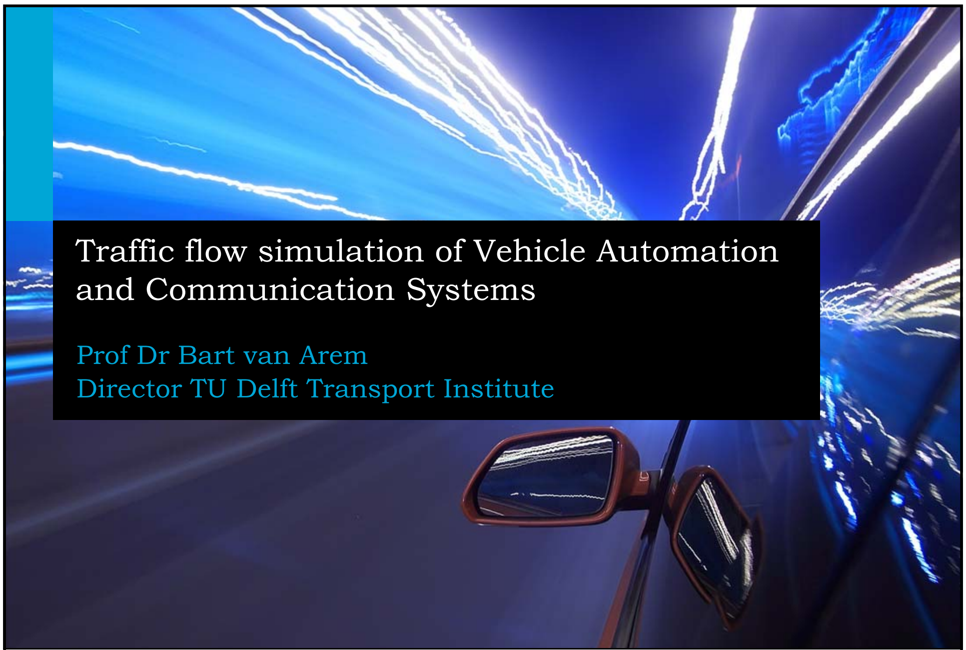


# Traffic flow simulation of Vehicle Automation and Communication Systems

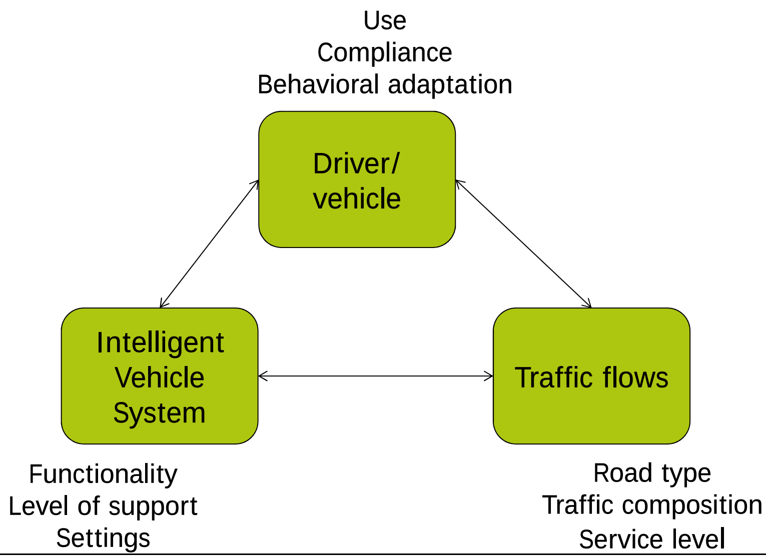
Prof Dr Bart van Arem
Director TU Delft Transport Institute



# Career summary

| | |
|---|---|
| 1982-1990 | MSc and PhD Applied Mathematics, University of Twente |
| 1991-2009 | TNO Netherlands Organization of Applied Scientific Research |
| 2003-2012 | Full professor (0,4 fte) Applications of Integrated Driver Assistance, University of Twente |
| 2009- present | Full Professor of Transport Modelling and Chair Department Transport & Planning, Faculty of Civil Engineering and Geosciences at TU Delft<br>Director TU Delft Transport Institute |

# Main field of interest






# Career highlights – so far

1996: Will ACC improve safety without sacrificing capacity?

Demo 98 Rijnwoude

IEEE Intelligent Vehicles 2008




# Career highlights- so far

# Content

- High level picture: the frontiers of automated driving
- Traffic flow simulation requirements and tools
- Congestion Assistant
- Connected Cruise Control
- Driver alert
- Cooperative Driving
- Outlook



# Automated driving in 1976….

# What is automated driving?

Partial automation

High automation

Full automation



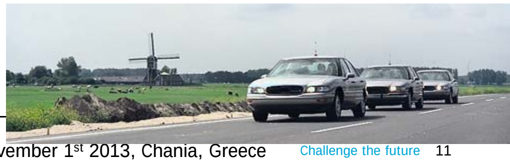
# High automation

# State of practice- supported driving

- Integrated Adaptive Cruise Control, Lane Keeping and Driver Monitoring commercially available
- High-end segment, low penetration rate

# State of art – automated driving

- Hands-off, feet-off and brain-off driving
- Research prototypes (numerous)
- Special permits, special drivers, dedicated tracks





# Potential impacts

Better travel experience

Solve traffic jams by increased outflow

Prevent traffic jams by better stability

Better distribution of traffic over network

No accidents


Less congestion delay

Better energy efficiency

# Challenges in Automated Driving

- Human factors
  - The remaining role of the driver (if any)
  - Safe transition of control
  - Acceptance
  - Perceived safety
- Technology
  - Reliable Environment Perception - Sensing
  - Robust / fail safe control – Algorithms
  - System safety
  - Integration with traffic management
- Legal
  - Type approval
  - Liability
- Public awareness & acceptance
  - Demonstrations




# Frontiers that were no frontiers….

- Electronic braking
- Adaptive Cruise Control (including braking)
- Lane Keeping
- Adaptive Cruise Control and Lane Keeping
- Automatic Emergency braking

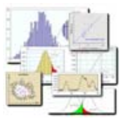
## Geneva Convention on Road Traffic, European Member States Article 8.5

" Drivers shall at all times be able to control their vehicles or guide their animals. When approaching other road users, they shall take such precautions as may be required for the safety of the latter."



## The road to automated driving…

Collect, analyse and publish large scale real-world experience



Case studies for regional transport networks

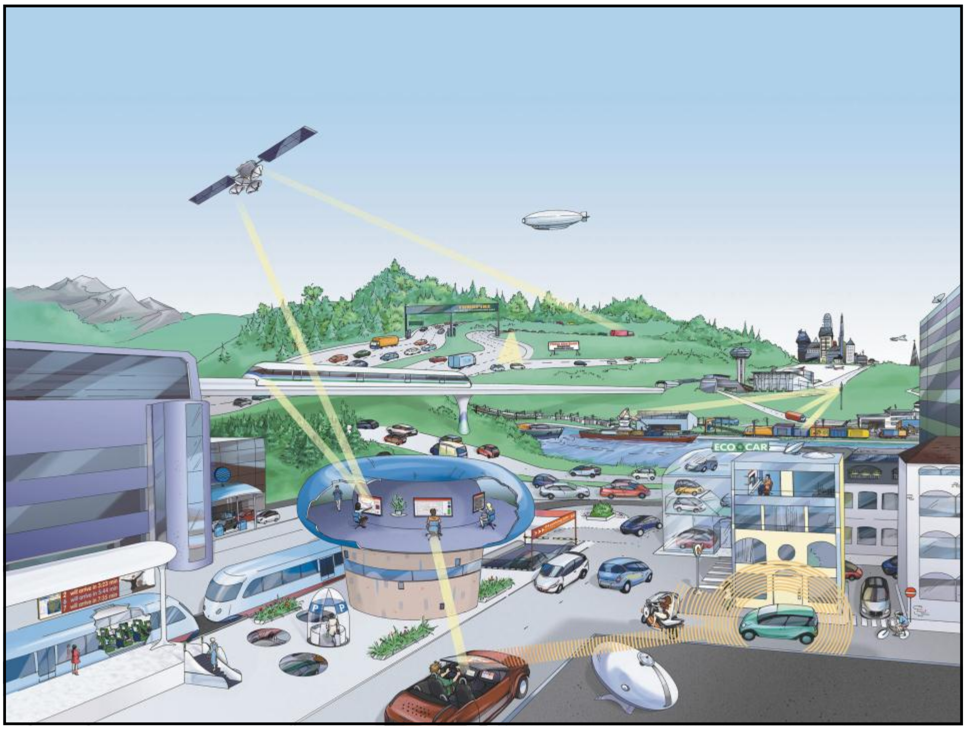
Regulations, type approval


Awareness, ambitions, expectations, reality checks

# Content

- High level picture: the frontiers of automated driving
- Traffic flow simulation requirements and tools
- Congestion Assistant
- Connected Cruise Control
- Driver alert
- Cooperative Driving
- Outlook

