Proceedings Paper:

Qiao, F., Sun, H., Guo, L. et al. (2 more authors) (2019) Multi-objective optimization coordination for urban arterial roadway based on operational-features. In: Fang, Q., Zhu, Q. and Qiao, F., (eds.) Advancements in Smart City and Intelligent Building. International Conference on Smart City and Intelligent Building , 15-16 Sep 2018, Hefei, China. Advances in Intelligent Systems and Computing, 890 . Springer , pp. 321-332. ISBN 9789811367328

https://doi.org/10.1007/978-981-13-6733-5_30

Multi-objective optimization coordination for urban arterial roadway based on operational-features

Feng Qiao[1*], Haochen Sun[1], Lingzhong Guo[2], Haolin Song[1] and Zhaoyan Wang[1]

[1]Faculty of Information and Control Engineering
Shenyang Jianzhu University, Shenyang, China
*E-mail: fengqiao@sjzu.edu.cn
[2]Department of Automatic Control and Systems Engineering
University of Sheffield, Sheffield S1 3JD UK

Abstract. In this paper, a new coordinated control model is proposed based on the vehicular operational features, and a multi-objective optimization algorithm NSGA-II is employed to the model for the operation of the vehicle traveling on an urban arterial road taking three evaluation indexes into consideration as the average vehicle delay, the queue length, and the vehicle exhaust emission. A numerical experiment was made in an urban arterial road with three intersections on VISSIM for the proposed strategy, and the simulation results were compared with two commonly used pre-timed methods: Webster's method and MAXBAND coordinated control method to verify the effectiveness of the proposed strategy in dealing with the unbalanced traffic volume condition, and it is proved its advantages in designing and managing traffic systems more efficiently.

Keywords: Multi-Objective Optimization, Coordinated Control, Urban Arterial Road, Vehicle Delay, Queue Length, Exhaust Emission.

1 Introduction

In the modern city, urban transportation is the basis for developing the urban economy. In recent years, with the rapid development of social economy and urbanization, the transportation problems have been paid more and more attention to, for solving or alleviating the transportation problems to improve the urban transportation system [1]. While the more developed the city always means the more vehicles the city has. So, some serious traffic problems are presented, such as the traffic congestion and the environmental pollution. In this case, it is the most important work for the urban traffic managers and researchers that how to solve the traffic congestion and environmental pollution due to the increasing number of vehicles. At first, all the transportation engineers focus on the improvement in the traffic infrastructure and the vehicle technology, which have no apparent effect on dealing with the traffic congestion and the environmental pollution. Then, it is required all the researchers have to find the other efficient way to solve such problems, for example, using the method of traffic management and control.

With further research on the traffic management and control, it is clearly recognized that the traffic control strategy should be made to improve the traffic efficiency, throughput, and capacity, and diminish the vehicle delay and travel time [2]-[4]. And the indexes for evaluating the intersection operational efficiency always include average vehicle delay, stop times, queue length, traffic capacity, fuel consumption, exhaust emission, etc., all of which have been influenced directly by the signal timing at intersections [5]-[7]. So, only by making a proper signal timing plan, can the operational efficiency be increased, and the vehicle exhaust emission be reduced, which mean a more environmentally-friendly transportation system is constructed.

In this paper, both the intersection operational efficiency and environmental benefit are taken into consideration, i.e., there are three operational features selected as the evaluation indexes employed comprehensively to optimize the intersection signal timing in this research, which are the average vehicle delay, queue length, and vehicle exhaust emission. But, it is bothersome that there exist some certain relations among these evaluation indexes, some of which even are contradictory. So, to handle such a contradiction, it is necessary to settle it as a multi-objective optimization problem, which means, in this study, the modeling and simulation of signal timing at intersections based on multi-objective optimization theory are researched. In this paper, a new delay model is proposed, which divides the vehicle delay into two parts: inbound and outbound, by which the problem of the coordinated control for the unbalanced traffic volume on each way of the urban arterial road is easy to be handled. And a multi-objective optimization tool NSGA-II is used to solve such a problem and figure out the optimal signal timing. It is desirable to apply the coordinated control method on the urban artery to decrease the average vehicle delay, queue length, and vehicle exhaust emission by constructing a multi-objective optimization model.

