A linked-bottleneck control method for urban expressway on-ramp

Hui-xin Jing, Wei Qian, Bing-feng Li and Yunji Zhao

Department of Electrical Engineering and Automation, Henan Polytechnic University, Jiaozuo, People’s Republic of China

ABSTRACT
In order to alleviate the congestion in the mainline of urban expressway caused by the uncertainty of the traffic flow, a linked-bottleneck control method for urban expressway on-ramp is proposed in this paper. Firstly, the downstream dynamic critical occupancy of the on-ramp under uncertainty is predicted by using ESN (Echo State Network). Then, a function for dividing the master-slave ramps is designed to dynamically determine the ramp numbers required coordination and expand the range of coordination control. Considering the designed function changes over time and some factors such as the traffic accidents, weather and so on also affect it, the BP neural network is used to improve its accuracy. The proposed method calculates the on-ramp regulating rate based on the downstream dynamic critical occupancy and expand the range of coordination control by the designed function, which can adapt the changes of actual traffic flow and overcome the defects of some methods such as Bottleneck, Linked-control, Swarm and so on. The simulations show that, compared with some existing methods, the congestion duration and the high density duration in the mainline of the urban expressway are significantly reduced by using the proposed method in this paper.

ARTICLE HISTORY
Received 3 April 2018
Accepted 26 May 2018

KEYWORDS
Urban expressway; on-ramp; coordination control; linked-bottleneck; congestion

1. Introduction
With the increase of vehicles driving in the urban expressway, the uncertainty of the traffic flow increases, which leads to the increasing congestion of the vehicle in the mainline of urban expressway. The current studies found that traffic-responsive ramp-metering strategy is an effective way to alleviate the congestion in the mainline of urban expressways (Hadiuzzaman, Qiu, & Lu, 2012; Letter & Elefteriadou, 2017), which can regulate vehicle flow of urban expressway on-ramp by using real-time measurements from sensors installed in the urban expressway networks and the on-ramps. According to the scope of the control, the existing strategies can be classified as local ramp regulating control and coordinated ramp metering control. The former adjusts the traffic flow of the expressway on-ramps by using sensor measurements near the single ramp, which includes feedback control methods such as the demand-capacity strategy (Papageorgiou, Hadj-Salem, & Blosseville, 1991) and model free adaptive control (Hou & Yan, 2009); feedback control methods such as the ALINEA strategies (Iordanidou, Papamichail, Roncoli, & Papageorgiou, 2014; Wang, Papageorgiou, Gaffney, Papamichail, & Guo, 2010, September), neural network and fuzzy-logic based methods (Vukanovic & Enrofer, 2006). The latter uses real-time measurements in the whole network to control all metered ramps, which can effectively alleviate the traffic congestion of the expressway mainlines and release the traffic pressure of the expressway on-ramps (Cassidy & Rudjanakanoknad, 2005). The main methods mainly include multivariable control strategies (Zhang, Ritchie, & Recker, 1996), optimal control strategies (Ntousakis, Nikolos, & Papageorgiou, 2016; Poole & Kotsialos, 2016), fuzzy control, status regulator control (Zhang & Wei, 2012), adaptive control (Rong-Hu & Zhong-Sheng, 2010; Zhao, Liu, & Yi, 2009) and heuristic algorithms.

Multivariable control method keeps traffic near the set point with feedback mechanisms, which can reduce errors and resist disturbance, but the control effect is not satisfactory when congestion is serious (Papageorgiou & Kotsialos, 2000). Based on the real-time data, the optimal control can identify traffic condition and optimize the amount of ramp adjustment, so that the traffic condition of the mainline is in desired state (Kotsialos, Papageorgiou, Mangeas, & Haj-Salem, 2002), but it is not widely used due to the complexity of the algorithms and programming and the difficulty to establish a control scheme under crowding (Ahn, Bertini, Auffray, Ross, & Eshel, 2007). Fuzzy control can overcome the error of original data amount without exact mathematical model (Ghods, Kian, & Tabibi, 2007, October), however, the fuzzy rules increases exponentially with the increase of ramps.
needed coordination, which makes it difficult to apply in practice. The state regulator control has feedback control mechanism, but when the disturbances occur, the system status deviates from the set value and the control stability decreases.

