# Ramp Metering with Entrance gap Restriction

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**Abstract:** In this paper, a new ramp metering strategy is proposed. It restricts the entrance of on-ramp vehicle by space gap. The vehicle from on-ramp can enter into the main road only when the space gap on the main road is large enough. The effectiveness of the new strategy is verified by cellular automata traffic simulation model. The simulation results show that the saturated flux of the main road will be high and not drop by introducing large entrance gap restriction value. The ramp metering strategy with entrance gap restriction is effective.

**Key words:** Ramp metering; Entrance gap; Cellular automata

## 0 Introduction

As the quantity of possessed motor vehicles sharply increasing in most large cities in China, traffic congestion has become a common problem. Traffic congestion not only makes the travel time longer, but also brings safety and environmental problem. Constructing traffic facilities is the traditional way to solve the problem. However, it takes limited effect on alleviating traffic congestion nowadays, as to the traffic volume is far beyond the capacity of road network. In this case, traffic control measures should be adopted to fully utilize the traffic infrastructure and reduce traffic congestion. Ramp metering, as an effective method in allocating limited expressway capacity, is an efficient traffic control measure.

The fundamental philosophy of ramp metering is that a freeway can maintain its optimal operation by regulating the inflow from on-ramp. Ramp metering strategies can be classified as fixed-time and reactive [1]. Fixed-time ramp metering strategies are derived off-line based on historical demands. They may either to over load of the mainline flow or to underutilization of the expressway. Reactive ramp metering strategies are based on real time measurements and can be classified as isolated or coordinated. Isolated ramp metering strategies make use of traffic measurements in the vicinity of the ramp to calculate the ramp metering value, such as demand-capacity strategy [2], feedback control strategy (ALINEA) [3], etc. Coordinated ramp metering strategies make use of traffic measurements on all road section of the metered expressway [4-6], such as the Bottleneck [7], Zone [8], Metaline [9] and Swarm [10].

In order to verify the effectiveness of the ramp metering strategy, traffic flow simulation are usually carried out before the implementation of the strategy. Nowadays, Cellular automata (CA) model has become an excellent tool for modeling traffic flow since the well-known Nagel-Schreckenberg (NaSch) model was proposed in 1992 [11]. Because it has efficient and fast performance in computer simulation and most importantly, it can reproduce most of the complex traffic phenomena, such as stop-and-go traffic, synchronized flow [12,13], hysteresis effect [14], etc. As a typical traffic bottleneck, the capacity drop is a significant property of the on-ramp. The traffic flow pattern around on-ramp is very complex. This has been widely studied by researchers with simulation model [15-18]. Since the CA model can be easily modified to describe realistic traffic conditions, many CA models for on-ramp system have been proposed. Some models deal with the on-ramp in a simple manner, where a ramp region is selected and the vehicles are inserted directly into the region [15,16]. So the ramp lane is neglected and we called those models as

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without ramp lane model. Other models take the ramp lane into account and are named as with ramp lane model [17,18]. The ramp lane model can describe the realistic driving behavior and the vehicle should change from the ramp lane to the main road. Although the without ramp lane model is very simple, it can also reproduce some realistic features of on-ramp system. Furthermore, it is also used to explore the complex traffic flow patterns induced by on-ramp under the three phase traffic theory [13,19].

In this paper, the without ramp lane model is used to study the ramp metering strategy. In our previous work, the dynamic of on-ramp system has been systematically studied [20,21]. It shows that approaching vehicle should slow down to avoid crashing into the lane-changing vehicle. Once the vehicle stops, it need much time to gain high speed, especially when the acceleration rate is lower. Here we propose a ramp metering strategy in which the vehicle from on-ramp is allowed to enter into the main road only when the entrance gap is large enough. Thus the approaching vehicle upstream does not need to stop.

# 1 Traffic flow model

In CA traffic flow model, the road is divided into *L* cells, and a vehicle has a length of *l* cell(s). It is usually assumed that the length of a vehicle is 7.5 m, then the length of a cell corresponds to 7.5/*l* m. In the original NaSch model, *l*=1 was selected. In this paper *l*=3 is used. There are 4 sub-steps: (1) acceleration: $v_n \to \min(v_n+1, v_{max})$; (2) deceleration: $v_n \to \min(v_n, d_n)$; (3) randomization: $v_n \to \max(v_n-1, 0)$ with probability *p*; (4) position update: $x_n \to x_n + v_n$. Here $v_n(t)$ and $x_n(t)$ denote the velocity and position of the vehicle *n* respectively; $v_{\max}$ is the maximum velocity; $d_n = x_{n+1} - x_n - l$ denotes the number of empty cells in front of the vehicle *n*; *p* is the randomization probability.