The remaining part of this paper is organized as follows. In Section 2, some necessary background knowledge is introduced. In Section 3, the multi-objective optimization model is constructed. Then, the numerical experiments of optimizing the arterial road signal coordinated control based on Webster's method, MAXBAND model, and the proposed model are carried out on MATLAB for an arterial roadway with three-intersection, respectively, in Section 4, the optimal results are applied on VISSIM for simulation with analysis and discussion. The conclusions are drawn in Section 5.

2 Background Knowledge

2.1 Multi-Objective Optimization Problem

As the name suggests, multi-objective optimization means optimizing multiple objectives simultaneously [8]. But, the challenge is when the objectives are of contradiction to each other, i.e., the optimal solution of one of the objective functions is different from that of the other. In multi-objective optimization problems, the objective functions are to be either minimized or maximized. As in a single-objective optimization problem, the multi-objective optimization problem may involve a number of constraints, which any feasible solution must satisfy. According to the optimization theory, the objective which is maximized can be transformed into that which is minimized, so, in this paper, we state the multi-objective optimization problem in its general form as:

$$\left.\begin{array}{lll} \text{minimize} & f_m(\boldsymbol{x}), & m = 1,2,\ldots,M; \\ \text{subject to} & g_j(\boldsymbol{x}) \geq 0, & j = 1,2,\ldots,J; \\ & h_k(\boldsymbol{x}) = 0, & k = 1,2,\ldots,K; \\ & x_i^{(L)} \leq x_i \leq x_i^{(U)} & i = 1,2,\ldots,n \end{array}\right\} \quad (1)$$

where $\boldsymbol{x} \in \boldsymbol{R}^n$ is a solution vector of n decision variables, written as $\boldsymbol{x} = (x_1, x_2, \ldots, x_n)^T$; $f_m(\boldsymbol{x})$ is the mth objective function; $g_j(\boldsymbol{x})$, and $h_k(\boldsymbol{x})$ mean the jth inequality constraint and the kth equality constraint, respectively; $x_i^{(L)}$, and $x_i^{(U)}$ represent the lower bound and the upper bound of the variable x_i, respectively.

2.2 Non-Dominated Sorting Genetic Algorithm: NSGA-II

The traditional multi-objective evolutionary algorithms (MOEAs) have some deficiencies as they use non-dominated sorting and sharing have been criticized primarily for them: 1) the high-cost computational complexity $O(MN^3)$; 2) the non-elitism approach; and 3) the requirement for specifying a sharing parameter. So, in 2002, an improved multi-objective genetic algorithm NSGA-II is presented, which is a non-dominated sorting-based MOEA, alleviating all the three principal difficulties [9]. And the simulation results on some complex test problems show that the proposed NSGA-II is able to find a much better spread of solutions and better convergence near the true Pareto-optimal front compared to other elitist MOEAs in most cases. In the field of traffic engineering, up to now, there are many researchers employing the NSGA-II or its improved versions for optimizing the traffic signal timing plan at urban intersections [10]-[11].

2.3 Selection of the Evaluation Indexes

In this paper, three evaluation indexes are taken into consideration: the average vehicle delay, queue length, and vehicle exhaust emission. For the urban arterial road signal coordinated control, there exist some conditions that if the artery satisfies to these conditions, employing the signal coordinated control will improve the overall operational efficiency; but if not, employing the coordinated control strategy arbitrarily will get an opposite result. There is much research work which shows that the signal coordinated control is preferred to be set on a one-way road in undersaturated conditions.

Average Vehicle Delay Model. According to the conditions, a new vehicle delay model is proposed. This new model has two parts: inbound delay and outbound delay, which are different from the delay model employed on the existing previous researches. Through the proposed delay model, the coordinated control of the urban arterial road that has unbalanced traffic volume on each way can be accomplished. And the outbound delay model is expressed as:

$$d_{(i+1)d} = 0.5t_r q_d (t_d + t_r) = \frac{t_r^2 q_d u}{2(u - q_d)} \tag{2}$$

$$d'_{(i+1)d} = 0.5t_{ed} q_d (t_d + t_{ed}) = \frac{t_{ed}^2 q_d u}{2(u - q_d)} \tag{3}$$