Heuristic control is widely used in the ramp control of the United States (Zhang & Wei, 2012), based on the measured data and experience, by using local control and coordination control comprehensively, this method can generate the amount of ramp adjustment, which has low technical complexity and wide range of applications. The main representative algorithms include Zone method (Stephanedes, 1994), Helper method (Lipp, Corcoran, & Hickman, 1991), Bottleneck method (Chai & Gao, 2013; Jacobson, Henry, & Mehyar, 1989), Swarm method (Papageorgiou, Blosseville, & Hadj-Salem, 1990), Hero method (Papageorgiou et al., 1990) and Linked-control method (Faulkner, Dekker, Gyles, Papamichail, & Papageorgiou, 2014; Xu, Chai, Li, Guo, & Li, 2016). The Helper method does not need accurate OD information and traffic flow model, but due to the lack of optimization objectives, the optimal control is difficult to achieve, and the lack of prediction mechanism also leads to the control errors caused by time delay. The Swarm method identifies traffic bottlenecks based on the predicted traffic parameters and expects to eliminate traffic congestion in the budding stage, but this method requires an accurate prediction model and accurate OD data to achieve a reasonable choice of adjustment rate. Zone method has the characters of real-time and flexibility, but due to the lack of clear control objectives and consideration of traffic flow breakdown, it is difficult to deal with traffic congestion. Bottleneck method control method has the characteristics of real-time, flexibility and logic simplicity, but the number and location of on-ramps to be adjusted are uncertain.

Based on the above discussion, to alleviate the congestion in the mainline of urban expressway caused by the uncertainty of the on-ramp enters the mainline traffic flow, a linked-bottleneck control method for urban expressway on-ramp is proposed in this paper. Firstly, the downstream dynamic critical occupancy of the on-ramp under uncertainty is predicted by using ESN. Then, a function for dividing the master-slave ramps is designed to dynamically determine the ramp numbers required coordination and expand the range of coordination control. Considering the designed function changes over time and some factors such as the traffic accidents, weather and so on also affect it, the BP neural network is used to improve its accuracy. The proposed method calculates the on-ramp regulating rate based on the downstream dynamic critical occupancy and expand the range of coordination control by the designed function, which can adapt the changes of actual traffic flow and overcome the defects of some methods such as Bottleneck, Linked-control, Swarm and so on. The simulations show that, compared with some existing methods, the congestion duration and the high density duration in the mainline of the urban expressway are significantly reduced by using the proposed method in this paper.

2. Linked-bottleneck control method

In this section, a linked-bottleneck control method for urban expressway on-ramp is designed. The scope of this method is similar to that of traffic-responsive ramp metering strategy, the final ramp outflow is generated by combining local control with coordinated control. The flow chat of the Linked-bottleneck control method is shown in Figure 1:

2.1. Local control

The local control regulates the traffic flow in the mainline of urban expressway by calculating the final local on-ramp outflow \( R(i, k) \) of the ramp. The calculation method is as follows:

\[
R(i, k) = \max\{\tilde{q}_r(i, k), q_w(i, k)\},
\]

\[
\tilde{q}_r(i, k) = \tilde{q}_r(i, k-1) + K [\hat{P}_i(k) - P_i(k)],
\]

\[
q_w(i, k) = \frac{1}{T} [N_{i}^{\text{max}} - N_i(k)] + d_{i}^{\text{pred}}(k-1),
\]

**Figure 1.** The flow chat of the Linked-bottleneck control.
where \( R(j, k) \) is the is the local final on-ramp outflow; \( \hat{q}_j(k) \) is the outflow ordered by the regulator during the \( k \) control period; \( K > 0 \) is the gain factor for the proportional term added, \( \hat{P}_j(k) \) is the dynamic critical occupancy rate of downstream of ramp \( j \) in the \( k \) control period; \( \hat{P}_j(k) \) is the measurement of the traffic density from the downstream bottleneck; \( q_j^* (k) \) is the ramp outflow ordered in the \( k \) control period of ramp \( j \); \( N_j^{\text{max}} \) is the maximum admissible number of vehicles in the queue of the on-ramp \( j \); and \( d_j^\text{pred} (k − 1) \) is the arriving ramp demand.

