Intersection Management with Constraint-Based Reservation Systems

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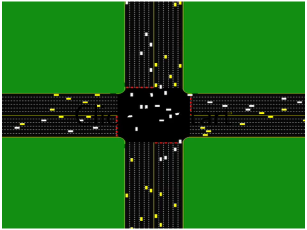
Intersection Management: Present and Future

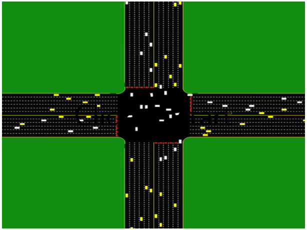
- Today's transportation infrastructure is designed for human drivers.
- In the future: **Autonomous Intersection Management**. Utilize the capacity of autonomous vehicles, as a large multi-robot system, to improve traffic in transportation systems.

Previous Work: Autonomous Intersection Management



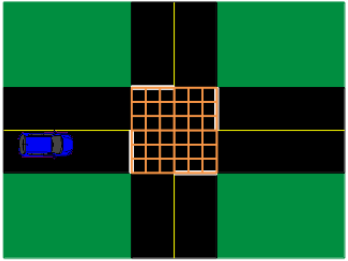
- Multi-agent approach. [Dresner and Stone, 2008].
- First Come First Serve (FCFS). Use Grid-Based Collision Detection.

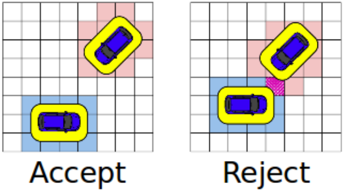
Previous Work: Autonomous Intersection Management

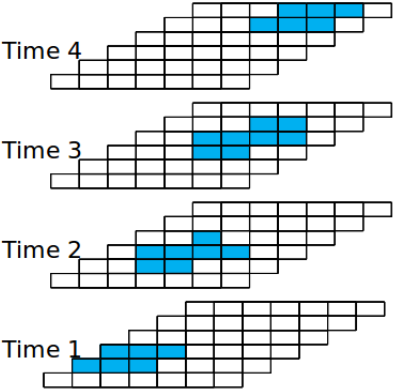


- Multi-agent approach. [Dresner and Stone, 2008].
- First Come First Serve (FCFS). Use Grid-Based Collision Detection.
- Dramatically reduce the traffic delay.
- Reduce the overhead of fuel consumption by approximately two thirds.

Grid-Based Collision Detection







Sharing the Road with Human Drivers

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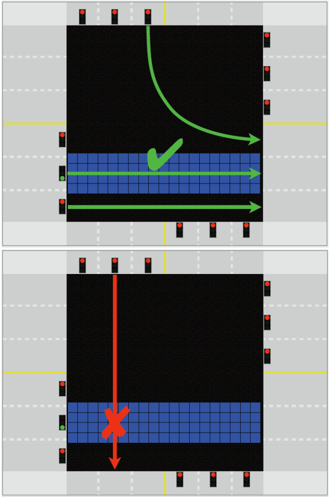
- Autonomous vehicles won't displace manual-controlled vehicles in one day. Some people enjoy driving.
- One solution: FCFS-Signal = First-Come First-Served Policy + Traffic Signals [Dresner and Stone, 2008]



Observation

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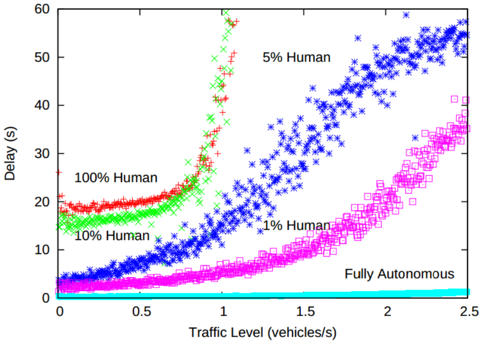

Observation

Goal: find a way to make all types of vehicles to achieve the benefits (better than traffic signal, may not be as good as 100% fully autonomous vehicles).

Definition

Semi-autonomous vehicles: vehicles with limited autonomous driving and wireless communication capabilities.

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They are able to follow a *limited number* of predictable trajectories at intersections more precisely than human drivers.

Set of Equipments

- **Communication Device (Com)**: a component in a vehicle's on-board electronic system that enables the vehicle to wirelessly communicate with the transportation infrastructure including the IM.

