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Poster

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Abstract

The delays imposed by an intersection management (IM) system are a measure of the Quality of Service (QoS) provided to vehicles at signalized intersections (SIs). The QoS of the IM system can be related to the variability of travel time, speed, and capacity. Incorporating these factors, we defined the response time (RT) for any vehicle served by the IM system. A particularly important issue in areas with intense traffic is the QoS provided by existing IM protocols during saturated traffic conditions. To research this issue, we carry out an empirical simulation using SUMO, in which we compare the RT results of five state-of-the-art IM approaches. The results show that the SIMP IM consistently exhibits the best QoS.

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Quality of Service of IM Approaches under Saturated Traffic

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Abstract

The delays imposed by an intersection management (IM) system are a measure of the Quality of Service (QoS) provided to vehicles at signalized intersections (SIs). The QoS of the IM system can be related to the variability of travel time, speed, and capacity. Incorporating these factors, we defined the response time (RT) for any vehicle served by the IM system. A particularly important issue in areas with intense traffic is the QoS provided by existing IM protocols during saturated traffic conditions. To research this issue, we carry out an empirical simulation using SUMO, in which we compare the RT results of five state-of-the-art IM approaches. The results show that the SIMP IM consistently exhibits the best QoS.

Keywords: Intersection Management, Signalized Intersections, Quality of Service, Waiting Time, Response Time;

1. Reliable IM Operations at Signalized Intersections

Numerous intersection management (IM) systems were introduced to minimize traffic congestion, associated delays, and fuel wastage relying on reinforcement learning (Wei et al., 2019), metaheuristics (Jamal et al., 2022), connected and autonomous vehicles (Khayatian et al., 2020), and other technologies. However, the Quality of Service (QoS) provided by these IM systems is strongly penalized under traffic saturation, with the demand exceeding capacity, queues overflowing and leading to spillbacks, i.e., fully occupied road lanes blocking the traffic from the other road lanes (Urbanik et al., 2015). In our research, we defined the Response Time (RT) of vehicles at isolated SIs with single lane as a quality measure of IM operations leveraging real-time systems analysis (Reddy et al., 2021). The relationship between the RT and the QoS of IM operations is inversely proportional. In this long abstract, we report on ongoing work to extend the RT analysis to networks of complex SIs, each with multiple road lanes.

Fig. 1a shows a road network with four SIs (I_0, I_1, I_2, I_3) arranged in a $D \times D$ area with $D = 1540m$ and intersection crossing space $20m^2$, thus the length of each road is $500m$. Each SI is associated with an edge node named the intersection management (IM) unit for traffic signal decisions. The figure also shows the names of all roads. Fig. 1b displays the three components that make up the RT in an SI, i.e., $RT = QT + WT + ICT$. When a vehicle enters any

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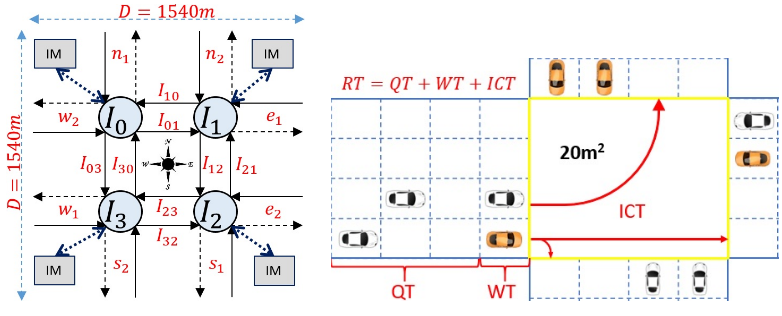
road lane, the time it takes to join the queue is the queue joining time (QT); then the time it waits to access the SI is the waiting time (WT); and after accessing the SI, the time to cross the SI is the intersection crossing time (ICT). Each SI has a dedicated left-crossing lane and a shared straight/right-crossing lane.

We built the road network and implemented five IM approaches for comparison using the SUMO simulator (Lopez et al., 2018). Among the five, two are conventional: Round-Robin (RR) and Trivial Traffic Light Control (TTLC); two are adaptive: Max-pressure Control Algorithm (MCA) and Websters Traffic Light Control (WTLC); and one is the Synchronous Intersection Management Protocol (SIMP). For a detailed description of these IM approaches see Reddy et al. (2022). We used 50% of human-driven cars and 50% of autonomous cars. We employed a maximum speed of $30km/h$, which is typical in residential urban roads. The simulation parameters and assigned values can be found in Reddy et al. (2022). From the throughput results of Reddy et al. (2022), we chose the arrival rate of $0.133veh/s$ that leads to saturated traffic conditions. Using *Poisson distribution* we generated traffic for $1h$ simulated time and let the simulations run until all the vehicles exited the road network. We logged the floating-car data of all vehicles, i.e., timestamped speed and position. The best-case RT values, i.e., when vehicles do not suffer any delays, are $60.6s$ (right-crossing) and $62.43s$ (left/straight-crossing).



(a) 2×2 road network. (b) Response Time (s) in an SI.

Fig. 1: An example road network and the components that make up RT.

2. Response Time Results

Figs. 2a to 2p show the RT results of the four roads of each SI, for I_0, I_1, I_2, and I_4, respectively. The SIMP protocol exhibits the lowest RT results in all roads and intersections and does not saturate at $0.133veh/s$ due to its lowest cycle time and synchronous nature in serving vehicles.

