FUZZY LOGIC APPROACH FOR TRAFFIC SIGNALS CONTROL OF AN ISOLATED INTERSECTION

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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 pre-set 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.

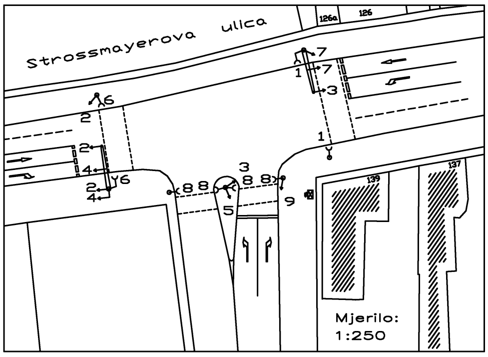

Fig. 1. Plan of T-type intersection.

2.1. Isolated intersection, a case study

Fuzzy method will be tested on an intersection shown in figure 1. It is an existing intersection of streets Strossmayerova and Kanizliceva in Osijek, Croatia [3]. Each approach has two lanes. Each lane enables only one direction of movement. All directions of movements are shown in figure 2.

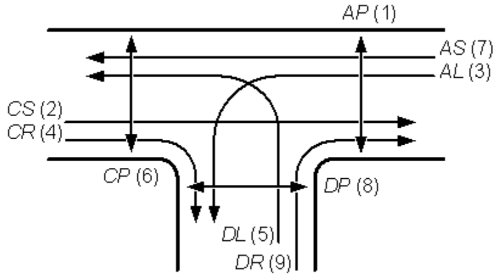

Fig. 2. Directions of movements.

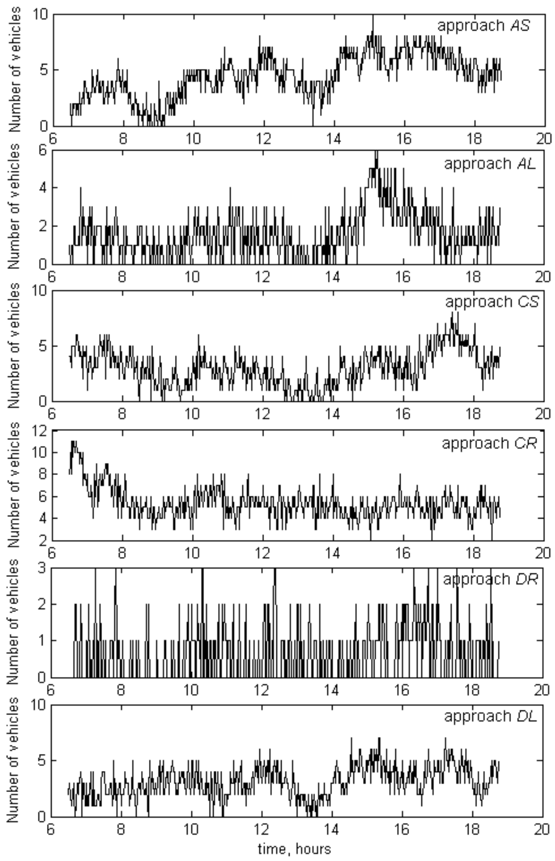

Fig. 3. Typical weekday traffic intensity.

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).

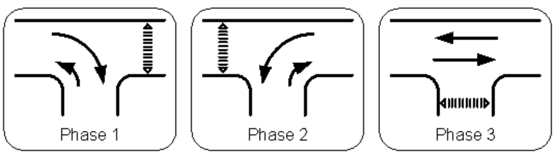

Fig. 4. Three-phase cycle diagram.

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.

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

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.

