Development and Controlled Field Evaluation of an Automated Eco-Cooperative Adaptive Cruise Control System in the Vicinity of Signalized Intersections

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Introduction

- Signalized intersections produce excessive fuel consumption and global pollution.
- When coming close to a signalized intersection, drivers are completely unaware of exactly when the traffic signal will change. Therefore, drivers may have to accelerate/decelerate aggressively to respond to traffic lights.
- Non-smooth driving consumes excessive fuel as it follows a non-ideal speed profile.
- Many Eco-Speed control (ESC) algorithms have been introduced to provide an optimal speed profile for approaching vehicles by optimizing deceleration/acceleration vehicle profiles.
- However, none explicitly attempted to minimize vehicle fuel consumption. In addition, most of the proposed algorithms have been developed and tested in traffic simulation environments where recommended speeds are enforced and many issues, such as the delay in the system and human-vehicle interaction, are not considered.

Eco-CACC System

- We developed a new ESC algorithm named Eco-Cooperative Adaptive Cruise Control (Eco-CACC) in the Center for Sustainable Mobility at the Virginia Tech Transportation Institute.
- The objective function of the Eco-CACC system is the explicit minimization of the total fuel consumed to travel from some distance upstream of the intersection to a distance downstream of the intersection.
- The Eco-CACC system computes and recommends real-time fuel-efficiency speeds using V2I communicated data that can be delivered to drivers as an audio message or be implemented directly in an ACC system.