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- **Simple Cruise Control (CC)**: An optional speed control subsystem in vehicles' drivetrain that automatically controls the vehicle speed by taking over the throttle of the vehicles.
- **Adaptive Cruise Control (ACC)**: an advanced cruise control system that automatically adjusts the speed of a vehicle in order to maintain a certain distance from vehicles ahead.

Type of Semi-Autonomous Vehicles

Vehicle Type	Communication Device	Cruise Control	Adaptive Cruise Control
SA-ACC	X	X	X
SA-CC	X	X	
SA-Com	X		

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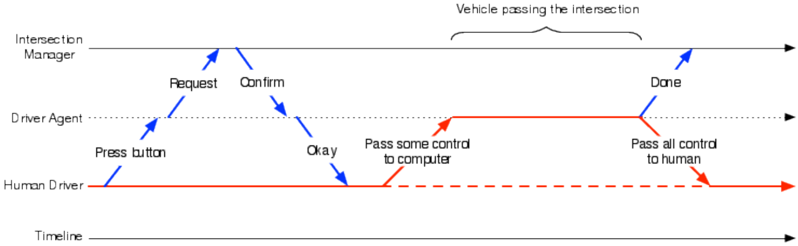

Figure: Adjustable Autonomy

Constraint-Based Reservation

We turn AIM into a *constraint-based reservation system*, which allows vehicles to make reservations in terms of constraints over

- their driving profiles such as their arrival time and arrival velocity
- the relationships with other vehicles.

Basic Elements

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- **Vehicle Type**: The type of vehicle.
- **Entry Condition**: The condition under which the vehicle will enter the intersection.
- **Acceleration Profile List**: The list of possible acceleration schedules from among which the vehicle will choose one to follow during the traversal of the intersection.

Constant-Velocity Request

- Intent $= (l_1 \vee l_2 \vee \ldots \vee l_n)$ in which l_i is a possible lane from which the vehicle exits the intersection;
- Type is the vehicle type;
- Entry $= ((l'_1 \vee l'_2 \vee \ldots \vee l'_n), [t_1,\ t_2], [v_1,\ v_2])$ is the entry statement; and
- AP $= (\langle (t_1, 0) \rangle)$

For the performance of Simple Cruise Control.

Whole-Row Request

- Intent $= (l_1 \vee l_2 \vee \ldots \vee l_n)$ l_i is a possible lane from which the vehicle exits the intersection;
- Type is the vehicle type;
- Entry $= ((l'_1 \vee l'_2 \vee \ldots \vee l'_n), [t_1,\ t_2], [v_1,\ v_2])$ is the entry statement; and
- AP is the acceleration profile list, and may not be provided.

For the performance of Communication Device.

Anchor Request

Semi-autonomous vehicles with adaptive cruise control can use a special constraint-based request called *anchor requests* to make reservations.

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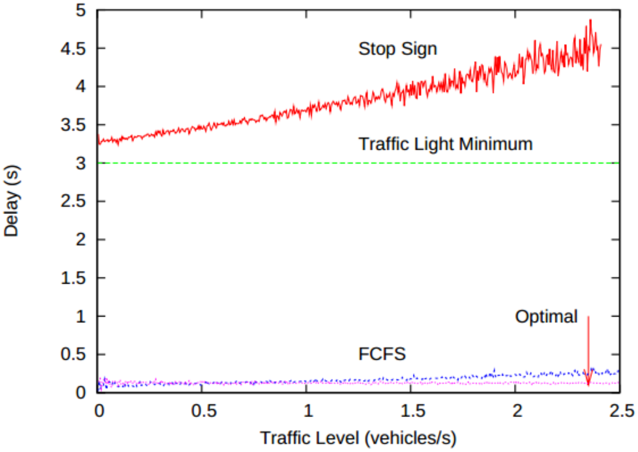
An anchor request is $\langle \text{Type}, \texttt{vin}, d \rangle$
For the performance of Adaptive Cruise Control.