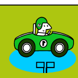




# Many choices to make…


Floating Car Data

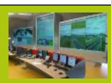

Sensor networks


Loop detectors

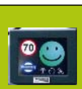
Collect

$$q_i = \min\{n_{i-1}, Q_i, \alpha(N_i - n_i)\}$$
$$\alpha = \begin{cases} 1 & n_{i-1} < n_i \text{ or } n_{i-1} < Q_i \\ w/v & \text{otherwise} \end{cases}$$

Traffic state estimation and prediction


Assessment of alternative actions

Process


In-vehicle information

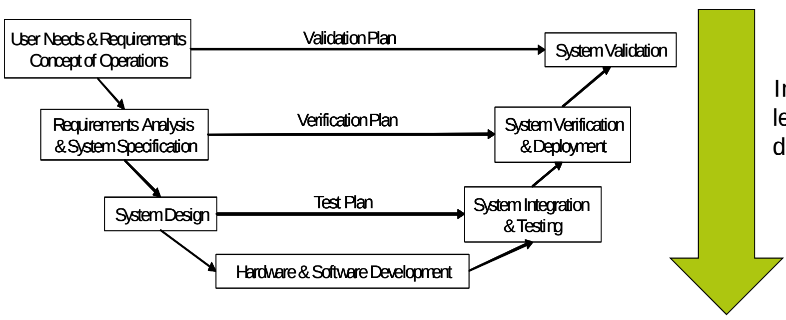

Vehicle control


Road based Information

Act



# Systems engineering V model



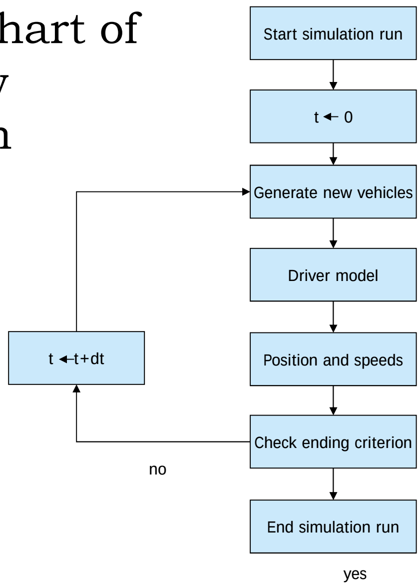

Increasing level of detail

# Microscopic traffic flow simulation

- Computer imitation of traffic flows based on hypothesized behaviour of driver-vehicle combinations
- Cheaper and safer than real-world pilots
- Useful to support design choices of new systems
- Realism limited by realism of hypothesized driver-vehicle combinations.



# Generic flow chart of traffic flow simulation



# Considerations for using simulation

- Level of detail
  - Microscopic: vehicle/driver combinations
  - Submicroscopic: vehicle and driver models
- Time step (0.01-1 s)
- Scale
  - 1-2 up to 10.000 vehicles
  - 500 m up to 10 km
- Type of network (motorway, rural, urban)
- Software
  - Single multiple use
  - Openness, availabiality
- Experimental set up
  - Reference case (calibration, validation)
    - Speed, flow, density; congestion formation and propagation
  - Replications



# Autonomous Intelligent Cruise Control can improve traffic safety without sacrificing capacity (Mauro, 1992)

Does it?

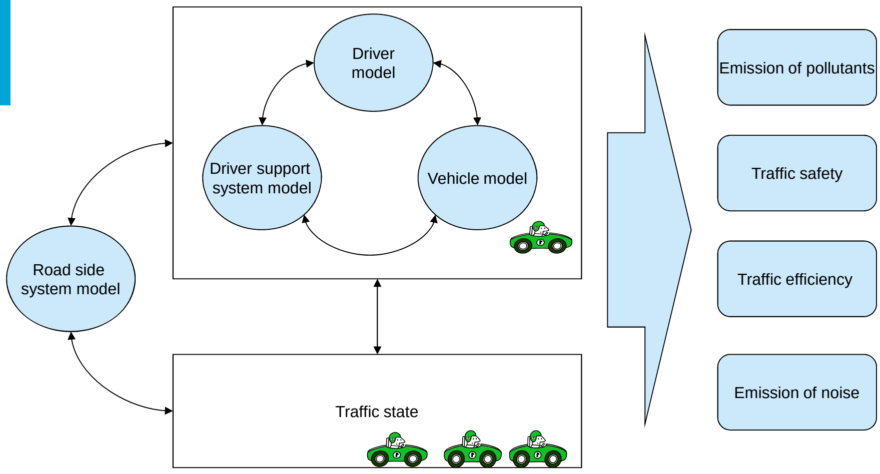
# Mauro (1992)

| AICC target headway (s) | perc. AICC (%) | maximal density (veh/km) | maximal traffic volume (veh/h) |
|---|---|---|---|
| - | 0 | 51 | 3365 |
| 0.6 | 40 | 59 | 4073 |
| 1.0 | 40 | 56 | 3873 |
| 1.5 | 40 | 51 | 3381 |
| 2.0 | 40 | 44.5 | 3060 |
| 1.0 | 20 | 55 | 3613 |



# MIXIC framework

Object oriented, ANSI-C



# Driver model features

- Car following (Helly including multi-anticipation)
- Free lane changing/mandatory lane changes (including gap forcing and courtesy)
- Perceptual thresholds (based on angular speed)
- Gear shifting, gas pedal and brake pedal modelling



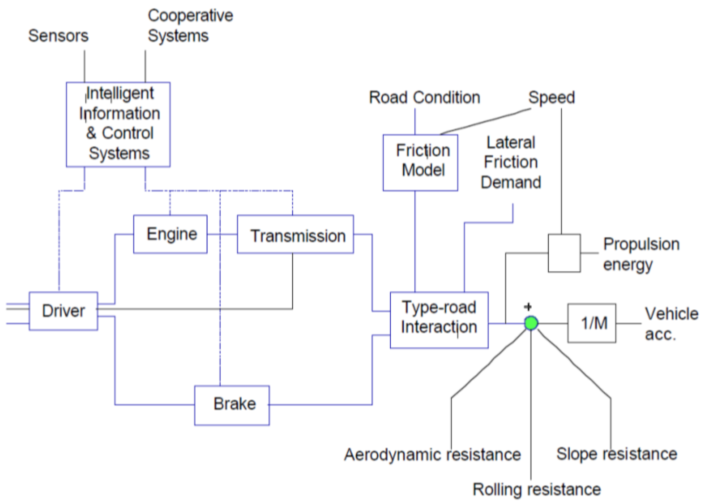
# Human car following

| | | |
|---|---|---|
| d_ref | $= c_1 + c_2 * v + c_3 * v^2$; | [A2] |
| d_err | $= d(t-t_r)$ -d_ref; | [A3] |
| a_ref_d | = cd * d_err + cv_p * v_dif_p($t-t_r$) + cv_pp * v_dif_pp($t-t_r$) | [A4] |

where:

| | |
|---|---|
| a_ref_d | = driver's intended acceleration for car-following [m/s$^2$] |
| d_ref | = the desired distance headway as a function of speed [m] |
| $c_1, c_2, c_3$ | = constants (set at 3, 0.25, and 0.02, respectively) (3, 0.25, 0.01) |
| d_err | = deviation from desired distance [m] |
| d($t-t_r$) | = distance headway at current time minus $t_r$ [m] |
| v_dif_p($t-t_r$) | = relative speed to predecessor [m/s] at current time minus $t_r$ |
| v_dif_pp($t-t_r$) | = rel. speed to pre-predecessor [m/s] at current time minus $t_r$ |
| cd | = constant factor for distance deviation 0.3 |
| cv_p | = constant factor for speed deviation predecessor 1.5 |
| cv_pp | = constant factor for speed deviation pre-predecessor 0.2 |

