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OPTIMUM SIGNALIZATION ALGORITHM SUGGESTION WITH THE INTERSECTION DELAY OPTIMIZATION

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ABSTRACT: In this study, a sample has been carried out in order to discharge the current vehicle flow in minimum time at the intersection. The sample has been carried out at an isolated and lossless four-legged intersection. An ideal traffic signaling algorithm have been presented by simultaneously calculating the minimum total intersection delay at this intersection. The suggested algorithm that is actuated method have been compared with classical and different actuated methods. It has been observed that the presented algorithm reduces the intersection delay by 65 % compared to the classical method and 51 % compared to some actuated methods.

Keywords: Isolated and lossless intersection, intersection delay, actuated method, optimum traffic signalization.

1. INTRODUCTION

Today, with the increase in population, especially in big cities, the number of vehicles in traffic is also increasing. Air pollution caused by the increasing number of vehicles causes serious health problems [1, 2]. At the same time, negativities such as the increase in the number of vehicle accidents with traffic density, high fuel costs, travel stress, environmental problems; pushes countries to seek solutions to reduce traffic density [3]. Some of the solutions found: In order to reduce the use of private vehicles, public transportation usage fees have been reduced, road works have been carried out for better public transportation [4, 5], and in some countries, citizens have been encouraged to use the shared vehicles instead of private vehicles [6, 7]. In addition, there have been some attempts to introduce some new methods to traffic systems in order to find a solution to the increasing traffic density [8-10]. In order to provide efficient transportation with less time loss and reduce fuel consumption, studies have also been carried out on vehicle engine control [11].

Although some specific solutions have been presented due to problems that are caused from traffic density, more permanent and general solutions are still seeking for. Different studies have been performed for managing of intersections. Some of those are as follows: Vehicle delay at intersections have been work with fuzzy logic method to be modeled [12]. A different fuzzy logic study have been done to reduce vehicle delays at the three-legged intersection [13]. There are also studies with the artificial neural networks at the intersections in addition to fuzzy logic ones in which the reduction of vehicle delays at the intersections targeted [14]. While there are studies on creating a network and sharing the data collected by vehicles with each other to reduce accidents that increase waiting times at intersections and roads [15], there are also studies on preventing motorcycle accidents that will reduce delay times by reducing traffic volume [16]. In the another performed study, intersection possibilities and jams were endeavored to be minimized with average delay and cross-blocking methods [17].

Arrangement of traffic signal times carry great importance for the intersection be dynamically managed. Various studies with different methods for the reduction of vehicle delay and arrangement of signalization times in the intersection management have been performed. Studies for the arrangement of somehow actuated traffic signals somehow actuated have been performed [18]. In addition to this, some other studies presenting cooperative method for traffic signalization and adaptively changing signalization methods have also been brought about [19-22].

With the studies that carried out the aim of this study is to bring about ideal traffic signalization by reducing the intersection density for the best using of the current road capacity.

2. MATERIAL AND METHODS

The intersection studied in this field is an isolated one. And at that study, losses in the vehicles and roads have been ruled out. Vehicles queue on the road are assumed to be completely discharged at a signal cycle time. There are a lot of methods to minimize the vehicle delay at the intersection. Among the most used methods, there are Australia (Akcelik) [23], HCM [24] and Webster methods [25]. In this study, intersection vehicle delay formulas that belong to Australia have been used. With Formula 1, average queue length formula which takes part in the intersection delay formula of Akcelik (Australia) has been given.

$$N_0 = \frac{QT_f}{4}\left(z + \sqrt{\frac{12(x+x_0)}{QT_f}}\right) \qquad (1)$$

The abbreviations for Formula 1 are as follows:

N_0 is the average queue length (vehicle/h), Q is the capacity (Vehicle/h), T_f is the flow time (s), QT_f is the max number of vehicles during Tf (vehicle), x is the degree of saturation, q is the flow (vehicle/s) z is equal to x minus one, x_0 is the max degree of saturation at which its queue is approximately zero.

$$x_0 = 0.67 + sg/6000 \qquad (2)$$

g is the effective green time (s), s is the saturation flow (vehicle/s),

Total delay at the intersection is showed with Formula 3.

$$D = \frac{qc(1-u)^2}{2(1-y)} + N_0 x \qquad (3)$$

The abbreviations for Formula 3 are as follows:

D the total intersection delay (s), qc: the number of average vehicles in each signal cycles (vehicle), q the flow (vehicle/s), u is the green time rate, y is the flow rate (q/s).

$$D = \frac{\lambda r^2}{2(1-q)} \quad (4)$$

Formula 4 is a simpler version of Formula 3, which can be used at lossless intersections.