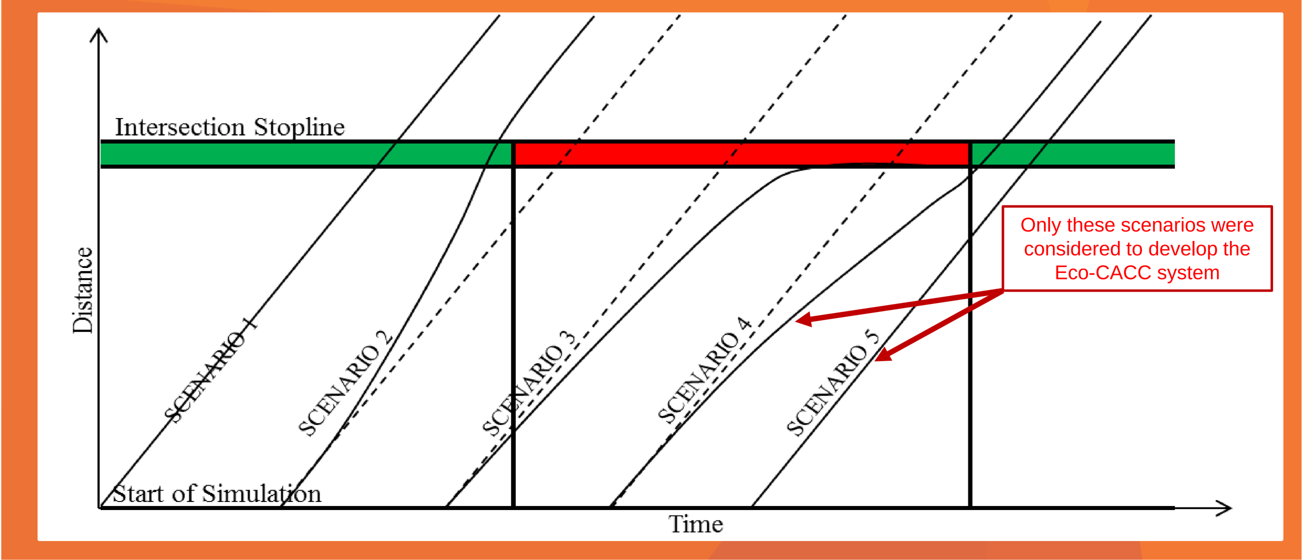
Objective

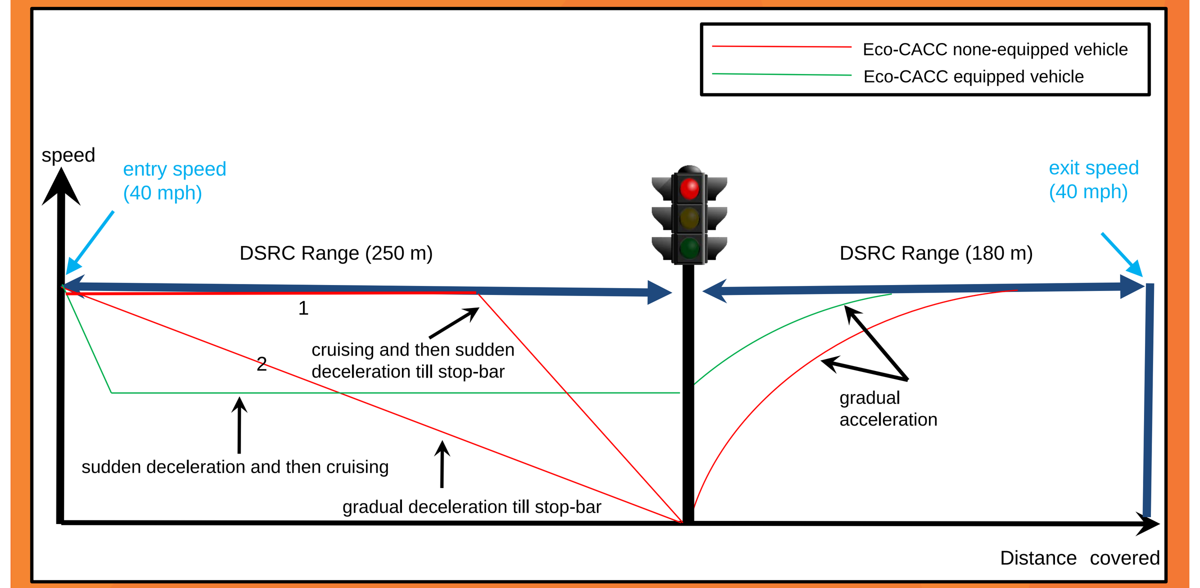
A controlled field experiment was conducted on the Smart Road test facility at the Virginia Tech Transportation Institute **to quantify the benefits of the Eco-CACC system**. The field experiment included four different scenarios, namely: normal driving, driving with count down information provided to drivers, driving with recommended speed information also provided to drivers, and finally automated driving.

