Integrating an actuated signal control policy with queue-based green light optimal speed advisory (Q-GLOSA) systems

Dohyeon Kim[a], Sooncheon Hwang[a], Jihye Byun[a], Dongmin Lee[a], Wai Wong[b] and Seunghyeon Lee[a,*]

[a] Department of Transportation Engineering, University of Seoul, Seoul, Republic of Korea
kdhcow97@uos.ac.kr, tseven37@naver.com, jhbyun@uos.ac.kr, dmlee@uos.ac.kr, Seunghyeon.lee@uos.ac.kr

[b] Civil and Natural Resources Engineering, University of Canterbury, Christchurch, New Zealand
wai.wong@canterbury.ac.nz,

[*] Corresponding author

Extended abstract submitted for presentation at the Conference in Emerging Technologies in Transportation Systems (TRC-30)
September 02-03, 2024, Crete, Greece

April 30, 2024

Keywords: Optimal speed advisory, Real-time queue length estimation, Actuated signal control policy, Integrated simulation platform

1 INTRODUCTION

A Green Light Optimal Speed Advisory (GLOSA) service has been shown to reduce CO_2 emissions and fuel consumption by up to 13% by suggesting the optimal speed for intersection passage based on information provided by Traffic Light Signals (TLS), thereby reducing unnecessary acceleration and deceleration of vehicles Bodenheimer *et al.* (2015). The critical inputs for the GLOSA system to calculate the optimal speed are the distance and estimated arrival time between the target vehicle and the TLS. Using cellular network technologies such as 4G/LTE and 5G, the target vehicle sends its location and speed information to the nearest traffic light. Therefore, the GLOSA algorithm should have low error rates as it uses individual vehicle location data, and real-time data sharing between vehicles is required.

Optimal speed advisory algorithms aim to predict the passing speed of vehicles entering approaches to the intersection and then transfer this information to the target vehicles equipped with the OBU. Various algorithms have been introduced to minimize fuel consumption while considering road conditions and incorporating more realistic traffic situations. To verify the excellent performance of the proposed algorithms in reducing urban traffic congestion and fuel consumption, microscopic simulation-based validation methods have proven to be more useful in Katsaros *et al.* (2011) and Coppola *et al.* (2022). Nevertheless, several algorithms have been implemented without considering diverse traffic signal control strategies and real-time traffic conditions in the simulation environment. Therefore, this study aims to construct an actuated signal control policy with the improved GLOSA algorithm considering real-time queue lengths at isolated intersections. We present three unique contributions:

- The GLOSA incorporates queue length estimation methods to reflect the actual conditions by applying spatial and temporal ranges, which overcomes over-calculated speed advice that can enhance the accuracy of advised optimal speed to the vehicle. We call this creative algorithm the Q-GLOSA.

- The Q-GLOSA is deployed in the actuated signal control policy to minimize unnecessary vehicle stops and carbon emissions along with a signalized corridor.
- The proposed mathematical framework is validated in the integrated microscopic traffic simulation, SUMO, under diverse traffic congestion levels and V2X communication scenarios.

2 METHODOLOGICAL FRAMEWORK

The overall process is depicted in Figure 2, illustrating the sequential processing of three methodologies in the combined model.

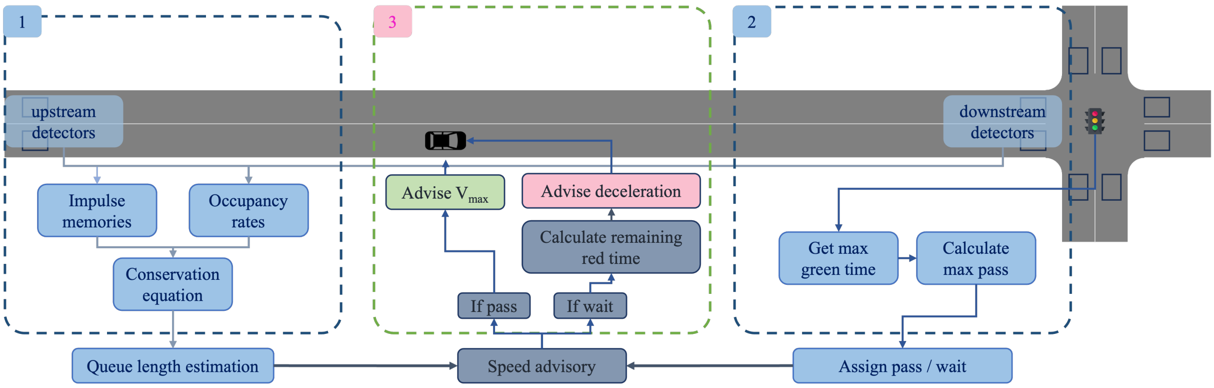

Figure 1 – *The overall process of the integrated mathematical framework*

In the first step, occupancy rates and impulse memories are collected from both upstream and downstream detectors in seconds. Occupancy rates are defined as the percentage of time a vehicle presented within a designated time frame. Subsequently, the queue length for each vehicle is estimated using conservation equations suggested in Lee *et al.* (2019).