# Vehicle model

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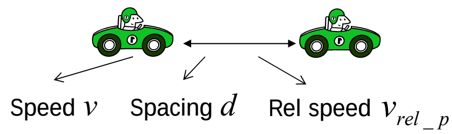
# Adaptive Cruise Control model

Regular cruise control

$$a_{ref\_v} = r_{st} \cdot (v_{ref} - v)$$




Distance keeping

$$d_{ref} = d_0 + t_{ref} \cdot v$$

Speed synchronization

$$a_{ref\_d} = k_d \cdot (d - d_{ref}) + k_v \cdot v_{rel\_p}$$

$$a_{ref\_ACC} = \min(a_{ref\_v}, a_{ref\_st})$$

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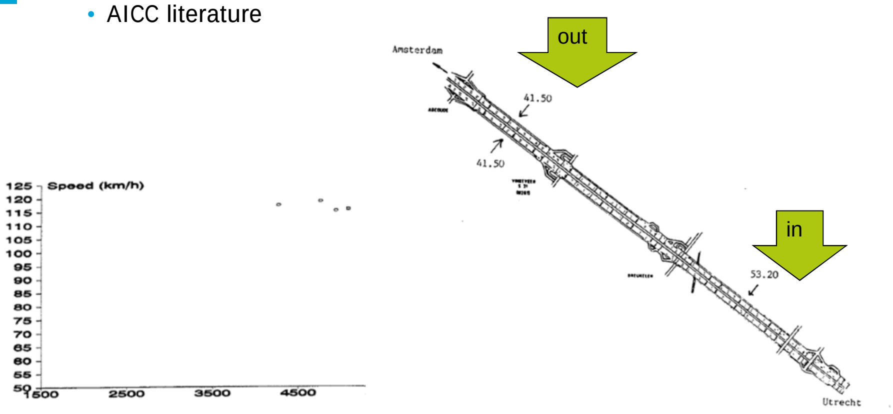
# Calibration and validation

- Driver, vehicle and AICC model parameters
  - Test drives real world, simulator
  - Real vehicle parameters (Opel Astra, VW Van and Volvo truck)
  - AICC literature

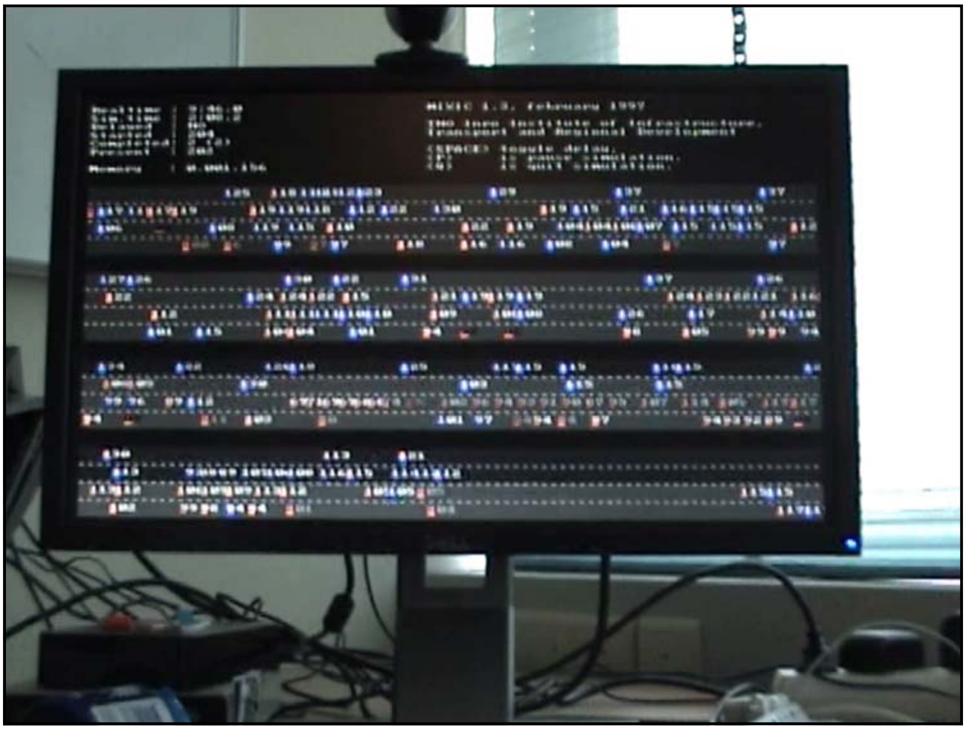





# MIXIC applications

- Adaptive Cruise Control (1994)
- Fog warning (1996)
- Road trains (1996)
- Special lane for Intelligent Vehicles (1997)
- Energy friendly variable cruise control (1997)
- Cooperative following (1999)
- Cooperative merging (1999)
- External cruise control (2002)
- V2V communication Cartalk (2004)
- Chauffeur Assistant (2004)
- Cooperative Adaptive Cruise Control (2006)

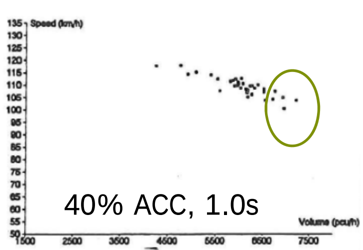
Google scholar:
10 documents
220 citations
H index 7
Best paper cited 107 times

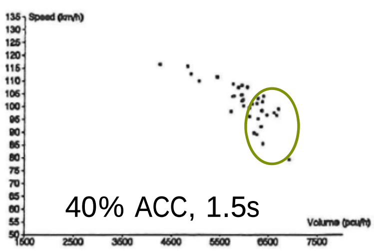


# Potential impact of ACC: traffic flow simulations

| Headway s | Pen % | Dmax veh/km | Gain % | F max veh/h | Gain % |
|---|---|---|---|---|---|
| - | | 51 | | 3365 | |
| 0.6 | 40 | 59 | +16 | 4073 | +31 |
| 1.0 | 40 | 56 | + 10 | 3873 | +15 |
| 1.5 | 40 | 51 | 0 | 3381 | +1 |
| 2.0 | 40 | 45 | -13 | 3060 | -9 |
| 1.0 | 20 | 55 | +8 | 3613 | +7 |

2 lane motorway
Mauro (1992)




3 lane motorway Van Arem, Hogema & Smulders (1996)

# Results

| Quantity | no AICC | 20% AICC (1.0) | 20% AICC (1.5) | 40% AICC (1.0) | 40% AICC (1.5) |
|---|---|---|---|---|---|
| Average travel time (s) | 33.46 | 33.67 (x) | 34.27 (x) | 34.91 (x) | 39.20 (x) |
| Stand. dev. travel time (s) | 3.70 | 3.64 (x) | 3.66 | 3.58 (x) | 6.55 (x) |
| Average speed (km/h) | 109.51 | 108.72 (x) | 106.97 (x) | 107.95 (x) | 97.09 (x) |
| Stand. dev. speed (km/h) | 11.26 | 11.09 (x) | 11.16 | 10.82 (x) | 14.53 (x) |



# Content

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- Connected Cruise Control
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## The congestion assistant

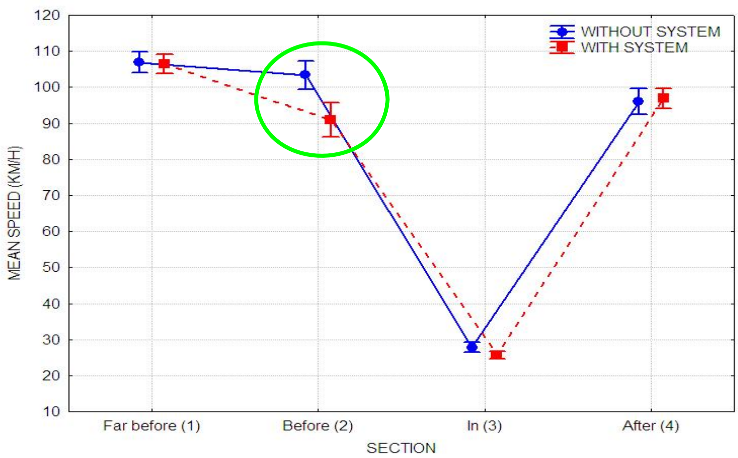
- Detects downstream congestion
- Visual and auditive warning starting at 5 km before congestion
- Active gas pedal at 1,5 km to smoothly slow down
- Takes over longitudinal driving task during congestion