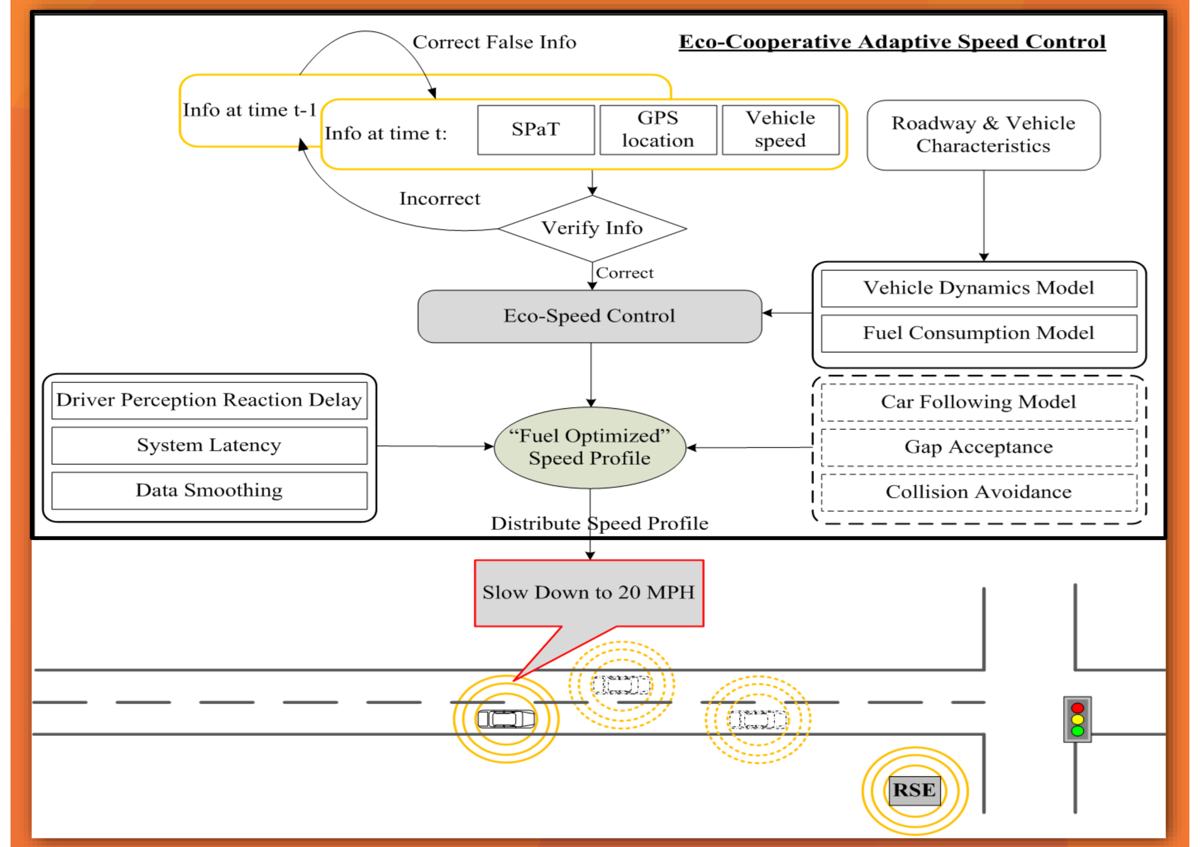
Methodology

1. Algorithm

When a vehicle is approaching a signalized intersection, the vehicle may accelerate, decelerate, or cruise (keep its current speed) depending on its speed, distance to the intersection, signal timing, etc. The anticipated scenarios that the vehicle may encounter are shown below:

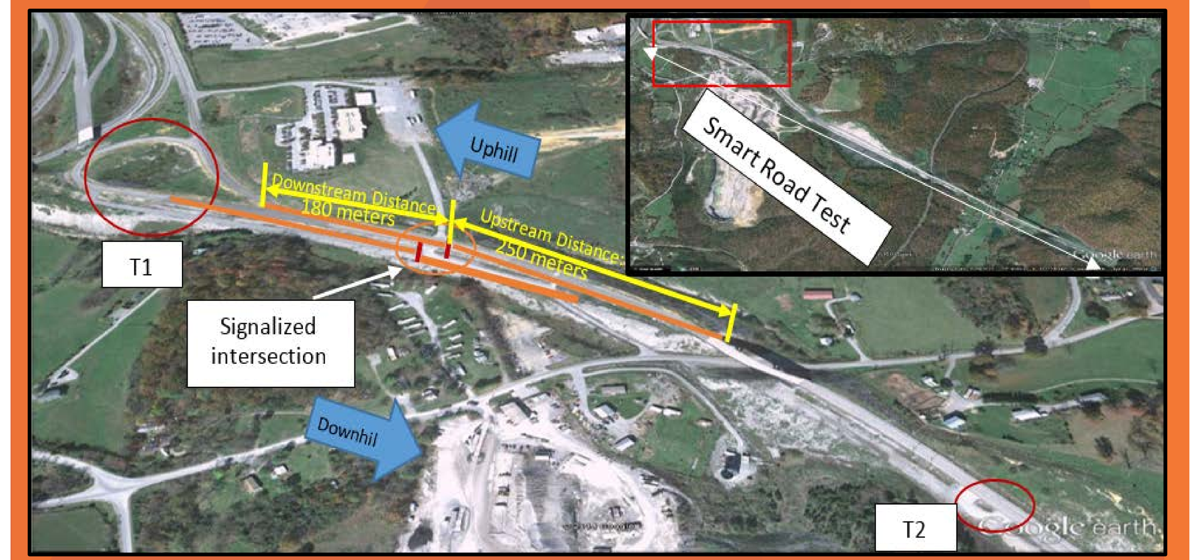






2. Test Facility

- The Virginia Smart Road facility at VTTI as shown below:



