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Fuzzy Logic Model for Traffic Signal Intersection

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Abstract. We investigate the development of a fixed-time signal intersection optimization system using Fuzzy Logic. The conventional method utilizes the method of Indonesia Highway Capacity Manual (IHCM) model 1997 which is adopted from American version of the Highway Capacity Manual (HCM). The Fuzzy Logic potentially brings some efficiency in the optimization, through decreasing the length of the vehicle queue and therefore increasing the capacity of the traffic passing through the intersection. The main feature of the Fuzzy Logic system is that the analysis involves linguistic variables. Optimization of the signal intersection is obtained through a series of combinations of variable analysis of membership function calculations in the fuzzy inference engine. The model is verified with fuzzified data from the 2015 traffic research survey in Bandung. The final analysis shows that the number of vehicle queues decreases while the traffic passing through the intersection increases, therefore this Fuzzy Logic model is expected to contribute and to give alternative handling for optimum intersection with a fixed-time signal.

Keywords: Fuzzy Logic, signal intersection, vehicle queue

INTRODUCTION

Traffic control with signal lights is critical to controlling traffic flow at intersections, especially for the purpose of reducing the number of vehicles queueing at each approach, and preventing vehicle accidents. Traffic signal systems at intersections are the most effective tools of traffic management to control the volume of traffic on each approach.¹⁻³ The system measures the performance of a signal intersection based on IHCM, so as to avoid a congested intersection yielding conflicts from opposing traffic flows; to maintain the intersection capacity as efficiently as possible.⁴ At the same time it is expected that the system should not cause long queues. The system also provides benefit to riders and pedestrian as well, in term of the clarity of the rules. Traffic signal phase operation contributes significantly to reducing conflicts at intersections, as well as ensuring a smooth traffic flow, from/to any direction ⁴. Even in a non-peak hour, the system is still essential. A non-peak hour potentially invites drivers to violate traffic signals, in turn the violation provokes a queue, which reduces the intersection capacity.

Analysis of the isolated intersection traffic control can be done by several methods, for example the method of Humberger and Kell to analyze cycle time, the Webster method to search for the optimum cycle and minimum delay, and the Pignataro method, which uses Peak Hour Factor (PHF) and headway.⁵ This traffic control involving a fuzzy logic model uses the input variables used in traditional control systems, but expressed in “fuzzy states” of linguistic states, e.g., low, moderate, high.³ The system is coupled with a fuzzy inference engine. As interface, the system requires fuzzification of the data, and defuzzification of the output to get an executable instruction. Abbas et al used fuzzy theory to control additional green time based on the flow of priority vehicles (ambulance, police, fire truck). They also discussed green time extension for public vehicles.⁶
The Minimum-And fuzzy logic model is used in for controlling traffic. In this article we utilize an equivalent system, Max-Or Methods, through the De Morgan Rule, which is supported by fuzzy language theory and fuzzy sets.\textsuperscript{1,2} The objective of the optimization of traffic signal intersections is to maintain normal traffic flow, under the assumption of a non-peak hour. The performance of the proposed fuzzy method will be compared to conventional methods.

**EXPERIMENT**

The data was gathered in the period April–May 2015 by taking the field data at the isolated signal intersection Pasteur Street – Pasirkaliki Street located in the city of Bandung.

**Sample and Intersection Criteria**

Sampling data is obtained by direct survey in situ: measuring, enumeration and direct observation in field. Data taken includes geometric data of the intersection, condition of the road markings, intersection approach and legs; whereas traffic data includes vehicle flow, number of vehicle queues, duration of signal time, number of vehicle violations in Motorcycles Stop Rooms (MSR). The samples were selected using two-stage cluster sampling of the available population, especially the intersections in Bandung with an isolated signal. The process of sampling based on two stage cluster sampling were done through the following stages. The first stage is choosing the model of an intersection with a fixed time signal in the city of Bandung, there are 61 such intersections in all. The second stage is taking the intersections with a leg intersection, MSR, zebra cross and isolated signal system. We selected four intersections which satisfy the aforementioned conditions: those are Pasteur-Pasirkaliki, Cibaduyut-Soekarno Hatta, Kiaracondong-Soekarno Hatta, and Gedebage-Soekarno Hatta.

