

## Off-Ramp Control near Surface Road

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**Abstract:** To enhance the overall performance of operation of urban expressway, a ramp metering control strategy is proposed to delays and queues of vehicle platoon along off-ramp near the surface road. This control mode measures the real time traffic conditions at off ramps through the derived occupancy data and then optimizes the green time and length of cycle. A Vissim based simulation analysis is used to verify the effectiveness of this proposed control strategy using the field data of Zhuque Bridge and Taoyuan Bridge of South 2 Ring Road in Xi'an city. The simulation results show that the traffic flows can be allocated homogeneously, even during the peak hours and the average traveling time and platoon queue can be reduced approximate 5~7%, compared with the simulated findings of no control mode and fixed time control mode.

**Keywords:** Occupancy, off-ramp control, platoon queue, surface road metering, vissim simulation

### INTRODUCTION

With the rapid development of economy in China, the problem of traffic congestion has become more and more serious nowadays. In Beijing, Shanghai and Guangzhou, three typical metropolitans in China, the average traveling speed of major arterials and expressways is generally below 20 km/h during the peak time. Therefore, more and more bridge based expressways have been built and put into service. However, these types of expressways have also met with the increasing congestion since the past decade, particularly near the locations of on and off ramps. Compared with design ideas in US and Europe, the off ramp directly connects the basic segment with the off road with a shorter length in China's style of designing the ramp. Thus the queue of vehicles is much easier to be spilled-over to the surface roads.

Clearly, the Intelligent Transportation System (ITS) based techniques have significant effectiveness in alleviating the level of road congestion, thus numerous of studies have been placed on the ramp metering control, such as the reports from Wei (2001), Chang and Li (2002), Oscar and Luis (2007), Chien and Luo (2008), Papamichail and Papageorgiou (2008), Papamichail *et al.* (2010), Edara *et al.* (2011), Kattan and Saidi (2013) and Zhang and Wang (2013). But few attentions have been paid on the off ramp control. Gunther *et al.* (2012) studied the congestion induced by the off-ramp traffic flow through an example of urban freeway in Santiago, Chile and found the design of connecting the off-ramp with a weaving section decreased the capacity of this section.

Therefore, the primary purpose of this research is to develop a control strategy for surface road near off-ramp so as to reduce the queues and delays of vehicle platoon and enhance the overall capacity.

### CONTROL STRATEGY

**Control mode design:** In order to guide the metering of surface road vehicles' and reduce the conflicts between vehicles on off-ramp and surface road, two adaptive control strategies are proposed for light and heavy flows of traffic, respectively. Timing parameters are optimized dynamically using the derived occupancy data concerning the off-ramp conditions to control and decrease the vehicle queues:

$$x_n - x_n^- - l > \lambda v_n^- \quad (1)$$

$$x_n^+ - x_n - l > \lambda \min(v_n + \Delta v, v_n^+) \quad (2)$$

where,

$x$  = The position of vehicle

$v$  = The velocity of vehicle

$l$  = The vehicle length,  $\lambda$  reflects the personality of the driver

$\Delta v$  = The change of vehicle after merging

Let's define two thresholds  $o_c$  and  $o_s$ . If the off-ramp occupancy  $o_{off}$  is detected to be below the threshold  $o_c$ , it indicates that off-ramp traffic is uncongested. But if it satisfies  $o_{off} > o_c$ , then the level of congestion is measured through the ratio of  $o_{off}$  to

desired saturated occupancy  $o_s$ , and the vehicle queues on off ramp and surface road are measured to determine the surface road metering rate  $R_s$ .

The minimums queue of vehicles on surface Road is taken into account while optimizing the length of circle. Using the above mentioned two thresholds of occupancy, traffic conditions are monitored dynamically and proper metering strategy is then chosen. In order to ensure a smooth metering operation, it considers  $o_c = 0.15$  and  $o_s = 0.45$  in this research. The control rule is used:

$$q_{on} = \begin{cases} q_{on1} & \text{if } O_{det} \leq O_{cri} \\ q_{on2} & \text{if } O_{det} > O_{cri} \end{cases} \quad (3)$$

where,

$q_{on}$  = The flow rate to the on-ramp

$O_{det}$  = One minute average occupancy

**Green time optimization:** The metering rate of surface road is a key parameter and thus, the ALINEA method is used to control on-ramp metering rate through the closed-loop feedback control law, which checks the off-ramp occupancy and metering rate of surface road periodically and adjust the volume of metering vehicles using the off-ramp occupancy feedback.