The definitions of abbreviations in Formula 4 are as follows:

D is the total intersection delay (s), λ is the arrival vehicle to the intersection (vehicle/s), r is the red light time on the each road, q is the ratio of arriving vehicles to outgoing vehicles.

$$\frac{\partial D}{\partial (c-u)} = 0(5) \quad (5)$$

In this study, Formula 1, which is defined as average delay formula at the total delay one of Formula 3, has not been used since it is as worthless as to neglect. The total intersection delay calculation has been calculated with Formula 4. The total conclusion has been equalized by getting the differentiation of Formula 4 with respect to r. So, the minimum intersection delay has been obtained for the total intersection. This formula has been showed with Formula 5. The intersection optimization has been performed with the calculated minimum intersection delays. The algorithm example presented to calculate the optimum signalization time has synchronously been performed with the intersection delay times in Matlab (Matrix Laboratory).

3. INTERSECTION OPTIMIZATION

This study has been performed on the intersection type in Figure 1. Only straight and right turns allowed as two phases at the intersection. Signalization time is accepted equal on the opposing roads at the intersection. Min. vehicle delay calculated at the intersection. An algorithm has been offered for the traffic signalization time optimization on the basis of minimum intersection delays. Intersection delay calculations, the algorithm and its confirmation have been carried out on the Matlab program.

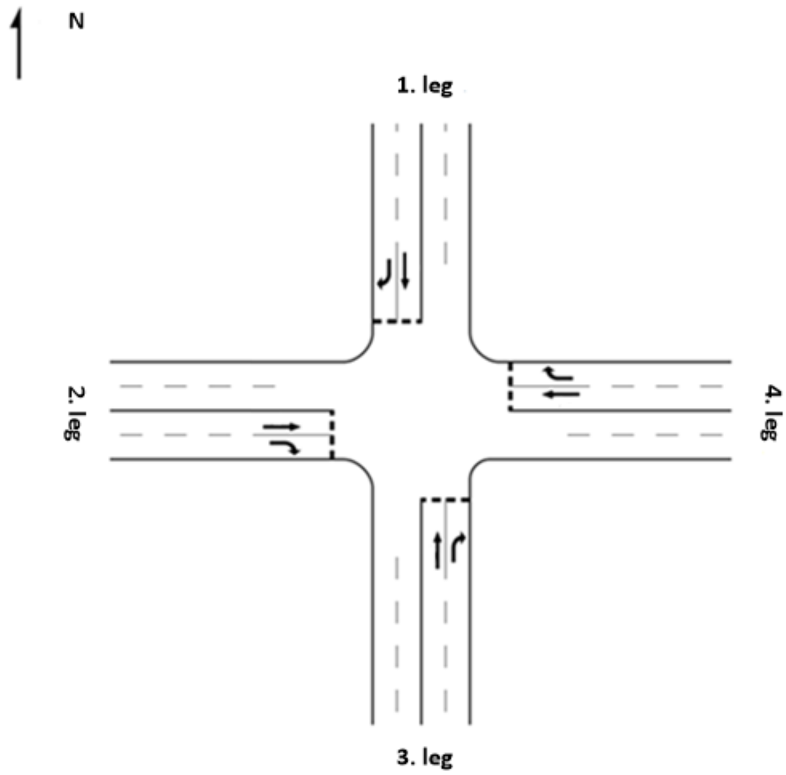

Figure 1. The Studied intersection

In this study, with random vehicle flows, which have been supposed to be obtained from any sensor, have been performed to all legs at the intersection. There are single flow with current value 170 at a single leg, and nine different flows (100,170, 200, 400, 500, 600, 700, 800, 900, 1000), which are randomly selected, at the other three-legged of an isolated and lossless four-legged intersection. The calculations of this example study conducted with the 10 flows, one is 170 current value others are 9 different flows explained / detailed in the previous sentence.

In this example, the most suitable algorithm offered by comparing different algorithms which are traffic signalization classic system independent from environment and actuated method. The intersection saturation flow of this example, leg flow values and the period of the system flow have been given all together in Figure 2.