3. Experimental Equipment

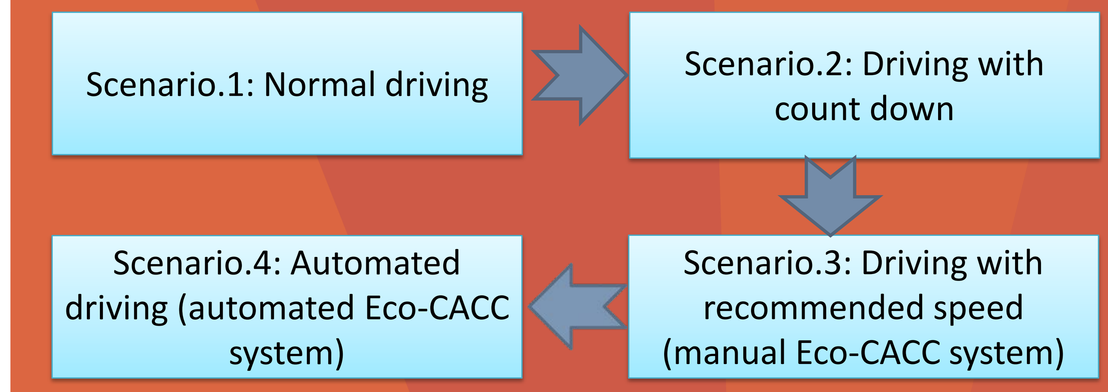
2014 Cadillac SRX (automated vehicle) quipped with:
- Onboard vehicle unit for V2V and V2I communication.
- Differential Global Positioning System (DGPS).
- Real-time data acquisition system (DAS).
- Laptop with software to control the trips and road scenarios.

4. Participants

- 32 Participants.
- 16 males and 16 females.
- 18-30 years old.
- Experienced U.S. drivers for at least two years.

5. Procedure

Participants drove loops on the Smart Road, crossing a four-way signalized intersection between two turnarounds. Each participant was assigned to four different scenarios with 16 trips each. Each scenario had four different red phase offset values (**10**, **15**, **20**, and **25** seconds) with downhill and uphill directions. The following are the four scenarios:



6. Results

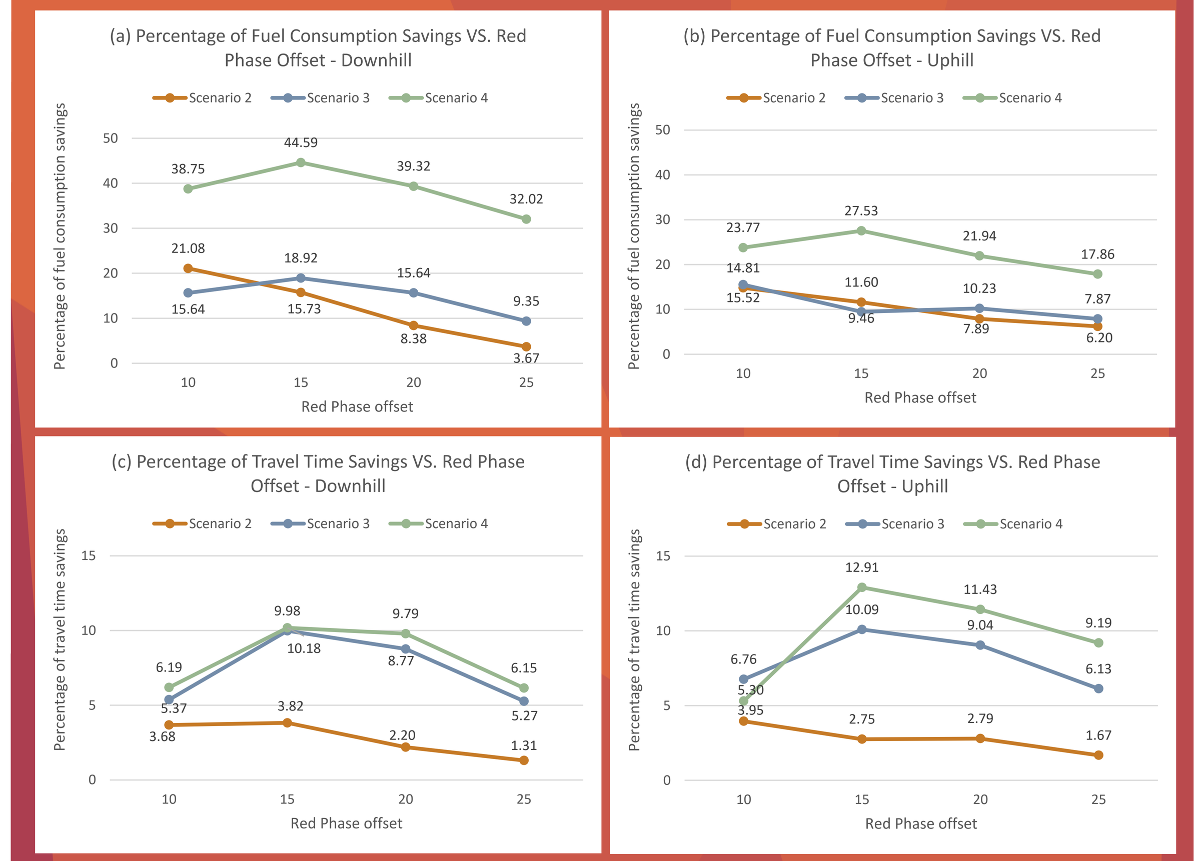


Figure.1 The percentage of fuel consumption and travel time savings continually increases from scenario 2 to 4, and generally the automated scenario has the most fuel consumption and travel time savings levels among all tested scenarios.

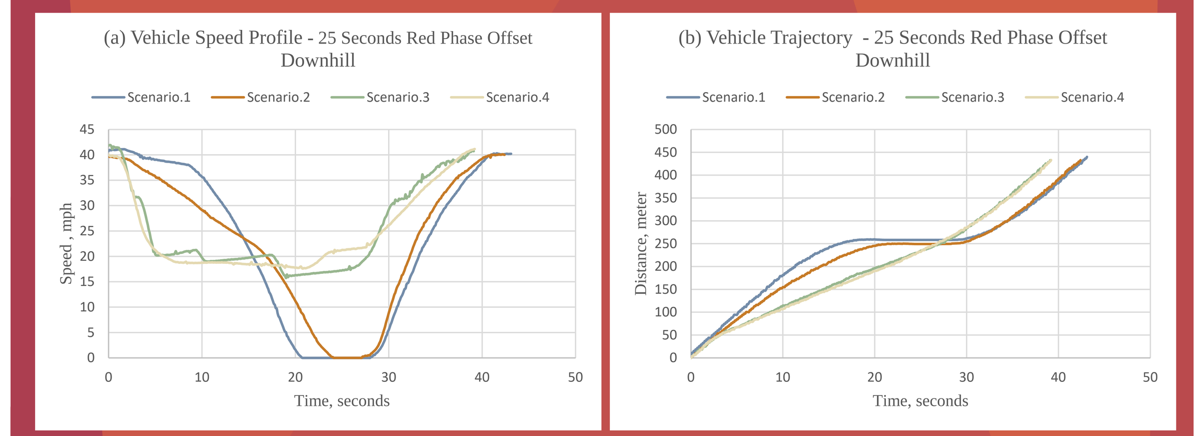


Figure.2 Both the manual and automated Eco-CACC systems improved the vehicle trajectory for all of the treatment combinations. In particular, it decreases acceleration and deceleration maneuvers and provides a smooth speed profile.