$$D_d = \sum_{i=2}^{n} [\alpha_i d_{id} + (1 - \alpha_i) d'_{id}] \tag{4}$$

where $d_{(i+1)d}$ is the delay of vehicles when arriving at red at the $(i+1)$th intersection, and $d'_{(i+1)d}$ is the delay of vehicles when arriving after red at the $(i+1)$th intersection; t_r, t_d represent the red time in a cycle, and the outbound evanescing time, respectively; u is the maximum traffic capacity of the intersection during green; q_d is the outbound traffic volume; t_{ed} is given as $t_{ed} = \varphi_{i,i+1} - \left[\frac{l_i}{v_d}\right]$ (mod T); and α_i is a Boolean function.

The inbound delay model is expressed as:

$$d_{iu} = 0.5t_r q_u (t_u + t_r) = \frac{t_r^2 q_u u}{2(u - q_u)} \tag{5}$$

$$d'_{iu} = 0.5t_{ed} q_u (t_u + t_{ed}) = \frac{t_{ed}^2 q_u u}{2(u - q_u)} \tag{6}$$

$$D_u = \sum_{i=2}^{n} [\beta_i d_{iu} + (1 - \beta_i) d'_{iu}] \tag{7}$$

where d_{iu} is the delay of vehicles when arriving at red at the ith intersection, and d'_{iu} is the delay of vehicles when arriving after red at the ith intersection; q_u and t_u are the inbound traffic volume and the inbound evanescing time, respectively; t_{ed} is given as $t_{ed} = T - \varphi_{i,i+1} - \left[\frac{l_i}{v_u}\right]$ (mod T); and β_i is a Boolean function.

Then, the integrated vehicle delay at all intersections in all directions is expressed as:

$$\begin{aligned} D =\ & D_u + D_d \\ =\ & \sum_{i=2}^{n} [\beta_i d_{iu} + (1 - \beta_i) d'_{iu}] + \sum_{i=2}^{n} [\alpha_i d_{id} + (1 - \alpha_i) d'_{id}] \\ s.t.\ & 0 \le \varphi_{i,i+1} \le T \end{aligned} \tag{8}$$

Queue Length Model. As the intersection is in an undersaturated condition, the queue length during the nth cycle can be expressed as:

$$l_n = \frac{\exp[-\frac{4}{3}\sqrt{\lambda C q_s} \times \frac{1 - x}{x}]}{2(1 - x)} + q_n C(1 - \lambda) \tag{9}$$

where λ is the green split; C means the cycle length; q_s is the saturated vehicle flow rate; x represents the degree of saturation; q_n represents the vehicle arrival rate in the nth cycle.

Vehicle Exhaust Emission Model.

$$E = \sum_j \left[EF^{PCU} \times q_j \times \left(L_j - l_j\right)\right] + \frac{1}{3600}\sum_j \left(EFI^{PCU} \times q_j \times D_j\right) \qquad (10)$$

where E is the total quantity of the exhaust emissions; EF^{PCU} represents the emission factor; EFI^{PCU} is the idling emission factor; q_j means the traffic flow volume on the jth segment of the roadway; L_j and l_j represent the length of the jth segment and of the queue on the jth segment, respectively; and D_j is the average vehicle delay at the intersection.

According to the above, a general expression of the multi-objective signal coordinated control for the arterial road can be written as:

$$\min(D, l_n, E) \qquad (11)$$

3 Modelling the Multi-Objective Optimization Problem on the Urban Arterial Roadway

The basic consideration of the arterial road coordinated control is that regarding all the intersections on the artery as an integrated system, every two adjacent intersections have a spatio-temporal relationship admitting that as the first vehicle of a platoon just arrives at the downstream signal and the light turns green, i.e., the platoon can pass through the arterial roadway without stop. And in doing so, it can be guaranteed that the vehicle running on the arterial road is able to maintain a best high speed during its travel, and the platoon can pass through intersections freely as much as possible. This approach improves the operational efficiency of the whole traffic system.