## Impacts on driving behaviour

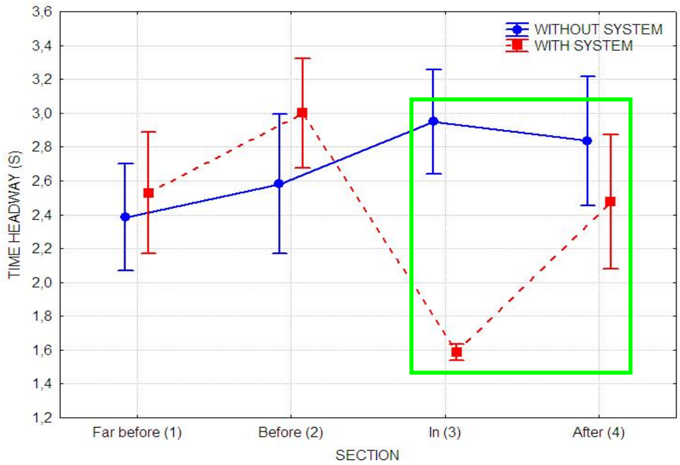
Motorway scenario with congestion
Impacts on driving behaviour
Acceptance

# Effects on mean speed






# Effects on time headway



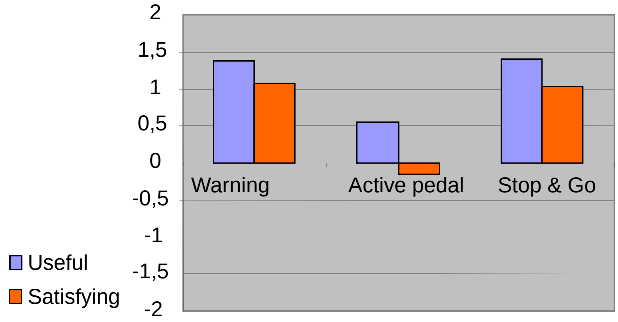

May 31, 2006



Applications of 40

## Acceptance (van der Laan scale)

- Van der Laan scale
- Warning and Stop & Go most accepted
- More useful than satisfying

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## Commercial traffic flow simulation

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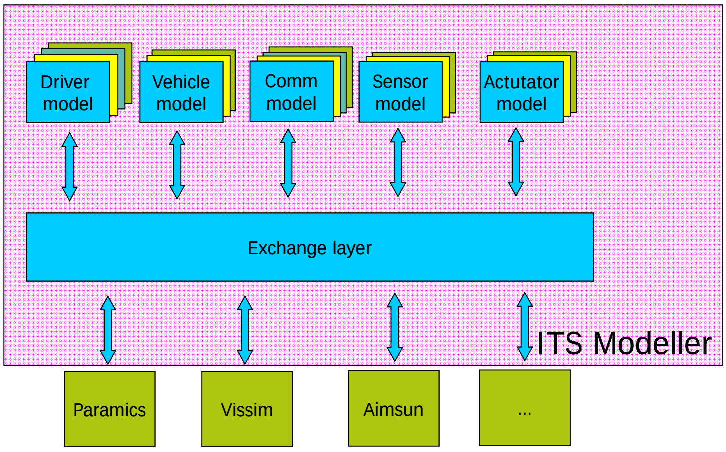
# ITS Modeller






# Longitudinaal bestuurdersmodel

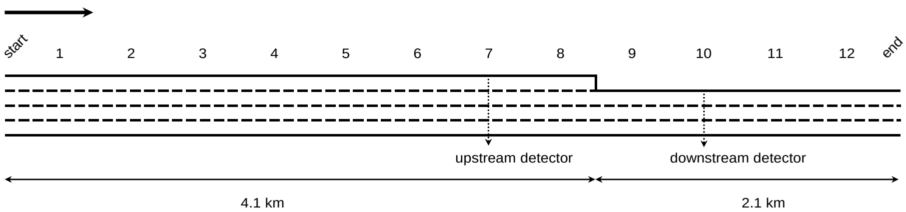
$$a_{ref\_v} = r \cdot (v_{ref} - v)$$

$$a_{ref\_d} = c_d \cdot (d(t-t_r) - d_{ref}) + c_{v\_p} \cdot v_{rel\_p}(t-t_r) + c_{v\_pp} \cdot v_{rel\_pp}(t-t_r)$$

$$d_{ref} = c_1 + c_2 \cdot v + c_3 \cdot v^2$$

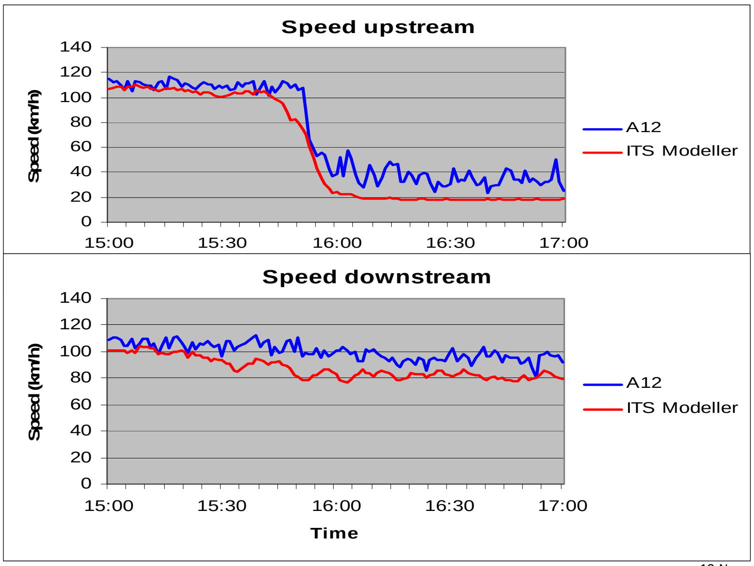
13 November 2009
44

# Study area: merging area A12 motorway, Woerden, the Netherlands






# Calibratie




13 November 2009
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# Model file assistent

Actief gaspedaal: $a_{ac} = \dfrac{v_j^2 - v^2}{2 \cdot x}$

Stop & Go

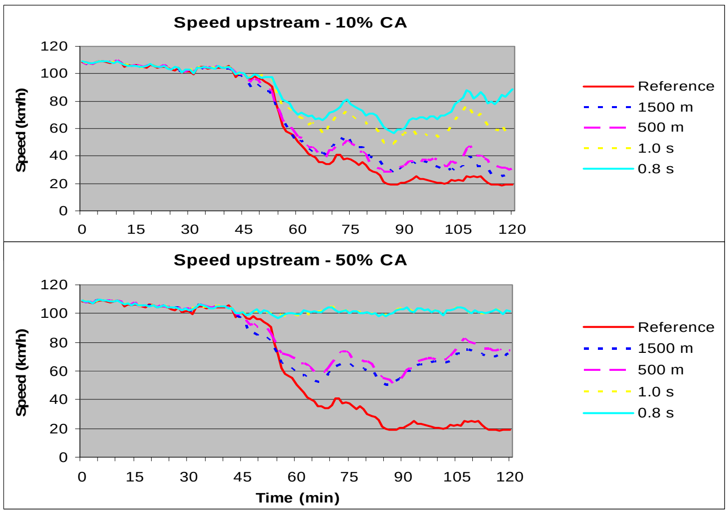
$$d_{st} = d_0 + t_{st} \cdot v$$

$$a_{st\_v} = r_{st} \cdot (v_{\text{int}} - v)$$

$$a_{st\_d} = k_a \cdot (k_d \cdot (d - d_{st}) + k_v \cdot v_{rel\_p})$$



# Resultaten



## Resultaten-2

| | Travel time (min) | Delay (min) | Delay reduction |
|---|---|---|---|
| Free flow (110 km/h) | 3.4 | - | - |
| Reference | 5.7 | 2.3 | - |
| 500 m / 0.8 s (10%) | 5.0 | 1.6 | 30% |
| 500 m / 0.8 s (50%) | 4.3 | 0.9 | 60% |