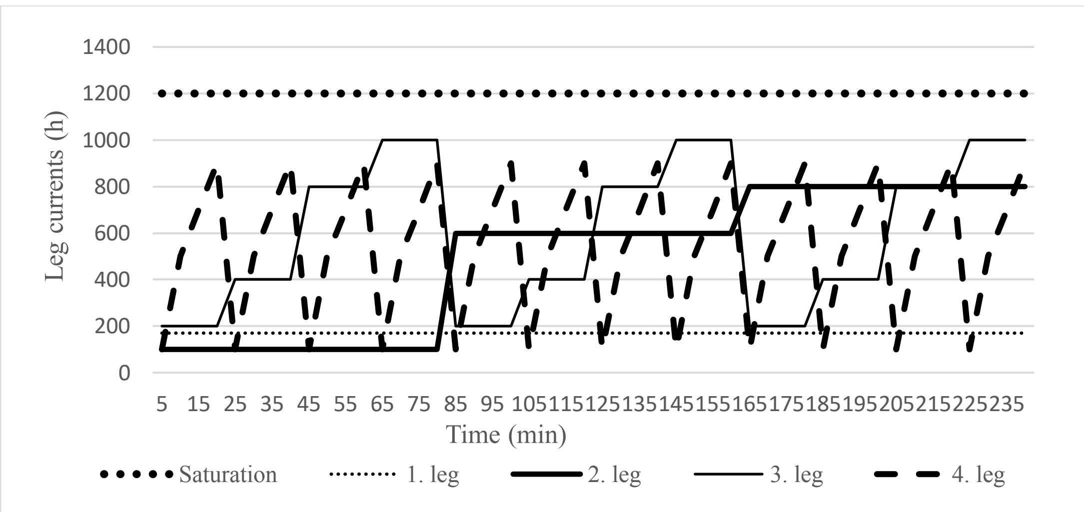

Figure 2. Leg flows on the example

Vehicle flows at the legs have changed in each five minutes. This study consisting of 48 cycles lasted 240 minute in total.

Study comparisons carried out on seven different methods have been showed with Table 1. Traffic signalization cycle times have been decided on 120 s in these studies. Each studies in this table according to 48 different leg flows that be given with Figure 2 have been performed. There is a classical method operating the fixed signalization time in Status 1. Status 2, 3, 4, 5, 6, 7 shows different algorithms of the actuated method.

Status 2 is an algorithm that is instantly defined traffic signalization times with vehicle flows at legs. Although this status is hard to carry out at the intersection, it has been included to compare with the other statuses in the table.

In Status 3, the signalization and the delay time of vehicles has been defined according to previous leg vehicle flows.

At fourth status that is the decimal-cycle algorithm has been calculated traffic signalization times by being considered the leg averages of the past ten cycles. Statuses of sixth and seventh contain algorithm that studies similar to each other. These statuses consist of algorithms that have been proposed in times that require instant intervention like the forth status. This instant intervention: It performs if the instantaneous incoming vehicle flows exceeds 1.5, 2 or 3 times of flow average of the past decimal vehicles. That is, if the instantaneous vehicle flow is at least 1.5, 2 or 3 times of the average determine; the instantaneous vehicle flow instead of the average vehicle flow is used and the traffic signalization time is determined for the delay time calculation. Instant interventions can only study for a single leg at the intersection. If the immediate response studies in all legs. It will lead to confusion in the determination of signalization time.

If it is considered the efficiency obtained the intersection delay times of the statuses compared with Table 1, it is seen that the most efficient algorithm is in the sixth status, which have been suggested within the scope of this study. The classical signalization method has the highest delay time or the lowest efficiency. The methods with the highest efficiency are the last three statuses, which are the methods with immediate intervention. In these last three statuses, the most efficient algorithm is the recommended algorithm and its efficiency exceeds 65%.

Table 1. Intersection delay and efficiency comparisons in the seven different intersection optimizations

Status	Method/Algorithm (loop)	Cycle Time (s)	Cycle Number	D (Total intersection vehicle delay) (s)	Efficiency %
1	Classical	120	48	166132	0
2	Instant interference	120	48	94420	43.16
3	Single-cycle transfer	120	48	119101	28.30
4	Decimal-cycle transfer	120	48	67647	59.28
5	1.5-fold instant transfer	120	48	66435	60.01
6	***2-fold instant transfer***	***120***	***48***	***57851***	***65.17***
7	3-fold instant transfer	120	48	65552	60.54

The suggested algorithm flowchart has been given in Figure 3. This algorithm calculates the average of past ten vehicle flows at each legs. If a vehicle flow of twice the average or more comes in, has been used it instead of decimal average in the intersection delay calculation.

