Evaluation of a new intelligent speed advisory system using hardware-in-the-loop simulation

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Motivation
- Intelligent Transportation Systems
- Methodologies for Evaluation
- Our proposal

The Proposed Advisory System
- First stage: Traffic scenario determination
- Second stage: Speed and distance recommendations

SUMO-phone Integration
- The simulation platform
- HIL capabilities

Experimental Results
- Simulation Setup
- Tests
- Graphical results
Transportation systems

- **TS**: vehicles + infrastructure + human component.

- **Problems**: congestion, carbon emissions, routing, safety.

- **Trivial solutions**: building additional capacity, incorporating new physical infrastructure.
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Braess's paradox

65 min 80 min

(Driver's travel time)
Intelligent Transportation Systems

- Intelligent solutions: Information Technologies + wireless communication systems.
- **Intelligent Transportation Systems (ITS)**: flexibility, adaptation, scalability, better-informed decisions.

**Intelligent Transportation Systems (ITS)**

- Advanced Traveler Information: Real-Time Traffic Information.
- ITS-based Transportation Pricing: Electronic Toll Collection.
- Advanced Public Transportation: Electronic Fare Payment.
- Fully integrated systems (VII + V2V integration): Intelligent Speed Adaptation.
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  - Static: fixed/localised speed limits.
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Methodologies for Evaluation

Real-world tests

- Pros:
  - Realistic results, straight conclusions.

- Cons:
  - Impractical: Availability and costs of required resources.
  - Risks of damage: vehicle collision, human injuries.

Simulation-based tests

- Pros:
  - Quicker, safer and cheaper tests.
  - More comprehensive tests (more quality).
  - Results easily reproducible.

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- **Traditional simulation:**
  - Ideal situations (sometimes not very realistic).
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- **Hardware-in-the-loop simulation:**
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- An dynamic advisory ISA system:
  - First stage: Traffic scenario determination supported on vehicle-to-vehicle (V2V) communication.
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- Evaluation using a off-line simulation:
  - The target vehicle and all the other vehicles are simulated.

The current work:

- Evaluation using a hardware-in-the-loop simulation:
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- Depends on both space and time.
- Thus, a reference in space and time is needed.

Next point of interest (NPI)

- The NPI is a spatial-temporal reference for the Host Vehicle (HV), i.e., a point in the future trajectory of the HV.
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Next Vehicle (NV)

The NV is a vehicle representing the NPI. It can be a real vehicle or a virtual vehicle.

Real NV

The nearest vehicle to the NPI inside a radius $r_N$.

Virtual NV

Placed at the NPI if no one vehicle is inside a radius $r_N$. 
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Vehicular density

It is estimated using information from V2V communication [3]:

\[ \delta = \frac{n_r + 1}{A} \]

\( n_r \) is the number of vehicles inside a radius \( r_D \), \( A \) is the “polling” area.

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SUMO-phone Integration

Experimental Results

Summary

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Polling area

If $2r_D \leq W_R$
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Finally...

Traffic scenario is determined with a rule-based inference engine:

- Inputs: density ($\bar{\delta}_H, \bar{\delta}_N$) and speed ($\bar{V}_H, \bar{V}_N, \Delta \bar{V}_H$) information.

- Outputs: Free Traffic (FT), Approaching Congestion (AC), Congested Traffic (CT), Passing Bottleneck (PB) and Leaving Congestion (LC).

- 28 IF-THEN rules:

  \[ R_9: \text{IF } \bar{V}_H, \bar{V}_N, \bar{\delta}_N \text{ are LOW and } \bar{\delta}_H \text{ is HIGH and } \Delta \bar{V}_H \text{ is NEG} \]

  \[ \text{THEN } (\text{CT is YES and FT, AC, PB, LC are NOT}) (1.0) \]

Then, the scenario is given by:

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Virtual vehicle dynamic

Position of the Virtual NV is given by the NPI, but... what about its speed?

The speed model

A simple model is used:

\[ V(t) = \alpha V(t - 1) \]

In our case we have:

\[ V_N(t) = \min(\alpha_{NV}(t), V_N(t - 1), \text{Speed limit}) \]

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Second stage: Speed and distance recommendations

Recommended speed

Our speed recommendation is a time-variant weighted sum of $V_H$ and $V_N$:

$$V_R(t) = \alpha_R(t) V_N + (1 - \alpha_R(t)) V_H$$

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**Safe distance**

Distance recommendation is based on a policy for safe distance:

\[
D_R (t) = h_0 + h_1 V_H (t) + h_2 (V_H^2 (t) - V_N^2 (t))
\]

- \(h_0\) is the minimum safe distance,
- \(h_1\) is the reaction driver time,
- \(h_2\) is a design parameter.

**Distance recommendation**

Finally, we use \(e = D_{H-V} - D_R\) and the following convention for the distance recommendation:

- If \(e > 0\), then distance is OK.
- If \(-1m < e \leq 0\), then distance is “Close”.
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Hardware-in-the-loop simulation

- A HIL simulation to evaluate the performance of the proposed advisory system.
Hardware-in-the-loop simulation

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The basic components
Hardware-in-the-loop simulation

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Hardware-in-the-loop simulation

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The basic components
Interconnection of components
Interconnection of components
Interconnection of components

- A diagram showing the interconnection of components:
  - PC
  - Python
  - Main
  - SUMO
  - Matlab

- A car model is also depicted on the right side of the diagram.
Interconnection of components
Interconnection of components
Icons for recommendations

Traffic scenarios:
- FT
- AC
- CT
- PB
- LC

Distance recommendation:
- OK
- Close
- Very close

Recommended Speed

HMI

Distance recommendation
Traffic scenario

Current speed
Recommended speed

Hello, SUMO!
Goodbye, SUMO!
SUMO

The road: A street circuit around the North Campus, National University of Ireland - Maynooth.

Parameters

- Simulated vehicles: 23.
- Attributes of vehicles:

<table>
<thead>
<tr>
<th>Type</th>
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<th>B</th>
<th>C</th>
<th>D</th>
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<td>4.54</td>
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<tr>
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Simulation Setup

Smartphone

The phone:
- Samsung Galaxy S III mini (GT-I8190N),
- Android Jeally Bean (V 4.1.2), Torque Pro.

The updating rate: 1 second.

Host Vehicle

The real vehicle:
2008 Toyota Prius 1.5 5DR Hybrid Synergy Drive.

The OBD2 adaptor: Kiwi Bluetooth (PLX devices).
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A video

Test with a real car
Following/ignoring the recommendations
Summary

- HIL simulation let us evaluate non-obvious issues:
  - frequency/format of recommendations,
  - technical problems (e.g. synchronisation),
  - evaluation in risk conditions using a scenario under control.

Future work

- general paper: detailed setup, more illustrative examples.
R.H. Ordonez-Hurtado et al.
Intelligent Speed Advising Based on Cooperative Traffic Scenario Determination.
Lecture Notes in Control and Information Sciences, Springer, accepted.

W.M. Griggs and R.N. Shorten.
Embedding Real Vehicles in SUMO for Large-Scale ITS Scenario Emulation.
Accepted in ICCVE 2013.

L. Garelli, C. Casetti, C. Chiasserini, and M. Fiore.
Mobsampling: V2V communications for traffic density estimation.