**Remark 2.1:** The dynamic critical occupancy rate \( \hat{P}_j(k) \) is a constant value in the Bottleneck and Linked-control methods. However, the shock wave occurs when the traffic flow propagates from the high-density downstream to the low-density upstream, and the traffic flow of the low-density upstream suddenly becomes clogged without passing through the critical occupancy state. As a result, on the one hand, the critical occupancy rate of the downstream ramp will change dynamically with the traffic conditions of the adjacent ramps. Moreover, other external factors such as the environment also cause disturbance. So, in this paper, \( \hat{P}_j(k) \) is set as the dynamic critical occupancy state, and is predicted by ESN to determine the value of \( \hat{P}_j(k) \).

Here, we choose ESN with \( K \) input units, \( N \) internal network units and \( L \) output units. The sampling time \( n \) is divided into intervals \( \{k_1, k_2, \ldots, k_n\} \), and the data collected in different time periods is \( \hat{P}_{in} \), then

\[
\hat{P}_{in} = (\hat{P}_{1}, \hat{P}_{2}, \ldots, \hat{P}_{n}), \tag{4}
\]

where \( i = 1, 2, \ldots, n \).

Then the data \( \hat{P}_{in} \) is divided into \( m \) groups, and every group has \( M + 1 \) data. The \( \lambda \)-th \( (\lambda = 1, 2, \ldots, m) \) group, we let:

\[
u_{\lambda} = [\hat{P}_{\lambda}, \hat{P}_{\lambda+1}, \ldots, \hat{P}_{\lambda+1}]^T. \tag{5}
\]

Selecting the preceding \( M \) terms of \( u_{\lambda} \) as the input of ESN and the \( M + 1 \) value as the expected output of the network, then we have:

\[
\begin{aligned}
\{u_{\lambda} &= [u_{\lambda}(1), u_{\lambda}(2), \ldots, u_{\lambda}(M)]^T, \\
y_{\lambda} &= u_{\lambda}(M + 1)
\end{aligned} \tag{6}
\]

To the above groups of data, the input matrix set and the target output matrix set of the network are denoted as:

\[
u = [u_1, u_2, \ldots, u_n], \tag{7}
\]

\[
y = [y_1, y_2, \ldots, y_n]. \tag{8}
\]

Let \( W_{in}, W, W_{back} \) and \( W_{out} \) be the input connection weight, the reserve connection pool weight, the feedback connection weight and the output pool weight, respectively, and their dimensions are \( N \times K, N \times N, N \times L \) and \( L \times (K + N + L) \). The structure of ESN is shown in Figure 2, where the dotted arrow indicates possible but not necessary connection.

The \( W_{in}, W \) and \( W_{back} \) are randomly generated during the initialization phase of the network, and then the connection weight \( W_{out} \) of the hidden layer to the output layer is determined, at last, the prediction value \( \hat{P}_j(k) \) is obtained by training.

![Figure 2. The structure of ESN.](image)

### 2.2. Coordination control

In order to achieve the coordination control, the location of the traffic bottleneck needs to be determined firstly, and then the coordinated numbers of ramps \( u \) need to be judged. Finally, the final outflow of the ramp \( R_{end} \) can be calculated, which is used to adjust the traffic flow of the mainline urban expressway. The calculation process is as follows.

#### 2.2.1. Traffic bottleneck

If the average occupancy across the downstream of link \( i \) exceeds occupancy threshold for the downstream detector station link \( i \), or the length of the on-ramp queue in segment \( i \) upstream exceeds the maximum length of the on-ramp queue, a traffic bottleneck will occur, that is:

If the segment \( i \) downstream average occupancy \( P_{i,k-1} \) exceeds the average occupancy threshold \( P_c(i) \), or the length of the on-ramp queue \( N_j(k) \) in segment \( i \) upstream exceeds the maximum length of the on-ramp queue \( N_j^{\text{max}} \), a traffic bottleneck will occur, that is:

\[
P(i, k - 1) \geq P_c(i), \tag{9}
\]

\[
N_j(k) \geq N_j^{\text{max}}, \tag{10}
\]

\[
Q_{up}(i, k - 1) + Q_{on}(i, k - 1) \geq Q_{off}(i, k - 1) + Q_{down}(i, k - 1), \tag{11}
\]