## Content

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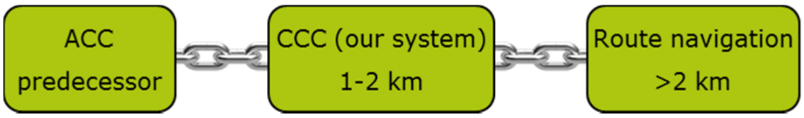
# Connected Cruise Control




Advisory in-car system

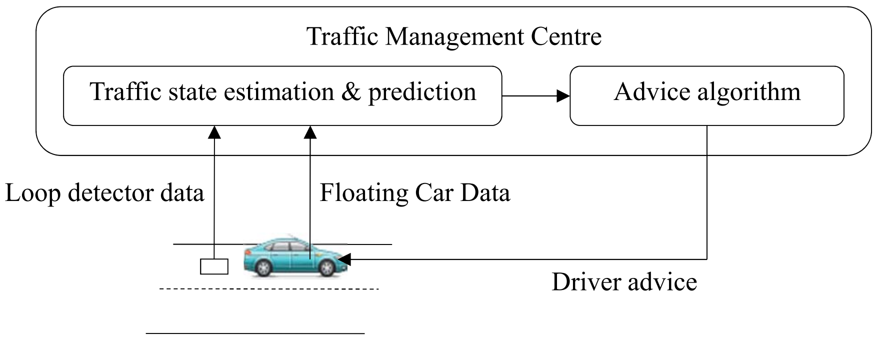
Gives advices in (nearly) saturated conditions

Advices at critical locations, e.g. lane-drop, ramps

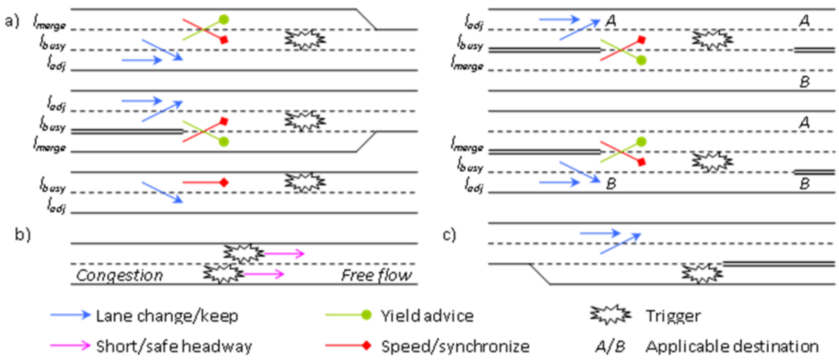
Extends driver response to conditions within about 1-2km



# CCC control loop

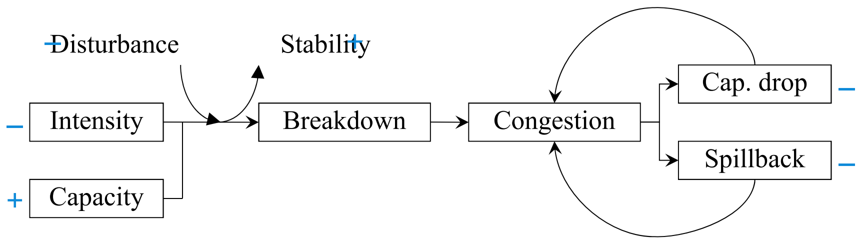


# Connected Cruise Control






# Expected impacts of Connected Cruise Control



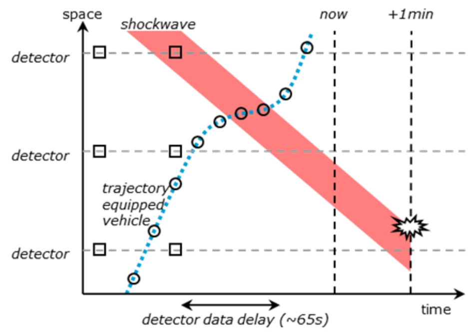

Prevent breakdown by redistributing over lanes and smooth lane change

Reduce capacity drop by increasing outflow

Preventing spillback by directing drivers to left lanes

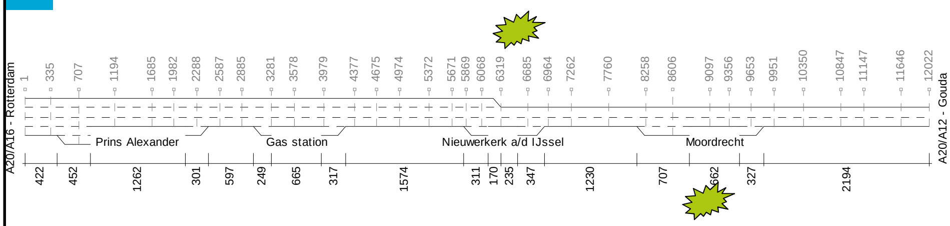
# Traffic state prediction

- Based on Adaptive Smoothing Method (ASM)
- Propagates traffic state according to typical speeds
- Can be used for short-term predictions
- 1 minute prediction to allow drivers time to act
- Used at lane level





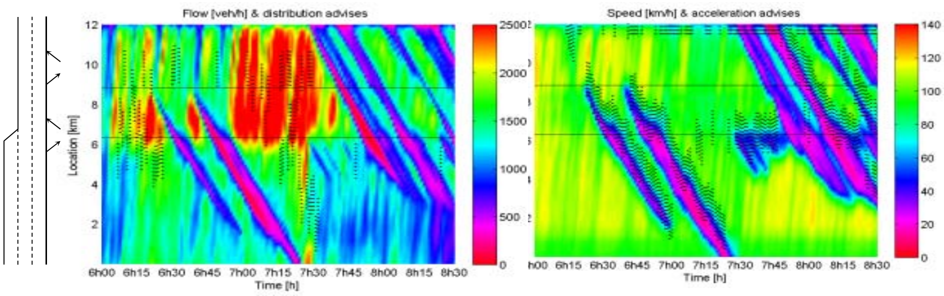

# Test stretch



*End of queue at off-ramp with spillback:*
*maintain short but safe headway*

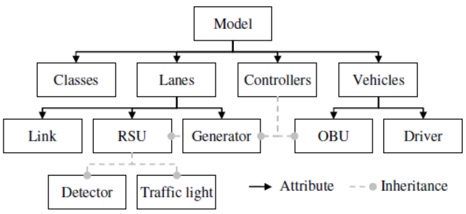


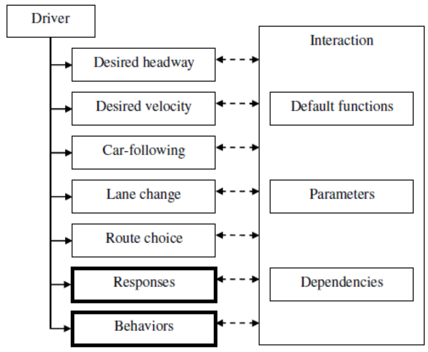
# Advices given on real data



# Microscopic Open Traffic Simulator (MOTUS)

- Object oriented, Java
- Matlab User Interface
- Automatic calibration
- Open source
- http://homepage.tudelft.nl/05a3n/





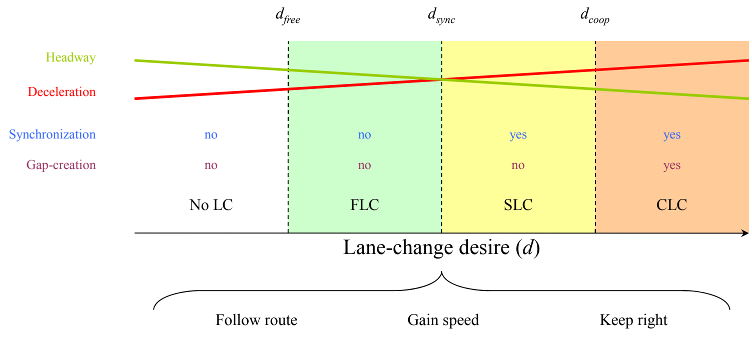

# Longitudinal model: IDM+

$$\dot{v} = a \cdot \min\left(1 - \left(\frac{v}{v_{des}}\right)^4, 1 - \left(\frac{s^*}{s}\right)^2\right)$$

$$s^* = s_0 + v \cdot T + \frac{v \cdot \Delta v}{2\sqrt{a \cdot b}}$$

Speed advice affects $v_{des}$
Maintain short but safe headway affects max acceleration a

