Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 187 (2017) 295 – 300

Procedia Engineering

www.elsevier.com/locate/procedia

10th International Scientific Conference Transbaltica 2017: Transportation Science and Technology

Optimization of Traffic Signal Timing at Oversaturated Intersections Using Elimination Pairing System

Ekinhan Eriskin, Sebnem Karahancer, Serdal Terzi*, Mehmet Saltan

Department of Civil Engineering, Engineering Faculty, Suleyman Demirel University, Turkey

Abstract

Many methods used for traffic signal timing are useless if the conditions in the intersection are oversaturated. With an increase in the number of vehicles, the saturation degree approaches or exceeds the limit value at intersections. This creates a scenario where many signal timing methods become overwhelmed. In this paper, the elimination pairing system – a new method for designing traffic signal timing at oversaturated intersections – is expressed. An object function with vehicle delay and stop-start numbers has been generated. Total cost value has been calculated according to the object function. Obtained results were compared with Webster as a traditional traffic signal timing design method and Transyt 14 signal timing software. While Webster gives exaggerated results, Transyt 14 and Elimination Pairing Systems provide better results. As a result of this study, the elimination pairing system could be used for optimizing the traffic signal timings.

Peer-review under responsibility of the organizing committee of the 10th International Scientific Conference Transbaltica 2017

Keywords: traffic signal timing, oversaturated intersectio, optimizatio, elimination pairing system, delay, cost

* Corresponding author.
E-mail address: serdalterzi@sdu.edu.tr

1877-7058
Peer-review under responsibility of the organizing committee of the 10th International Scientific Conference Transbaltica 2017
doi:10.1016/j.proeng.2017.04.378

1. Introduction

Intersections are junctions of two or more traffic flows. They have a very high importance because of the rate of accident occurrence. Therefore, the flowing pattern of traffic through them should be rightly organized to ensure a safe drive for road users. The organization of the traffic flows can be made using signalization.

Signalization is very useful for organizing the flow. However, a wrong set of signal timings could harm the flow. The green time for a phase of the cycle should be long enough to allow the accumulated queue and new oncoming traffic to pass. If the green time for the phase is longer, either the green timings for the other phases are shorter or the cycle time is greater than necessary. By shortening the green times, the accumulated queue wouldn't be discharged and by extending the cycle time, waiting times on the queue would be increased which increases travel time. As a result, setting a right signalization pattern is an optimization problem.

V/C ratio determines the traffic status at a signalized intersection. The status went oversaturated by approach with residual queue [1]. When the intersection achieves the oversaturation level, the flow becomes unstable. Even small instability from any car in a platoon may result in terrible consequences [2]. A condition of oversaturation may firstly appear in several isolated intersections. Then, it begins to spread to adjoining intersections. Therefore, it is important to optimize the traffic signal timings to avoid the oversaturation condition.

Current methods used for planning traffic signal timings are only useful for under saturated intersections. When the intersection becomes oversaturated, most of the methods give bad results. There are some studies for solving the traffic signal timings at oversaturated intersections [3–11].

In this paper, the elimination pairing system (EPS) is used for solving the green times for oversaturated intersection. An object function has been created according to the delay occurring in as intersection and stop – start numbers for the cars approaching the intersection. With these two input parameters, a performance index has been calculated and optimized. Then the results have been compared with Transyt 14 software and Webster method.

This paper starts with an introduction about signalized intersections and optimization of the green times followed by material and method where obtaining the objective function and the methodology used to optimize the traffic signal timing is explained. These sections are followed by a results and discussion and, at last, a conclusion.

2. Formulation

Traffic signal timing optimization is made using EPS. Experimental traffic volumes used by Li et al. [3] has been used (shown in Table 1). An object function from Table 1 is obtained with the arguments delay and stop-start numbers of the vehicles and cost parameter as value (Equation 1). The experimental intersection in their study was a four leg intersection where Northbound and Southbound legs had a width of 4.5 m and Eastbound and Westbound legs had a width of 6.6 m.

Table 1. Traffic volumes.