3.1 Some Main Parameters for Describing the Arterial Traffic Coordinated Control

It is required all the signal intersections on the arterial road should have a **critical cycle** (always select the maximum cycle length among all intersections as the critical cycle) to make the signal coordinated control among the intersections easier. **Split** is calculated based on the intersection phasing and expected demand, so it is a portion of time allocated to each phase at an intersection. And in traditional coordination logic, the split for the non-coordinated phases defines the minimum amount of green in the coordinated phases. In the research on the arterial traffic coordinated control, all the intersections employ a critical cycle, but apply different splits due to the different traffic operational conditions. **Offset** is a very important control parameter in the green-wave coordinated control. This term defines the time relationship between coordinated phases at subsequent traffic signals, and is the time difference between the beginning of green phases for a continuous traffic movement at successive intersections that may give rise to a green wave along the arterial road.

3.2 Webster's Arterial Traffic Coordinated Control Model

The Webster coordinated control model is one kind of pre-timing models, which mean all the intersections on the arterial road have a same pre-determined cycle length as the critical cycle. And in the Webster model, the critical cycle is the maximum cycle length among all the cycle lengths of intersections, obtained by the Webster's optimal cycle length method. The formula for measuring the optimal cycle length of each intersection is expressed as:

$$C_o = \frac{1.5L + 5}{1 - Y} \tag{12}$$

where C_o means the optimal cycle length; L is the total loss time at the intersection, given as $L = \sum(l + I - A)$, l being the start loss and always being set as equal to 3 seconds, I being the green interval set as equal to 7 seconds, and A being the amber time set as equal to 3 seconds; and Y is the sum of the maximum flow rate in each phase, given as $Y = \sum \max[y_1, y_2, \dots]$.

Then, select a proper offset, which defines the time relationship between coordinated phases at subsequent traffic signals, and is the time difference between the beginning of green phases for a continuous traffic movement at successive intersections that may give rise to a green wave along the arterial road. For a two-way coordinated control, the offset is expressed as:

$$\Delta p = \text{mod}\left(\frac{T}{C_c}\right) \tag{13}$$

where Δp represents the offset between the adjacent intersections; T means the average travel time along the section between the two adjacent intersections; and C_c is the critical cycle length.

3.3 An Improved MAXBAND Arterial Traffic Coordinated Control Model

The MAXBAND model is proposed by Little to maximize the width of the green wave [11]. Give names to the n intersections along the arterial road, such as $I_1, I_2, \dots, I_n$, and assume the direction that from I_1 to I_n is **outbound**, and the opposite direction is the **inbound** (seen Fig. 1 as a detail).
The expression of MAXBAND model is shown as:

$$
\begin{aligned}
Z_2 = \quad & \max\left(b+\bar{b}-K_P\left|K_R b-\bar{b}\right|\right) & & \\
s.t. \quad & w_i+b' \leq 1-r_i, \bar{w}_i+\bar{b}' \leq 1-\bar{r}_i & & i=1,2,\ldots,n \\
& w_i+\bar{w}_i-(w_{i+1}+\bar{w}_{i+1})+t_{(i,i+1)}+\bar{t}_{(i,i+1)} & & \\
& +\Delta_i-\Delta_{i-1}=-0.5(r_i+\bar{r}_i)+0.5(r_{i+1}+\bar{r}_{i+1}) & & \\
& +m_{(i,i+1)} & & i=1,2,\ldots,(n-1) \\
& m_{(i,i+1)} \in \boldsymbol{Z} & & i=1,2,\ldots,(n-1) \\
& w_i, \bar{w}_i \geq 0 & & i=1,2,\ldots,n \\
& b=\varepsilon(b')b', \bar{b}=\varepsilon(\bar{b}')\bar{b}' & &
\end{aligned} \tag{14}
$$

where $b(\bar{b})$ means the ratio of the outbound (inbound) bandwidth to the critical cycle; K_P is an influencing factor for distributing the green-wave bandwidth of inbound and outbound; K_R is a proportionality coefficient of the demand of the inbound and the outbound bandwidths; $r_i(\bar{r}_i)$ means the ratio of the outbound (inbound) red time to the critical cycle at I_i; $w_i(\bar{w}_i)$ represents the ratio of the time from the right (left) side of red to the left (right) edge of outbound (inbound) green band to the critical cycle at I_i; $t_{(h,i)}(\bar{t}_{(h,i)})$ represents the ratio of the travel time from I_h to I_i outbound (I_i to I_h inbound) to the critical cycle; $b'(\bar{b}')$ represents an intermediate variable; Δ_i is the ratio of the time from the center of $\bar{r}_i$ to the nearest center of r_i to the critical cycle,; $m_{(i,i+1)}$ is the loop integer in recognition of the more general case of networks, given as $m_{(i,i+1)}=\Phi_{(i,i+1)}+\bar{\Phi}_{(i,i+1)}+\Delta_i-\Delta_{i+1}$, $\Phi_{(h,i)}(\bar{\Phi}_{(h,i)})$ being the ratio of the time from the center of an outbound (inbound) red at I_h to the center of a particular outbound (inbound) red at I_i to the critical cycle; and $\varepsilon(x)$ is a step function.