In the second step, an actuated control policy determines whether the current green phase is extended or terminated according to an instant vehicular arrival at a signalized intersection. The control policy calculates travel time from the current position of vehicles passing the upstream detector approaching the mid-block at the intersection. Then, the control policy decides to assign a "pass" or "wait" to each vehicle by comparing the remaining time of the current green phase in the current signal cycle. Finally, if the control policy assigns a "pass" to a vehicle, the GLOSA recommends the vehicle drive at the restricted speed of the link connected to the intersection to pass the intersection without any deceleration. Conversely, if the control policy assigns a "wait" to a vehicle, the GLOSA provides the suggested deceleration speed to the vehicle by calculating the remaining time of the current red phase, allowing the vehicle to pass through the intersection without stopping when the signal phase changes upon its arrival. The detailed flowchart and equations of the proposed method are well described in Kim *et al.* (2024).

3 MODEL RESULTS

We illustrate the excellent performance of the proposed model by comparing six models, as shown in Table 1. The columns for each model indicate whether to contain each signal control strategy. Model 1 denotes a fixed signal control strategy only, whereas Model 2 includes the fixed signal control strategy and the GLOSA. Model 3 integrates the fixed signal control strategy and the GLOSA, considering real-time queue lengths. Model 4 presents an actuated signal control policy, whereas Model 5 contains the actuated signal control policy with the GLOSA. Model 6 is the proposed model in this study, which includes the actuated signal control policy with

Q-GLOSA considering real-time queue length estimations. We evaluate the CO_2 emission of each model under free-flow traffic conditions. To apply free flow conditions, we used a $120veh/h$ demand for each approach direction and evaluated the model's performance at three consecutive intersections, each with three lanes.

Table 1 – *Model specifications*

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6 (proposed model)
Fixed	O	O	O	X	X	X
Actuated	X	X	X	O	O	O
GLOSA	X	O	X	X	O	X
Q-GLOSA	X	X	O	X	X	O

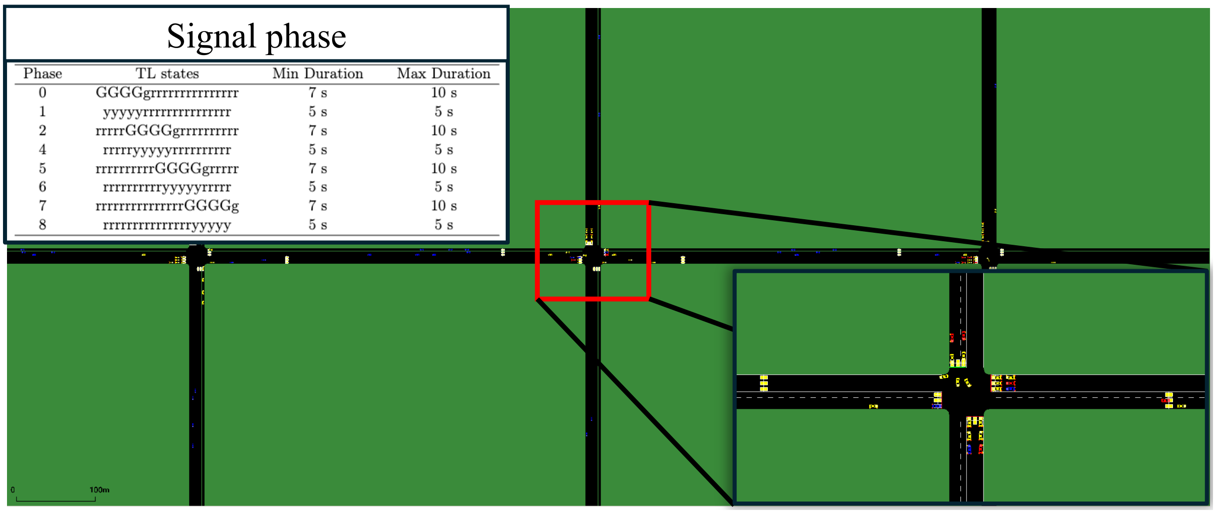

Figure 2 – *Simulation environments*

The model results are described in figure 3. We observed that for emissions, Model 6 produces the lowest exhaust emissions, specifically in free-flow situations, indicating that the presented Model 6 outperforms others in emission reduction across all scenarios. This effect arises due to the interaction between the GLOSA considering queue lengths and the actuated control technique, which leads to a reduced sample of vehicles exhibiting abrupt accelerations or decelerations.

On the other hand, Figure 4 illustrates the emissions according to the OBU penetration rate in Model 6. The results are most effective when the penetration rate is 100%.

