Dynamic Traffic Light Timing Control System using Fuzzy TOPSIS Algorithm

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Abstract. Intelligent Traffic Light System with Dynamic timing control employs sensor and algorithm that has been design to solve the original problem of ordinary traffic light which is applied static timing for vehicle traffic flow control. Therefore to build a dynamic traffic light timing control system an algorithm and a sensor is a must. In this paper we proposed a Fuzzy TOPSIS algorithm to be used for traffic light timing control system based on real time quantity vehicle and vehicle classification. Using Fuzzy TOPSIS algorithm we can sets priority vehicle based on its parameter (in this paper we set to vehicle length). We can determine that the trailer truck gets more prioritize based on its length, the second priority would be bus, and the third one was car. Also using its coefficient we found the timing for each vehicle. For every trailer truck the timing would be 2.771552 seconds, for every bus the timing would be 2.581965 seconds and for every car would be 1.862602 second.

1. Introduction
Traffic light system is one of technological development that aims to provide safety of the road user [1]. Road user can confidently place their safety to the traffic light signal that allowed them to cross, to turn left or right or even to go ahead. Unfortunately most traffic lights systems still use fixed-time setting for a very long cycle (see figure 1). These systems cannot dynamically adjust traffic light timing in response to unexpected situations such as traffic accidents, natural calamities, or sudden incidents [2]. Because of this static system it’s vulnerable to external disturbance such as interference and other [3].

Figure 1. Traffic light control with timer display system
An intelligent traffic light system has been introduced to overcome this problem. This system has the dynamic timing control system based on real time traffic road flow [4]. This system is design to analyze road dynamic situation and make the best decision. Some researchers are develop an intelligent traffic light system using traffic-light-to-vehicle communication (TLVC), that aims at increasing comfort and safety of the driving experience as well as reducing fuel consumption and emissions to mitigate the environmental impact [5]. Another researchers are using hardware such as IR and ultrasonic sensor [6], wireless communication [7], and microcontroller [8] to detect and compute amount of traffic. While others are developing special algorithm to tuning and optimize the traffic light timing [9]–[15]. Table 1 shows matrix related research.

| Publication | Research Focus                                                | Remark                                                                 |
|-------------|---------------------------------------------------------------|------------------------------------------------------------------------|
| J.D. Lacoste and T. Stutzle [8] | Tuning of a Stigmergy-based Traffic Light Controller as a Dynamic Optimization Problem | Using particle swarm to detect vehicle queue for timing control          |
| Z. Li et al [4] | Intelligent Traffic Light Control System Based on Real Time Traffic Flows | Using sensor and microcontroller to detect Real Time Traffic Flows |
| G. Lee et al [16] | Traffic Light Recognition Using Deep Neural Networks | Using Image Recognition to detect vehicle class                        |
| Hakim et al (this work) | Dynamic Traffic Light Timing Control System Based on Vehicle | Timing Control Algorithm complement for G. Lee Research |

A Fuzzy Logic controller has been introduce to solve many problem, such as behavior based problem [17] and others. In this paper we propose Fuzzy TOPSIS to be used as a traffic light dynamic timing control system algorithm. With Fuzzy TOPSIS algorithm, we analyze the timing that needed to empty the channel road based on vehicle classification (see figure 2). This research is a complement with research conducted by G. Lee [16] that can detect vehicle class using image recognition.

![Figure 2. Traffic light Crossroad with multiple vehicle class](image)

2. Fuzzy TOPSIS Algorithm

Fuzzy TOPSIS is general problem solver that mimic human understanding to determine which one that computer should chose if there are lot of alternative with multiple criteria. A traffic light timing based on vehicle classification is a problem that can be categorize as a Multiple Criteria Decision Making (MCDM), and one of algorithm that best to solve the problem would be Fuzzy TOPSIS.

A Fuzzy TOPSIS algorithm is a method based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution and also has the longest geometric distance from the negative ideal solution. Therefore this method is a compensatory
aggregation that compares a set of alternatives by identifying weights for each criterion, normalizing scores for each criterion and calculating the geometric distance between each alternative and the ideal alternative, which results are showing the best score in each criterion [18].

Matrix Decision
Matrix Decision is an input based on multiple alternatives with multiple attributes/parameter. In this paper we describe multiple roads act as multiple alternatives, it’s filled with multiple vehicle classification and multiple vehicle length that both serve as parameters.