For the remaining IM approaches (RR, TTLC, MCA, and WTLC), most roads experienced moderate traffic. However, some roads experienced saturated traffic conditions with queue overflows and spillbacks. This is visible with RR, MCA, and WTLC on n_1 (Fig. 2a); TTLC and MCA on w_2 (Fig. 2b) and n_2 (Fig. 2e); MCA on e_1 (Fig. 2f); TTLC on e_2 (Fig. 2i); and finally RR and WTLC on w_1 (Fig. 2n). The only internal lane that showed saturation is I_{30} with RR (Fig. 2d) due to saturated traffic on the internal road I_{01} (Fig. 2g); this consequently blocked the traffic from the other internal road I_{30} and caused spillback and queue overflow on connecting external inflow lanes n_1 and w_1.

Overall, the best-case RT values for all IM approaches are $62s$ (external roads) and $61s$ (internal roads), except for RR on e_1 with $82s$. The observed worst-case RT values are $168s$ (SIMP), $863s$ (RR), $999s$ (TTLC), $911s$ (MCA), and $846s$ (WTLC). These numbers expose a strong asymmetry of QoS between SIMP (which is better) and the other four IM approaches.

3. Summary

In this long abstract we present response time results of vehicles with five state-of-the-art IM approaches, measured in a network of independent road intersections. The results show that common IM approaches reach saturation sooner than SIMP, thus showing worse QoS. This was visible with the arrival rate used (0.133veh/s).

We are currently modeling the road network to come up with analytical RT estimations that we can compare with these simulation results.

Acknowledgments

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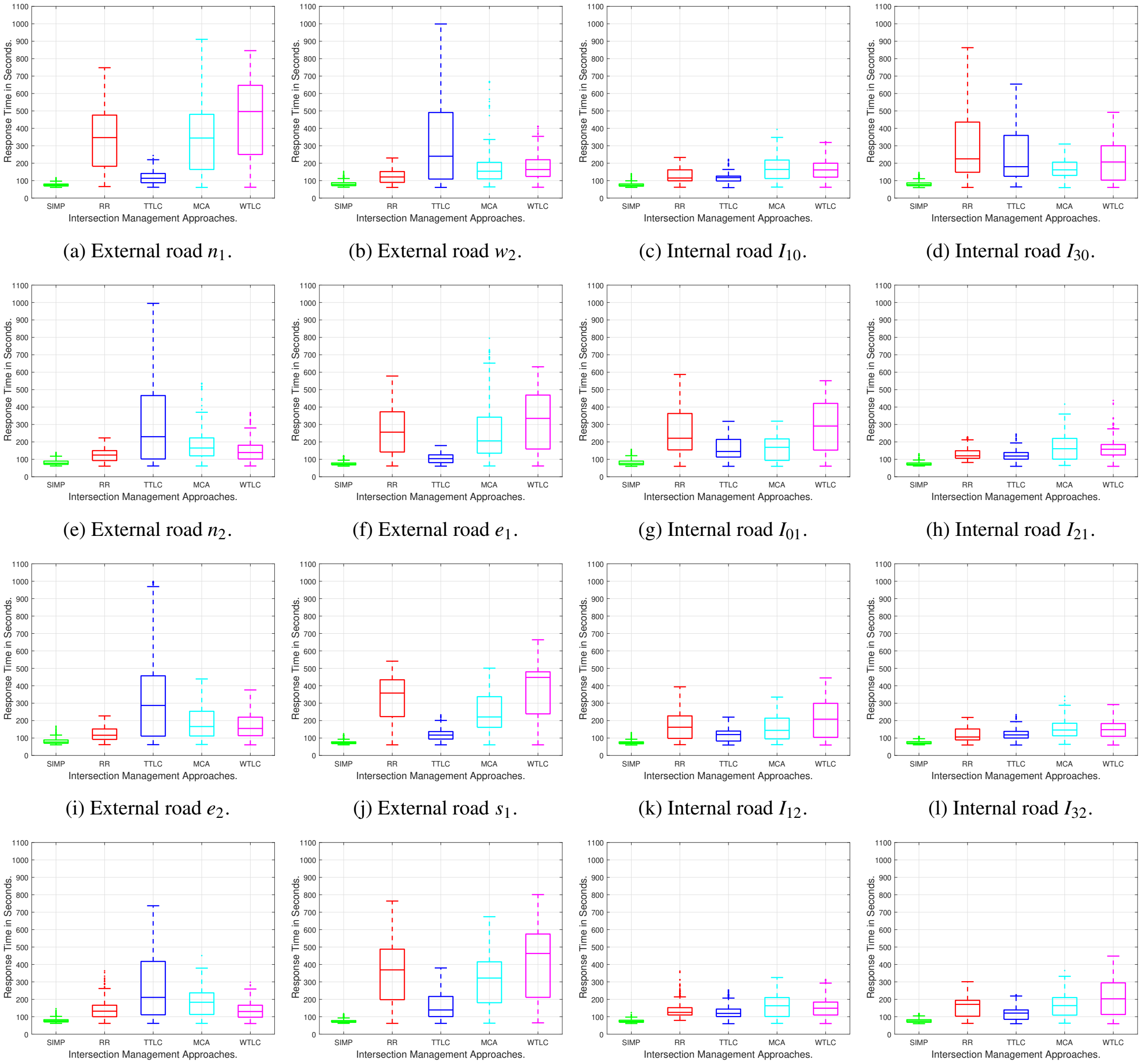

(a) External road n_1. (b) External road w_2. (c) Internal road I_{10}. (d) Internal road I_{30}.

(e) External road n_2. (f) External road e_1. (g) Internal road I_{01}. (h) Internal road I_{21}.

(i) External road e_2. (j) External road s_1. (k) Internal road I_{12}. (l) Internal road I_{32}.

(m) External road s_2. (n) External road w_1. (o) Internal road I_{03}. (p) Internal road I_{23}.

Fig. 2: Response Time (s) of tested IM approaches for every inflow road of SIs I_0, I_1, I_2, and I_3 in the road network.

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