4 CONCLUDING REMARKS

We develop a novel actuated signal control strategy for consecutive signalized intersections under a V2X connected environment. The proposed methodology consists of the traditional actuated signal control policy, the GLOSA, and the estimation procedure of queue lengths in real time. This study involves three primary challenges. First, we introduce pass-or-wait algorithms to implement GLOSA in the actuated signal control policy to maximize operational efficiency for a signalized corridor. Second, we deploy dynamic estimation methods of vehicular queues in GLOSA to consider actual traffic conditions for suggesting optimal speed to a vehicle equipped with an OBU within the coverage of V2X communications. Third, we create the integrated simulation platform using SUMO to calibrate and validate the proposed methods under a virtual traffic environment. We designed two conditions, including the penetration rates of OBU and the

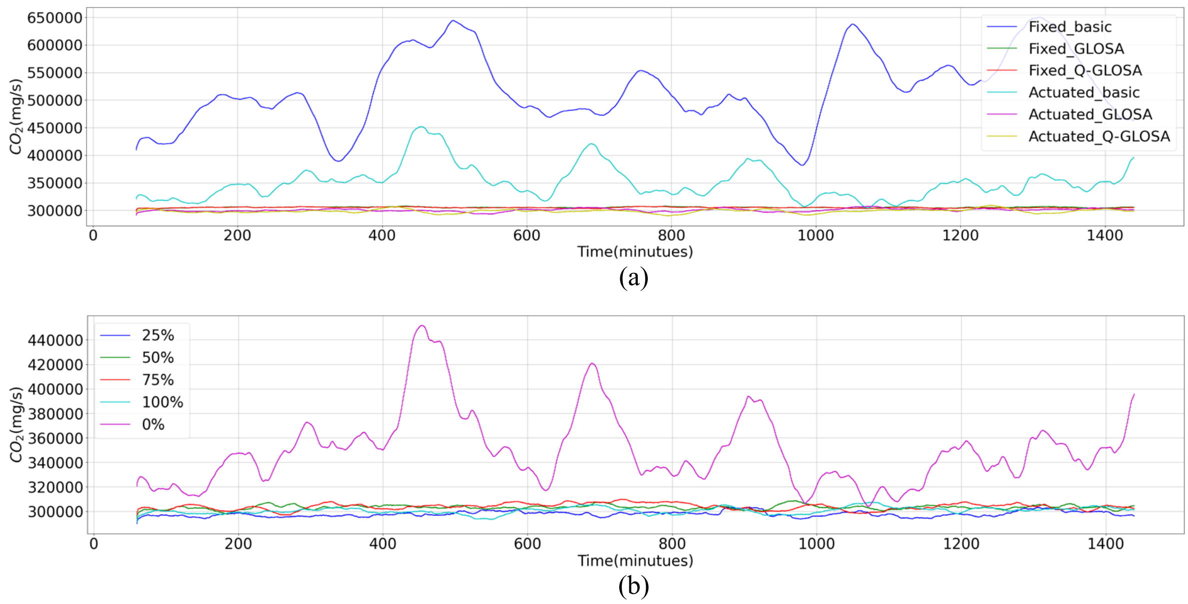

Figure 3 – *CO_2 emissions (a) Six models and (b) Actuated Q-GLOSA with different OBU penetration rates*

level of traffic congestion, to evaluate the proposed methodological framework by comparing the traditional fixed, GLOSA, and actuated signal algorithms in the integrated simulation platform.

The numerical results indicate that the proposed methodology outperforms traditional algorithms under free-flow scenarios of traffic conditions. The proposed method paves the way for the applicability of GLOSA, considering queue lengths in real-time to improve the performance of the actuated signal control policy under diverse traffic and V2X communication conditions. Besides, it lays the foundation stone for the real-time queue lengths estimation method in the GLOSA algorithm to suggest realistic optimal speeds to vehicles approaching the intersection. We used microscopic simulation SUMO for analysis, and the proposed Q-GLOSA algorithm outperformed other models, especially in under-saturated traffic scenarios, in terms of reducing emissions. Overall, the study shows promising results for optimizing traffic flow and reducing fuel consumption at signalized intersections, providing valuable insights for future research in this field.

References

Bodenheimer, Robert, Eckhoff, David, & German, Reinhard. 2015. GLOSA for adaptive traffic lights: Methods and evaluation. *Pages 320–328 of: 2015 7th International Workshop on Reliable Networks Design and Modeling (RNDM)*. IEEE.

Coppola, Angelo, Di Costanzo, Luca, Pariota, Luigi, Santini, Stefania, & Bifulco, Gennaro Nicola. 2022. An Integrated Simulation Environment to test the effectiveness of GLOSA services under different working conditions. *Transportation research part C: emerging technologies*, **134**, 103455.

Katsaros, Konstantinos, Kernchen, Ralf, Dianati, Mehrdad, & Rieck, David. 2011. Performance study of a Green Light Optimized Speed Advisory (GLOSA) application using an integrated cooperative ITS simulation platform. *Pages 918–923 of: 2011 7th International Wireless Communications and Mobile Computing Conference*. IEEE.

Kim, Dohyeon, Hwang, Sooncheon, Byun, Jihye, Lee, Dongmin, Wong, Wai, & Lee, Seunghyeon. 2024. Enhancing actuated signal control policies with optimal speed advisory considering real-time queue lengths. *Transportation Research Board Annual Meeting.*

Lee, Seunghyeon, Xie, Kun, Ngoduy, Dong, & Keyvan-Ekbatani, Mehdi. 2019. An advanced deep learning approach to real-time estimation of lane-based queue lengths at a signalized junction. *Transportation research part C: emerging technologies*, **109**, 117–136.