Developing Intersection Cooperative Adaptive Cruise Control System Applications

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I. Introduction & Objectives

- The presentation describes some of the research efforts being conducted by the CSM at VTTI in the area of Connected Vehicles
  - V2I/I2V Intersection CACC systems
    - Congestion mitigation systems
    - Green CACC systems
  - V2V CACC systems
    - Eco-drive systems
  - Developing and testing various in-vehicle technologies
  - Multi-modal connected vehicle systems
I. Introduction & Objectives

- As far as we know:
  - None of the previous approaches used an explicit optimization algorithm to reduce delay

- This research presents several research efforts with CACC at intersections:
  - Eco-vehicle speed advisory at signalized intersections
  - Queue estimation using probe data
  - Unsignalized Game Theory collision avoidance
  - Unsignalized delay optimization simulator
2. Eco-vehicle Speed Advisory

- I2V communication during red indication
- Optimum vehicle trajectory considers:
  - Upstream (deceleration to achieve desired delay)
  - Downstream (acceleration to original speed)
3. Queue Estimation along Arterials

- Current adaptive traffic signal control systems:
  - Not good at dealing with oversaturated conditions

- Major problems:
  - Data and logic in mitigating queue spillback effects

- Opportunity:
  - Probe data for the better estimation of queues and traffic stream speeds
4. Game Theory Collision Avoidance

- The proposed multi-agent system (MAS) approach consists of two types of agents:
  - Reactive agents (vehicles equipped by CACC) and
  - Manager agent (intersection controller).
- The proposed system involves the manager agent communicating with the reactive agents in the intersection study zone (ISZ).
- Thereafter, the manager determines the optimum movement for each reactive agent based on a "Game Theory Decision Framework".
34 Game Theory Collision Avoidance

- Make decisions each time step
- At each time step, the optimization process is divided into two main stages:
  1. Calculate the Conflict Zone Occupancy Time (CZOT) for each conflict area,
  2. Select a single vehicle to communicate some action that is computed using Game Theory.
- Progress in time to next time step and return to step 2
4. Game Theory Collision Avoidance

1. Calculate the Conflict Zone Occupancy Time (CZOT) for each conflict area:
4. Game Theory Collision Avoidance

2. Game Theory Optimization:

- The proposed cooperative game framework:
  - CACC-CG (Cooperative Adaptive Cruise Control - Cooperative Game).

- The outcome of the game is simply:
  - A speed change (acceleration, deceleration or constant) for a chosen vehicle that would produce the least total delay and eliminate conflicting movements (CZOT=0).
4. Game Theory Collision Avoidance

2. Game Theory Optimization (Continued):

The elements of the game:

<table>
<thead>
<tr>
<th>Elements</th>
<th>Description</th>
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<tbody>
<tr>
<td>Players (s)</td>
<td>The manager agent (intersection Controller) and the reactive agents (vehicles) existed in the ISZ at the current time step.</td>
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<tr>
<td>Actions (A)</td>
<td>The intersection controller: select one vehicle among the conflicting vehicles to change its speed profile;</td>
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<td>Information (I)</td>
<td>The information is symmetric and certain for all players.</td>
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<tr>
<td>Strategy (S)</td>
<td>The decision taken is the one corresponding to the maximum benefit for all players.</td>
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<td>Pay-off (U)</td>
<td>The summation of the total CZOT (conflict occupancy time) values and the total delay.</td>
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<tr>
<td>Outcome (O)</td>
<td>An optimum speed profile for each reactive agent (vehicle).</td>
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<td>Equilibrium ((\vec{\pi}))</td>
<td>The action combination which no player would be willing to change it.</td>
</tr>
</tbody>
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\[
U_{i,j} = \sum_{p=1}^{P} CZOT_{i,j} + \sum_{i=1}^{N} D_{i,j}
\]

Where, \(CZOT_{i,j}\) is the conflict zone occupancy time value; \(N\) is the total number of reactive agents (vehicles); and \(D_{i,j}\) is the delay value for each reactive agent corresponding to the action set \((i, j)\).
4. Game Theory Collision Avoidance

2. Game Theory Optimization (Continued):

The optimum decision taken by the players would be the action set that results in the minimum utility function (conflict zone and delay minimization).
5. Moving Horizon Delay Minimization

- This approach:
  - Seeks collision avoidance while at the same time minimizing the total delay at the intersection;
  - Reducing the fuel;
  - Account for weather and roadway conditions on driver and vehicle behavior; and
  - Uses vehicle physical characteristics
    - Considers the vehicle propulsive, braking and various resistance forces (aerodynamic, rolling, and grade resistance)
5. Moving Horizon Delay Minimization

- Vehicles modeled in three zones
  - Zone I, Zone II and the Intersection Box (IB)
5. Moving Horizon Delay Minimization

- The simulator manages the speed profile of each vehicle in Zone II to ensure that by the arrival at intersection box:
  - All vehicles are running at the maximum speed for the specific movement without stopping and certainly without conflicting with other vehicles.
5. Moving Horizon Delay Minimization

- The proposed framework was tested and compared to a traditional signal control:
  - Different levels of congestion (v/c ranging from 0.28 to 0.80) on a 4-legged intersection
  - The delay/vehicle was calculated for each scenario

![Bar chart showing comparison between Signal Control and CACC-I2 Control]
5. Moving Horizon Delay Minimization

A video sample of simulator output
6. Summary & Conclusions

- Automated vehicles are considered one of the future reliable intelligent transportation systems.
- With fully automated vehicles it is possible to replace traditional intersection control with more advanced systems.
- The research attempts to present an innovative approach for optimizing the movements of CACC vehicles.
- Further research is needed to conduct further testing and incorporation of non-equipped vehicles.
Thank You!