Fuzzy Control of Traffic Junctions in Undersaturated Urban Networks

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***Abstract*—the paper describes the design and implementation of a fuzzy controller for traffic network management in urban areas. the controller uses expert knowledge for the derivation of its fuzzy rules. the proposed controller is simulated and compared to a conventional proportional controller by means of the software platform for traffic management Aimsun.**

***Keywords*—traffic light management, fuzzy controller, proportional controller, traffic network crossroads, microsimulation**

I. INTRODUCTION

An approach to control traffic in network of crossroads in urban environment is by traffic lights. There are studies locally (Pavlova et. al., 2017; Trichkova–Kashamova, 2021) as well as worldwide (Murat and Gedizlioglu 2005; Lu et. al., 2018) that consider various logic as well as fuzzy logic for the purpose of managing traffic light settings.

The general structure of the designed light control system for the traffic junction is shown in Figure 1.

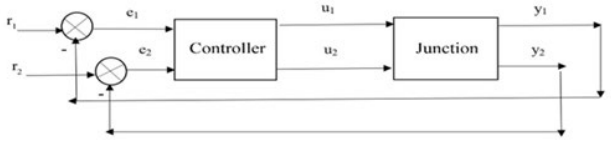

Fig. 1. Light control system for traffic junction

Junction include network of two intersections called later Junction 1 and Junction 2.

The simulation is carried out for two sections of the crossroad using the software platform AIMSUN for traffic planning and modelling. The meanings of all variables used in Figure 1 are explained below. In this case, the reference number of vehicles is assumed to be zero and the duration of the green light is given in seconds.

y_1 is the actual number of vehicles in section 1
y_2 is the actual number of vehicles in section 2
r_1 is the reference number of vehicles in section 1
r_2 is the reference number of vehicles in section 2
e_1 is the green light control error for section 1
e_2 is the green light control error for section 2
u_1 is the duration of the green light for section 1
u_2 is the duration of the green light for section 2.

II. CONTROLLERS DESIGN

A. Fuzzy controller

The fuzzy controller is designed as a Mamdani fuzzy system with inputs e_1, e_2 and output u_1 (https://www.matlabi.ir/). Once output u1 for section 1 has been derived from the simulation of the fuzzy system, output u_2 for section 2 is calculated as the difference between the fixed duration of the full cycle of the green light and the duration of u_1. In this case, the fixed duration of the full cycle of the green light is 100 seconds and the following equation holds:

$$u_1 + u_2 = 100 \quad (1)$$

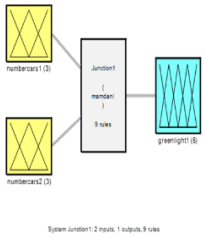

Fig. 2. 1. Fuzzy controller for Junction 1 with two inputs, one output and 9 rules

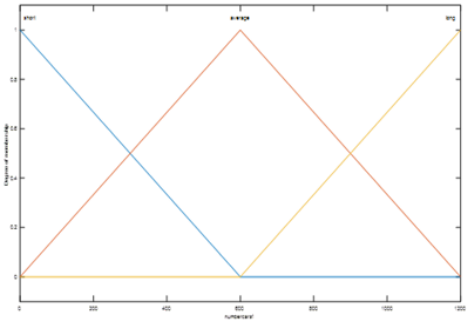

Fig. 2.1.1 First input to fuzzy controller for Junction 1 with three linguistic values

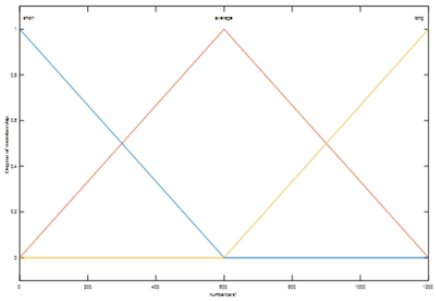

Fig. 2.1.2. Second input to fuzzy controller for Junction 1 with three linguistic values