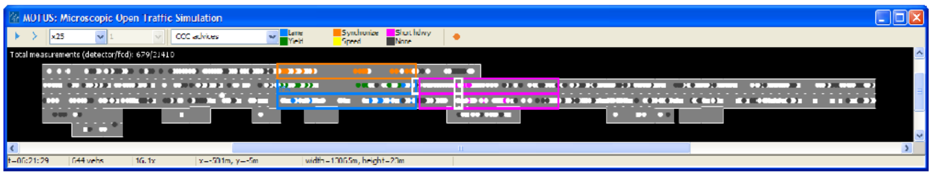
# Lane Change Model with Relaxation and Synchronization

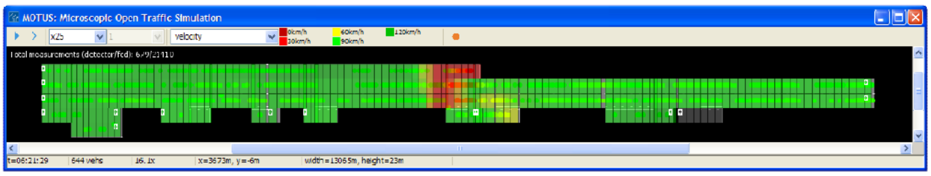



Lane use advice alters lane change desire d.

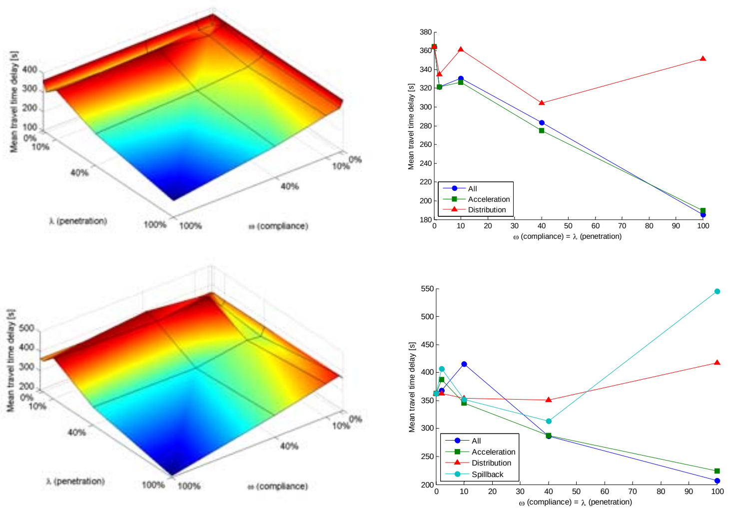


Vehicle advice view




Traffic prediction view






# Results

Slight increase of capacity and saturation flow

Distribution advices have significant effect at low rates

Distribution advices may have negative effects (day 2); increased disturbance of ramps

Acceleration advices effective at high rates; less blocking by predecessor

Potential delay savings 40-50% at 100% penetration and compliance

# Content





# Traffic simulation based on variable driver behaviour

- Traffic simulation models assume constant driver behaviour
- In reality driver behaviour and driving style varies between
  - persons
  - locations
  - conditions
- Successful operation and acceptance of and behavioural response to ADAS and IVIS may depend on taking into account driver state

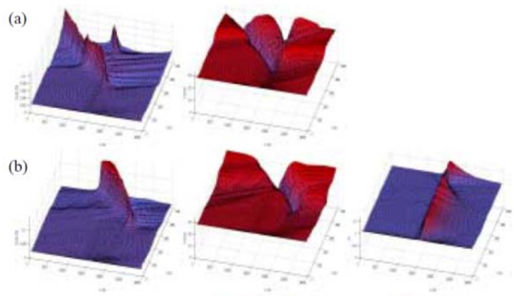
## Pioneering work: variable driver based on gas kinetic modelling (2005)

$$\frac{\partial k}{\partial t} + \frac{\partial kV}{\partial x} = \left(\frac{dk}{dt}\right)_{discrete}$$

$$\frac{\partial kV}{\partial t} + \underbrace{\frac{\partial k\left(V^2 + \Theta^e(k)\right)}{\partial x}}_{convection} = \underbrace{k\langle \dot{v}\rangle_{v,a}}_{continuous\ beh.} + \underbrace{\int_a\int_v v\left(\frac{d\rho}{dt}\right)_{discrete} dv\,da}_{discontinuous\ behaviour}$$

$$\frac{\partial kA}{\partial t} + \underbrace{\frac{\partial kAV}{\partial x}}_{convection} = \underbrace{k\langle \dot{a}\rangle_{v,a}}_{continuous\ beh.} + \underbrace{\int_a\int_v a\left(\frac{d\rho}{dt}\right)_{discrete} dv\,da}_{discontinuous\ behaviour}$$

Speed (V), density (k) and alertness (A)




k v a



## The Intelligent Driver Model

$$a(t) = a_{\max}\left[1 - \left(\frac{v(t)}{v_0}\right)^{\delta} - \left(\frac{s^*\left(v(t), \Delta v(t)\right)}{\Delta x(t)}\right)^2\right]$$

$$s^*\left(v(t), \Delta v(t)\right) = s_0 + v(t)T + \frac{v(t)\Delta v(t)}{2\sqrt{a_{\max} b_{\max}}}$$

Parameters estimated from trajectory using log likelihood.

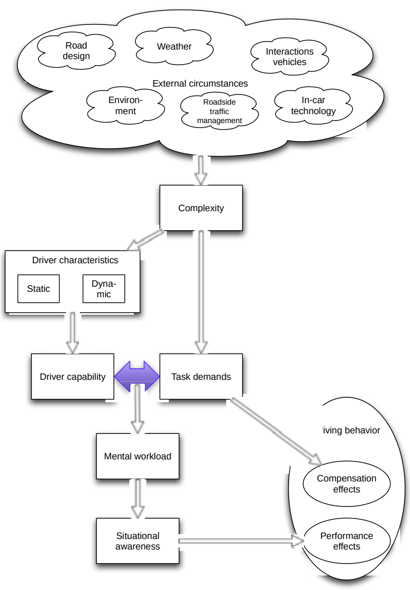
Assume *n* subtrajectories.

Goodness of fit will improve with increasing n if driving style is indeed variable

# Estimation results

| | $N=1$ | | $N=10$ | | $N=25$ | | $N=100$ | |
|---|---|---|---|---|---|---|---|---|
| Parameter | mean | std | mean | std | mean | std | mean | std |
| $a$ | 1.52 | 1.31 | 1.54 | 0.62 | 1.40 | 0.28 | 1.43 | 0.13 |
| $b$ | 2.55 | 3.71 | 0.79 | 0.74 | 0.95 | 0.41 | 0.78 | 0.15 |
| $s_0$ | 14.53 | 9.25 | 13.06 | 5.68 | 13.57 | 3.78 | 12.47 | 1.32 |
| $T$ | 1.29 | 1.33 | 1.11 | 0.53 | 1.08 | 0.27 | 1.17 | 0.16 |
| $v_0$ | 37.1 | 16.4 | 37.9 | 13.3 | 33.0 | 6.6 | 32.9 | 6.2 |





# Combining TCI and IDM

- Task demands [0,1]: $m_t(t)$
- Driver capability [0,1]: $m_c(t)$
- $m_d(t)=m_t(t)-m_c(t)$
  - *Negative: capability larger than demand* 
  - *Postitive: demand larger than capability* 
- Compensation: driver adapts behaviour toward restoring balance between demand and capability (in terms of goals)
- Performance: difference demand and capability affects quality of task execution