3.4 The Operational-Feature Based Urban Arterial Traffic Coordinated Control Model

The original method for optimizing the arterial traffic signal is the maximum green wave band method that only takes the vehicles on the major road into account and ignores the traffic operational condition on the minor road, i.e., this method just guarantees the maximization of the green wave bandwidth on the major road, which will induce the average vehicle delay on the minor road being increasing. So, in this paper, a new optimization model is expressed as:

$$
\begin{gathered}
\begin{cases}
F_1=\min\left(\sum_{i=1}^{n} d_{1i}, \sum_{i=1}^{n} l_{1i}, \sum_{i=1}^{n} e_{1i}\right) \\
F_2=\min\left(\sum_{i=1}^{n} d_{2i}, \sum_{i=1}^{n} l_{2i}, \sum_{i=1}^{n} e_{2i}\right)
\end{cases} \\
s.t. \begin{cases}
g_{ij\,\min} \leq g_{ij} \leq g_{ij\,\max} \\
C_{i\,\min} \leq C_i \leq C_{i\,\max} \\
x_{i\,\min} \leq x_i \leq x_{i\,\max} \\
\varphi_{i,i+1\,\min} \leq \varphi_{i,i+1} \leq \varphi_{i,i+1\,\max}
\end{cases}
\end{gathered} \tag{15}
$$

where $F_1(F_2)$ means the multi-objective optimization function in the inbound (outbound) direction; $d_{1i}(d_{2i})$ is the average vehicle delay at I_i in the inbound (outbound) direction; $l_{1i}(l_{2i})$ represents the vehicle queue length at I_i in the inbound (outbound) direction; $e_{1i}(e_{2i})$ is the quantity of the vehicle exhaust emissions at I_i in the inbound (outbound) direction; C_i is the cycle length at I_i; $C_{i\,\min}$ and $C_{i\,\max}$ represent the lower bound and the upper bound of the cycle length at I_i, respectively; g_{ij} is effective green time at I_i in the jth phase; $g_{ij\,\min}$ and $g_{ij\,\max}$ are the lower bound and the upper bound of the effective green time at I_i in the jth phase, respectively; x_i is the degree of saturation at I_i; $\varphi_{i,i+1}$ is the phase difference between I_i and I_{i+1}; $\varphi_{i,i+1\,\min}$ and $\varphi_{i,i+1\,\max}$ are the lower bound and the upper bound of the phase difference between I_i and I_{i+1}, respectively; and $x_{i\,\min}$ and $x_{i\,\max}$ mean the lower bound and the upper bound of the degree of saturation at I_i, respectively. In this paper, $x_{i\,\min}$ and $x_{i\,\max}$ are equal to 0.7 and 0.9, respectively.

4 Numerical Experiment

Assume there is a three-intersection artery with a no-left-turn two-way six-lane major road (east-west) and a two-way four-lane minor road (south-north). And the major road has a right turn lane in each direction at each intersection. At each intersection, the signal is set with three phases. The experimental arterial road and the corresponding signal phases are shown in Fig. 1. The traffic data of each approach at each intersection is listed in Table 1.

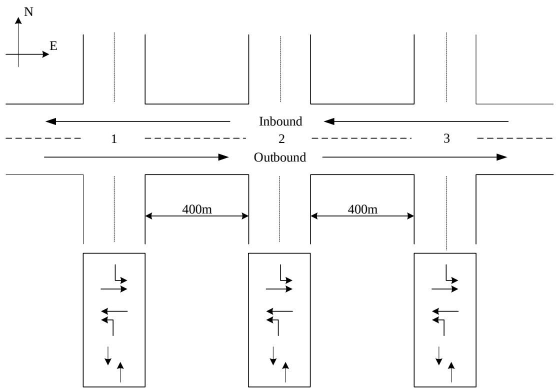


Fig. 1. The diagram of the arterial road and the signal phases.

