Automated Driving: The Future of Transport Starts Today
Bart van Arem

Who is Bart van Arem?

1982-1990: MSc (1986) and PhD (1990)
Applied Mathematics University of Twente

2003-2012 Part-time full professor University of Twente

2009-now: Delft University of Technology
• Full Professor Transport Modelling
• Chair Department Transport & Planning
• Director Transport Institute

Automated Vehicle demonstrations:
• 1998 Rijnwoude
• 2008 Eindhoven
• 2013 Amsterdam

IEEE ITS Society
• 2004-2006 EiC Newsletter
• General Chair IV 2008, Eindhoven
• General Chair ITSC 2013, The Hague
Content of this keynote

- Local context in the Netherlands
- Interest in Automated Driving
- Definitions and scenarios
- Driver behaviour
- Traffic flow behaviour
- Acceptance and deployment
- Impacts on strategic decision making
- The future of transport starts today

The Netherlands
### The Netherlands and South Korea

<table>
<thead>
<tr>
<th>Population (million inhabitants)</th>
<th>Area (km²)</th>
<th>Population density (inhabitants/km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Korea</td>
<td>51.3</td>
<td>100210</td>
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<tr>
<td>The Netherlands</td>
<td>16.8</td>
<td>41543</td>
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<tr>
<td>Seoul Capital Area</td>
<td>25.6</td>
<td>11704</td>
</tr>
<tr>
<td>Randstad Area</td>
<td>7.8</td>
<td>8200</td>
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</table>

### Semi final World Cup Soccer 2002

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### Main cities of the Netherlands

- **Amsterdam (825.000)**
- **Rotterdam: (625.500)**
  - International port
- **The Hague (515.000)**
  - International city of peace and justice

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Delft, the Netherlands

101,022 inhabitants

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20,000 BSc and MSc students
2,700 Scientific staff members

Physics
Mathematics, electronics, information sciences
Mechanical, Maritime and Materials Engineering
Civil Engineering and Geosciences
Aerospace Engineering
Industrial design
Technology, policy and management

Times Higher Education ranking 71
Part of Leiden (64) – Delft – Erasmus (Rotterdam, 72) federation

Transport Institute
Robotics Institute

(...)

TU Delft
INTEREST IN AUTOMATED DRIVING

A first drive with fully automated vehicle...
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Self-driving cars can improve traffic efficiency and safety.

Netherlands to facilitate large scale testing of self-driving vehicles.

Dutch minister of Infrastructure & Environment
Mrs Melanie Schultz
King Willem-Alexander of the Netherlands

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Rijnwoude 1998
AGVs Port of Rotterdam 1993
Parkshuttle Rivium 1999
IEEE IV 2008, Eindhoven
Grand cooperative driving challenge, Helmond 2011
Innovation relay 2013

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Dutch society and economy depend on transport

Dense road network  Port of Rotterdam

High traffic volumes  Schiphol airport

Automated vehicle field tests

Scania: truck platooning. Test on public road: 09-02-15 on the A28 Motorway at Zwolle

Province of Gelderland, TU Delft, TNO: Automated Public Transport in “Foodvalley” at Wageningen, 2016
TU Delft (Transport and Rail group): Automatic taxis as last mile transport, TU Delft Campus, 2016

TU Delft: partial automation with communication on the A10 motorway near Amsterdam, 2016

TU/e: Automated and Cooperative Renault Twizy’s, 2015
TNO/TU/e: Grand Cooperative Driving Challenge, 2016
### Definitions and Scenarios

**SAE's draft levels of automation are descriptive rather than normative and technical rather than legal. Elements indicate minimum rather than maximum capabilities for each level. “System” refers to the driver assistance system, combination of driver assistance systems, or automated driving system, as appropriate. NHTSA’s levels of automation are provided to indicate approximate correspondence.**

