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

R.H. Ordóñez-Hurtado[1] W.M. Griggs[1] K. Massow[2] R.N. Shorten[1,3]

[1]The Hamilton Institute, National University of Ireland Maynooth, Co. Kildare, Ireland

[2]Fraunhofer FOKUS, Berlin, Germany

[3]IBM Research Ireland, Dublin, Ireland

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1. Motivation
   - Intelligent Transportation Systems
   - Methodologies for Evaluation
   - Our proposal
2. The Proposed Advisory System
   - First stage: Traffic scenario determination
   - Second stage: Speed and distance recommendations
3. SUMO-phone Integration
   - The simulation platform
   - HIL capabilities
4. 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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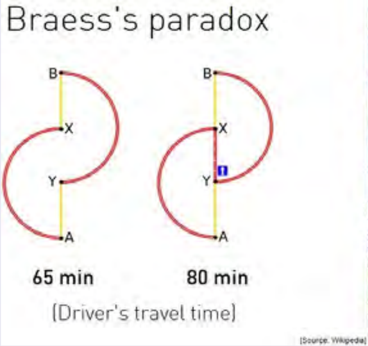

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- Intelligent solutions: Information Technologies + wireless communication systems.
  - **Intelligent Transportation Systems (ITS):** flexibility, adaptation, scalability, better-informed decisions.

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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- 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.
- Cons:
  - Accurate mathematical models/representations are required.
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Type of simulations

- **Traditional simulation:**
  - Ideal situations (sometimes not very realistic).
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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)

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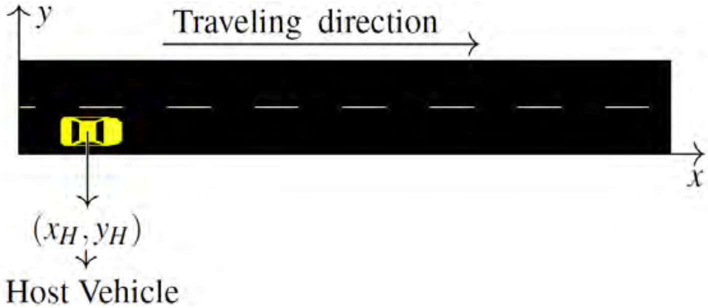

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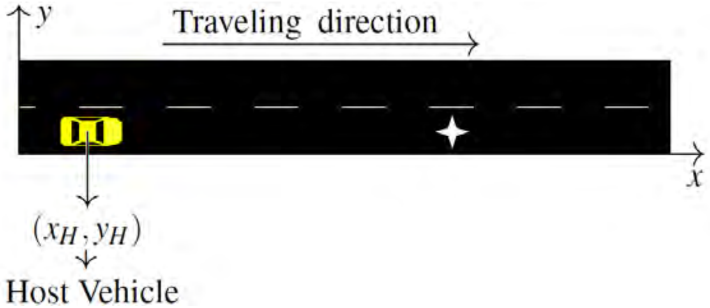

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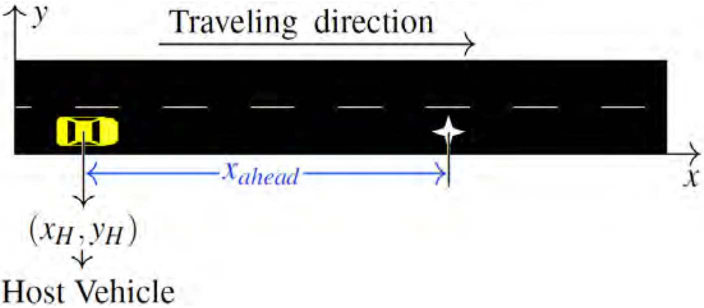

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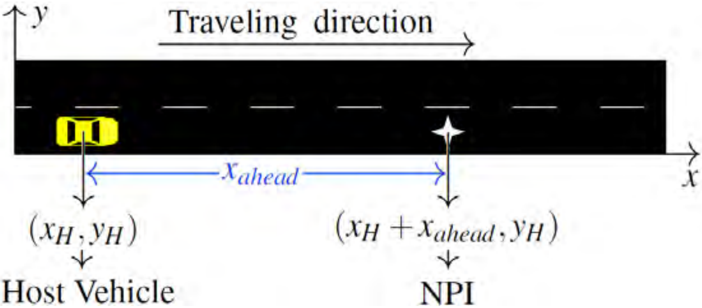

Next Vehicle (NV)

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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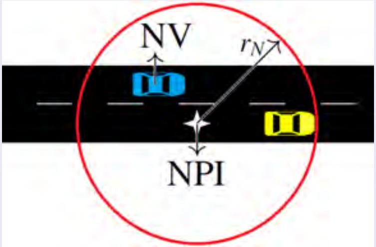