The on-ramp is an important part of urban expressway system, since it enables the vehicle enters into the expressway (See Fig.1). And as a typical bottleneck, it usually causes capacity drop and complex traffic flow patterns. The on-ramp is simply described as a region where vehicles can be inserted into the main road (see Fig.2). The main road is represented by one lane, and the vehicle inserting region starts at the position $x_{on}$ and has a length of $L_r \times l$ cells. The gap of each vehicle in the region is calculated. Then the vehicle with the largest gap $d_{\max}$ is signed and its position is denoted as $x_i$.

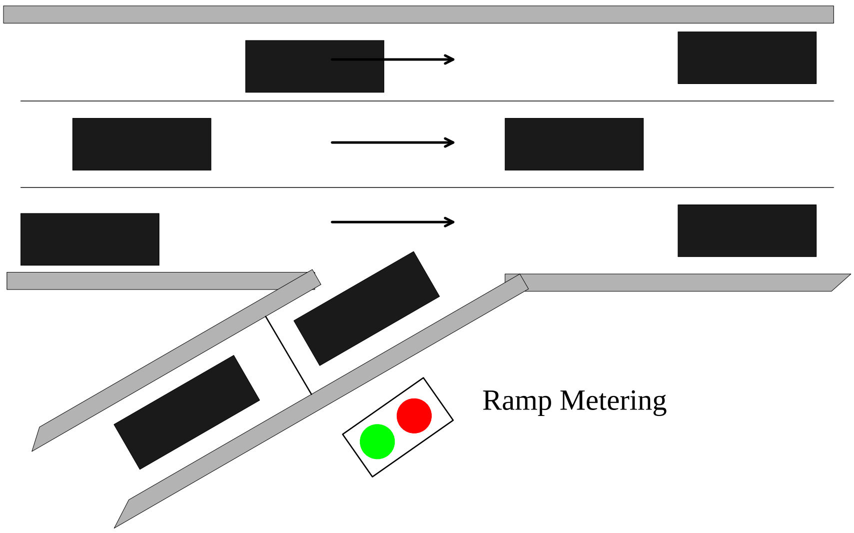


Fig. 1 Schematic illustration of ramp metering

The boundary conditions are adopted as follows. The vehicle enters the main road from the leftmost cell or the inserting region, and leaves the road from the rightmost cell. In each time step, when the update of the vehicles on the road is completed, the position of the last vehicle and that of the first vehicle, which are denoted as $x_{last}$ and $x_{first}$ respectively, are checked. If $x_{last} > v_{\max}$, a vehicle with velocity $v_{\max}$ is injected with probability $q_1/3600$ at the cell $\min[x_{last} - v_{\max}, v_{\max}]$. $q_1$ is the traffic demand of main road in unit of veh/h. The leading vehicle is removed if $x_{first}$ is larger than the road length. Then the following vehicle becomes the new leading vehicle and it moves without any hindrance. As to the on-ramp, the vehicle is inserted at the position $x_i + \lfloor (d_{\max} + l)/2 \rfloor$ with probability $q_2/3600$, and the velocity is set as the minimum between the velocity of the leading vehicle and $\lfloor d_{\max}/2 \rfloor$. $q_2$ is the traffic demand of on-ramp in unit of veh/h. The function $\lfloor x \rfloor$ denotes the integer part of *x*. As to a vehicle occupies several consecutive cells in the refined NaSch model, the position of a vehicle is defined as the first cell it occupies.