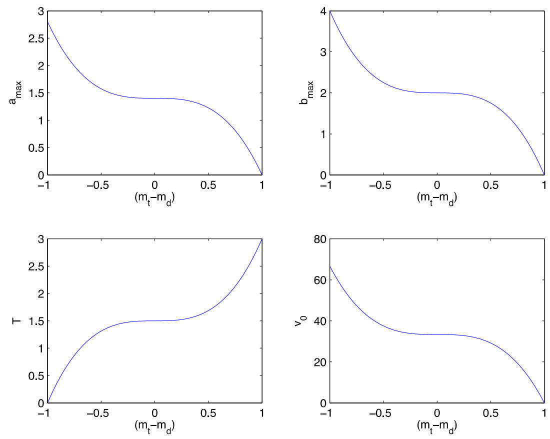
# IDM including compensation and performance effects

$$a(t)=\left(1-m_p(t)\right)\left(\left(-m_d(t)^3 a_{\max}\right)+a_{\max}\right)\left[1-\left(\frac{v(t)}{\left(-m_d(t)^3 v_0\right)+v_0}\right)^{\delta}-\left(\frac{s^*\left(v(t),\Delta v(t)\right)}{\Delta x(t)}\right)^2\right]$$

$$s^*\left(v(t),\Delta v(t)\right)=s_0+v(t)\left(\left(m_d(t)^3 T\right)+T\right)+\frac{v(t)\Delta v(t)}{2\sqrt{\left(\left(-m_d(t)^3 a_{\max}\right)+a_{\max}\right)\left(\left(-m_d(t)^3 b_{\max}\right)+b_{\max}\right)}}$$

$$m_p(t)=-\left(\alpha m_d^2+\beta m_d+\gamma\right)$$

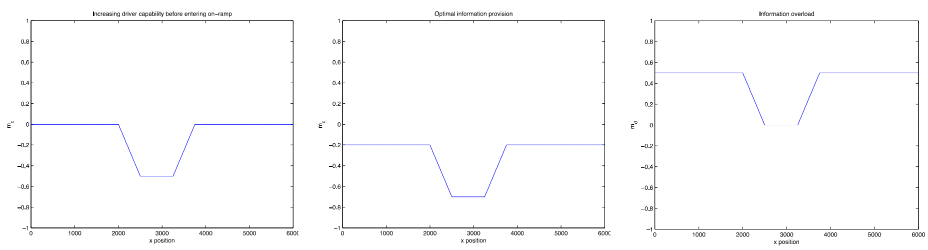
# IDM including compensation and performance effects





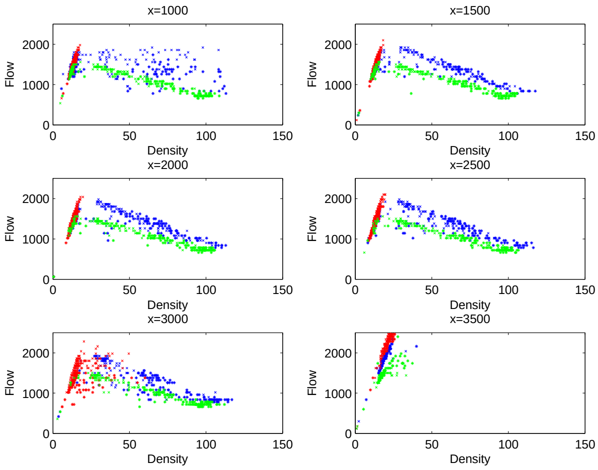

# Application

- Traffic flow simulation using IDM
- On-ramp
- Three scenarios:



Increase driver cap. Optimal information Information overload

# Results…




Blue: balanced demands/capabilities Red: optimal information Green: information overload



# Conclusions

Driving behaviour not constant

Empirical evidence from trajectories

Task demand and capability moderating a new generation of driver models

Simulation results show plausible behaviour

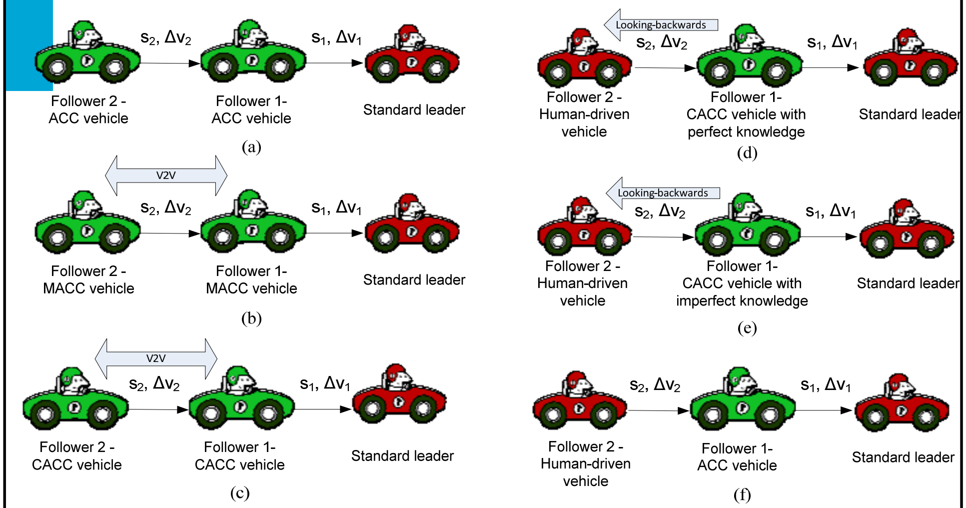
Future work: analysis and modelling task demand, capability, compensation and performance in relation to ADAS and IVIS.

# Content

- High level picture: the frontiers of automated driving
- Traffic flow simulation requirements and tools
- Congestion Assistant
- Connected Cruise Control
- Driver alert
- Cooperative Driving
- Outlook



# Controllers in cooperative systems



## Control framework: assumptions for decentralised controller

- Automated control of vehicle throttle and brake pedal
- Relative position and speed of preceding vehicle can be detected by on-board sensors; in cooperative systems, this information can be transmitted through V2V/V2I communications
- Fixed range of on-board sensors, i.e. 150 m
- No lag in vehicle response



## Mathematical formulation

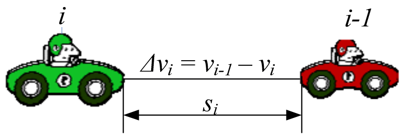
$$\mathbf{u}^* = \arg\min \left\{ \int_0^{T_p} L(\mathbf{x}, \mathbf{u})\, dt + G(\mathbf{x}(T_p)) \right\}$$

$$s.t. \quad \dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}(t), \mathbf{u}(t)), \mathbf{x}(0) = \mathbf{x}_0$$

- $\mathbf{x}$: (local traffic) system state
- $\mathbf{u}^*$: (optimal) control signal, i.e. acceleration
- $L$: running cost
- $G$: terminal cost
- $T_p$: prediction horizon ( = control horizon in our case)

Tool: Matlab using OCM/MPC

# Non-cooperative controller - ACC




- Local traffic state:

$$\mathbf{x} = (x_1, x_2)^T = (s_i, \Delta v_i)^T$$

$s_i$ - following gap

$\Delta v_i$ - relative speed to predecessor

- State dynamics:

$$\dot{\mathbf{x}} = \frac{d}{dt}\begin{pmatrix} s_i \\ \Delta v_i \end{pmatrix} = \begin{pmatrix} \Delta v_i \\ a_{i-1} - u_i \end{pmatrix}$$



# ACC Cost specification

- Two regime running cost function

$$L = \begin{cases} \underbrace{c_1 e^{\frac{s_0}{s}} \Delta v^2 \cdot \Theta(\Delta v)}_{safety} + \underbrace{c_2 (s_d - s)^2}_{efficiency} + \underbrace{\frac{1}{2} u^2}_{comfort}, \text{ if } s \le s_f & \text{Following mode} \\ \underbrace{c_3 (v_0 - v)^2}_{efficiency} + \underbrace{\frac{1}{2} u^2}_{comfort}, \text{ if } s > s_f & \text{Cruising mode} \end{cases}$$

- $s_d$ : desired gap
- $s_f$: gap threshold for distinguishing two operational modes
- $v_0$: free (cruising) speed

# Including V2V communications under the framework

- Cooperative sensing

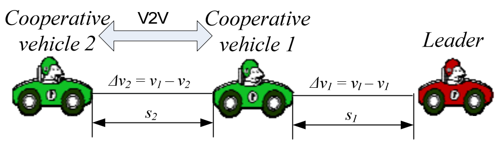
Equipped vehicles exchange information to improve the situation awareness

- Cooperative control

Equipped vehicles negotiate, collaborate, and manoeuvre together under a common goal