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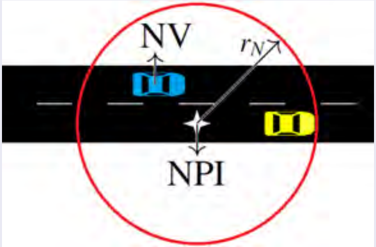

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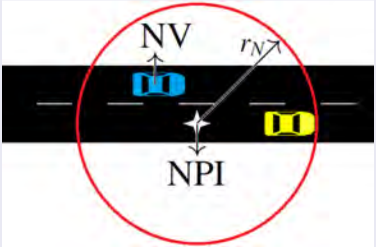

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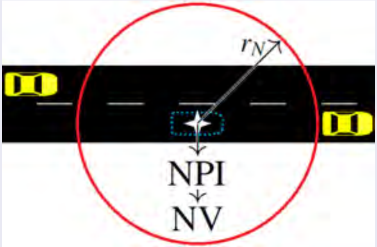

Vehicular density

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

$$\delta = \frac{n_r + 1}{A}$$

n_r is the number of vehicles inside a radious r_D, A is the "polling" area.

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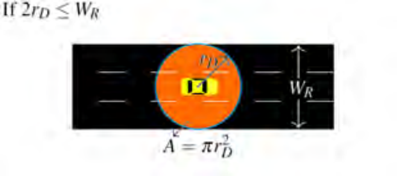

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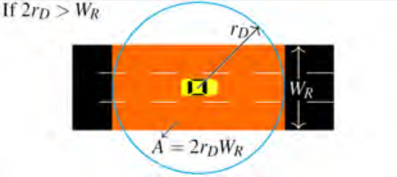

Finally...

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:

$$\underline{R_9}: \textbf{IF} \quad \bar{V}_H, \bar{V}_N, \bar{\delta}_N \text{ are LOW } \textit{and } \bar{\delta}_H \text{ is HIGH } \textit{and } \Delta\bar{V}_H \text{ is NEG}$$

$$\textbf{THEN} \quad (\text{CT is YES} \quad \textit{and} \quad \text{FT, AC, PB, LC are NOT})\ (1.0)$$

Then, the scenario is given by:

$$T = \text{argmax}(\text{FC}, \text{AC}, \text{CT}, \text{PB}, \text{LC})$$

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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:

$$V_N(t) = \min\left(\alpha_{NV}(t)\, V_N(t-1), \text{Speed limit}\right)$$

Traffic scenario	FT	AC	CT	PB	LC
α_{NV}	1.4	0.7	0.9	0.9	1.4

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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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α_R	0.7	0.7	0.7	0.45	0.7

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

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α_R	0.7	0.7	0.7	0.45	0.7

Safe distance

Distance recommendation is based on a policy for safe distance:

$$D_R(t) = h_0 + h_1 V_H(t) + h_2 \left(V_H^2(t) - V_N^2(t)\right)$$

- 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 $-1\text{m} < e \leq 0$, then distance is "Close".
- If $-2\text{m} < e \leq -1\text{m}$, then distance is "Very close".

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Hardware-in-the-loop simulation

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

The basic components

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The basic components

Interconnection of components

Interconnection of components

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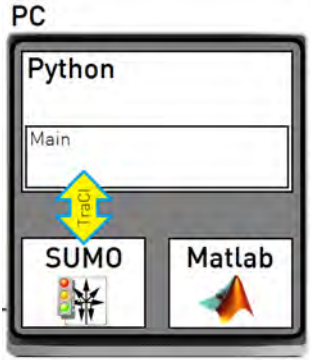
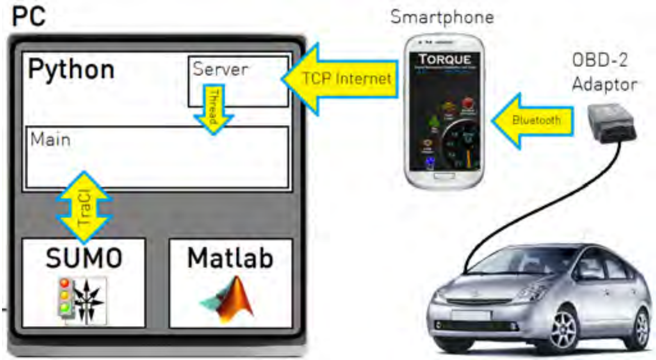