Normalize Matrix Decision
To limit criterion between 0 ~ 1, the decision matrix need to be normalized. This also to ensure that we able to compare for each criteria we are using [19].

\[
r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}
\]

Where \(i=1,2,\ldots,m\) and \(j=1,2,\ldots,n\)

Normalize Matrix Decision Weight
The weight is an emphasis for criteria that have the biggest/most value for user/system. This weight can be derived from Shannon entropy theorem concept [20] or the weight can be based on user request [21]. For weight using Shannon entropy theorem concept were:

\[
NMw_j = \frac{w_{ij}}{\sum_{j=1}^{n} w_{ij}}
\]

Where \(j=1,2,\ldots,n\)

For Positive Ideal Solution
The Weight of the normalize matrix decision can be shown as a positive ideal solution as below

\[
A_b = \left\{ \left( \min(t_{ij} | i = 1,2,\ldots,m) \right) | j \in J^- \right\} \left\{ \max(t_{ij} | i = 1,2,\ldots,m) \right\} | j \in J^+ \}
\]

Where \(J^+ = \{ j=1,2,\ldots,n | j \} \) Associated with the criteria having a positive impact

For Negative Ideal Solution
The Weight of the normalize matrix decision can be shown as a negative ideal solution as below

\[
A_w = \left\{ \left( \max(t_{ij} | i = 1,2,\ldots,m) \right) | j \in J^- \right\} \left\{ \min(t_{ij} | i = 1,2,\ldots,m) \right\} | j \in J^+ \}
\]

Where \(J^- = \{ j=1,2,\ldots,n | j \} \) Associated with the criteria having a negative impact

Distance for Positive Ideal Solution
Using the best alternative, the distance between target alternative with the criteria having the most positive impact is shown below

\[
d_{ib} = \sqrt{\sum_{j=1}^{n}(t_{ij} - t_{bj})^2}
\]

Where, \(i = 1,2,\ldots,m\)

Distance for Negative Ideal Solution
Using the worst alternative, the distance between target alternative with the criteria having the most negative impact is shown below

\[
d_{iw} = \sqrt{\sum_{j=1}^{n}(t_{ij} - t_{wj})^2}
\]

Where, \(i = 1,2,\ldots,m\)
Closeness Coefficient
Using the worst alternative distance and the best alternative distance, closeness coefficient is calculated to shown the best of the alternatives performance as shown below:

\[ C_i^* = \frac{d_{iw}}{d_{iw} + d_{ib}}, \quad 0 \leq C_i^* \leq 1 \]  (7)

Where, \( i = 1, 2, \ldots, n \)

3. Research Method
To build a dynamic Timing system for a traffic light, there are 2 important component which is sensor to detect vehicle (in this case G. Lee) and the second one will be algorithm to compute total score for each road channel that contain multiple class vehicle. Based on that score each road channel can be determined its priority and using its score coefficient we can count how many seconds needed for each road channel.

3.1. Vehicle Classification as a MCDM Problem
Vehicle has been classified using its utility such as truck, car, and Bus [22], [23]. This problem has multiple classifications and each classification it has multiple parameter/criteria which is portrait of a MCDM problem. Therefore to solve this problem, Fuzzy TOPSIS is use in this paper to compute traffic light control timing based on vehicle classification. The output will indicate where bigger and weightier vehicle will get more priority and also get more time to go through crossroad.

3.2. Fuzzy TOPSIS Input
We simulate an intersection road which has 3 road channels, and each road has different vehicle classification such as bus, truck and car (See Figure 3). For first parameter in this simulation we define quantity road 1 has 1 car, for road 2 we have 1 bus, and also in road 3 we have 1 trailer truck. For each car, trucks, and buses, their first attributes/criteria/parameter would be vehicle classification. In Indonesia vehicle has been classified for 5 classification (4 wheel, another additional is for motor 2 wheel) [24], which is slightly different with America based on FWHA report [22]. For second attributes/criteria/parameter we define on a vehicle length. We are using vehicle datasheet for reference, for bus we are using hino bus which has 11.470 Meter [25], for car we are using common Indonesia MPV such as Toyota avanza MPV which has 4.190 Meter [26], and because variation of truck trailer, we set for maximum length according to FHWA, which is 14.63 Meter [27].

![Figure 3. 3 Ways Intersection Road](image)

3.3. Fuzzy TOPSIS Weight
In this paper, we would like to use weight based on vehicle classification and length. For vehicle classification parameter weight point will be 5 (based on 5 vehicle classification). For vehicle length parameter weight point will be 3 (based on 3 vehicles comparison).
3.4. **Traffic light Timing**

Timing for each vehicle will be taken from Fuzzy TOPSIS output, which is closeness coefficient. We also use maximum passengers comfortable acceleration threshold as other component \( a = 0.93 \) [28]. Therefore we derive the timing equation using acceleration describe above, total all vehicle length, and closeness coefficient. Using parameter above we define the timing for each road channel based on the derive equation below:

\[
T = \sqrt{\frac{1}{2} \left( \sum_{i=1}^{n} L_i \right) \cdot a \cdot cci}
\]