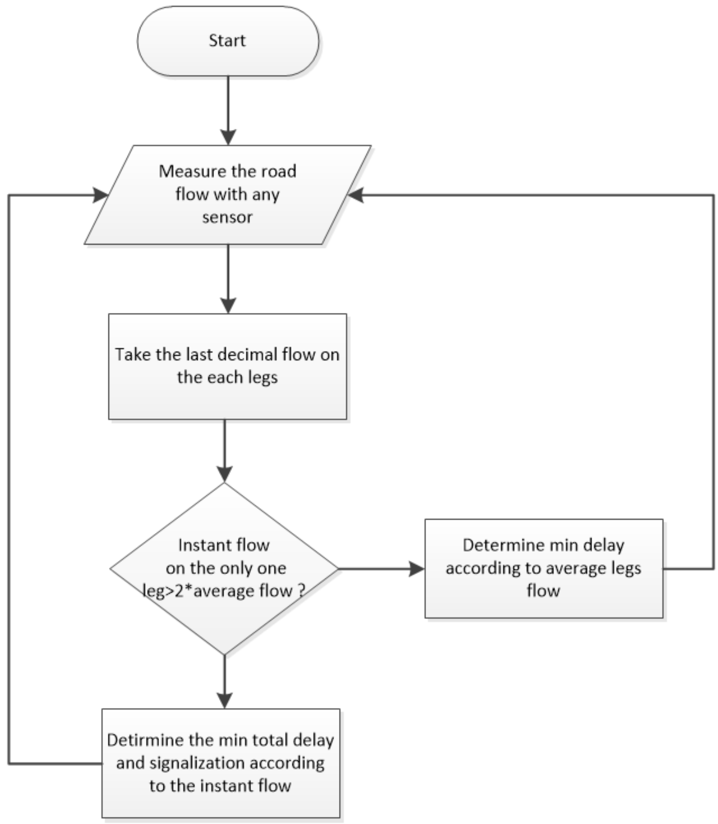

Figure 3. The suggested algorithm flowchart

Total intersection delay that belong to only the actuated method have been given their efficiency in Table 2 without the classical method. All efficiency calculations in this table have been done according to the first status.

Status 4 that is the best efficiency algorithm has 51.42 % efficiency and to minimize the vehicle delays which is clearly seen in Table 2.

Table 1. The actuated method delay time and efficiency comparisons

Status	Method/Algorithm (cycle transfer)	Cycle Time (s)	Cycle Number	D (Total intersection vehicle delay) (s)	Efficiency %
1	Single	120	48	119101	0
2	Decimal average	120	48	67647	43.20
3	1.5-fold instant	120	48	66435	44.21
4	***2-fold instant***	***120***	***48***	***57851***	***51.42***
5	3-fold instant	120	48	65552	44.91

With Figure 4 has been given efficiency comparisons of vehicle delays that belong to the actuated method in Table 2.

The superiority of the suggested 2-fold algorithm is clearly seen when it is compared to the other algorithms.

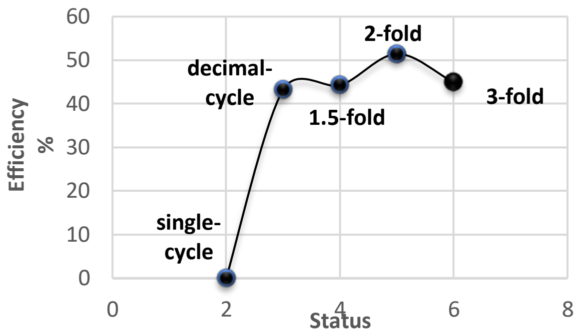

Figure 4. The actuated method delay efficiency comparisons

4. CONCLUSION AND EVALUATION

In this study, with the intersection vehicle delay flow parameters supposed to have been imported from sensors the intersection signalization time optimization have been realized in Matlab. In the study done on an example a new algorithm propounded by being compared different ones submitted.