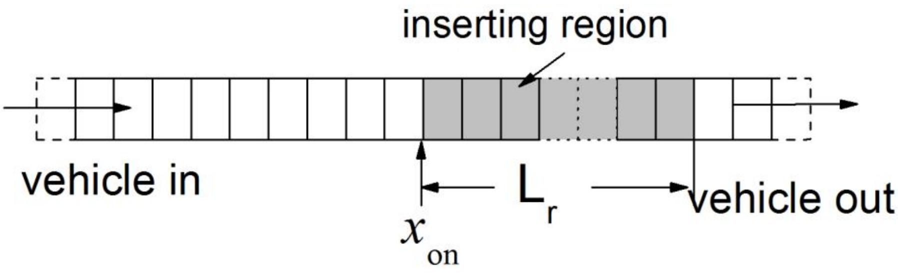


Fig.2 Cellular automata model for on-ramp system

## 2 Ramp metering strategy

Ramp metering is activated via installation of traffic light at on-ramp. Then the vehicle from on-ramp is restricted to entering the main road when the light is red. The key issue is to determine the ramp metering rate. It could be determined by the traffic variables, i.e., occupancy, speed, etc., detected downstream of the on-ramp merging region. As we know that the time gap between vehicles can also be detected, then the space gap can be estimated. If the vehicle from on-ramp was inserted into the main road just before the one with large enough space gap, the traffic will be less disturbed. Here we propose a ramp metering strategy considering the entrance gap restriction effect. The entrance gap is denoted by *E*.

The entrance gap restriction ramp metering strategy can be realized by simply revised the vehicle inserting rules as : if $d_{\max} \geq E$ is satisfied, the vehicle is inserted at the position $x_i + \lfloor (d_{\max} + l)/2 \rfloor$ with probability $q_2/3600$, and the velocity is set as the minimum between the velocity of the leading vehicle and $\lfloor d_{\max}/2 \rfloor$. Note that *E* is the control parameter, and large value of *E* means that large entrance gap is needed for the vehicle entering the main road.

## 3 Simulation results

In this section, the simulation results are presented to show the effectiveness of the entrance gap restriction strategy. In the simulations, the length of the main road is $L$=6000, and the ramp section start at $x_{on}$=3000. The length of a vehicle corresponds to 7.5m, and one vehicle occupies 3 cells, i.e., $l$=3. One time step corresponds to 1 s. The acceleration rate of vehicle is 1 cell/ s$^2$, corresponding to 2.5m/s$^2$. According to HCM2000 [22], vehicle acceleration rates of passenger cars accelerating after a stop range from 1m/s s$^2$ to 4m/s s$^2$. So the acceleration rate selected in this paper is reasonable. Other parameters are $v_{\max}$=15, $p$=0.3 and $L_r$=5. The flux of the main road upstream (downstream) on-ramp is $q_{m1}$ ($q_{m2}$) , and that of the on-ramp is $q_o$.

Firstly, the traffic demand from on-ramp $q_2$ is fixed, and the flux as a function of $q_1$ is studied. The flux $q_{m1}$ and $q_o$ as a function of $q_1$ is plotted in Fig.3. Fig.3(a) shows the case of $q_2$=720 veh/h. One can see that $q_{m1}$ increases linearly when $q_1$ is small, then it reaches a saturated value and keeps unchanged when $q_1$ grows beyond a critical value. As to the flux of on-ramp $q_o$, it first does not change as $q_1$ increasing, then it decreases to a saturated value. One can also see that as the entrance gap $E$ increasing, the saturated value of $q_{m1}$ becomes larger but the saturated value of $q_o$ becomes smaller. Fig.3(a) shows the case of $q_2$=1800 veh/h. Similar results are observed. The difference is the change of $q_o$. It decreases even $q_1$ is small. The reason is that the traffic demand is high in the latter case. Those results indicate that a larger entrance gap restriction value can really increases the flux on the main road and decreases the flux of the on-ramp at the same time.

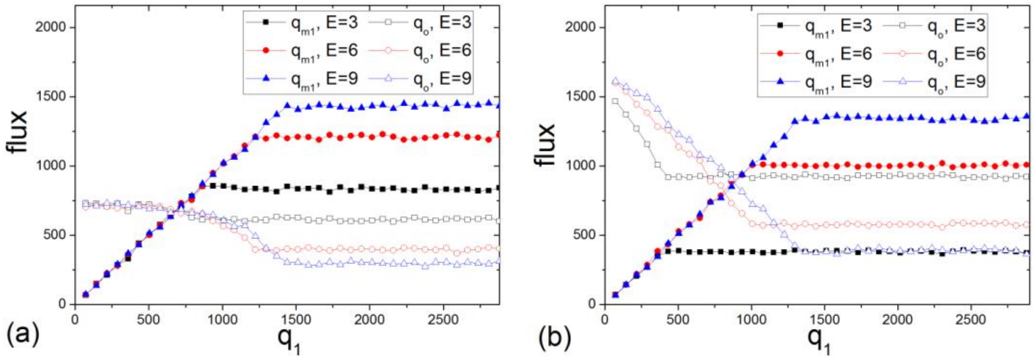


Fig.3 The flux as a function of $q_1$ with different $E$. (a) $q_2$=720 veh/h; (b) $q_2$=1800 veh/h.