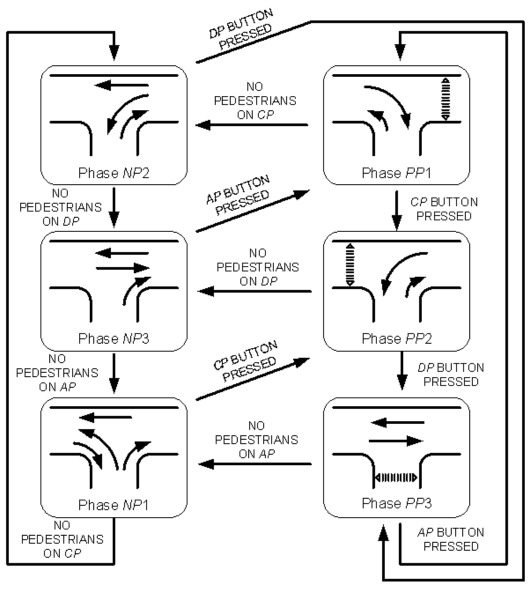

Fig. 5. Phase diagram with pedestrian push button.

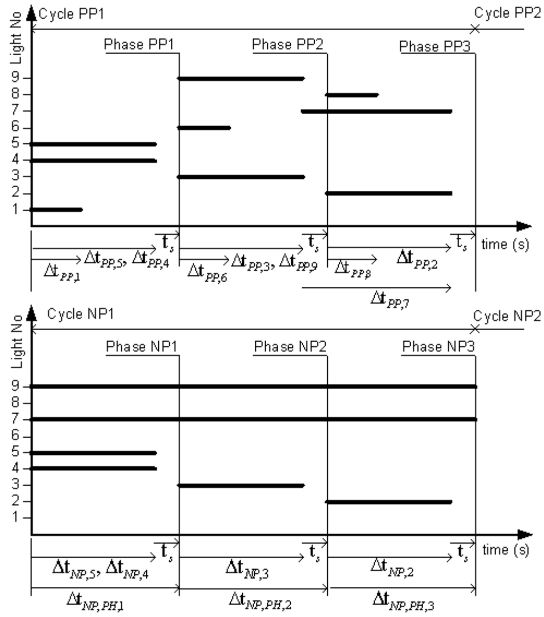

Fig. 6. Diagram of time sequences.

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 dependant to the former six, according to (1).

$$\begin{aligned}
&\Delta t_{PP,5} = \Delta t_{PP,4} \ , \quad \Delta t_{NP,5} = \Delta t_{NP,4}, \\
&\Delta t_{PP,1} = \Delta t_{PP,4} - 10 \quad [s], \\
&\Delta t_{PP,6} = \Delta t_{PP,3} - 10 \quad [s], \\
&\Delta t_{PP,8} = \Delta t_{PP,2} - 8 \quad [s], \\
&\Delta t_{PP,7} = \Delta t_{PP,2} + 5 \quad [s].
\end{aligned} \tag{1}$$

2.3. Fuzzy controller

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

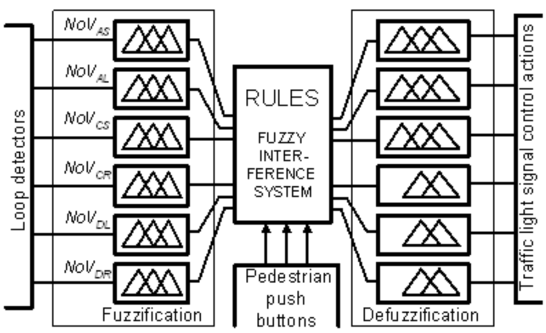

Fig. 7. Fuzzy logic controller block diagram.

Six inputs are number of vehicles in each lane (NoV_{AS}, NoV_{AL}, NoV_{CR}, NoV_{CS}, NoV_{DR} 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 *NoV*s 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.

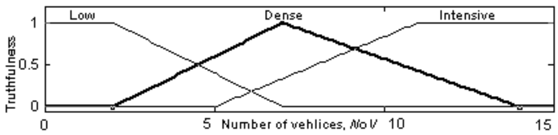

Fig. 8. Input variables' membership functions.

