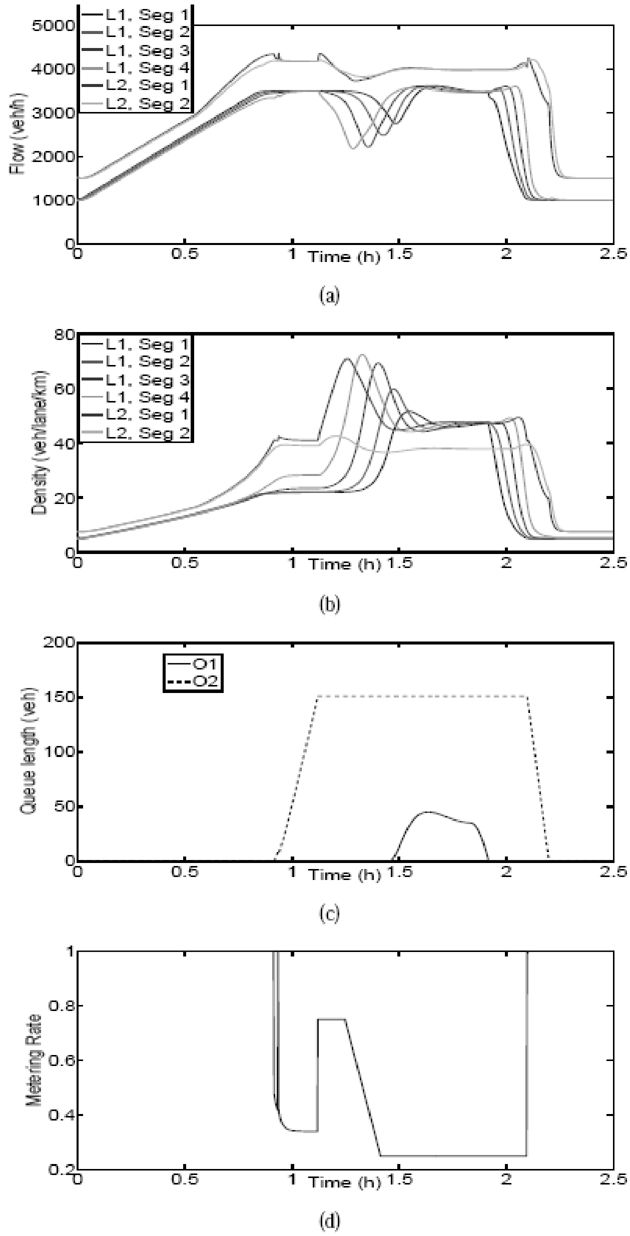

Fig. 6. The simulation for the 'ramp metering' case

Table 2

Comparison of the values of the TTS for different strategies

Strategy	L1 (veh-h)	L2 (veh-h)	Queue O1 (veh-h)	Queue O2 (veh-h)	TOTAL (veh-h)
No-control case	558.05	306.35	150.9	0	1015.3
Alinea case	484.6	292.06	32.9	163.7	973.2
Improvement %	13.17	4.66	78.2	—	4.15
Ramp metering case	469.1	292.2	14.7	169.1	944.9
Improvement %	15.94	4.62	90.26	—	6.93

5. Conclusion. In this paper, we have defined a new local ramp metering con- trol, we have, also, shown that this approach can be used as control strategy to reduce con-gestion. We applied this control strategy on a section of six segments. In this paper we have pre- sented simulation results of our control algorithm, and we have compared it with the no-control case and with ALINEA. We envisage to apply this control strategy in order to eliminate the disturbances that can alter the variables measures. Furthermore, we plan to coordinate this control strategy with the variable speed limits (VSL) on a second order model METANET.

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УДК 71-57

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SIZING OPERATING ROOMS IN CASE OF A DISASTER PLAN

In case of a disaster, the need for medical and surgical treatments overwhelms hospitals' capabilities with respect to standard operating procedures. In this paper, we deal with the preparation phase of the disaster management plan. We focus on the sizing activity of emergency resources, more precisely on operating rooms. So, we propose integer linear programming model. This model provides the optimal number of operating rooms that best respond to mass casualty events such that all victims are treated. Computational experiments performed by the Cplex solver show that a substantial aid is proposed by using this model in hospital disaster management.

Integer programmingж Disaster plan, Sizing; operating rooms.

1. Introduction. The annual report of the International Federation of Red Cross and Red Crescent Societies proves that the national societies were impacted by 429 different disasters or crises in 2006. This shows an increase of 22 % from 2005 and 47 % from 2003 (Ghezail and *al.*, 2007). Such an incident, affects hospitals of all sizes and geographic locations. Different countries require that their hospitals have plans for emergency preparation and disaster preparedness. For example, in the USA, the Joint Commission on the Accreditation of Healthcare Organizations requires US hospitals to have a disaster management plan (DMP). In other countries, like in France and in Tunisia, state requirements or laws impose each hospital to have a disaster plan so called white plan (Ministère de la santé et de la solidarité, 2006) (Ministère de la santé publique, 2002).

Any emergency management plan must address the following phases: preparation, response, and recovery (Kimberly and *al.*, 2003). The preparation phase is considered as the driving force behind a successful response. Indeed, it is vital to have a strong framework to activate in case of a disaster (Lipp and *al.*, 1998). It includes all emergency preparedness activities such as defining medical and technical supplies, maintaining accu-