Generally, the metering rate of surface road  $R_s(i+1)$  measured in vehicles per hour is estimated using the detected metering rate  $q_s(i)$  as:

$$R_s(i+1) = q_s(i) + \varphi [o_s - o_{off}(i)] \quad (4)$$

where,

$o_s$  : The desired over-saturate off-ramp occupancy

$o_{off}(i)$  : The measured over-saturate off-ramp occupancy

$\varphi$  : A parameter concerning the off-ramp features

Therefore, the split of surface road  $\lambda(i+1)$  could be measured in  $g(i+1)/c(i+1)$ . Obviously, the off-ramp occupancy  $o_{off}$  is considered as the key parameter in optimizing the metering rate of surface road. If  $o_{off} < o_s$ , then  $R_s(i+1)$  should be increased; in overall, the metering rate should be balanced within a boundary through continuous feedback.

**Cycle length optimization:** In this research, the number of stops and that of delay are balanced for under saturated and over saturated conditions. Let's suppose  $q$  is the arrival rate of vehicle flow in pcu per hour,  $g$  is the green time in second,  $c$  is the cycle length in second,  $X$  is the level of saturation,  $k$  is the adjustment factor,  $I$  is the adjustment factor related to the upstream metering traffic,  $Q$  is the capacity of lane in pcu per hour,  $f$  is the adjustment factor related to

vehicle stops. If  $X < 1$ , therefore, the total delay and number of stops within period  $T$  are estimated by:

$$D_s = \frac{0.5qc(1-g/c)^2}{1-Xg/c} + 900qT \left[ \sqrt{(X-1)^2 + \frac{8kIX}{QT}} + X - 1 \right] \quad (5)$$

$$H_s = qf \frac{1-g/c}{1-Xg/c} + qf \frac{900T}{c} \left[ \sqrt{(X-1)^2 + \frac{8kIX}{QT}} + X - 1 \right] \quad (6)$$

Since the off ramp occupancy based  $\lambda$  is significantly associated with the cycle length, let's consider the performance index  $PI = D_s/q + H_s/q$  and thus it reaches:

$$PI = \frac{0.5c(1-\lambda)^2 + f(1-\lambda)}{1-X\lambda} + 900T \left( 1 + \frac{f}{c} \right) \left[ (X-1) + \sqrt{(X-1)^2 + \frac{8kIX}{QT}} \right] \quad (7)$$

and then:

$$\frac{dPI}{dc} = \frac{0.5(1-\lambda)^2}{1-X\lambda} - \frac{900fT}{c^2} \left[ \sqrt{(X-1)^2 + \frac{8kIX}{QT}} + X - 1 \right] \quad (8)$$

If  $dPI/dc = 0$ ,  $c$  is optimized as:

$$c = \frac{\sqrt{1800Tf(1-X\lambda)} \sqrt{(X-1)^2 + \frac{8kIX}{QT}} + X - 1}{1-\lambda} \quad (9)$$

## SIMULATION EXPERIMENT

Vissim is used to simulate the traffic environment and verify the proposed control strategy under different inputs. Here detectors D1 and D2 are located at the upstream lanes to detect the length of platoon queue and arrival rate. Similarly, detectors D3 and D4 located at the stop line of surface road are used to measure the leaving vehicles and detectors D5 and D6 are to record the off ramp queue and occupancy, respectively (Fig. 1).

Three control strategies are verified: no control, fixed-time signal control (cycle length = 80s, green time = 50s) and this proposed control. The timing parameters of the proposed control strategy are determined by Eq. (4) to (9). The expected speed for freeway main line and surface road are 110 and 70 km/h. Other parameters are defined as follows:  $\varphi = 1200$  and  $S_s = 1600$  pcu/(h.lane). The average vehicle travel time are recorded for the simulated control strategies. In the beginning 1200s, the detectors neglect the flow messages and then to record the necessary data since the following 1201s.