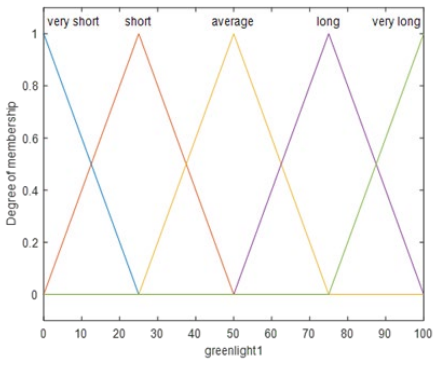

Fig. 2.1.3. Output from fuzzy regulator for Junction 1 with five linguistic values

The Rules for Junction 1 are:

1. If (numbercars1 is short) and (numbercars2 is short) then (greenlight1 is average)
2. If (numbercars1 is short) and (numbercars2 is average) then (greenlight1 is short)
3. If (numbercars1 is short) and (numbercars2 is long) then (greenlight1 is very short)
4. If (numbercars1 is average) and (numbercars2 is short) then (greenlight1 is long)
5. If (numbercars1 is average) and (numbercars2 is average) then (greenlight1 is average)
6. If (numbercars1 is average) and (numbercars2 is long) then (greenlight1 is short)
7. If (numbercars1 is long) and (numbercars2 is short) then (greenlight1 is very long)
8. If (numbercars1 is long) and (numbercars2 is average) then (greenlight1 is long)
9. If (numbercars1 is long) and (numbercars2 is long) then (greenlight1 is average)

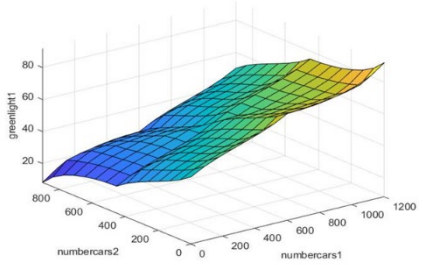

Fig. 2.1.4. Surface of the fuzzy controller with one output and two inputs for Junction 1

The design of fuzzy controller for Junction 2 is similar to fuzzy controller for Junction 1 except the range values for the inputs. The rules for Fuzzy Controller for Junction 2 are equivalent the rules for Junction 1.

For better illustration we show only the output surface of fuzzy controller with different inputs range for Junction 2.

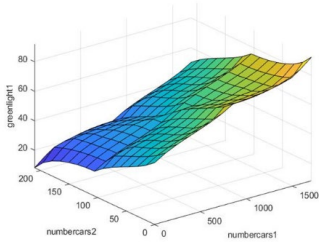

Fig. 2.1.5 Surface of the fuzzy controller with one output and two inputs for Junction 2

B. Proportional controller

The proportional controller is designed analytically under the assumption that the ratio between the green light durationsfor the two sections should be equal to the ratio between the control error magnitudes for these sections. In

this case, the proportional controller is defined by the following system of algebraic equations with two unknowns:

$$e_1/e_2 = u_1/u_2 \quad (2)$$

$$u_2=100-u_1 \quad (3)$$

Equation 3 for the proportional controller is identical with Equation 1 for the fuzzy controller. However, the presentation format used in this section shows the way in which the system of algebraic equations could be solved, i.e. by replacing u_2 from Equation 3 in Equation 2.

III. RESULTS AND DISCUSSION

The model of the network crossroads with the two sections is given in Figure 3. This study has been investigated in the previous papers for the high traffic density, high-case scenario. The purpose of paper is to investigate the behavior of two controllers and simulate the moderate traffic flow, low-case scenario. The network with two junctions is shown in figure 3. The red arrows indicate the traffic flow in network. For example, for Junction 1, the traffic flows are respectively 1 and 2, for Junction 2 the traffic flows are 3 and 4.