Interconnection of components



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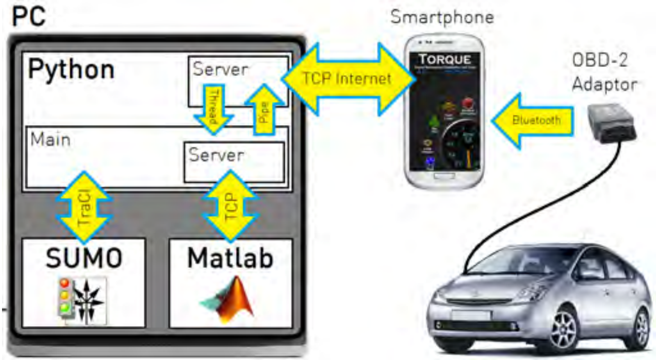
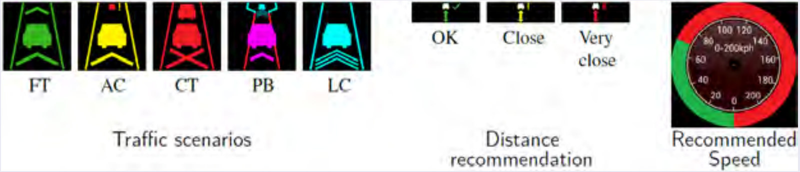
Interconnection of components



HIL capabilities

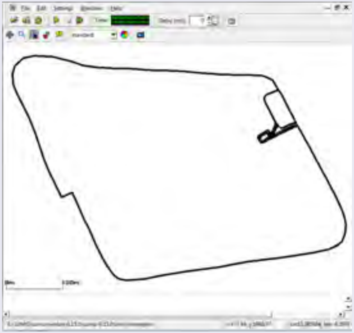
Icons for recommendations



HMI

SUMO

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



Parameters

- Simulated vehicles: 23.
- Attributes of vehicles:

Type	A	B	C	D
Accel	2.15	5.5	4.54	50
Decel	1.22	5.0	4.51	30
Length	1.75	6.1	4.45	40
Max.S.	2.45	6.1	4.48	50

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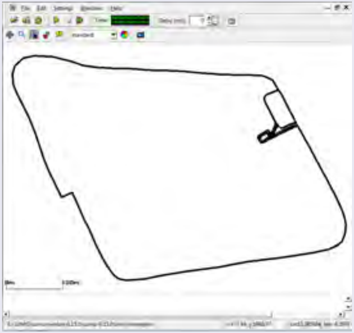

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The phone:

- 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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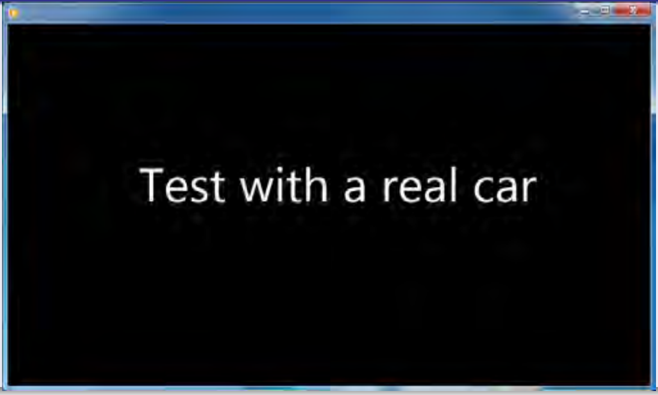
A video



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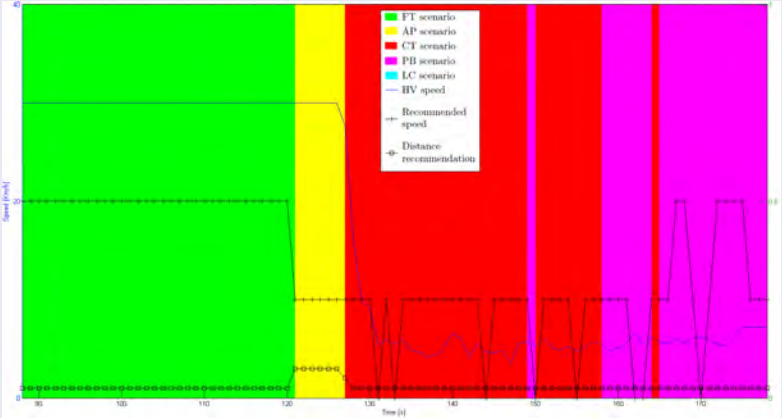
Following/ignoring the recommendations



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 etal.
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.
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Accepted in ICCVE 2013.

L. Garelli, C. Casetti, C. Chiasserini, and M. Fiore.
Mobsampling: V2V communications for traffic density estimation.
In 2011 IEEE 73rd Vehicular Technology Conference (VTC Spring), Budapest, Hungary, May 15-18 2011.