<table>
<thead>
<tr>
<th>NHTSA level</th>
<th>SAE level</th>
<th>SAE name</th>
<th>SAE narrative definition</th>
<th>Execution of steering and acceleration/deceleration</th>
<th>Monitoring of driving environment</th>
<th>Backup performance of dynamic driving task</th>
<th>System capability (driving modes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>Non-Automated</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Human driver</td>
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<tr>
<td></td>
<td>1</td>
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<td>Assisted</td>
<td>Human driver and system</td>
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<td>Human driver</td>
<td>Some driving modes</td>
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<tr>
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<td>Partial Automation</td>
<td>System</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
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<td>Conditional Automation</td>
<td>System</td>
<td>System</td>
<td>Human driver</td>
<td>Some driving modes</td>
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<tr>
<td></td>
<td>4</td>
<td>4</td>
<td>High Automation</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Some driving modes</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>5</td>
<td>Full Automation</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>All driving modes</td>
</tr>
</tbody>
</table>

**Summary of SAE International’s Draft Levels of Automation for On-Road Vehicles (July 2013)**
Automated, autonomous, cooperative?

Two paths for deployment

Functional

Spatial
Development of automated vehicles in the Netherlands: scenarios for 2030 and 2050

Commissioned by Dutch Environmental Planning Agency

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Scenarios about development and implications of automated vehicles in the Netherlands.

**AV ...in standby**
- Fully automated & cooperative vehicles (V2V) in 2030.
- Legislation favourable for AVs. Transport policies restraining use of AVs. High regulation of AV trials.
- Modest economic growth.
- "Wait and see..." customers attitude, mid-low demand for AVs.
- No major environmental problems, but still low penetration of electric vehicles.

**High technological development**

**AV ...in bloom**
- Fully automated & cooperative vehicles (V2V & V2I) in 2030.
- High economic growth.
- Positive customers attitudes, strong demand for AVs.
- Limited environmental problems. Clean technologies prevail.

**Restrictive AV policies**
- Fully automated vehicles in 2040.
- Limited legislation for AV integration. No AV trials allowed.
- Recession economy, high unemployment.
- Negative customers attitude, almost no demand for AVs.
- Important environmental problems. Very slow transition to low-carbon economy.

**Supportive AV policies**
- Fully automated & cooperative (V2I) vehicles in 2040.
- Slow economic growth.
- "Not really interested..." customers attitude, low demand for AVs.
- Increased environmental problems. Transport sector still among major polluters.

**AV ...in doubt**
- Low technological development

**AV ...in demand**

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Automated Vehicles will be included in Dutch environmental planning scenarios

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DRIVER BEHAVIOUR

 Fundamental changes in driving behaviour

Driver in control  →  Vehicle in control

Driver supervision

Workload,
driving performance,
attention,
situation awareness
risk compensation,
Driver Vehicle Interface,
acceptance,
mode transition,
purchase and use
The congestion assistant

- Detects downstream congestion
- Visual and auditory 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

Acceptance
Effects on mean speed

Effects on time headway

May 31, 2006

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TRAFFIC FLOW BEHAVIOUR

Potential impacts on traffic

- Solve traffic jams by increased outflow
- Prevent traffic jams by better stability
- Better distribution of traffic over network

Less congestion delay

- Decreased throughput by larger headways
- Decreased stability by lack of anticipation

Increased risk of congestion

Non-connected large penetration
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

Traffic flow simulation: merging area A12 motorway, Woerden, the Netherlands
Results

General findings on motorway capacity

- Many micro simulation studies
- Difficult to compare
- Focus on ACC and CACC
- Hardly any bottlenecks

ACC can either have a small negative or a small positive effect on capacity (~ -5% to +10%)
- Bottlenecks: increase <10%
- Positive effect stability and capacity drop
- Lower level roads?
A20: bottleneck motorway, no more space to expand

How can AVs relieve congestion here?

3+2 cross weaving
Short on-ramp

ACCEPTANCE AND DEPLOYMENT
Acceptance

• Drivers state that they prefer warnings over control
• Control could be acceptable in special conditions such as congestion driving
• Acceptance of (different levels of) automation increases after (positive) experience
• Scepticism is declining
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Development of penetration rate

- Technological development
- Barriers
- Lifetime of cars/fleet turnover
- Costs of the cars
- Services
- Car software updates
- ...