where \( Q_{up} \) is the upstream demand of ramp \( i \) in the \( k \) control period; \( Q_{on} \) is the on-ramp demand of ramp \( i \) in the \( k \) control period; \( Q_{off} \) is the off-ramp demand of ramp \( i \) in the \( k \) control period; and \( Q_{down} \) is the downstream demand of ramp \( i \) in the \( k \) control period.
where, $P_{i(k-1)}$ is average occupancy across the downstream of link $i$ in period $k-1$; $P_c(i)$ is the occupancy threshold for the downstream detector station link $i$; $N_j$ is the length of the on-ramp queue in segment $i$; $N_j^{\text{max}}$ is the maximum length of the on-ramp queue; $Q_{\text{up}}(i, k-1)$ is the volume entering link $i$ across the upstream detector station during the past time. $Q_{\text{on}}(i, k-1)$ is the volume entering link $i$ during the past minute from the entrance ramp. $Q_{\text{down}}(i, k-1)$ is the volume exiting link $i$ across the downstream detector station during the past minute. $Q_{\text{off}}(i, k-1)$ is the volume exiting link $i$ during the past minute on the off-ramp.

**Remark 2.2:** In the Bottleneck method, whether the occupancy rate $P_{i(k-1)}$ is greater than $P_c(i)$ is used to determine the occurrence of a traffic bottleneck in the segment $i$, but the traffic bottleneck caused by overspill of the on-ramp queue length is not considered. In fact, when the length of the on-ramp queue overspills, the congestion between the adjacent junctions on the ordinary roads and the mainline of expressways happens inevitably. Therefore, in this paper, in order to overcome this shortage, not only the comparison between $P_{i(k-1)}$ and $P_c(i)$ but also the comparison between $N_j(k)$ and $N_j^{\text{max}}$ is used to judge the bottleneck.

**2.2.2. Coordination metering rate**

To the bottleneck link $i$, we need calculate the total reduction of the adjacent upstream ramp regulation ratio and distribute it to the adjacent on-ramp according to experience weight, where the weight coefficient is set according to the distance from upstream ramp to link $i$. Because the influence area of different bottlenecks may overlap, which leads to the result that the on-ramp $j$ often falls in the overlapping area of multiple adjacent bottlenecks. Therefore, we select the maximum one of bottleneck metering rate reductions to calculate the final bottleneck metering rate, that is:

$$Q_{\text{reduction}}(i, k) = [Q_{\text{up}}(i, k-1) + Q_{\text{on}}(i, k-1)] - [Q_{\text{off}}(i, k-1) + Q_{\text{down}}(i, k-1)],$$

$$R_{\text{reduction}}(j, i, k) = Q_{\text{reduction}}(i, k) \frac{W_{ji}}{\sum_{j=1}^{u} W_{ji}},$$

$$r(j, k) = Q_{\text{on}}(j, k-1) - \max_{i} [R_{\text{reduction}}(j, i, k)],$$

where $Q_{\text{reduction}}(i, k)$ is the upstream ramp volume reduction of link $i$ in period $k$; $R_{\text{reduction}}(j, i, k)$ is bottleneck metering rate reduction for ramp $j$ based on link $i$ in period $k$; $W_{ji}$ is the weight coefficient of the upstream entrance ramp $j$; $\sum_{j=1}^{u} W_{ji}$ is summation of weighting factors for all ramps within the area of influence for link $i$; $Q_{\text{on}}(j, k-1)$ is the actual inflow of the ramp $j$ in the period $k-1$; $r(j, k)$ the final bottleneck metering rate for the ramp of ramp $j$ in the period $k-1$.

**Remark 2.3:** In the methods of Linked-control, Bottleneck and Swarm, the numbers of on-ramp $u$ needed coordination are unknown. So, in this paper, according to the on-ramp occupancy rate and the on-ramp queue length, the function $E_L$ that divides the master-slave ramps is designed to determine the position and quantity of the coordinated ramps, when bottleneck occurs in the urban expressway. The ramp $j + u$ is the upstream ramp of $j$, the function $E_L$ is designed as follows:

$$E_L = \begin{cases} 
E_{L1} &= E_N + E_O + A(k-1) \\
&= \frac{N_j(k)}{N_j^{\text{max}}} + \frac{P_j(k)}{P_j(k)} + A(k-1), \\
E_{L2} &= \frac{\sum_{u=0}^{u} N_{j+u}(k)}{\sum_{u=0}^{u} N_j^{\text{max}}} + A(k-1) \quad (15)
\end{cases}$$

where $E_N$ is the relative queue length of ramp $j$, $E_O$ is the ratio of the occupancy rate to the critical occupancy downstream of ramp $j$, and $E_{L1}$ is the sum of the two values; $A(k-1)$ is the correction parameter and its value is mainly affected by detained vehicles in the previous period; $E_{L2}$ is the ratio of the sum of the current queue length in ramp $j + u$ to the sum of the maximum queue length.