**Experimental Design**

There are three variables used in this experiment: flow, queue, and MSR. The values of these variables were obtained through a survey during non-peak hour conditions. The experimental variables are divided into two categories, namely the numerical variables, such as traffic flow and the number of queued vehicles. Here the linguistic variable includes the number of vehicles making violations in the MSR. The optimized intersection optimization method used a Fuzzy Logic System model, while the design process follows the flowchart.

![Fuzzy Logic Design](image_url)

**FIGURE 1. Fuzzy Logic Design**

Based on data we determine fuzzy sets representing them, specifically we choose 8 triangular membership functions as follows,
A(\(a, m, b\)) = \begin{cases} 
0, & \text{if } x \leq a \\
\frac{x-a}{m-a}, & \text{if } x \in [a, m] \\
\frac{b-x}{b-m}, & \text{if } x \in [m, b] \\
0, & \text{if } x \leq b,
\end{cases} \tag{1}

where: \(a < m < b\), \(x = \) data input, \(a = \) lower bound, \(b = \) upper bound; \(m = \) middle top; \(A(x) = \) degree of membership, written as

\[ A(x, a, m, b) = \max\{\min\left[\frac{x-a}{m-a}, \frac{b-x}{b-m}\right] \} \tag{2} \]

Fuzzy Inference uses max-or percentage with the union "U" notation. This is a combining process of each fuzzy inference \(I_k\) by finding the maximum value of \(I_k\). The number of fuzzy numbers configured in the inference is \(2^n\), where \(n = \) number of variables\(^8\). In fuzzy inference, union and intersection ("or" and "and") are defined by

\[ f \wedge g := \min\{f, g\}, f \vee g := \max\{f, g\}, \tag{3} \]

where \(f, g\) are fuzzy sets, or, more specifically, our fuzzy triangular (membership) functions.

The fuzzy logic model with Center of Average (COA) formula according to Shipa Mehta\(^7\), is defuzzification so that the center of average for each of the intersections is isolated. It is expressed by

\[ COA = \frac{\sum_{k=1}^{n} b_k \times I_k}{\sum_{k=1}^{n} I_k}. \tag{4} \]

**Measured Parameters**

Measurement of variable parameters was implemented for non-peak hours. Input included the behaviour of the traffic in a traffic violation, such as a stop in Special Motorcycles Stop Rooms (MSR), were observed at each intersection, being measured in the morning, afternoon, and in the evening. Intersection conditions, e.g., flow pattern and driving behavior, may vary according to the hour of the day. Parameter values were adjusted based on geometric measurements and traffic flows of the intersection. The geometric indicators of an intersection are the width of the lane, the legs of the intersection, including the road markings such as zebra cross, stop line and MSR. Furthermore, traffic is categorized based on vehicle type, the pattern of movement, and number of vehicles flowing. In this particular study, we observed three parameters, namely the amount of traffic flow, the number of vehicles queuing, and the number of cars stopped in the Motorcycles Stop Rooms (MSR).

**Data Analysis**

Data obtained from the experiment, upon fuzzification, is fed into Microsoft Excel, based on formula (2) above.

**RESULT AND DISCUSSIONS**

We have analyzed the three variables (traffic flow volume, length of queues of vehicles from each approach, and the number of vehicles violating the MSR. The result of the intersection survey Pasteur-Pasirkaliki can be seen in (Table 1).
The relevant variables were calculated using the conventional methods in the *Indonesia Highway Capacity Manual*, so as to know the predicted value of green time on each of the intersection approaches, with the following formula: \[ g_i = (c \cdot LT) \times \left( \frac{\sum FR \cdot crit}{(\sum FR) \cdot crit} \right) \] where \( c \) = cycle time, \( FR \) = Flow Ratio, \( LT \) = Loss Time Intersection. Furthermore, for the analysis of the form and generating linguistic variables, the fuzzy logic model was used, with the stages of its process: fuzzifier, fuzzy inference, rule base, defuzzifier and center of average. The variable output of the membership function in the fuzzifier process results the green time, and then plotted in the form of the fuzzy curve seen in (Fig. 2). The fuzzy inference value results from the formula \[ Fl = \max \{Vi\} \] where \( Fl \) = fuzzy set, \( i = 1,2, ..., 6 \) intrusion Kandel. The maximum-or combination arrangement is the number of membership functions raised by the number of variables: the results can be seen in (Table 2). Overall the analysis for all intersection approaches, based on the comparison with the results for “existing” conditions, the “conventional” model, and the “Fuzzy” model, can be seen in (Table 3).
### TABLE 3. Recapitulation of comparison of existing values and conventional model with fuzzy logic model