Comparison between algorithms of actuated signalization that is dependent to the environment and classical signalization method that is independent from environment have been conducted. It has been showed how much the proposed algorithm reduces the vehicle delays at the intersection and how high its efficiency is compared to other methods with the tables and graphs. The proposed 2-fold actuated method according to the classical method has reduced % 65 the intersection delay. The 2-fold actuated method has become more and more successful among others. The 2-fold actuated method has been % 51 more successful than the single method that is define next traffic cycle. In other words, it has reduced vehicle delay at the rate of %51 at the intersection. Other methods, which are the closest to this rate, have become % 44 more successful than single-method.

Table 3. Literature comparisons

Studies	Intersection type	Proposed algorithm	Compared method	Delay efficiency %
This study	*Isolated*	*2-fold Instant (Akcelik)*	*Classical (fixed-time)*	*65.17*
[21]	Isolated	Signal control scheme	Akcelik	16.24
[26]	Isolated and Multiple	Adaptive Traffic Signal Control Model (Deep Learning)	Webster	35.1
[27]	*Isolated*	Recurrent Q-learning (Deep Learning)	Classical (fixed-time)	44.35
[28]	*Isolated*	Optimization Method (Artificial Intelligence)	Webster	27.5
[29]	*Isolated*	Signal control optimization	Akcelik	36.9
[30]	*Isolated*	Genetic	Webster	15
[31]	*Multiple*	Improved	Standard Genetic	34.57

The comparisons of this study and the literature studies on similar subjects are given in Table 3. These studies have been examined in terms of the intersection type, the proposed method, the compared method and the percentages of reducing the intersection delay times of the proposed methods. It is clearly seen that this study is successful and much more efficient in reducing the intersection delay time compared to other studies in Table 3.

The performed study has been carried out on a single intersection. Each study has been compared with different methods in term of reducing the delay time of the vehicles at the intersection delay and transferred to table as percent efficiency. The carried out study has been compared with classic method using the formulate of Akcelik and showed in Table 3 that 65.17 % efficiency has been obtained compared to the classic method in the intersection delay.

On different algorithms for the intersection management might be conducted in the sequel of this study. The different studies may be engineered for the determination of signalization time by the instant intersection vehicle density. In the meantime, this algorithm may be engineered at the lossy intersections.

REFERENCES

[1] Cai, M., Yin, Y., Xie, M., (2009). Prediction of hourly air pollutant concentrations near urban arterials using artificial neural network approach. Transportation Research Part D: Transport Environment, 14, pp. 32-41.
[2] Sharma, A. R., Kharol, S. K., Badarinath, K., (2010). Influence of vehicular traffic on urban air quality–A case study of Hyderabad, India. Transportation Research Part D: Transport Environment, 15, pp. 154-159.
[3] Akanbi, Olajubu, (2012). A fuzzy-based intelligent traffic control system for managing VIP-induced chaos at road intersections. African Journal of Computing ICT, 5, pp. 109-119.
[4] Nuzzolo, A., Comi, A., (2016). Advanced public transport and intelligent transport systems: new modelling challenges. Transportmetrica A: Transport Science, 12, pp. 674-699.
[5] Ding, J., Zhang, Y., Li, L., (2018). Accessibility measure of bus transit networks. IET Intelligent Transport Systems, 12, pp. 682-688.
[6] Nie, Y. M., (2017). How can the taxi industry survive the tide of ridesourcing? Evidence from Shenzhen, China. Transportation Research Part C: Emerging Technologies, 79, pp. 242-256.
[7] Dong, Y., Wang, S., Li, L., Zhang, Z., (2018). An empirical study on travel patterns of internet based ride-sharing. Transportation research part C: emerging technologies, 86, pp. 1-22.
[8] Wang, F.-Y., (2010). Parallel control and management for intelligent transportation systems: Concepts, architectures, and applications. IEEE Transactions on Intelligent Transportation Systems, 11, pp. 630-638.
[9] Hamilton, A., Waterson, B., Cherrett, T., Robinson, A., Snell, I., (2013). The evolution of urban traffic control: changing policy and technology. Transportation planning technology, 36, pp. 24-43.
[10] Li, L., Wang, F.-Y., (2018). A review of past 100-yera and perspective of next 50-year development of ground traffic control. Autom. Sin. 44 (4), 101, pp. 577–583.
[11] Chen, H., Zuo, C., Yuan, Y., (2013), Control strategy research of engine smart start/stop system for a micro car. in SAE Technical Paper 2013-01-0585, Detroit Michigan, United States.
[12] Murat, Y. Ş., (2006). Sinyalize kavşaklardaki taşit gecikmelerinin bulanik mantik ile modellenmesi. Teknik Dergi, 17, pp. 3903-3916.
[13] Akgüngör, A. P., E., D., (2016). Bulanık mantık ile diğer sinyal denetim sistemlerinin karşılaştırılması: üç kollu sinyalize kavşak örneği. El-Cezeri Journal of Science and Engineering . 3, pp. 110-117.
[14] Mutlu E., E., Y. M., (2008). Bulanık Mantık ve Yapay Sinir Ağı ile Sinyalize Kavşaklardaki Taşıt Gecikmelerinin Modellenmesi. Elec Lett Sci Eng, 4, pp. 11-18.
[15] Zekri, D., Defude, B., Delot, T., (2010). Summarizing sensors data in vehicular ad hoc networks. RAIRO-Operations Research, 44, pp. 345-364.
[16] Ospina-Mateus, H., Quintana Jimenez, L. A., Lopez-Valdes, F. J., Sankar Sana, S., (2021). Prediction of motorcyclist traffic crashes in Cartagena (Colombia): development of a safety performance function. RAIRO-Operations Research, 55, pp. 1257 - 1278.
[17] Arel, I., C. Liu, T. Urbanik and A. Kohls, (2010). Reinforcement learning-based multi-agent system for network traffic signal control. IET Intelligent Transport Systems., 4, pp. 128-135.
[18] R. P. Roess, E. S. P., and W. R. McShane, (2004). Traffic Engineering. Pearson, NJ, USA: Prentice-Hall.