Let $E_{\text{NOS}}$ be the activation threshold of $E_{L1}$, and $E_{\text{NHS}}$ be the activation threshold of $E_{L2}$. When $E_{L1} > E_{\text{NOS}}$, the upstream adjacent ramp of ramp $j$ is the slave ramp and ramp $j$ is the master ramp. When $E_{L2} > E_{\text{NHS}}$, the upstream adjacent ramp of on-ramp $j + u$ is the slave ramp and ramp $j + u$ is the slave ramp. The introduction of $A(k-1)$ can increase the activation threshold and expand the scope of the ramp control subareas. If the ramp $j$, $j + u$, etc. meet the equation (15), the ramps between them form the master ramp, if not, those ramps are the slave ramp. The master ramp and the adjacent upstream slave ramp form a coordinated ramp group.

Because function $E_L$ designed in this paper is dynamic, and traffic accidents, weather and other factors will also affect it, the BP neural network is used to improve its accuracy. For example, the forecast process is as follows (Figure 3).

The sampling time $m$ is equally divided into $(k_1, k_2, \ldots, k_m)$, the sampling data in different periods is $E_{L1}^m$, that is:

$$E_{L1}^m = (E_{L1}^1, E_{L1}^2, \ldots, E_{L1}^m), (m \in N_+).$$

(16)
Dividing it into $n$ groups, each group has $M + 1$ data and satisfies:

$$n + M = m, \ (n \in N_+, M \in N_+). \ (17)$$

Denoting the $p$-th $(p = 1, 2, \cdots, n)$ group as:

$$X_p = [a_p, a_{p+1}, \cdots, a_{p+M}]^T. \ (18)$$

Selecting the preceding $M$ terms of $X_p$ as the input of BP neural network and the $M + 1$ as the expected output of network, then we have

$$\begin{cases} X_p = [X_p(1), X_p(2), \cdots, X_p(M)]^T \\ Y_p = X_p(M + 1) \end{cases}. \ (19)$$

For the above data divided into $n$ groups, the input matrix set $X$ and the target output matrix set $Y$ of the formed network are:

$$X = [X_1, X_2, \cdots, X_n], \ (20)$$

$$Y = [Y_1, Y_2, \cdots, Y_n]. \ (21)$$

Establishing the neural network by selecting the neuron numbers of network input layer, hidden layer and output layer, and then the prediction results can be got by training.

2.2.3. The final outflow of the ramp

By comparing the final local on-ramp outflow $R(j, k)$ with the bottleneck metering rate $r(j, k)$, and taking the smaller one of them, the final outflow of the ramp $R_{end}$ of the ramp $j$ can be obtained, that is:

$$R_{end} = \min[R(j, k), r(j, k)]. \ (22)$$

2.3. Linked-bottleneck control flow process

When the $E_L$ is less than the activation threshold $E_{NOS}$ or $E_{NHS}$, the local control is adopted; when the $E_L$ is greater than the activation threshold $E_{NOS}$ or $E_{NHS}$, the coordinated control is adopted. The control methods are as follows:

First, determine the dynamic critical occupancy rate $\hat{P_i}(k)$ of the on-ramp by ESN, and substitute it into Eq.
(2) to calculate the maximum adjustment rate of the on-ramp, and then substitute Eq. (3) and Eq. (2) into Eq. (1) to calculate the final local on-ramp outflow $R(j,k)$.

Then, determine the position and quantity of the on-ramp needed coordination by the designed function, and substitute $u$ into Eq. (13) to calculate $R_{\text{reduction}}(j,i,k)$, and then substitute Eq. (13) into Eq. (14) to calculate the bottleneck metering rate $r(j,k)$.

Finally, substitute $R(j,k)$ and $r(j,k)$ into Eq. (22) to calculate the final outflow of the ramp $R_{\text{end}}$.

**Remark 2.4:** In this paper, in order to the congestion duration and the high density duration in the mainline of the urban expressway, ESN algorithm is applied to value calculation to estimate $\hat{P}_j(k)$, and a new function was designed to divide the master-slave ramps to determine the original uncertain value $u$. So, compared with existing traditional heuristic control methods, the time or computational complexity of the adopted control scheme increased.