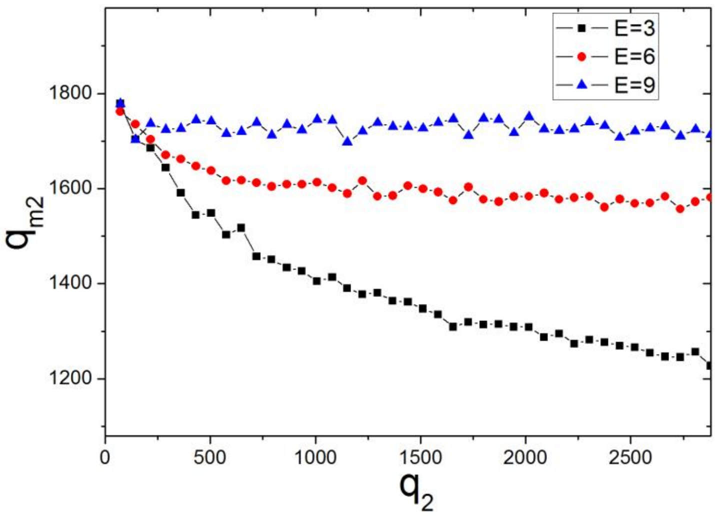


Fig.4 The flux $q_{m2}$ as a function of $q_2$ with different $E$.

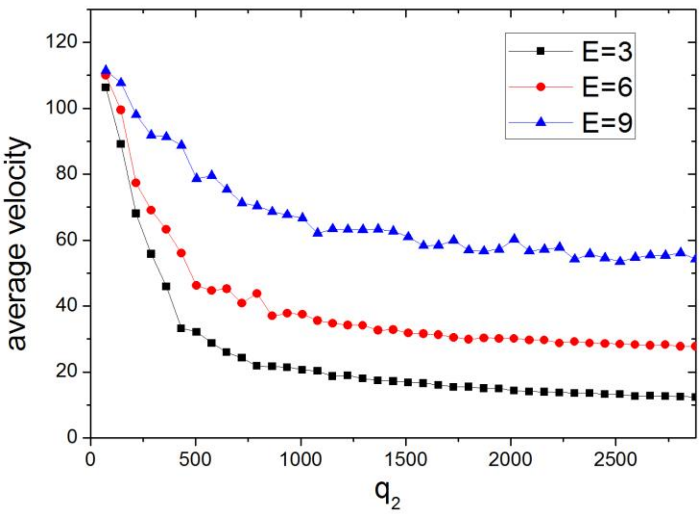


Fig.5 The average velocity of the inserting vehicle as a function of $q_2$ with different $E$.