<table>
<thead>
<tr>
<th>Approach</th>
<th>Method</th>
<th>Queue pcu/g.h</th>
<th>MSR pcu/green.h</th>
<th>Flow pcu/green.h</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>NORTH</td>
<td>Existing</td>
<td>39</td>
<td>15</td>
<td>1502</td>
<td>pass 9 pcu/green.hour</td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>35</td>
<td>15</td>
<td>1012</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fuzzy</td>
<td>30</td>
<td>6</td>
<td>2313</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Existing</td>
<td>37</td>
<td>7</td>
<td>1372</td>
<td></td>
</tr>
<tr>
<td>SOUTH</td>
<td>Conventional</td>
<td>34</td>
<td>7</td>
<td>2176</td>
<td>pass 20 pcu/green.hour</td>
</tr>
<tr>
<td></td>
<td>Fuzzy</td>
<td>17</td>
<td>0</td>
<td>2127</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Existing</td>
<td>33</td>
<td>6</td>
<td>2114</td>
<td></td>
</tr>
<tr>
<td>EAST</td>
<td>Conventional</td>
<td>26</td>
<td>6</td>
<td>1520</td>
<td>pass 10 pcu/green.hour</td>
</tr>
<tr>
<td></td>
<td>Fuzzy</td>
<td>13</td>
<td>0</td>
<td>3277</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Existing</td>
<td>41</td>
<td>12</td>
<td>1640</td>
<td></td>
</tr>
<tr>
<td>WEST</td>
<td>Conventional</td>
<td>23</td>
<td>12</td>
<td>909</td>
<td>pass 5 pcu/green.hour</td>
</tr>
<tr>
<td></td>
<td>Fuzzy</td>
<td>36</td>
<td>7</td>
<td>2526</td>
<td></td>
</tr>
</tbody>
</table>

The final stage of the fuzzy process is the defuzzifier, which is the average value of each green time on each intersection approach, as the final result is calculated through the Center of Average formula instruction Abbas at al. 6 see Tables 4 and 5, as per the graph according to (Fig.3).

### TABLE 4. Additional percentage of green fuzzy model analysis

<table>
<thead>
<tr>
<th>Approach</th>
<th>Add Green From Existing (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>53</td>
</tr>
<tr>
<td>South</td>
<td>55</td>
</tr>
<tr>
<td>East</td>
<td>55</td>
</tr>
<tr>
<td>West</td>
<td>54</td>
</tr>
</tbody>
</table>

### TABLE 5. Recapitulation of green signal setting “existing” and “conventional model” with “fuzzy logic model”

<table>
<thead>
<tr>
<th>Approach</th>
<th>Variable</th>
<th>Existing (second)</th>
<th>Conventional (second)</th>
<th>Fuzzy Logic (second)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>Queue</td>
<td>85</td>
<td>191</td>
<td>132</td>
</tr>
<tr>
<td>South</td>
<td>Queue</td>
<td>178</td>
<td>200</td>
<td>279</td>
</tr>
<tr>
<td>East</td>
<td>Queue</td>
<td>95</td>
<td>69</td>
<td>148</td>
</tr>
<tr>
<td>West</td>
<td>Queue</td>
<td>51</td>
<td>86</td>
<td>80</td>
</tr>
</tbody>
</table>
CONCLUSION

The results of the analysis show that overall there is a significant increase in the performance of the intersection in terms of the values of the various variable, especially in the duration of the green time. The result indicates that the fuzzy model provides an improvement of performance at the signal intersection based on the increase in the green time. This improvement is achieved by increasing the average green time signal for each approach by 54%, so that there was a reduction in the number of vehicles queuing up and an increase in the traffic capacity of the intersection.

ACKNOWLEDGMENTS

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