# Optimizing Traffic Lights in Urban Corridors based on Fuzzy Logic: An Evaluation in SUMO

## Introduction

- Traffic congestion is a major problem for urban areas worldwide, leading to significant environmental and economic costs. Fuzzy logic technology has the potential to optimize traffic light timing and improve corridor performance using flow rate retrieved from traffic counters as a unique input requirement.

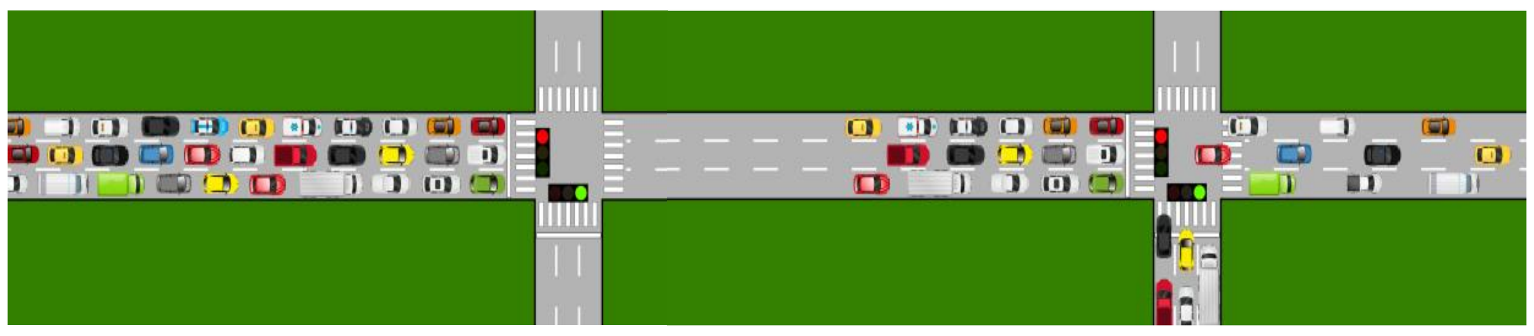

Fig. 1: Underestimation/Subestimation behavior of traffic from traffic light controllers.

## Fuzzy Inference System

- The simulation was conducted under different traffic conditions to assess the system's performance under various scenarios.
- The controller computes the cycle duration based on the arrival flow rates and executes a fuzzy inference system guided by the reasoning that the higher the traffic flow, the longer the cycle length.
- The computed cycle is split into different phases according to Webster's method for signalization. The process iterates every cycle to modify the membership function values based on the actual flow rate.

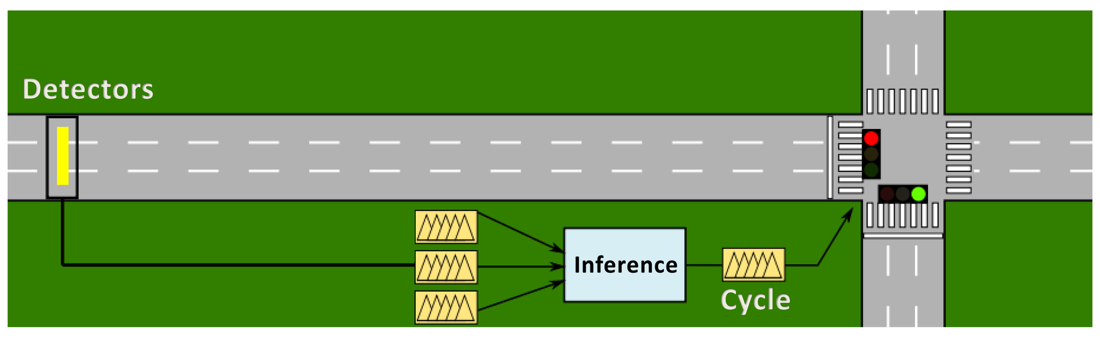


Fig. 2: Fuzzy Inference System representation. Input, inference, and output.

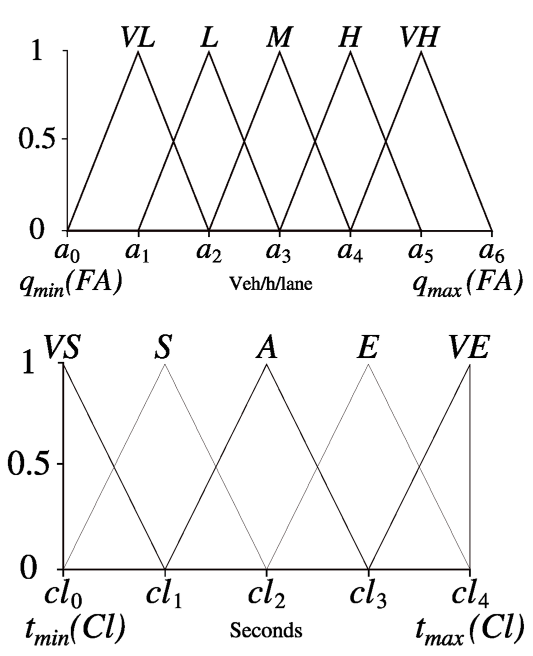


Fig. 3: Mamdani Triangular functions and memberships of the system.