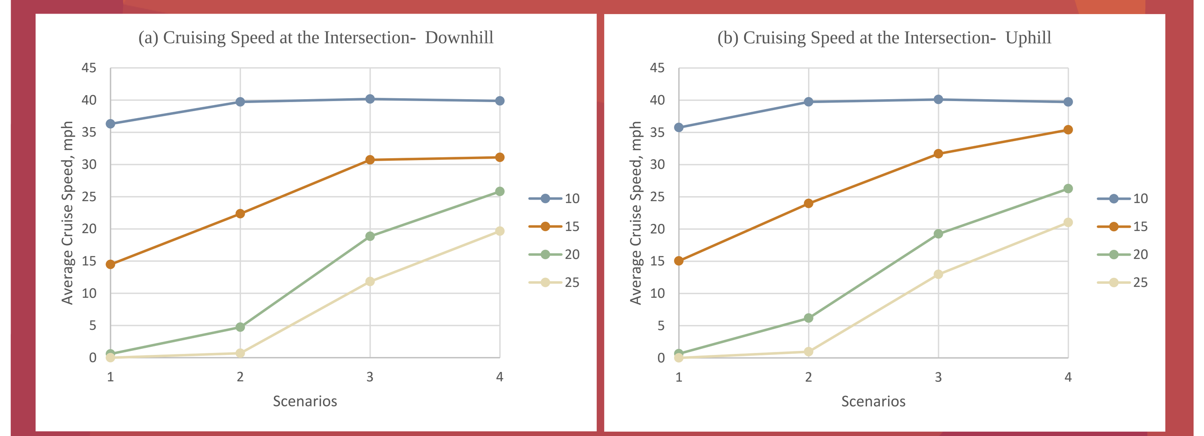


Figure.3 The average cruising speed continually increases from scenario 1 to 4, and generally scenario 4 has a higher speed than the other four scenarios for all the values of red phase offset.

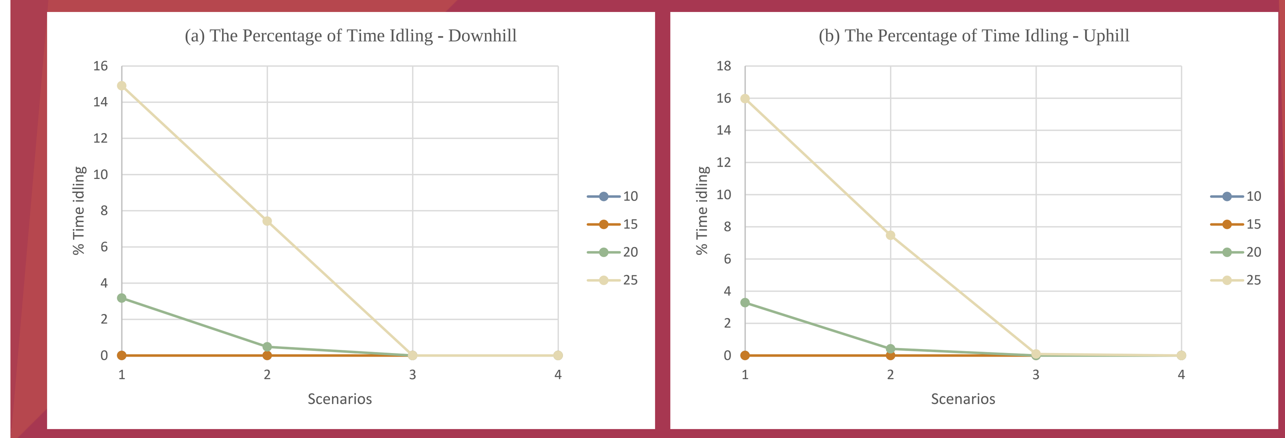


Figure.4 The percentage of time idling at the intersection continues reducing from scenario 1 to 4, and becomes zero at the third and fourth scenarios under all the values of red phase offset.