A General Request

In Lisp syntax,

```
(cc-profile (v verror angle)
  (is-auto-speed-control)
  (not is-auto-steering)
  (< velocity (+ v verror))
  (> velocity (- v verror))
  (< steer-angle angle) (> steer-angle -angle))
```

Evaluation on AIM (Previous Work)



[Dresner and Stone, 2008]

Goal

Recall, our **goal**:

Goal

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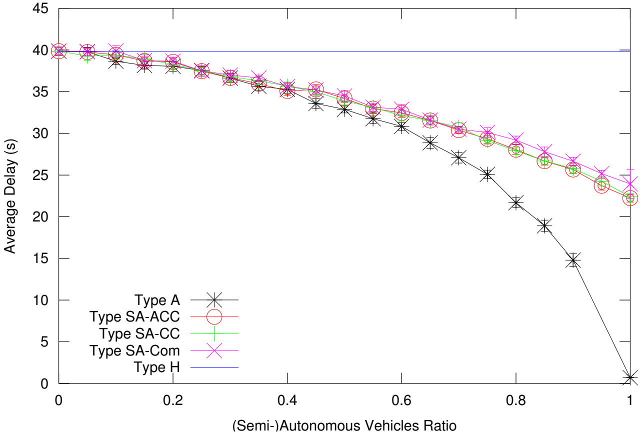
Implementation

Vehicle Type	Communication Device	Cruise Control	Adaptive Cruise Control
A	Fully Autonomous		
SA-ACC	X	X	X
SA-CC	X	X	
SA-Com	X		
A			

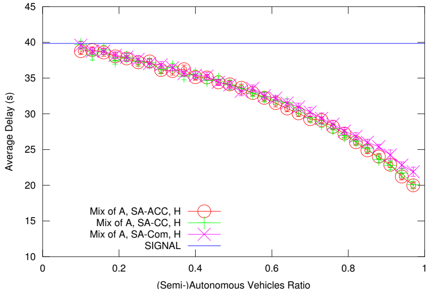
For each type of vehicle - always try the most *advanced* type of request first.

Evaluation on SemiAIM



(Semi-)Autonomous vehicles vs. Human-Driven vehicles. Traffic level = 360 vehicles/lane/hour.

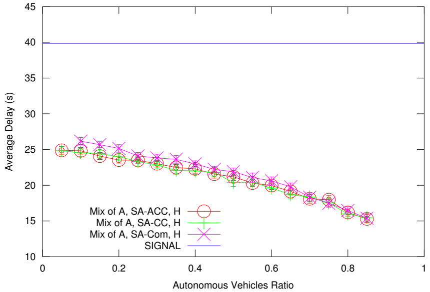
Evaluation on SemiAIM



Type H	SemiAuto	Type A
90%	9%	1%
87%	11%	2%
84%	13%	3%
...	...	...
0%	69%	31%

The average delay according to a deployment schedule. Traffic level = 360 vehicles/lane/hour.

Evaluation on SemiAIM



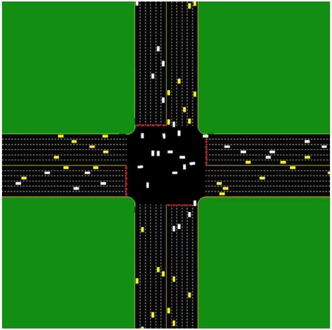
Type H	SemiAuto	Type A
10%	85%	5%
10%	80%	10%
10%	75%	15%
...	...	...
10%	5%	85%

The average delay according to a deployment schedule. Traffic level = 360 vehicles/lane/hour.

Related Works

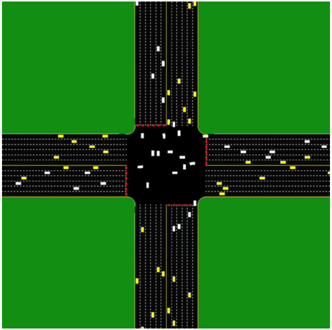
- The main context of our work is an extension to the FCFS policy proposed by Dresner and Stone [Dresner and Stone, 2008].
- Similar to the analysis of adaptive cruise control performance by Jerath and Brennan [Jerath and Brennan, 2010].
- Part of a series of robotic car competitions such as the *DARPA Grand Challenges* [DAR,].
- Jointly optimizing autonomous vehicles and road infrastructure, for example, the PATH program [Shladover et al., 1991].
- Vehicle-to-Vehicle (V2V) forms of autonomous intersection management [Naumann and Rasche, 1997, VanMiddlesworth et al., 2008].

Conclusion



- SemiAIM is the first multiagent protocol to enable smooth interactions between human-driven, fully autonomous, and semiautonomous vehicles.

Conclusion



- SemiAIM is the first multiagent protocol to enable smooth interactions between human-driven, fully autonomous, and semiautonomous vehicles.
- Our experiments showed that our system can greatly decrease trafc delay when most vehicles are semiautonomous, even when few (if any) are fully autonomous.

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