Summary

Intelligent control in road traffic intersections can be an alternative to a conventional control where duration of each signal phase is predetermined. In this article fuzzy logic approach for traffic signals control is considered and applied for an isolated intersection. Number of vehicles in each lane is measured with loop detectors. At the end of each phase these numbers are used as inputs to fuzzy controller. Fuzzy controller calculates the next signal phase duration. A case study conducted on a typical traffic density in an isolated intersection shows significant improvements in traffic flow, decreasing the total waiting time of vehicles.

1. INTRODUCTION

Fast increase in the number of vehicles in cities causes difficulties in road transportation. Problems are manifested in increase of traffic density, low travel speed and traffic jams, to name a few. Road intersections are main bottlenecks. Traffic control in most signalized traffic intersections is done with pre-timed signal. Pre-timed control is based on preset signal timings and is, therefore, non-responsive to real-time fluctuations in traffic demand. When road reconstruction is limited with existing urban plans or high investment costs, traffic flow can be improved even with low expenses using intelligent methods such as fuzzy logic for traffic light control [1]. Fuzzy logic can be used to adapt phase duration to real-time traffic demands. This approach reduces total waiting time, improving traffic flow compared to predetermined phase duration [2]. This paper presents the design and evaluation of a fuzzy logic traffic signal controller for a signalized isolated T-type intersection.

2. FUZZY APPROACH TO TRAFFIC SIGNALISATION CONTROL

In this section a case study of a T-type isolated intersection with improved signal phases proposal will be presented. A fuzzy controller that optimise signal phase duration will be introduced. Finally the proposed solution will be tested and performance results given.

Fig. 1. Plan of T-type intersection.

Fig. 2. Directions of movements.
The first letter of symbols in figure 2 indicates approach (approaches A, C, D). Second letter indicates direction of movement; S – straight, L – left turn, R – right turn, P – pedestrian crossing. Number in brackets is a numeric symbol for corresponding traffic light, also shown in figure 1.

Number of vehicles in each lane is measured with loop detectors. A typical weekday traffic intensity is shown in figure 3. Number of vehicles in each lane is counted in discrete time blocks of 90 seconds from 6:30 am till 6:45 pm. Existing traffic regulation is done in three-phase cycles (figure 4).

All traffic light durations are predetermined as constants (table 1). Second column represents time at which a change occurs, measured from the cycle beginning. Total cycle time is 90 seconds. Predetermined light duration is insensitive to daytime traffic fluctuations, unable to respond to real time traffic demands, thus is ineffective, producing drivers’ time waste. Introducing variable phase durations is expected to save total vehicles’ waiting time.

### Table 1. Traffic light status during one cycle.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Change time (s)</th>
<th>Light No.</th>
<th>Lane</th>
<th>New status</th>
<th>Duration (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>4, 5</td>
<td>CR, DL</td>
<td>G</td>
<td>$\Delta t_{PD,4} = 29$</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
<td>AP</td>
<td>G</td>
<td>$\Delta t_{PD,1} = 17$</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>1</td>
<td>AP</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4, 5</td>
<td>CR, DL</td>
<td>R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>37</td>
<td>6</td>
<td>CP</td>
<td>G</td>
<td>$\Delta t_{PD,6} = 8$</td>
</tr>
<tr>
<td></td>
<td>37</td>
<td>3, 9</td>
<td>AL, DR</td>
<td>G</td>
<td>$\Delta t_{PD,3} = 15$</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>6</td>
<td>CP</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td></td>
<td>52</td>
<td>3, 9</td>
<td>AL, DR</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td></td>
<td>56</td>
<td>7</td>
<td>AS</td>
<td>G</td>
<td>$\Delta t_{PD,7} = 30$</td>
</tr>
<tr>
<td></td>
<td>61</td>
<td>2</td>
<td>CS</td>
<td>G</td>
<td>$\Delta t_{PD,2} = 25$</td>
</tr>
<tr>
<td></td>
<td>61</td>
<td>8</td>
<td>DP</td>
<td>G</td>
<td>$\Delta t_{PD,8} = 25$</td>
</tr>
<tr>
<td></td>
<td>86</td>
<td>7, 2, 8</td>
<td>AS, CS, DP</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>1 new cycle</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 2.2. Signal phases proposal