[19] Robertson, D. I., Bretherton, R. D., (1991). Optimizing networks of traffic signals in real time-the SCOOT method. IEEE Transactions on vehicular technology, 40, pp. 11-15.
[20] Mirchandani, P., Head, L., (2001). A real-time traffic signal control system: architecture, algorithms, and analysis. Transportation Research Part C: Emerging Technologies., 9, pp. 415-432.
[21] Ren, Y., Wang, Y., Yu, G., Liu, H., Xiao, L., (2016). An adaptive signal control scheme to prevent intersection traffic blockage. IEEE Transactions on Intelligent Transportation Systems, 18, pp. 1519-1528.
[22] Xu, B., Ban, X. J., Bian, Y., Li, W., Wang, J., Li, S. E., Li, K., (2018). Cooperative method of traffic signal optimization and speed control of connected vehicles at isolated intersections. IEEE Transactions on Intelligent Transportation Systems, 20, pp. 1390-1403.
[23] Akcelik, R., (1981). Traffic signals: capacity and timing analysis. ARRB Transport Research Ltd., Greythorn Victoria 3104, Australia.
[24] Wachs, M., Samuels, J. M., Skinner, R. E., (2000). Highway capacity manual. TRB Business Office, United States of America.
[25] Webster, F. V., (1958). Traffic signal settings. Road Research Technical Paper, Road Research Laboratory, Her Majesty Stationary Office, London, UK.
[26] Li, D., Wu, J., Xu, M., Wang, Z., Hu, K., (2020). Adaptive traffic signal control model on intersections based on deep reinforcement learning. Journal of Advanced Transportation, 2020, pp. 1-14, DOI: 10.1155/2020/6505893.
[27] Zeng, J., Hu, J., Zhang, Y., "Adaptive traffic signal control with deep recurrent Q-learning." pp. 1215-1220.
[28] Chang, Y. L., Zhou, Y. Y., "Research of signalized intersection delay model by using optimization method." pp. 2742-2746.
[29] Li, Z., Elefteriadou, L., Ranka, S., (2014). Signal control optimization for automated vehicles at isolated signalized intersections. Transportation Research Part C: Emerging Technologies, 49, pp. 1-18.
[30] R. Qian, Z. L., Y. Wenchen, and Z. Meng, (2013). A traffic emission saving signal timing model for urban isolated intersections. Procedia Socia Behavioral Sciences, 96, pp. 2404–2413.
[31] X. Li, Z. Z., L. Liu, Y. Liu, and P. Li, (2017). An optimization model of multi-intersection signal control for trunk road under collaborative information. J. Control Sci. Eng., 2017, pp. 1-11.