Fig. 3 Model of the network crossroads in AIMSUN platform

The Results for Junction 1 for Fuzzy and Proportional Controller are given bellow in Table I. The traffic flow is equal to 900 veh/h for the first approach and 210 veh/h for the second approach of the intersection. The traffic light cycle is 100 seconds.

Table I. presents results for Fuzzy and Proportional Controller for Junction1 under low flow conditions.

TABLE I. JUNCTION 1 - FOR FUZZY AND PROPORTIONAL CONTROLLER

Simulation in AIMSUN (iteration number)	Fuzzy controller (number of vehicles per hour) e_1 e_2	Green light duration (seconds) u_1 u_2	Proportional controller (number of vehicles per hour) e_1 e_2	Green light duration (seconds) u_1 u_2
1	**900 210**	66 34	**900 210**	81 19
2	**897 100**	70 30	**897 100**	90 10
3	**897 100**	70 30	**897 100**	90 10
4	**897 100**	70 30	**897 100**	90 10

Table II presents traffic indicators only for Junction 1 for the fuzzy and the proportional controller iterations.

TABLE II. TRAFFIC INDICATORS FOR FUZZY AND PROPORTIONAL CONTROLLERS FOR EACH ITERATION

	Fuzzy Conroller Iteration 1	Fuzzy Conroller Iteration 2	Proportional Controller Iteration 1	Proportional Controller Iteration 2	UNITS
Flow	1101	1101	1101	1101	veh/h
Harmonic Speed	38.49	39.43	42.34	43.38	km/h
Mean Queue	1.77	1.63	1.31	1.32	veh
Total Travel Time	11.74	11.41	10.49	10.14	h

Figure 4 presents total Travel Time for fuzzy and proportional controllers for each iteration

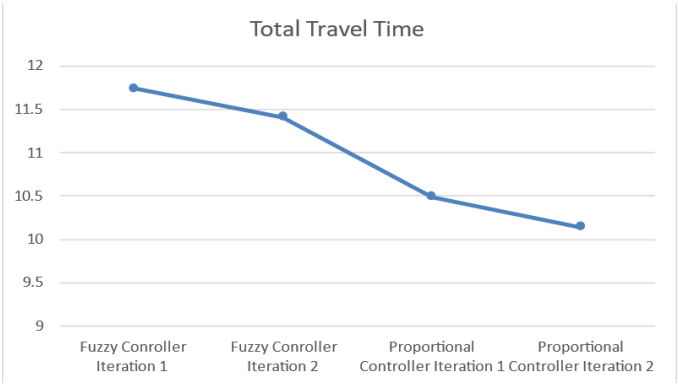

Fig. 4. Total Travel Time for fuzzy and proportional controllers for each iteration

We show only the first iteration for Junction 1, because they have similar for the second iteration.

Figure 5.1. to Figure 5.2 – flow of vehicles for each approach for Junction 1 with fuzzy controller.

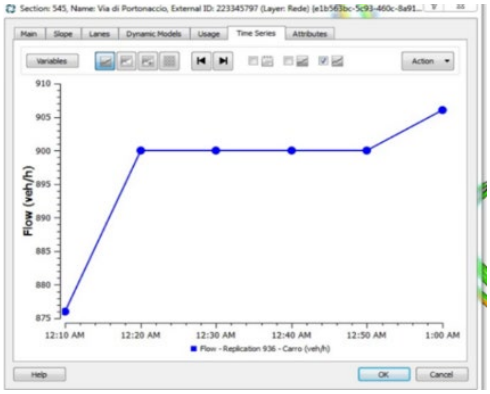

Fig. 5.1. Fuzzy controller – Section 1, Iteration 1

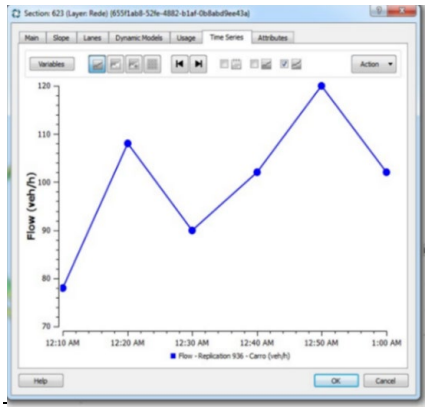

Fig. 5.2. Fuzzy controller – Section 2, Iteration 1

Figure 6.1. to Figure 6.2. – flow of vehicles for each approach for Junction 1 with proportional controller.