If the surrounding area of the intersection is not dense populated, as in this case study, then the possibility of pedestrian crossing not being used in each cycle is evident. In this case a pedestrian safety time, i.e. the time between turning lights red in one phase till turning lights green in the next phase, is additional time waste. In order to avoid this unnecessary time waste, a new, modified phase diagram is proposed (figure 5). Presence of pedestrian is detected by installing push button at each pedestrian crossing. If there are no pedestrians than cycle consists of phases $Phase_{NP1}$, $Phase_{NP2}$, $Phase_{NP3}$ circling. If a pedestrian, on e.g. pedestrian crossing CP, presses button than $Phase_{NP2}$ is being replaced with $Phase_{PP2}$ etc.
Diagram of time sequences is clearly shown in figure 6 where thick black lines represent green light. Time $t_S$ is safety time, set to 5 seconds. Notice that if there are no pedestrians on intersection, vehicles from $AS$ and $DR$ lanes have green light throughout whole cycle because their paths do not interfere with other paths. Times $\Delta t_{PP,4}$, $\Delta t_{PP,3}$, $\Delta t_{PP,2}$, $\Delta t_{NP,4}$, $\Delta t_{NP,3}$ and $\Delta t_{NP,2}$ are adjusted with fuzzy controller in real time and all other times are dependent on the former six, according to (1).

\[
\begin{align*}
\Delta t_{PP,5} &= \Delta t_{PP,4} + \Delta t_{NP,5}, \\
\Delta t_{PP,1} &= \Delta t_{PP,4} - 10 \text{ [s]}, \\
\Delta t_{PP,6} &= \Delta t_{PP,3} - 10 \text{ [s]}, \\
\Delta t_{PP,8} &= \Delta t_{PP,2} - 8 \text{ [s]}, \\
\Delta t_{PP,7} &= \Delta t_{PP,2} + 5 \text{ [s]}. 
\end{align*}
\]

2.3. Fuzzy controller

Fuzzy controller in figure 7 is constructed in order to calculate duration of phases using real time traffic situation.

Six inputs are number of vehicles in each lane ($NoV_{AS}$, $NoV_{DL}$, $NoV_{CR}$, $NoV_{CS}$, $NoV_{DA}$ and $NoV_{DL}$) that are acquired with loop detectors. Each of them is represented with three membership functions corresponding to human perceptive linguistic terms low traffic intensity, traffic middle density and traffic very intensive, figure 8. Three additional inputs are binary YES/NO functions that indicate presence of pedestrians on one of the three pedestrian crossings. Inputs $NoVs$ are further processed through fuzzy controller rules and finally defuzzified resulting with duration of green light for the forthcoming phase. Binary pedestrian functions are used to select one of the two defuzzification models NP (no pedestrian) or PP (pedestrian present), figure 9.

In table 2 rules for $\Delta t_4$ are given. Rules for $\Delta t_5$ and $\Delta t_2$ are made likewise. All other times are calculated according to (1). Note that fuzzy controller is constructed that $\Delta t_4$, which is basically the same as $\Delta t_5$, depends only on number of vehicles in lanes $DL$ and $CR$. The output surface of $\Delta t_{NP,4}$ as a function of $NoV_{CR}$ and $NoV_{DL}$ can be seen on figure 10.