As to $q_{m2}= q_{m1}+ q_o$, the saturated flux $q_{m2}$ is deemed as the capacity of the on-ramp system. Now $q_{m2}$ depending on $q_2$ is studied. Here we fix $q_{m1}$=1800 veh/h. $q_{m2}$ as a function of $q_2$ is plotted in Fig.4. One can see that as $q_2$ increasing, $q_{m2}$ keeps unchanged when $E$=9, and it decreases when $E$=3 and 6. With larger $E$, the saturated flux of $q_2$ also becomes larger. So there is no capacity drop when $E$=9, while the capacity drop happens when $E$<9. Fig. 5 shows the average velocity of the ramp vehicles at the inserting time. One can see that the average velocity decreases as $q_2$ increasing. When $q_2$ is very small, the inserting vehicles usually have high initial speed because the entrance gap is always large enough. As $q_2$ becomes larger, congestion happens and the initial speed of the inserting vehicle is always restricted by the entrance gap. The average velocity becomes smaller as $k$ decreasing. Lower speed means that more time is needed to recover to high speed. This is the reason for the lower capacity. In Fig.6, the density and velocity distributions near the on-ramp in the case of $q_1= q_2$=1800 veh/h are demonstrated. At the downstream of the ramp section, the vehicles can drive with free speed and there is no difference with different $E$; but the average density is higher with larger $E$. At the upstream of the ramp section, the average velocity increases while the average density decreases as $E$ growing. Thus the traffic on the main road will be seriously disturbed when $E$ is small. We know that $E$ =3 means that the ramp vehicle will be inserted into the main road as long as the space can hold a vehicle. That is to say the entrance gap is not restricted. $E$ >3 indicates the entrance gap should be large enough when the ramp vehicle is inserted. Based on the results presented above, we can conclude that the capacity of the on-ramp system can be enhanced by controlling the entrance gap and the capacity drop will not happen if the entrance gap is larger than 3 times vehicle length. We think the entrance gap should be taken into account in designing the on-ramp metering system.

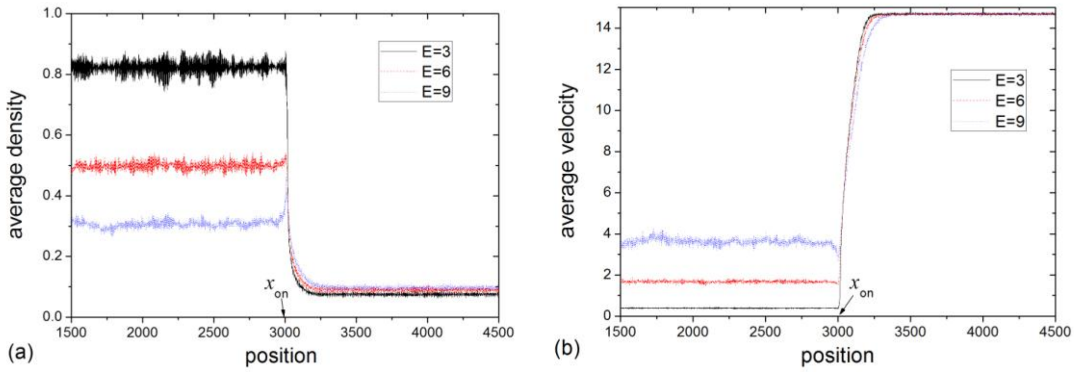


Fig.6 Road section profile with different $E$. (a) average density; (b) average velocity.

The simulation results obviously show that the capacity of the on-ramp system can be enhanced by controlling the entrance gap. If the entrance gap is restricted to the values larger than three times vehicle length, capacity drop phenomena disappears. Thus the entrance gap restriction ramp metering strategy is very effective.

## 4 Conclusion

In this paper, we propose an entrance gap restriction ramp metering strategy. And the cellular automata model was used to demonstrate the effectiveness of the strategy. In the simulation model, the on-ramp is simply modeled as an entrance region where ramp vehicles can be directly inserted into the main road.

With larger restricted entrance gap, the chances for the ramp vehicle entering the main road are rare and the traffic condition on the main road is improved. There will be capacity drop if the entrance gap is not restricted because the initial speed of the inserting vehicle is very low. This corresponds to the case that no ramp metering strategy is employed. The saturated flux of the on-ramp system will be kept with high value if the entrance gap ramp metering strategy is employed.

As we know that loop detectors can get the time gap not the space gap directly. So an effective space gap estimation method is needed to successfully apply the entrance gap ramp metering strategy. This will be done in our future work.

Note that the results are obtained through simulation by using cellular automata model. The ramp metering strategy should be checked by other simulation tools. Further more it should be verified by real traffic condition.

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# 基于安全间隙的匝道控制方法

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**摘要**：本文提出一种新的基于安全间隙的匝道控制方法。该方法限制匝道车辆进入主路时的安全间隙，只有当主路车辆空间车头距大于安全间隙时，匝道车辆才能够进入主路。基于元胞自动机模型对该方法进行了仿真验证。仿真结果显示当安全间隙足够大时，主路的饱和流量不会降低并且保持较大的值。因此所提出的方法是有效的，对于匝道控制系统具有指导意

义。

关键词：匝道控制；安全间隙；元胞自动机
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