### 3. Simulation

In this section, we use CTMSIM (Traffic Macro-simulator for MATLAB) software developed by the TPOL Group of University of California at Berkeley to testify the effectiveness and Superiority of the proposed method in this paper.

The 3rd Ring Expressway of Zhengzhou is selected as the simulation section, where the intersection of the North 3rd Ring-road and Suoling Road is the starting point of the test, and the intersection of the South 3rd Ring-road and Jingguang Expressway is the testing end. The total length of the simulation section is 23.62 km, which is divided into 40 links. The test data is 24-hour sampling data on one day in 2017. The main indexes are the congestion duration and the high density duration in the mainline of the urban expressway. The sketch map of the 3rd Ring Expressway of Zhengzhou and The model of test section are shown in Figures 4 and 5.
Figures 6–9 are the location-time-density diagrams of mainline of the 3rd Ring Expressway of Zhengzhou under the conditions of no control, ALINEA control, Bottleneck control and the control method proposed in this paper.

Figure 10. No control on the expressway on-ramp.

Figure 11. ALINEA control on the expressway on-ramp.

Figure 12. Bottleneck control on the expressway on-ramp.

Figure 13. Linked-bottleneck control method proposed in this paper on the expressway on-ramp.

Figures 10–13 are the location-time-flow diagrams of mainline of the 3rd Ring Expressway of Zhengzhou under the conditions of no control, ALINEA control, Bottleneck control and the control method proposed in this paper.

At the same time, the congestion duration and high density duration in the mainline of the urban expressway by different control methods as shown in Table 1.

The simulations show that, compared with some existing methods, the congestion duration and the high density duration in the mainline of the urban expressway

Table 1. The congestion duration and high density duration in the mainline of the urban expressway by different control methods.

| Strategy on on-ramp      | The congestion duration (min) | high density duration (min) |
|--------------------------|-------------------------------|----------------------------|
| No control               | 720                           | 656                        |
| ALINEA (Wang et al., 2010)| 482                           | 401                        |
| Bottleneck (Chai & Gao, 2013)| 256                           | 207                        |
| this paper               | 183                           | 125                        |
are significantly reduced by using the proposed method in this paper.

4. Conclusions

In this paper, through predicting the downstream dynamic critical occupancy of the on-ramp under uncertainty with ESN, designing a function to divide the master-slave ramps and using BP neural network to improve its accuracy, a linked-bottleneck control method for urban expressway on-ramp is proposed to alleviate the congestion in the mainline of urban expressway. The proposed method calculates the on-ramp regulating rate based on the downstream dynamic critical occupancy and expand the scope of coordination control. Compared with some existing methods, the proposed method reduce the congestion duration and the high density duration in the mainline of the urban expressway significantly.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work is supported by the National Natural Science Foundation of China under (grant number 61573130); the Innovation Scientists and Technicians Troop Construction Projects of Henan Polytechnic University and Henan Province with under (grant numbers T2017-1, CXTD2016054).

References

Ahn, S., Bertini, R., Auffray, B., Ross, J., & Eshel, O. (2007). Evaluating benefits of systemwide adaptive ramp-metering strategy in Portland, Oregon. Transportation Research Record: Journal of the Transportation Research Board, 2012, 47–56.

Cassidy, M. J., & Rudjanakanoknad, J. (2005). Increasing the capacity of an isolated merge by metering its on-ramp. Transportation Research Part B: Methodological, 39(10), 896–913.

Chai, G., & Gao, X. Y. (2013). Coordinated control method for freeway ramp with congestion of road link. Journal of Southeast University (Natural Science Edition), 43(3), 654–658.

Faulkner, L., Dekker, F., Gyles, D., Papamichail, I., & Papageorgiou, M. (2014). Evaluation of HERO-coordinated ramp metering installation at M1 and M3 freeways in Queensland, Australia. Transportation Research Record: Journal of the Transportation Research Board, 2470, 13–23.

Ghods, A. H., Khan, A. R., & Tabibi, M. (2007). A genetic-fuzzy control application to ramp metering and variable speed limit control. 2007. ISIC (pp. 1723–1728). Montreal, Que, Canada: IEEE International Conference on Systems, Man and Cybernetics.