<table>
<thead>
<tr>
<th>Table 2. Fuzzy rules for inputs $NoV_{CR}$ and $NoV_{DL}$.</th>
</tr>
</thead>
<tbody>
<tr>
<td>If push button $AP$ is pressed and $NoV_{CR}$ is Intensive or</td>
</tr>
<tr>
<td>if there are no pedestrians on $AP$ and $NoV_{CR}$ is NOT Intensive and $NoV_{DL}$ is Intensive then use defuzz model PP and $M_{PP,18}$ and $M_{PP,18}$</td>
</tr>
<tr>
<td>$NoV_{DL}$ is Low and $M_{PP,18}$ Middle Green</td>
</tr>
<tr>
<td>Intensive</td>
</tr>
<tr>
<td>$NoV_{DL}$ is Low and $M_{NP,18}$ Middle Green</td>
</tr>
<tr>
<td>$NoV_{DL}$ is Low and $M_{NP,18}$ Middle Green</td>
</tr>
<tr>
<td>Intensive</td>
</tr>
<tr>
<td>$NoV_{DL}$ is Low and $M_{NP,18}$ Short Green</td>
</tr>
</tbody>
</table>
2.4. Performance results

Vehicles’ waiting time at intersection is selected to be the criterion for performance measurement. Waiting time of a single vehicle \( t_w \) is basically the time from it’s arrival to the intersection till the beginning of the green light phase for the vehicle’s lane. If arriving vehicle has green light, then waiting time equals to zero. It is defined with (2):

\[
t_w(l,k,m) = \begin{cases} 
  t_{pha}(l,k) - t_a(l,k,m), & \text{for } t_{pha} > t_a \\
  0, & \text{for } t_{pha} \leq t_a
\end{cases}
\]

where:
- \( l \) – stands for lane, one of AS, AL, CS, CR, DL, DR.
- \( k \) – ordinal number of cycle.
- \( m \) – ordinal number of a single vehicle waiting in line during a particular cycle.
- \( t_{pha}(l,k) \) – beginning time of phase that has green light for vehicles in line \( l \), during cycle \( k \).
- \( t_a(l,k,m) \) – vehicle’s arrival time at the intersection.

Three phase/cycle duration models, labeled with \( n \), will be tested and compared, namely:
- \( n = PD \) – predetermined phase/cycle duration, i.e. the existing traffic light control shown in table 1.
- \( n = PP \) – model with fuzzy controller and push buttons, a worst case scenario, when pedestrians are present at each pedestrian crossing, at each cycle.
- \( n = NP \) – model with fuzzy controller and push buttons, the best case scenario, when there are no pedestrians at intersection.

When all vehicles’ waiting times during one cycle \( k \) are summed, as in (3), a cycle waiting time \( t_w^{(n)}(k) \) is acquired.

\[
t_w^{(n)}(k) = \sum_{l} \sum_{m} t_w(l,k,m)
\]

Performance of three models can be compared in diagram 11. Each curve in diagram 11 consists of cycle waiting times during one day (from 6:30 am till 6:45 pm) over the data for traffic intensity in figure 3. Fuzzy models show significant improvement in decreasing drivers’ waiting time.

One should have in mind that \( t_w^{(PP)}(k) \) and \( t_w^{(NP)}(k) \) curves consist of more dots then \( t_w^{(PD)}(k) \) because their cycle times are somewhat shorter while cycle times of \( PD \) are constant and equal to 90 s. This doesn’t degenerate fuzzy models which is verified by the following figures for total waiting time. If all waiting times are summed over the data in diagram 11, a total daily waiting time for each model is given in (4).

\[
t_{w_{TOTAL}}^{(n)} = \sum_{k} t_w^{(n)}(k) = \begin{cases} 
  50 h, 48 min, & \text{for } n = PD \\
  38 h, 45 min, & \text{for } n = PP \\
  18 h, 38 min, & \text{for } n = NP
\end{cases}
\]

Note that for a normal case scenario of pedestrian presence at intersection, total waiting time would be somewhere between 19 and 38 hours what makes improvement from 24% up to 63% compared to the existing model.

3. CONCLUSION

Real time fuzzy logic controller for traffic lights signal durations in combination with optimized phase diagram is an alternative to a classical fixed phase duration. Improvements are significant in saving drivers’ waiting time. Performance results indicate up to 63 % decrease of total idle time for a typical daily traffic flow.

4. REFERENCES