**Algorithm 1** Fuzzy inference module

**procedure** FuzzyInference($S = \{s_1, s_2, \ldots, s_n\}$)
** Fuzzification with triangular functions*
**for each** input value $s_i \in S$ **do**
  **for each** fuzzy set $f_{Q_j}(x), j \in \{1, 2, \ldots, c\}$, **do**
    $v_{i,j} = max\left(min\left(\frac{s_i - L_j}{C_j - L_j}, \frac{R_j - s_i}{R_j - C_j}\right), 0\right)$
  **end for**
**end for**
** z inference rules ($z < n^c$)*
$r_1 = min\left(v_{1,j}, v_{2,j'}, \ldots, v_{n,j}\right)$
⋮
$r_k = min\left(v_{1,j}, v_{2,j'}, \ldots, v_{n,j}\right)$
⋮
$r_z = min\left(v_{1,j}, v_{2,j'}, \ldots, v_{n,j}\right)$
** defuzzification with the WA method*
$cl = \frac{\sum_{k=1}^{z} \sum_{h=1}^{m} r_k \cdot \bar{x}_{T_h}}{\sum_{k=1}^{z} r_k}$
**return** $cl$
**end procedure**

Fig. 4: Algorithm performed by the inference module.

## Adaptive Mechanism

- The adaptive mechanism splits the computed cycle length into required phases and dynamically changes the phases' duration.
- The traffic signal reconfiguration is performed every cycle.
- The phase duration is computed proportionally to the flow rates and a minimum phase duration is defined.

**Algorithm 2** Adaptive mechanism module.

**Input:** $TL = (P, D)$
**Output:** Phases configuration
**while** true **do**
  **for all** traffic streams $s_i \in S$ **do**
    $s_i$ = Sensors.RetrieveFlowRate($i$)
  **end for**
  **if** TrafficLight.CycleRemainingTime() = 0 **then**
    $num\_cycles += 1$
  **end if**
  **if** $num\_cycles == \tau$ **then**
    $num\_cycles = 0$
    $cl$ = FuzzyInference($S$)
    ** cycle length distribution*
    **for each** phase $p_i \in P$ **do**
      $d_i = \frac{s_i}{\sum_{k=1}^{n} s_k} cl + y$
      ** complementary security rule*
      **if** $d_i <$ min_phase_duration **then**
        $d_i =$ min_phase_duration
      **end if**
    **end for**
    TrafficLight.setNewProgram($P, D$)
  **end if**
**endwhile**

Fig. 5: Algorithm performed by the mechanism module.

## Results

- The optimized traffic light timings reduced the waiting time at intersections, improved travel time, and reduced vehicle emissions.
- The system's decentralized approach allowed each traffic light to optimize its timing based on local traffic conditions, resulting in a competitive, responsive, and adaptive system.
- The proposed controller adaptively computes the cycle length, which is proportionally split into different phases, instead of estimating phase extensions.

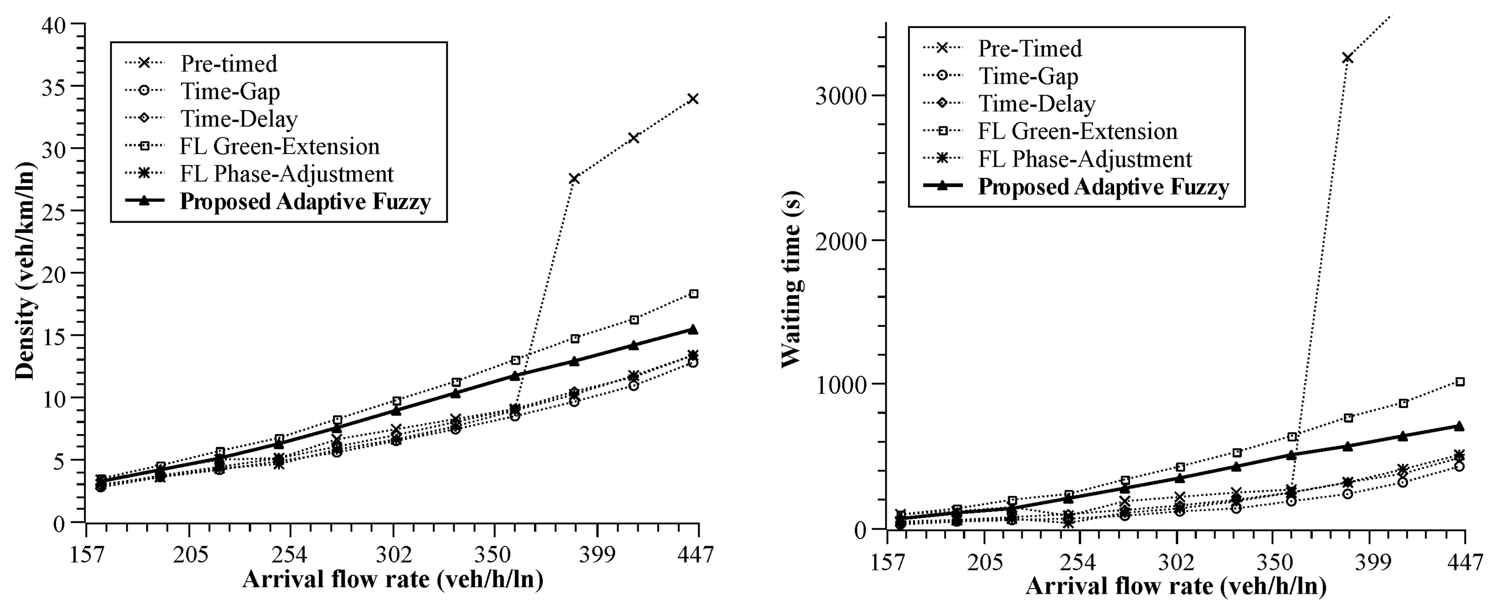


Fig. 6: Density (left) and waiting time (right) as functions of the averaged system's arrival flow.

## Conclusion

- Its decentralized approach and low-cost requirements make it a viable solution for developing countries that may have limited resources for implementing advanced traffic management systems.
- Simulations and analyses still need to be performed with the gathered data.

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