Where, \( i = 1,2,\ldots,n \)

4. **Simulation and Result**

Based on vehicle classification we have decision matrix at table 2.

| Road Channel | Vehicle Classification | Vehicle Length (L, meter) |
|--------------|------------------------|---------------------------|
| Road 1 Car   | 1                      | 4.16                      |
| Road 2 Bus   | 1                      | 11.47                     |
| Road 3 Trailer Truck | 5                  | 14.63                     |

Using equation 1 vehicle decision matrix normalization was given at table 3.

| Road Channel | Vehicle Classification | Vehicle Length (Meter) |
|--------------|------------------------|------------------------|
| Road 1 Car   | 0.192450               | 0.218372               |
| Road 2 Bus   | 0.192450               | 0.602099               |
| Road 3 Trailer Truck | 0.962250 | 0.767978               |

We applied the weight using vehicle classification and vehicle length to the vehicle decision matrix normalization. See at table 4.

| Road Channel | Vehicle Classification | Vehicle Length (Meter) |
|--------------|------------------------|------------------------|
| Road 1 Car   | 0.962250               | 0.655117               |
| Road 2 Bus   | 0.962250               | 1.806297               |
| Road 3 Trailer Truck | 4.811252 | 2.303934               |

Using weighted vehicle decision matrix normalization, for positive ideal solution would be

\[ y_1^+ = \text{Max} \{ 0.962250; 0.962250; 4.811252 \} = 4.811252 \]

\[ y_2^+ = \text{Min} \{ 0.655117; 1.806297; 2.303934 \} = 0.655117 \]

Therefore for positive ideal solution would be

\[ A^+ = \{ 4.811252; 0.655117 \} \]

Using weighted vehicle decision matrix normalization, for negative ideal solution would be

\[ y_1^- = \text{Min} \{ 0.962250; 0.962250; 4.811252 \} = 0.962250 \]

\[ y_2^- = \text{Max} \{ 0.655117; 1.806297; 2.303934 \} = 2.303934 \]

Therefore for negative ideal solution would be

\[ A^- = \{ 0.962250; 2.303934 \} \]
Using equation 5 distances with positive ideal solution become:

\[
d^- = \{4.16747, 3.02061, 4.85387\}
\]

Using equation 6 distances with negative ideal solution become:

\[
d^- = \{1.37639, 1.58510, 2.84372\}
\]

Using equation 7 closeness coefficient for each road channel become:

\[
CC = \{0.24827, 0.34415, 0.36942\}
\]

Using equation 8 we get total timing from acceleration derived from total vehicle length. We applied this to the closeness coefficient, therefore timing for each road would be:

Road 1 for 1 car timing would be 1.862602 second
Road 2 for 1 bus timing would be 2.581965 second
Road 3 for 1 trailer truck timing would be 2.771552 second

5. Conclusion

In this paper we propose Fuzzy TOPSIS algorithm to be applied at traffic light controller system to provide dynamic timing on the road. Using Fuzzy TOPSIS we can determine timing based on different vehicle classification, and length of the vehicle on the respective road. We can determine that the trailer truck gets more prioritize based on its length, the second priority would be bus, and the third one was car. Also using its coefficient we found the timing for each vehicle. For every trailer truck the timing would be 2.771552 second, for every bus the timing would be 2.581965 second and for every car the timing would be 1.862602 second.

References

[1] R. R. Gordon, W. Tighe, and I. Siemens, “Traffic control systems handbook,” U.S. Department of Transportation Management, Federal Highway Administration, 2005.
[2] Y. Chen, K. Chen, and P. Hsiung, “Dynamic Traffic Light Optimization and Control System using Model-Predictive Control Method,” in 19th International Conference on Intelligent Transportation Systems (ITSC), 2016, pp. 2366–2371.
[3] R. B. Bahaweres, F. Fikiansyah, and M. Alaydrus, “Analysis of Interference from Wireless Traffic Light Controller upon Remote Keyless Entry for Vehicles,” in 1st International Conference on Wireless and Telematics (ICWT), 2015.
[4] Z. Li, C. Li, Y. Zhang, and X. Hu, “Intelligent Traffic Light Control System Based on Real Time Traffic Flows,” in 14th IEEE Annual Consumer Communications & Networking Conference (CCNC) Intelligent, 2017, pp. 625–626.
[5] H. H. Tessa Tielert, Moritz Killat, “The Impact of Traffic-Light-to-Vehicle communication on fuel consumption and emissions,” in Internet of Things (IOT), 2010, pp. 1–8.
[6] B. Ilal Ghazal and K. Eikhatib, “Smart Traffic Light Control System,” in 2016 Third International Conference on Electrical, Electronics, Computer Engineering and their Applications (EECEA), 2016, pp. 140–145.
[7] N. Varga, L. Bokor, A. Takacs, J. Kovacs, and L. Virag, “An architecture proposal for V2X communication-centric traffic light controller systems,” in Proceedings of 2017 15th International Conference on ITS Telecommunications, ITST 2017, 2017, pp. 1–7.
[8] J. Dubois-Lacoste and T. Stutzle, “Tuning of a stigmergy-based traffic light controller as a dynamic optimization problem,” in 2017 IEEE Congress on Evolutionary Computation, CEC.
2017 - Proceedings, 2017, pp. 1–8.

