Impacts of connected and autonomous vehicles on the performance of signalized networks: A network fundamental diagram approach

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Project Objective

This project aims at studying the performance of an eco-driving strategy based on Vehicle-to-Infrastructure (V2I) communication via the advisory speed limit (ASL), and it is evaluated from the perspectives of both system mobility and environmental impacts.

Problem Statement

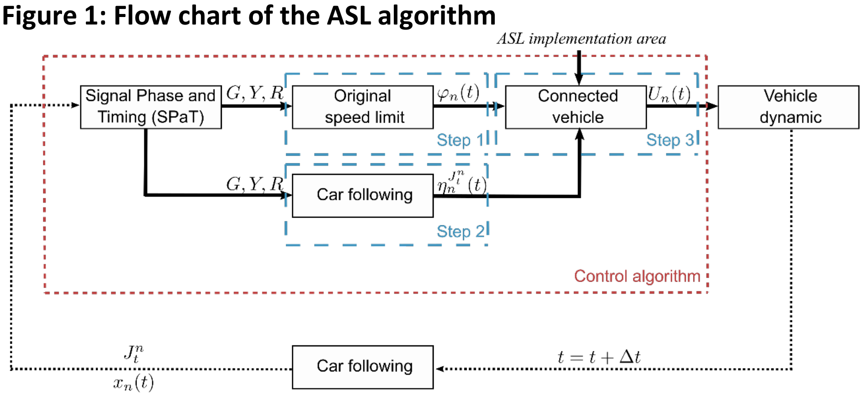
In this project, we formulate and analyze an ASL algorithm, which is robust to changes in the external environment. We theoretically illustrate how our algorithm can change vehicle trajectories at different congestion levels, and numerically show the performance of our algorithm in terms of system mobility and environmental impacts using network fundamental diagrams (NFDs) and fuel consumption as metrics. We further study how market penetration rates (MPRs) (the proportion of connected vehicles that adopt the ASL) and the ASL implementation area (the area in which connected vehicles can receive the ASL) can affect the efficacy of our algorithm.

Research Methodology

The algorithm provides an ASL to each connected vehicle, which is calculated based on the rule that vehicles at signalized intersections should enter the intersection at saturation headway intervals in the phase time. The illustration of our algorithm is shown in Figure 1. The algorithm begins to function when a connected vehicle enters the ASL implementation area. The algorithm consists of three steps:

1. We calculate the desired arrival time based on the speed limit.
2. We calculate the desired arrival time based on the minimum headway to front vehicles.
3. We calculate the ASL with the desired arrival time and the distance to the intersection.

Figure 1: Flow chart of the ASL algorithm

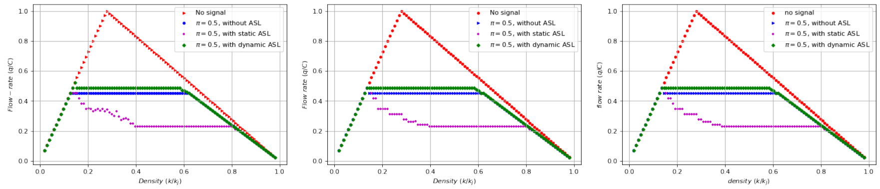


Results

We consider two implementations of the proposed algorithm: the static ASL (which is calculated only when a connected vehicle enters the ASL implementation area) and the dynamic ASL (which keeps updating once it enters the ASL implementation area) and simulate vehicles' movements with the BA Newell's car-following model, the simplified Gipps model, and the Krauss model. We investigate how it works with different MPRs, as well as how ASL implementation areas will affect its performance. Here are the results.

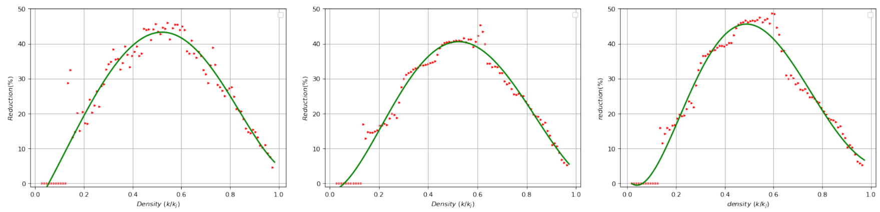
1. The NFDs are shown below. From the perspective of system mobility, the static ASL is unlikely to have a positive effect, it may diminish the system mobility. The dynamic ASL can improve the system mobility in the saturated condition by nearly 10%.

a) BA Newell's model b) Simplified Gipps model c) Krauss model



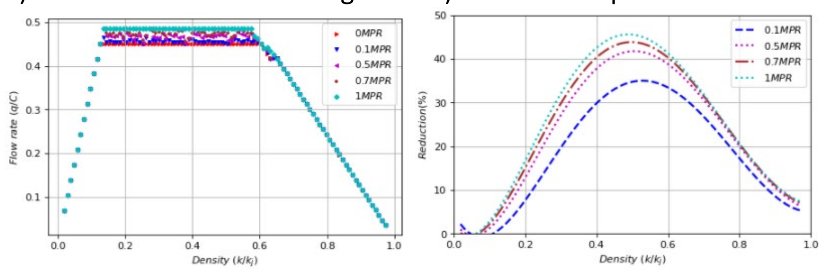
2. The reduction in fuel consumption is shown below. From the perspective of fuel consumption, the dynamic ASL can reduce fuel consumption by up to 45% in the saturated condition.

a) BA Newell's model b) Simplified Gipps model c) Krauss model



3. The NFDs and the fuel consumption reduction with different MPRs based on the Krauss model are shown below. Both the improvement rate of system mobility and the reduction rate of fuel consumption is positively related to the MPR. The improvement rate of system mobility is not obvious when the MPR is low, however, fuel consumption can reduce by about 35% with only 0.1 MPR.

a) Network fundamental diagram b) Fuel consumption reduction



4. The capacity and the fuel consumption reduction with different ASL implementation areas based on the Krauss model are shown below. We recommend the ASL implementation area to be about 100m, which can guarantee control results as well as reduce computation costs.

a) System mobility b) Fuel consumption