Movement	East	West	North	South
Left Turn	130	60	60	80
Through	1240	1400	740	1020
Right Turn	70	60	40	100

$$C(d,\Delta) = \sum d + \sum \Delta\,, \qquad (1)$$

where: (d, Δ) is the total cost value according to the delay and stop-start arguments ($); $\sum d$ is the total delay (pcu-hour/hour) and $\sum \Delta$ is the total stop-start number per hour. In order to optimize the traffic signal timings, the total cost value should be minimized.

Total delay is calculated by summing the delay occurring on each link of the intersection according to the Webster (1958) delay formula. Stop-start numbers for each link are calculated using Equation 2.

$$\Delta = \begin{cases} \varphi + Q_{clean} & \tau \leq g; \\ 2((\tau - g)\theta((3600/c) - 1) + \varphi) + (\varphi + (g * \theta)) * (3600/c) & \tau > g, \end{cases} \tag{2}$$

where: φ is the number of vehicles at the beginning of green time; Q_{clean} is the number of vehicles approaching the intersection during green time; τ is the time needed for cleaning up the queue; g is the green time; θ is the incoming flow rate; c is the cycle length. Using Equation 2, a calculation is made that all approaching vehicles are stopping one time when the queue clean up time is shorter than green time and all approaching vehicles are stopping two times when the queue clean up time is longer than green time. Other possibilities are neglected for the purposes of this study.

Calculated delay and stop-start number are converted to cost values by multiplying them with the corresponding unit cost.

3. Elimination Pairing System

Elimination Pairing System (EPS) is a pairing system used in tournaments to determine the best player or team. In an EPS, all players are lined up according to some criteria such as ranking, alphabetic order of name, etc. Then, the players get paired with another player. After the game ends, the winner is eligible for the next round. The loser of the game is eliminated from the tournament. This procedure continues until only one player remains. The number of rounds which should be played can be calculated using Equation 3:

$$\log_2(NP), \tag{3}$$

where NP is the number of players. The number of players should be rounded up to a power of two if this has not already been done. Fig. 1 shows an example of a tournament with eight players and three rounds.

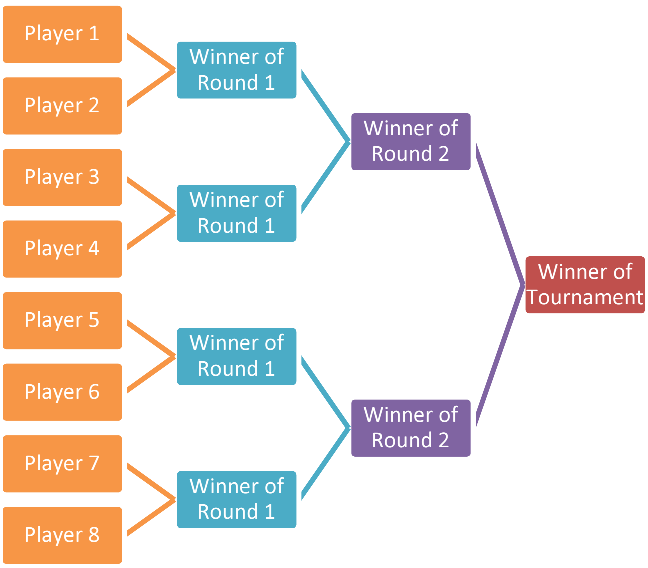

Fig. 1. Example of elimination pairing system.

In this study, a surface was created with obtained object function and limit values for the input parameters. The surface was split into 2n most similar areas. The center of gravity points for each area were determined and the cost value was calculated. Each center was paired randomly with another for ten rounds according to EPS. When the best value is obtained, the range between the limit values was shortened with a multiplier and the process was restarted until a predetermined loop number or the difference becomes smaller than the predetermined control value. For this process a matlab code was written and the algorithm for this code is as follows:

Step 1. Predetermine the max loop number, accepted difference value, min and max input values, α downsizing coefficient.