Car driving more attractive!

Partial automation
- Better comfort,
- Less accidents
- Less congestion

High automation
- Travel time can partially be used for other purpose

Full automation
- Travel time can fully be used for other purposes
Spatial implications

Functional
- Geometric redesign of roads and junctions
- Increasing sprawl residential and employment locations
- Concentration activities by better accessibility

Spatial
- Redesign of urban, commercial, touristic areas
- No on street parking
- Combinations with car sharing, electric driving

IMPACTS ON STRATEGIC DECISION MAKING
Implications of Automated Vehicles for National Transport Model

Dutch National Transport Model (LMS)
Updated every 2 year to identify main transport problems
Used to support major transport infrastructure decisions
Typical horizon 20 years

What if AVs could deliver substantial capacity improvement in 20 years?

Model structure

Spatial structure
Economy
Demography
Policy measures

Travel demand model

Trips (car, train, cycling, walking)
Flows, travel times, congestion

Assignment model

Transport network, Capacities, Passenger car equivalent, Value of time

Iterate until equilibrium

Prediction horizon reference scenario 2030

How can this model represent the impacts of Automated Driving?
Exploring the methodology

- Model extremely complex with many internal dependencies
- Limited ways to differentiate user and vehicle types
- Generic way of representing congestion

Parameters selected to represent the impacts of Automated Driving:
- Capacity primary road network
- Capacity secondary road network
- Passenger car equivalent factors of trucks
- Value of time

Automated Autonomous

5% capacity decrease on primary road network

<table>
<thead>
<tr>
<th></th>
<th>Index km travelled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train</td>
<td>100.3</td>
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<tr>
<td>Car driver</td>
<td>99.8</td>
</tr>
<tr>
<td>Car passenger</td>
<td>99.7</td>
</tr>
<tr>
<td>Bus, tram, metro</td>
<td>100.2</td>
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<tr>
<td>Cycling</td>
<td>100.1</td>
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<tr>
<td>Walking</td>
<td>100.1</td>
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<tr>
<td>Total</td>
<td>99.98</td>
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Index congestion 115.7

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Automated Cooperative

15% capacity increase on primary road network
10% capacity increase on secondary road network
10% decrease value of time commuting and business car trips

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<th>Index km travelled</th>
</tr>
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<tbody>
<tr>
<td>Train</td>
<td>98.8</td>
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<tr>
<td>Car driver</td>
<td>100.8</td>
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<td>Car passenger</td>
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<td>Bus, tram, metro</td>
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<tr>
<td>Cycling</td>
<td>99.3</td>
</tr>
<tr>
<td>Walking</td>
<td>99.4</td>
</tr>
<tr>
<td>Total</td>
<td>100.10</td>
</tr>
</tbody>
</table>

Index congestion 69.1

Findings

• Overall impacts credible but small
• Crude assumptions made for capacities
• Impacts on travel demand small (only modelled indirectly)

Further research planned
• Capacity estimation
• Impacts on travel demand

Automated driving will be included in 2017 update of the National Transport Model

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THE FUTURE OF TRANSPORT STARTS TODAY…

High Expectations

Efficient travel  Safety  Comfort, quality of life

Energy, emissions  Economy

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Huge investments in technology

- Sensing
- Communication
- Positioning
- Data fusion
- Situation awareness
- Trajectory prediction
- Cooperative control
- Traffic management
- Driver monitoring

Performance
- Complexity
- Security
- Privacy
- Liability
- Failure modes
- Weather conditions
- Energy
- Cost

Many uncertainties about implications

- Driving behaviour, traffic flows, travel behaviour
- Infrastructure land spatial impacts
- Societal implications

Current and future pilots will enable to study these impacts in a more realistic way than ever!
The road to automated driving…

- Develop efficient and reliable technology
- Collect, analyse and publish large scale real-world experience
- Study spatial, transport and societal impacts
- Regulations, type approval
- Awareness, ambitions, expectations, reality checks

Thank you! Have a great conference!

Cars automatic in 20 years

Tell it we don’t appreciate these types of jokes and to come back right away