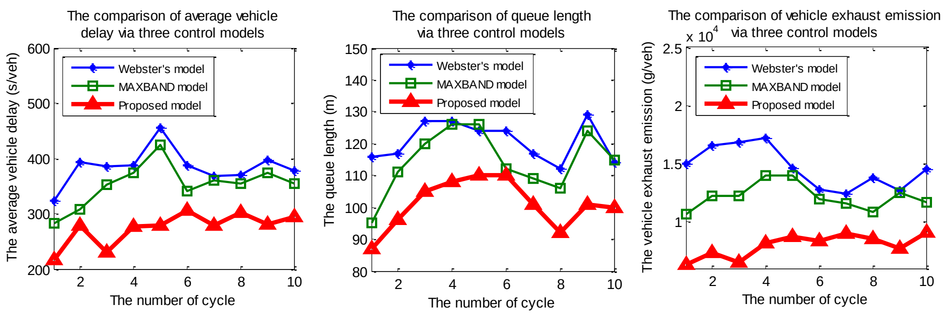
According to the cycle length at each intersection, some basic traffic parameters can be determined: the critical cycle is 179s; the initial phase differences are $\varphi_{1,2} = 50s$, and $\varphi_{2,3} = 40s$. The optimal signal timing results with 10 successive cycles of three mentioned models via MATLAB are obtained and listed in Table 2. And the results are carried on the microscopic traffic simulation software VISSIM, and the simulation values of evaluation indexes (average vehicle delay, queue length, and vehicle exhaust emission) of the three models are shown in Fig. 2.

Table 1. The experimental traffic data of each approach.

Intersection		Phase1	Phase2	Phase3
Intersection1	Saturation flow (veh/h)	6660	6660	2160
	Flow ratio	0.259	0.282	0.164
Intersection2	Saturation flow(veh/h)	6660	6660	2160
	Flow ratio	0.294	0.269	0.199
Intersection3	Saturation flow(veh/h)	6660	6660	2160
	Flow ratio	0.313	0.301	0.183

Table 2. The results via MATLAB with three models.

Webster's coordinated control			Original coordinated control ($\varphi_{1,2} = 29s$, $\varphi_{2,3} = 28s$)			Proposed optimization model ($\varphi_{1,2} = 20s$, $\varphi_{2,3} = 12s$)		
Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3
72s	68s	38s	59s	60s	24s	38s	38s	23s
cycle length=179s			cycle length=155s			cycle length=112s		



(a) The comparison of average vehicle delay on the whole artery calculated by three models

(b) The comparison of queue length calculated by three models

(c) The comparison of vehicle exhaust emission calculated by three models

Fig. 2. The diagram of comparison of the evaluation indexes via three control models.

From Table 2 and Fig. 2, it is obviously known that: (1) the general cycle-by-cycle trends obtained by three control models are similar approximately, and the Webster model has high average vehicle delay, queue length and exhaust emission, because it does not use the idea of the coordinated control method, while by employing the idea of coordination, the MAXBAND model plays a good performance that, in each cycle, in general, the values of three evaluation indexes all are lower compared with those obtained by Webster's method; (2) as the model proposed in this paper is used to solve this problem, one can get more perfect results, which are significantly lower than those calculated by the other two pre-timed methods; (3) the average vehicle delay obtained by the proposed model declined by an average of 28.6% with respect to Webster's method, and 21.8% with respect to the MAXBAND model, and the queue length computed by the proposed model decreased by an average of 16.4% with respect to the Webster method, and 11.6% with respect to the MAXBAND model, and a laudable thing is the vehicle exhaust emission calculated by the proposed model dropped by an average of 44.5% with respect to the Webster method, and 34.1% with respect to the MAXBAND model, which is more environmentally friendly.