Step 2. Split the square formed between the input values into 2n most similar areas. The numbers which edge should be split into is calculated as follows:

$$No_{edge1} = \begin{cases} 2^{[(n/2)-0.5]} & n \text{ is odd;} \\ 2^{(n/2)} & n \text{ is even;} \end{cases} \quad No_{edge2} = \begin{cases} 2^{[(n/2)+0.5]} & n \text{ is odd;} \\ 2^{(n/2)} & n \text{ is even.} \end{cases} \tag{4}$$

Step 3. Calculate the coordinate for the center of gravity for every area. Calculate the cost value for every center of gravity point using the object function.

Step 4. Pair each cost value with another value and check which is better. Delete the worse one and then pair two values from the remaining values till only one value remains.

Step 5. Shorten the range between the input limit values by multiplying with α and repeat from Step 2 to Step 5 for predetermined loop number or until the difference between obtained values are smaller than the predetermined control value.

4. Results and discussion

Input parameters are selected as green time from phase one and the cycle time. The min and max values for the input parameters are as follow;

- $c \in R, \quad 20 \le c \le 150$;
- $g \in R, \quad 1 \le g \le (c - t_{all\ red})$.

Intersection delay and stop-start numbers of the vehicles at signalized intersections have been calculated and converted in cost values using obtained object function. The surface has been plotted and split into 210 most similar areas. Every area's center of gravity coordinates were obtained and the corresponding cost values was calculated (Fig. 2).

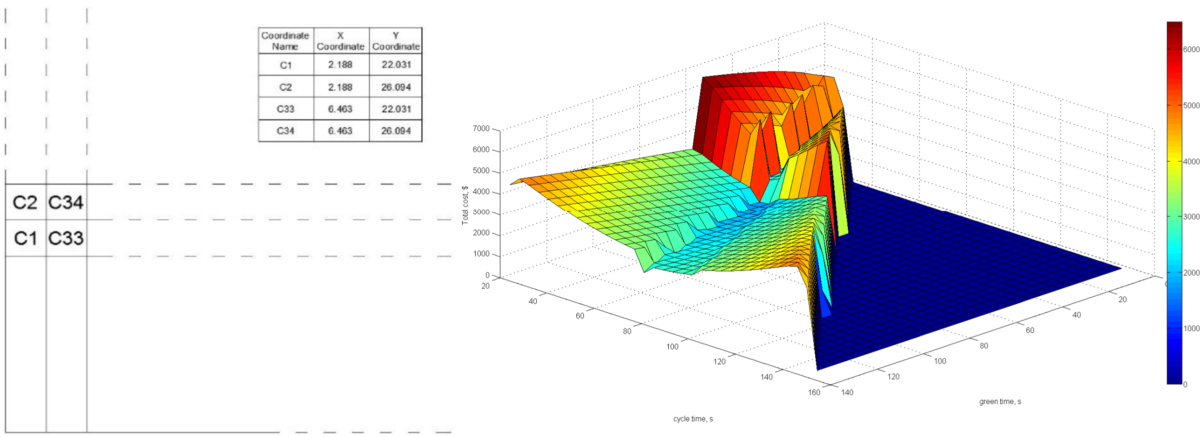

Fig. 2. Part of the split areas (left side), Cycle time and green time for phase one versus total cost (right side).

The EPS algorithm was stopped after five loops. The algorithm found that the best green time for phase one was 50 seconds and the corresponding cycle time was 119 seconds. Comparison of optimum cycle length and green time of phase one between Webster, Transyt 14 and EPS is seen in Table 2.

Table 2. Comparison of signal planning methods.

	Webster Method	Transyt 14	Elimination Pairing System
Critical flow for phase one	1565 pcu		
Critical flow for phase two	1260 pcu		
Sum of saturation degree	0.959722		
Calculated optimum cycle length	422 seconds	103 seconds	119 seconds
Green time for phase one	188 seconds	44 seconds	50 seconds
Green time for phase two	226 seconds	51 seconds	61 seconds

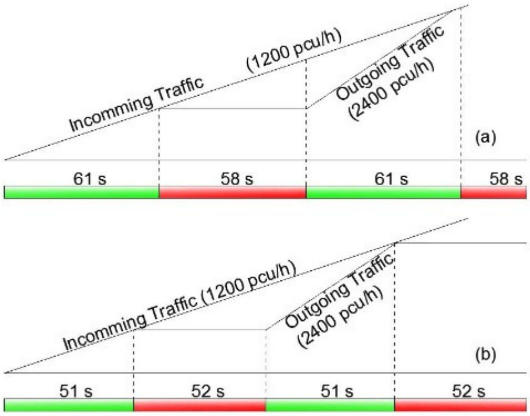

Fig. 3. Traffic signal timing calculated with elimination pairing system (a), Transyt 14 (b).