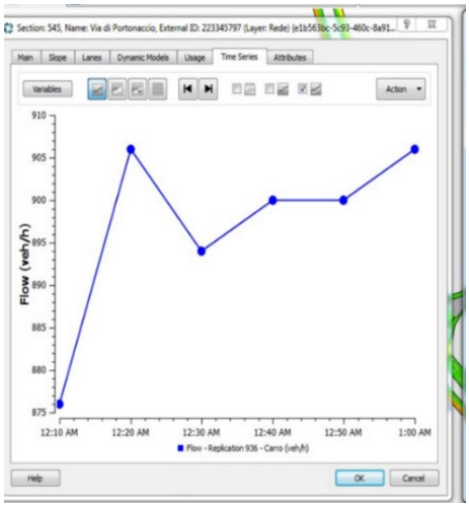

Fig. 6.1. Proportional controller – Section 1, Iteration 1

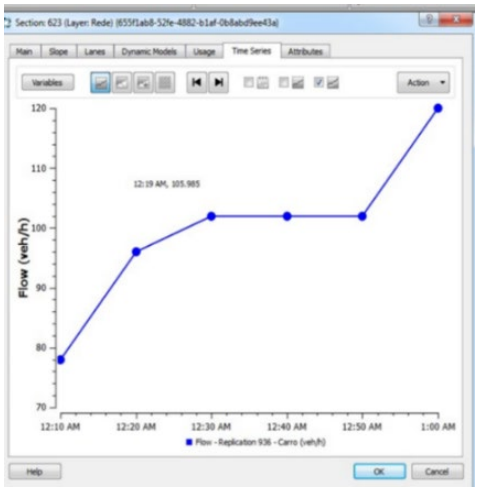

Fig. 6.2. Proportional controller – Section 2, Iteration 1

Results of the research for the second intersection at low -case scenario flow. First section there are 1000 cars, second section 110 cars. Traffic light cycle is 100 seconds. The results for Junction 2 for Fuzzy and Proportional Controller are given bellow:

Table III presents the iterations of the fuzzy and the proportional controller for the network of two intersections under low flow conditions.

TABLE III. JUNCTION 2 - FOR FUZZY AND PROPORTIONAL CONTROLLER2

Simulation in AIMSUN (iteration number)	**Fuzzy controller (number of vehicles per hour)**		**Green light duration (seconds)**		**Proportional controller (number of vehicles per hour)**		**Green light duration (seconds)**	
	e_1	**e_2**	**u_1**	**u_2**	**e_1**	**e_2**	**u_1**	**u_2**
1	**1000**	**110**	54	46	**1000**	**110**	90	10
2	**1248**	**427**	50	50	**832**	**160**	81	19
3	**834**	**285**	50	50	**832**	**186**	82	18
4	**834**	**285**	50	50	**832**	**186**	82	18

Table IV presents traffic indicators for each iteration for both controllers for the whole network.

Figure 7 presents Total Travel Time for fuzzy and proportional controller for each iteration.