Five hours are simulated and Fig. 2 shows the results of three control modes. Obviously, queues of

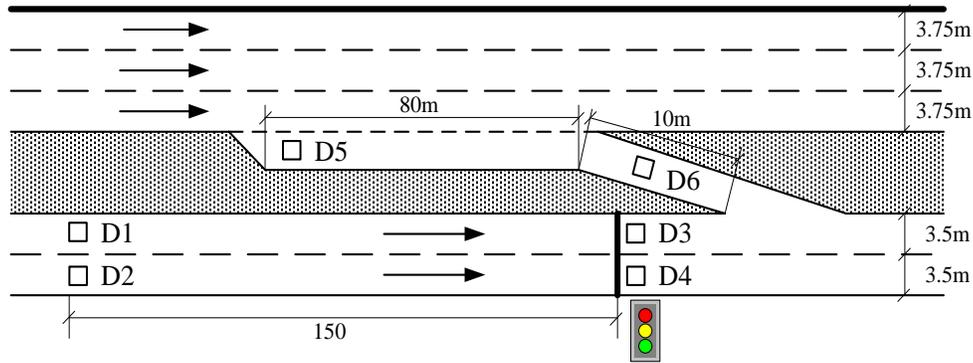


Fig. 1: Detector setting at off ramp locations

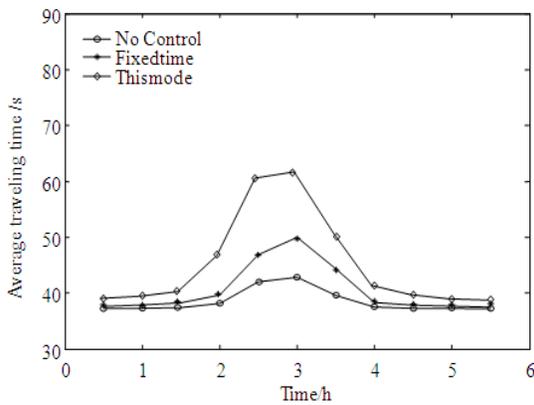


Fig. 2: Average traveling time under different control strategy

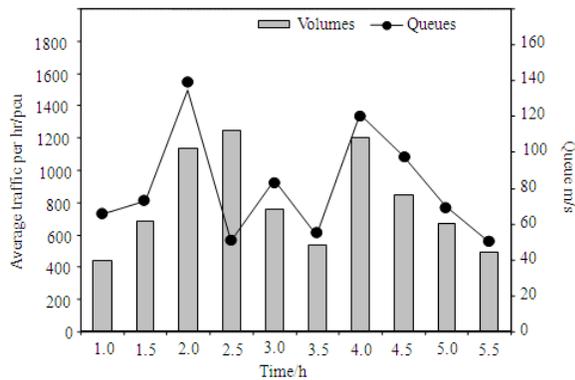


Fig. 3: Average volumes and lengths of queues per hour

vehicles on off-ramp are significantly reduced with this proposed control mode, which allocates the traffic demand more homogeneous than the other two control modes. Moreover, fixed-time control model cannot improve the capacity of ramp.

Based on the proposed surface road control strategies, we have surveyed its effectiveness in the ramp metering control of Zhuque Bridge and Taoyuan Briage of South 2 Ring Road in Xi'an city in July 2012, using the derived peak hour data 17:00 to 19:00. The

Table 1: Field test results

Bridge	No control			Proposed mode		
	ATV/s	Delay/s	ORQ/m	ATV/s	Delay	ORQ/m
Zhuque	86.32	37.74	67	80.25	35.17	63
Taoyuan	55.18	26.08	34	51.32	25.05	32

ATV: Average traveling time; ORQ: Off ramp queue

result also shows that this proposed control mode can reduce the queues of off ramps and increase the traveling speed, as shown in Table 1.

Figure 3 gives the average traffic volumes and lengths of queues per hour, which are significantly enhanced in performance by 5~7%.

## CONCLUSION

This study presented a control strategy of off ramp metering associated with the surface road and its effectiveness is verified through a Vissim based simulation text. The results from this proposed mode can distribute the traffic flows more homogeneously on basic segments and off ramps. Compared with no control and fixed time control modes, this method can reduce the length of platoon queues and delays while metering the off ramp locations, particularly during peak hours. These results will be transferable to other regions, states and countries in the future. Moreover, there leaves some further studies, such optimizing the signal parameters to reach an overall effective performance (Wang *et al.*, 2011) and making a systemic control of upstream or downstream locations, on ramps and off ramps together, etc.

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