Table 2 presents the results from Webster on whether cycle length or green time are applicable at intersections. Green time and cycle length calculated with Transyt 14 and EPS are a more realistic solution than Webster. The difference between Transyt 14 and EPS is that EPS optimizes the cycle length and green time together; so, they work better together. The timing plan obtained from Transyt 14 works well except a queue penalty occurs on the southbound side of the intersection (Fig. 3). As seen in Fig. 3, the green time obtained from Transyt 14 is not long enough to clean the queue while the green time calculated with EPS is long enough to clean the queue.

5. Conclusions

In this paper, the Elimination Pairing System, one of tournament pairing systems, has been used to calculate optimum cycle length and green times. The conclusions can be drawn as follows:

- EPS is useful because it optimizes the cycle length and green time together, where most software or methods calculates them separately. This makes the cycle length and green time is more compatible.
- Using EPS shows the usability of pairing systems as optimization methods.
- Cost of occurring delay and vehicles fuel consumption by stop-start at intersections is a useful output value for traffic signal timing optimization.
- EPS could be easily used for the traffic professionals as traffic timing optimization.
- EPS can optimize the traffic signal timings at oversaturated intersections more realistically than the widely used Webster method.
- EPS optimizes the traffic signal plan in a way where there is not any queue penalty, if possible.

EPS as a tournament system gives good results for optimizing cycle and green times. Therefore, it can be expected that other tournament pairing system could be useful as an optimization technique. It is recommended that the other pairing systems should be studied as well.

References

[1] R. W. Denney, Head L., K. Spencer, Signal Timing under Saturated Conditions. Federal Highway Administration. Washington, DC. 2008

[2] F. Zheng, H. Van Zuylen, Uncertainty and Predictability of Urban Link Travel Time: Delay Distribution-Based Analysis. Transportation Research Record 2192 (2010) 136–146.

[3] Y. Li, L. Yu, S. Tao, and K. Chen, Multi-Objective Optimization of Traffic Signal for Oversaturated Intersection. Mathematical Problems in Engineering. 2013. doi:10.1155/2013/182643

[4] G. Abu-Lebdeh, R. F. Benekohal, Development of Traffic Control and Queue Management Procedures for Oversaturated Arterials. Transportation Research Record 1603 119–127.

[5] H. Ceylan, M. G. H. Bell, Traffic Signal Timing Optimization Based On Genetic Algorithm Approach, Including Drivers' Routing. Transportation Research Part B 36 (2004) 329–342.

[6] M. D. Foy, R. F. Benekohal, D. E. Goldberg, Signal Timing Determination Using Genetic Algorithms. Transportation Research Record 1365 (1992) 108–115.

[7] M. A. Hadi, C. E. Wallace, Hybrid Genetic Algorithm to Optimize Signal Phasing and Timing. Transportation Research Record 1421 104–112.

[8] H. Liu, K. N. Balke, W. Lin, A Reverse Causal-Effect Modeling Approach for Signal Control of an Oversaturated Intersection. Transportation Research Part C 16(6) (2008) 742–754.

[9] A. Stevanovic, J. Stevanovic, J. So, and M. Ostojic, Multi-Criteria Optimization of Traffic Signals: Mobility, Safety and Environment. Transportation Research Part C 55 (2015) 46–68.

[10] J. Stevanovic, A. Stevanovic, P. T. Martin, and T. Bauer, Stochastic Optimization of Traffic Control and Transit Priority Settings in VISSIM. Transportation Research Part C 16(3) (2008) 332–349.

[11] F. V. Webster, Traffic Signal Settings. Road Research Laboratory. 1958.