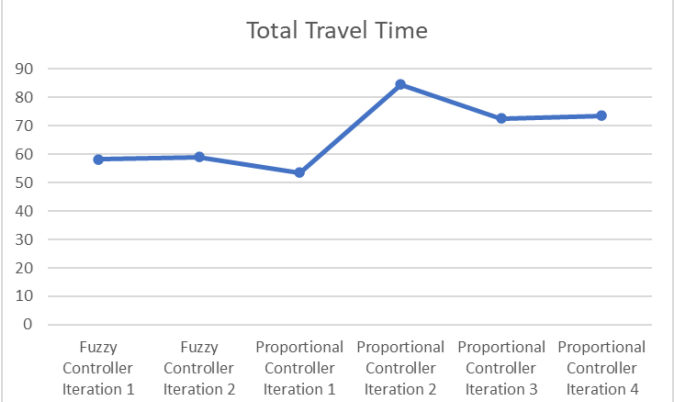

Fig. 7. Total Travel Time for fuzzy and proportional controller for each iteration

TABLE IV. TRAFFIC INDICATORS FOR FUZZY AND PROPORTIONAL CONTROLLERS FOR EACH ITERATION IN THE NETWORK

	Fuzzy Controller Iteration 1	Fuzzy Controller Iteration 2	Proportional Controller Iteration 1	Proportional Controller Iteration 2	Proportional Controller Iteration 3	Proportional Controller Iteration 4	Units
Flow	1964.67	1964.67	1865.33	1752	1860	1860	veh/h
Harmonic Speed	30.22	29.89	30.58	16.66	20.96	20.68	km/h
Mean Queue	11.71	12.25	10.59	31.02	21.34	21.85	veh
Total Travel Time	58.21	59.07	53.49	84.53	72.64	73.59	h

Figure 7. 1– to Figure 7.4 show count and flow of vehicles for each approach for Junction 2 with fuzzy controller. Here as an example is given the count of vehicles for iteration 1 compared to traffic flow in iteration 2 for the fuzzy controller. As it is visible from the line trend both types of traffic indicators follow the same pattern.

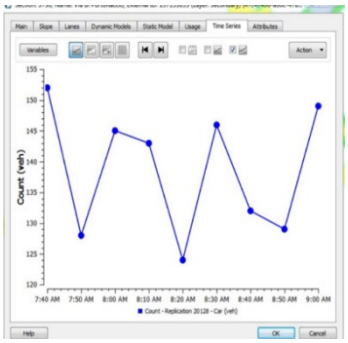

Fig.7.1. Fuzzy Controller- section 1, Iteration 1

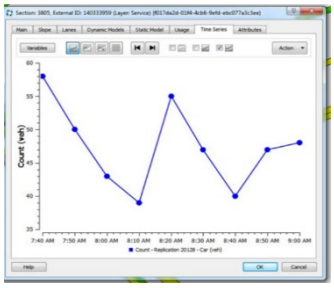

Fig. 7.2.Fuzzy Controller- section 2, Iteration 1

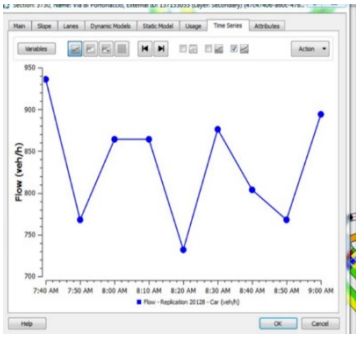

Fig.7.3. Fuzzy Controller- Section 1, Iteration 2

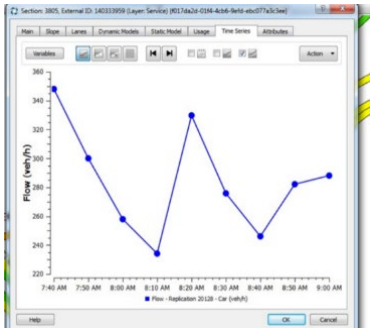

Fig.7.4. Fuzzy Controller- Section 2, Iteration 2

Figure 7. 5– to Figure 7.12 flow of vehicles for each approach for Junction 2 with proportional controller.