# Multi-anticipative ACC




$$\frac{d}{dt}\mathbf{x} = \frac{d}{dt}\begin{pmatrix} s_2 \\ \Delta v_2 \\ \Delta v_{l-2} \end{pmatrix} = \begin{pmatrix} \Delta v_2 \\ -u_2 \\ -u_2 \end{pmatrix} = \mathbf{f}(\mathbf{x},\mathbf{u})$$

$$L = \underbrace{c_1 e^{\frac{s_0}{s_2}} \Delta v_2^2 \cdot \Theta(\Delta v_2)}_{safety} + \underbrace{c_2 (s_d - s_2)^2}_{efficiency} + \underbrace{w \Delta v_{l-2}^2}_{multi-anticipation} + \underbrace{\frac{1}{2} u_2^2}_{comfort}$$

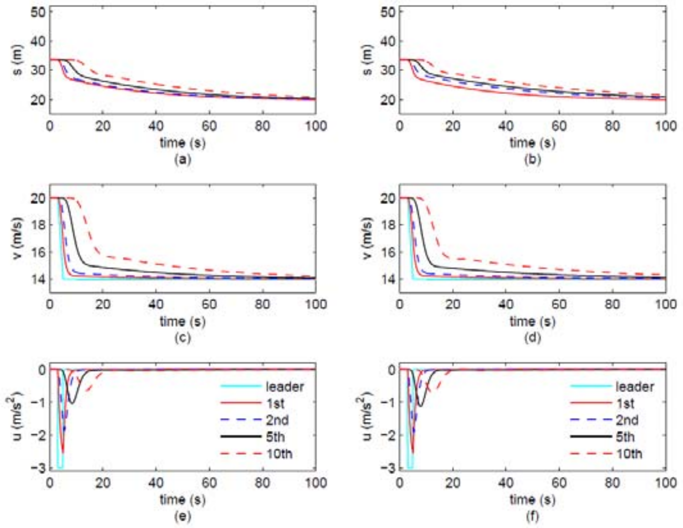
# Platoon behavioural characteristics of ACC and MACC

Simulation setup

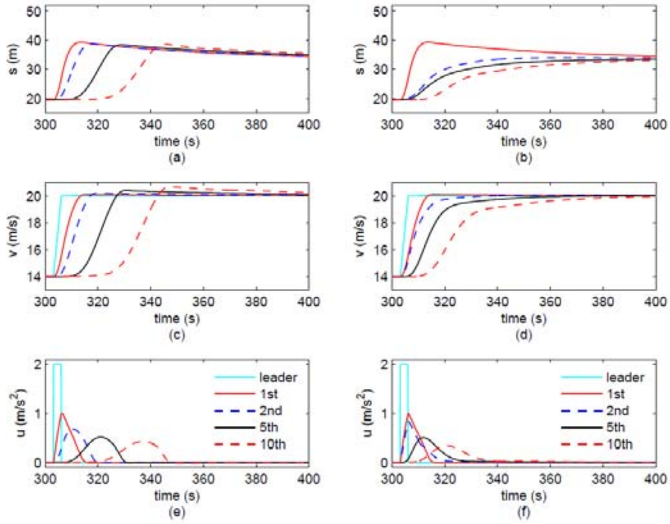
- One standard leader + ten followers (five pairs of followers in figures)
- Normal driving scenario
- Simulation long enough to reach equilibrium : 10 minutes
- The first 5 minutes is decelerating phase and the last 5 minutes is accelerating phase
- Decelerating and accelerating disturbances start after 3 seconds at both phases



# Decelerating phase of ACC v.s. MACC

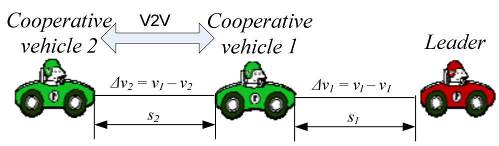


# Accelerating phase: ACC v.s. MACC






# Cooperative ACC (CACC)




- System state

$$\mathbf{x} = \left(s_1, \Delta v_1, s_2, \Delta v_2\right)^T$$

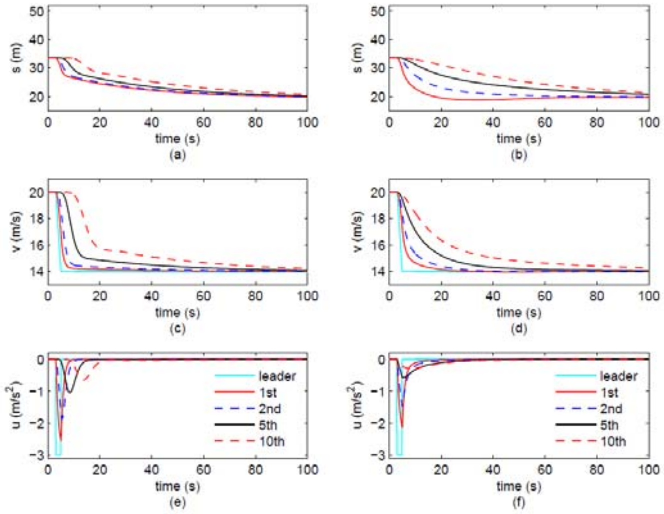
- State dynamics

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{x} = \begin{pmatrix} \Delta v_1 \\ -u_1 \\ \Delta v_2 \\ u_1 - u_2 \end{pmatrix} = \mathbf{f}(\mathbf{x}, \mathbf{u})$$

- Running cost function

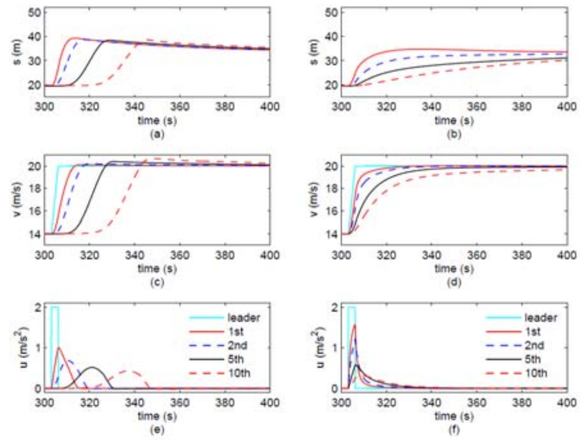
$$\mathcal{L} = \sum_{i=1}^{2} \{c_1 e^{\frac{s_0}{s_i}} \Delta v_i^2 + c_2(s_{di} - s_i)^2 + \frac{1}{2} u_i^2\}$$

# Decelerating phase: ACC v.s. CACC






# Acceleration phase ACC vs CACC



# Summary of MACC and CACC

Compared to ACC:

- MACC
  - Negligible influence in deceleration transition
  - More responsive behaviour in accelerating transition
  - Requires high penetration rate to function
- Improved CACC
  - Smoother decelerating behaviour
  - More responsive and agile behaviour in acceleration transition



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# Synthesis

**Simulation tools**

- MIXIC
- ITS Modeller
- MOTUS

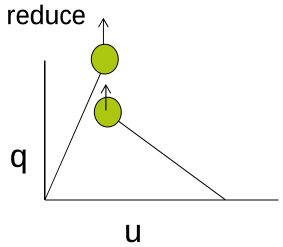
**Applications**

- ACC
- Congestion Assistant
- Connected Cruise Control
- Driver alert
- Cooperative driving



# General findings

- Simulation powerful to identify potential impacts on traffic flow
  - Transparency
  - Level of detail
  - Calibration and validation
- Automated and communication vehicles can reduce congestion delay
  - Increase outflow – reduce capacity drop
  - Shorter headways – increase capacity



# Future work

- Integration of MPC models in MOTUS (Shell)
- Human Factors:
  - Manual automated transitions, behavioral adaptation, acceptance (ITN HF Auto)
- Connected Cruise Control (BIC3 program)
  - Extension with Wifi-p (NXP)
  - Cooperative ITS Corridor (Rotterdam-Vienna)
  - Real life experiments in vehicles (Technolution and TomTom)
- High performance vehicle streams
  - realistic scenarios (PATH/FHWA)
- Reducing congestion at sags using cooperative vehicles (Toyota)
- Automated Vehicles in real traffic
  - Human factors
  - Traffic management
  - Type approval



# Dutch Automated Vehicle Initiative

Starting event:

12th November 2013
Demonstration in live traffic
A10 Motorway

TUDelft RDW Connekt TNO innovation for life