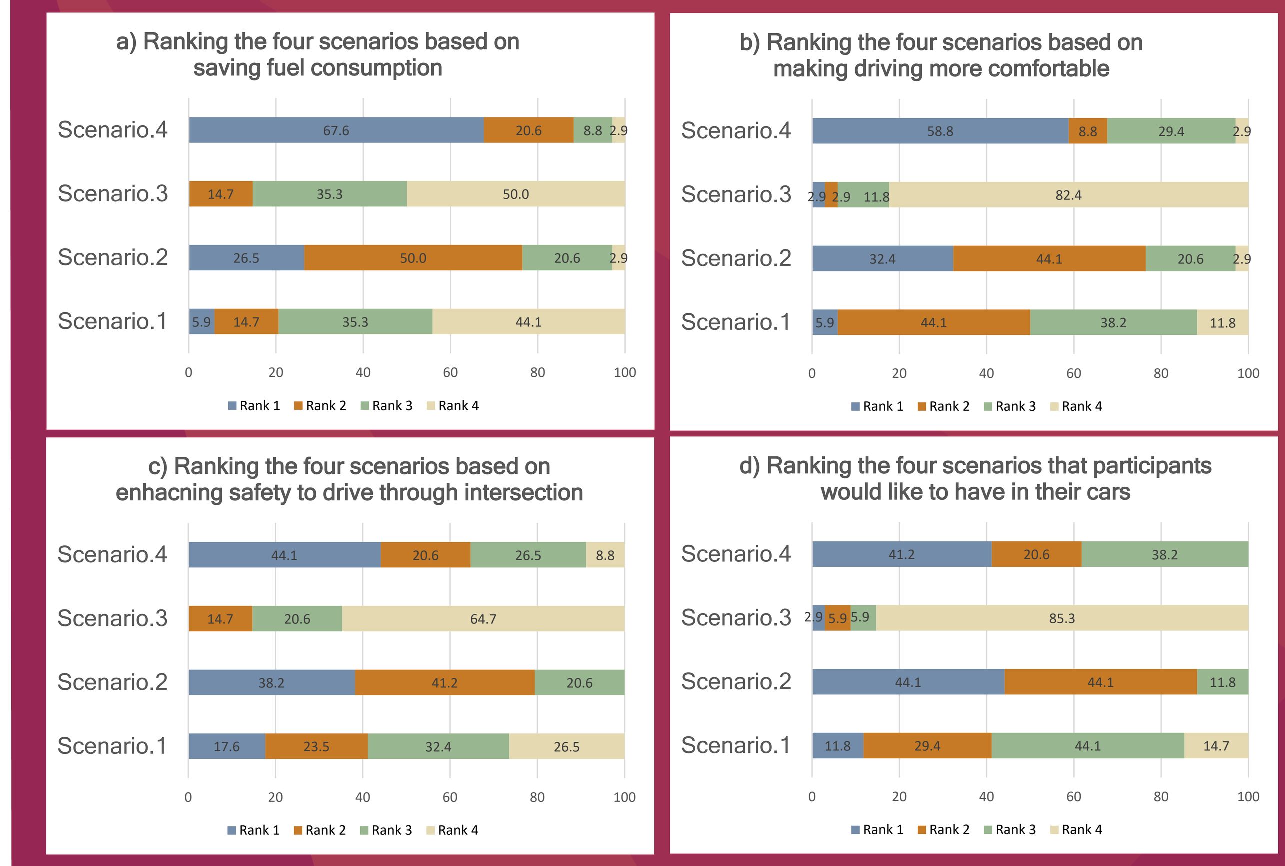


Figure.5 The participants ranking of the four scenarios.

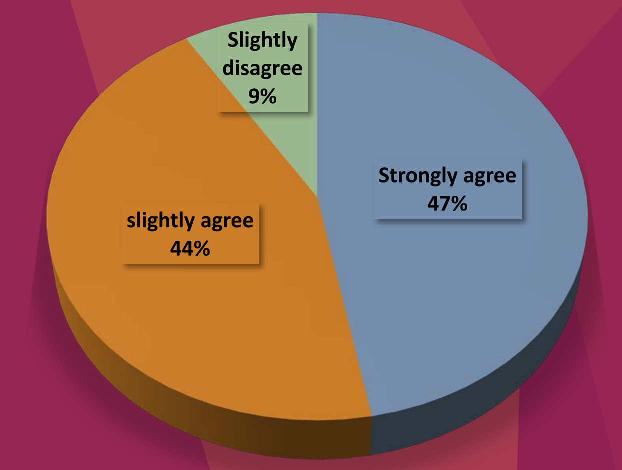


Figure.6 The participants-acceptance of the automated Eco-CACC system.

Conclusions

- The automated Eco-CACC system reduced fuel consumption levels and travel time by nearly 31 and 9 percent respectively ,on average.
- The manual Eco-CACC system reduced fuel consumption levels and travel time by nearly 13 and 8 percent.
- The Eco-CACC system reduced the waiting time at the intersection to zero.
- Survey's results show that the automated Eco-CACC scenario is the most preferred scenario among all the four, while the manual Eco-CACC system is the lowest preferred one.
- 91% of the participants supported adding the automated Eco-CACC system into their cars if it would save 10 to 15 percent in fuel consumption.