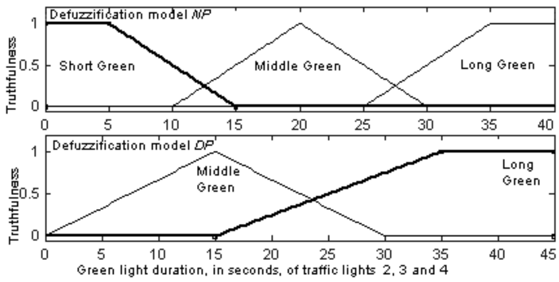

Fig. 9. Output variables' membership functions.

In table 2 rules for Δt_4 are given. Rules for Δt_3 and Δt_2 are made likewise. All other times are calculated according to (1). Note that fuzzy controller is constructed that Δt_4, which is basically the same as Δt_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. 2. Fuzzy rules for inputs NoV_{CR} and NoV_{DL}.

If push button AP is pressed and NoV_{CR} is	Intensive	or	NoV_{DL} is	Intensive	then use defuzz. model PP and $\Delta t_{PP,4}$ is	Long Green
	Low	and		Low		Middle Green
	Low			Dense		Middle Green
	Dense			Low		Middle Green
	Dense			Dense		Middle Green
If there are no pedestrians on AP and NoV_{CR} is	Intensive	or		Intensive	then use defuzz. model NP and $\Delta t_{NP,4}$ is	Long Green
	Dense	and		NOT Intensive		Middle Green
	NOT Intensive			Dense		Middle Green
	Low			Low		Short Green

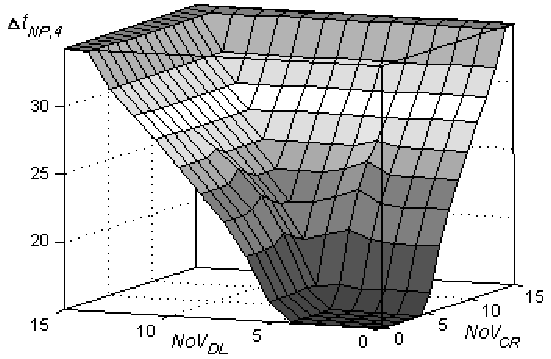

Fig. 10. Output surface $\Delta t_{NP,4} = f(NoV_{CR}, NoV_{DL})$.

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):

$$t_W(l,k,m) = \begin{cases} t_{PhB}(l,k) - t_a(l,k,m), & for\ t_{PhB} > t_a \\ 0, & for\ t_{PhB} \le t_a \end{cases} \quad (2)$$

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.

$t_{PhB}(l,k)$ – 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.

$$t_W^{(n)}(k) = \sum_l \sum_m t_W^{(n)}(l,k,m) \quad (3)$$

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.

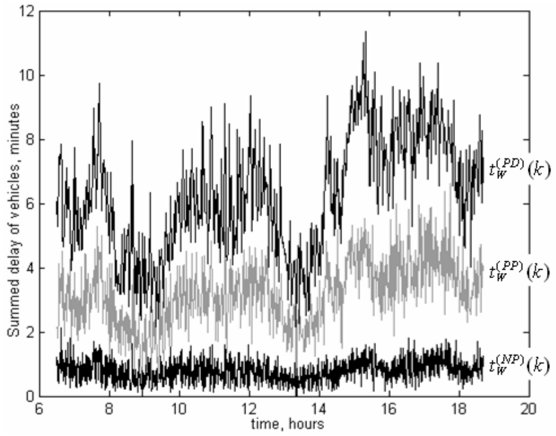

Fig. 11. Cycle waiting time.

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).

$$t_{W,TOTAL}^{(n)} = \sum_k t_W^{(n)}(k) = \begin{cases} 50\,h, 48\min, & for\, n = PD \\ 38\ h, 45\min, & for\, n = PP \\ 18\,h, 38\min, & for\, n = NP \end{cases} \quad (4)$$

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

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