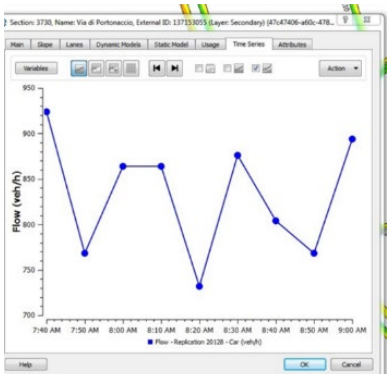

Fig. 7.5. Proportional Controller –iteration 1, section 1

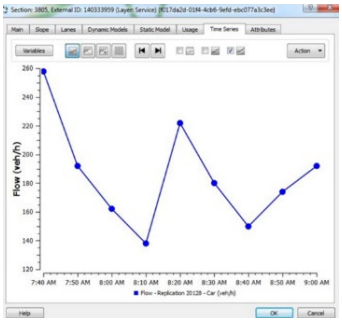

Fig. 7.6. Proportional Controller- iteration 1 section 2

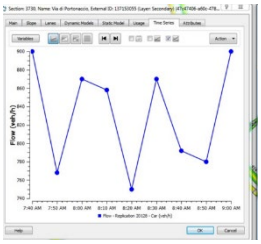

Fig. 7.7. Proportional controller- iteration 2, section 1

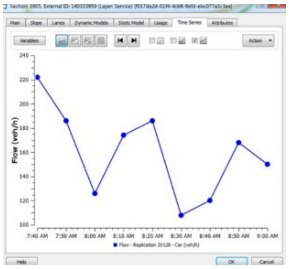

Fig.7.8. Proportional Controller, iteration2, section 2

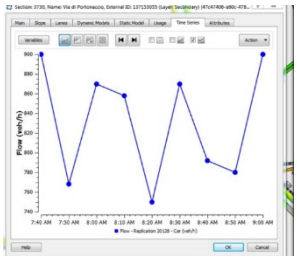

Fig. 7.9 .Proportional Controller – iteration 3 , section 1

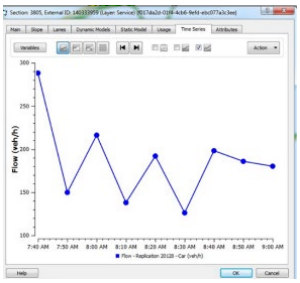

Fig.7.10. Proportional Controller - iteration 3, section 2

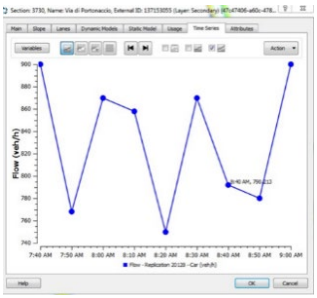

Fig.7.11 Proportional Controller- iteration 4, section 1

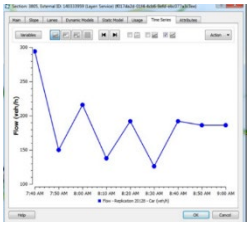

Fig.7.12. Proportional Controller , iteration 4, section 2

IV. CONCLUSIONS

The paper presented the design of two controllers – a fuzzy and a proportional controller for the purpose of traffic light control for high-case scenario (full density of the traffic). A simulation software was used to build a microsimulation of two intersections regulated by traffic lights. The control parameter was the duration of green light within the cycle length. The duration of the green light is in relationship to the flow. For this study an intense traffic flow was simulated. The aim was to research how the fuzzy and proportional controller behave in the case with intensive traffic flow. In terms of traffic flow the fuzzy controller performs better because it provides higher traffic flow and needs only one iteration to reach a performance that is comparable to the performance of the proportional controller after three iterations. The purpose of paper is to investigate behavior of the two controllers for the same network junctions in case for lower traffic density. The previous study was towards the same network junctions with regulation of fuzzy and proportional controllers, in case of high- traffic intensity.

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