Hadiuzzaman, M., Qiu, T. Z., & Lu, X. Y. (2013). Variable speed limit control design for relieving congestion caused by active bottlenecks. Journal of Transportation Engineering, 139(4), 358–370.

Hou, Z. S., & Yan, J. W. (2009). Model free adaptive control based freeway ramp metering with feedforward iterative learning controller. Acta Automatica Sinica, 35(5), 588–595.

Iordanidou, G. R., Papamichail, I., Roncoli, C., & Papageorgiou, M. (2014). A feedback-based approach for mainstream traffic flow control of multiple bottlenecks on motorways. IFAC Proceedings Volumes, 47(3), 11344–11349.

Jacobson, L. N., Henry, K. C., & Mehray, O. (1989). Real-time metering algorithm for centralized control. Transportation Research Record. Journal of the Transportation Research Board, 1232, 17–26.

Kotsialos, A., Papageorgiou, M., Mangeas, M., & Haj-Salem, H. (2002). Coordinated and integrated control of motorway networks via non-linear optimal control. Transportation Research Part C: Emerging Technologies, 10(1), 65–84.

Letter, C., & Elefteriadou, L. (2017). Efficient control of fully automated connected vehicles at freeway merge segments. Transportation Research Part C: Emerging Technologies, 80, 190–205.

Lipp, L. E., Corcoran, L. J., & Hickman, G. A. (1991). Benefits of central computer control for Denver ramp-metering system. Transportation Research Record. Journal of the Transportation Research Board, 1320, 3–6.

Ntousakis, I. A., Nikolos, I. K., & Papageorgiou, M. (2016). Optimal vehicle trajectory planning in the context of cooperative merging on highways. Transportation Research Part C: Emerging Technologies, 71, 464–488.

Papageorgiou, M., Blosseville, J. M., & Hadj-Salem, H. (1990). Modelling and real-time control of traffic flow on the southern part of Boulevard Peripherique in Paris: Part I: Modelling. Transportation Research Part A: General, 24(5), 345–359.

Papageorgiou, M., Hadj-Salem, H., & Blosseville, J. M. (1991). ALINEA: A local feedback control law for on-ramp metering. Transportation Research Record, 1320(1), 58–67.

Papageorgiou, M., & Kotsialos, A. (2000). Freeway ramp metering: An overview. IEEE Transactions on Intelligent Transportation Systems, 3(4), 271–281.

Poole, A., & Kotsialos, A. (2016). Second order macroscopic traffic flow model validation using automatic differentiation with resilient backpropagation and particle swarm optimisation algorithms. Transportation Research Part C: Emerging Technologies, 71, 356–381.

Rong-Hu, C. H. I., & Zhong-Sheng, H. (2010). A model-free periodic adaptive control for freeway traffic density via ramp metering. Acta Automatica Sinica, 36(7), 1029–1033.

Stephanedes, Y. J. (1994). Implementation of on-line Zone Control Strategies for optimal ramp metering in the Minneapolis Ring Road (pp. 181–184). London,UK: Seventh International Conference on Road Traffic Monitoring and Control.

Vukanovic, D. I. S., & Ernhofer, D. I. O. (2006). Field evaluation of the fuzzy logic based ramp metering algorithm ACCEZZ. IFAC Proceedings Volumes, 39(12), 119–123.

Wang, Y., Papageorgiou, M., Gaffney, J., Papamichail, I., & Guo, J. (2010). Local ramp metering in the presence of random-location bottlenecks downstream of a metered on-ramp (pp. 1462–1467). Funchal,Portugal: The 13th International IEEE Conference on Intelligent Transportation Systems.
Xu, K., Chai, G., Li, Q. Q., Guo, J. H., & Li, X. D. (2016). Coordinated control method of ramp based on automatic tracking dynamic critical occupancy. *Journal of Transportation Engineering, 16*(2), 150–158.

Zhang, H., Ritchie, S. G., & Recker, W. W. (1996). Some general results on the optimal ramp control problem. *Transportation Research Part C: Emerging Technologies, 4*(2), 51–69.

Zhang, Y., & Wei, G. U. A. N. (2012). Variable structure control discrete traffic flow. *Control and Decision, 27*(1), 009.

Zhao, D. B., Liu, D. R., & Yi, J. Q. (2009). An overview on the adaptive dynamic programming based urban city traffic signal optimal control. *Zidonghua Xuebao/Acta Automatica Sinica, 35*(6), 676–681.