5 Conclusions

In this paper, some work has been done. First, an introduction of some basic knowledge is presented as the base of the whole research work in this paper. Then, the multi-objective optimization problem a three-intersection arterial road in an urban area has been discussed adequately, and some key parameters of it are suggested, including the critical cycle, green split, and offset. Thereafter, the parameter offset has been discussed further that divide the offset into two parts: one-way offset, and two-way offset. And, a commonly used coordinated control model MAXBAND is introduced. After this, a new model an operational-feature based coordinated control model for the arterial roadway is proposed in this paper, and in this model, three vehicular operational features are selected as the evaluation indexes: the average vehicle delay, the queue length, and the vehicle exhaust emission. Additionally, this new proposed model separates the average vehicle delay into two segments: inbound vehicle delay, and outbound vehicle delay, by which, the problem that the coordinated control for the unbalanced traffic volume on each way of the arterial road can be solved perfectly to make the operational efficiency of the whole traffic system optimal. Then, a numerical experiment is suggested, in this experiment, the signal phase has three parts, by which the minor road and the major road are both taken into consideration that the traditional models did not. And in the simulation experiment, firstly, three models: Webster's model, improved MAXBAND model, and proposed model (solved by a multi-objective optimization tool NSGA-II), are employed on MATLAB to output the corresponding optimal results; secondly, the obtained results are put in a traffic simulation software VISSIM. From the resulting simulation, it is clearly known that the proposed model can solve the coordinated control problem better than the other two previous models, especially, the proposed model has a strong ability to decrease the vehicle exhaust emission, which is becoming an important goal in the management and control of the modern intelligent transportation system. From this paper, the transportation engineers and professionals will get a preferable tool for managing the traffic system.

Acknowledgements

This research is partially supported by the National Natural Science Foundation of China (No. 61703288).

References

1. Pisarski, A. E.: Prescriptions for research: Reviewing the history of TRB's critical issues in transportation. Tr News. (2003).
2. Zhang, X., Yu, L., & Liu, M.: Traffic demand-based traffic congestion measurement models for road networks. Modern Transportation Technology, 5(6), 71-75. (2008). (in Chinese)
3. Vreeswijk, J. D., Mahmod, M. K. M., & Van Arem, B.: Energy efficient traffic management and control - the eCoMove approach and expected benefits. International IEEE Conference on Intelligent Transportation Systems (pp.955-961). IEEE. (2010).
4. Kirkby, P., & Kadengal, R.: Traffic management and control using a single 'congestion price' like variable across multiple layers of network hierarchy. Control of Next Generation Networks (Vol.67, pp.4/1-4/6). IET. (2002).
5. Samadi, S., Rad, A. P., Kazemi, F. M., & Jafarian, H.: Performance evaluation of intelligent adaptive traffic control systems: a case study. Journal of Transportation Technologies, 2(3), 248-259. (2012).
6. Tang, T., Lu, J., Zhang, C., Zhang, W., & Zhang, Y.: Optimal speed limit investigation on highway for emission reductions. Modern Transportation Technology, 15(1), 82-86. (2018). (in Chinese)
7. Grote, M., Williams, I., Preston, J., & Kemp, S.: Including congestion effects in urban road traffic co2, emissions modelling: do local government authorities have the right options?. Transportation Research Part D Transport & Environment, 43, 95-106. (2016).
8. Xiao, X. W., Xiao, D., Lin, J. G., & Xiao, Y. F.: Overview on multi-objective optimization problem research. Application Research of Computers, 28(3), 805-167. (2011).
9. Deb, K., Pratap, A., Agarwal, S., & Meyarivan, T.: A fast and elitist multiobjective genetic algorithm: nsga-ii. IEEE Transactions on Evolutionary Computation, 6(2), 182-197. (2002).
10. Cui, M. Y., Liu, H. Z., Liu, W., Jiang, H. L., Wang, Z. P., & Huang, Y. D.: Multi-objective optimization based on improved nsga-II algorithm. Journal of Nanyang Normal University, 13(12), 8-12. (2014).
11. Qiao, F., Sun, H., Wang, Z., & Tobi, F. A.: NSQGA-Based Optimization of Traffic Signal in Isolated Intersection with Multiple Objectives. Innovative Techniques and Applications of Modelling, Identification and Control, 291-305. (2018).
12. Little, J. D. C., Kelson, M. D., & Gartner, N. H.: Maxband: a program for setting signal on arteries and triangular network. Transportation Research Record Journal of the Transportation Research Board, 795, 40-46. (1981).