[9] J. Pang, “Review of Microcontroller Based Intelligent Traffic Light Control,” in 12th International Conference and Expo on Emerging Technologies for a Smarter World (CEWIT), 2015, pp. 1–5.

[10] Z. Cao, S. Jiang, J. Zhang, and H. Guo, “A Unified Framework for Vehicle Rerouting and Traffic Light Control to Reduce Traffic Congestion,” IEEE Trans. Intell. Transp. Syst., vol. 1, pp. 1–16, 2016.

[11] R. Elchamaa, B. Dafflon, Y. Ouzzrout, and F. Gechter, “Agent Based Monitoring for Smart Cities: Application to Traffic Lights*,” in 10th International Conference on Software, Knowledge, Information Management & Applications (SKIMA), 2016.

[12] M. B. Younes, A. Boukerche, and A. Mammeri, “Context-Aware traffic light self-scheduling algorithm for intelligent transportation systems,” in IEEE Wireless Communications and Networking Conference, WCNC, 2016.

[13] O. Younis and N. Moayeri, “Cyber-physical systems: A framework for dynamic traffic light control at road intersections,” in 2016 IEEE Wireless Communications and Networking Conference, 2016, no. Wenc, pp. 1–6.

[14] K. Gao, Yicheng Zhang, A. Sadollah, and Rong Su, “Improved artificial bee colony algorithm for solving urban traffic light scheduling problem,” in 2017 IEEE Congress on Evolutionary Computation (CEC), 2017, pp. 395–402.

[15] K. Jintamuttha, B. Watanapa, and N. Charoenkitkarn, “Dynamic traffic light timing optimization model using bat algorithm,” 2016 2nd Int. Conf. Control Sci. Syst. Eng., pp. 181–185, 2016.

[16] G. Lee and B. K. Park, “Traffic Light Recognition Using Deep Neural Networks,” in IEEE International Conference on Consumer Electronics (ICCE), 2017, pp. 4–5.

[17] S. H. M. Amin and A. Adriansyah, “Particle Swarm Fuzzy Controller for Behavior-based Mobile Robot,” in 9th International Conference on Control, Automation, Robotics and Vision, 2006.

[18] M. Fedrizzi and A. Molinari, “A Multi-Expert Fuzzy TOPSIS-based Model for the Evaluation of e-Learning Paths,” 8th Conf. Eur. Soc. Fuzzy Log. Technol. EUSFLAT, no. Eusflat, pp. 554–558, 2013.

[19] T. Wang and H. Lee, “Expert Systems with Applications Developing a fuzzy TOPSIS approach based on subjective weights and objective weights,” Expert Syst. Appl., vol. 36, no. 5, pp. 8980–8985, 2009.

[20] F. Dammak, L. Baccour, and A. M. Alimi, “The Impact of Criterion Weights Techniques in TOPSIS Method of Multi-Criteria Decision Making in Crisp and Intuitionistic Fuzzy Domains,” in International Conference on Fuzzy Systems (FUZZ-IEEE), 2015, no. 9.

[21] C.-L. HWANG, Y.-J. LAI, and T.-Y. LIU, “A NEW APPROACH FOR MULTIPLE OBJECTIVE,” Comput. Ops Res. Vol. 20, vol. 20, no. 8, pp. 889–899, 1993.

[22] “MAG Internal Truck Travel Survey and Truck Model Development Study, FHWA Vehicle Classes With Definitions.” U.S. Department of Transportation Management, Federal Highway Administration, pp. 9–10.

[23] F. Sayyady, Y. Fathi, G. F. List, and J. R. Stone, “Locating Traffic Sensors on a Highway Network Models and Algorithms,” J. Transp. Res. Board 2339, no. 2339, pp. 30–38, 2013.

[24] “Hino Bus Product Specification,” Hino Indonesia, 2012.

[25] “Avanza Product Specification,” PT. Toyota Astra Motor, 2018.

[26] “FHWA Commercial Vehicle Size and Weight Program,” U.S. Department of Transportation Management, Federal Highway Administration, 2003.

[27] “AA Investigation of acceleration and jerk profiles of public transportation vehicles,” J. Dyn. Syst. Meas. Control, vol. 99, no. 2, pp. 76–84, 1977.