Automatisch rijden- effecten op verkeer en leefomgeving

Bart van Arem
A first drive with fully automated vehicle...
<table>
<thead>
<tr>
<th>SAE Level</th>
<th>Name</th>
<th>Narrative Definition</th>
<th>Execution of Steering and Acceleration/Deceleration</th>
<th>Monitoring of Driving Environment</th>
<th>Fallback Performance of Dynamic Driving Task</th>
<th>System Capability (Driving Modes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Automation (Human)</td>
<td>the full-time performance by the <em>human driver</em> of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Human driver</td>
<td>n/a</td>
</tr>
<tr>
<td>1</td>
<td>Driver Assistance</td>
<td>the <em>driving mode</em>-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the <em>human driver</em> perform all remaining aspects of the dynamic driving task</td>
<td>Human driver and system</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>2</td>
<td>Partial Automation</td>
<td>the <em>driving mode</em>-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the <em>human driver</em> perform all remaining aspects of the dynamic driving task</td>
<td>System</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
</tbody>
</table>

**Automated driving system ("system") monitors the driving environment**

| 3         | Conditional Automation    | the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a request to intervene | System                                              | System                             | Human driver                               | Some driving modes                  |
| 4         | High Automation           | the *driving mode*-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a *human driver* does not respond appropriately to a request to intervene | System                                              | System                             | System                                     | Some driving modes                  |
| 5         | Full Automation           | the full-time performance by an *automated driving system* of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a *human driver* | System                                              | System                             | System                                     | All driving modes                   |
Automated driving

Driver assistance/
Partial automation

Driver needs to be able
to intervene at all times

Automated parking,
autocruise

Conditional/ High
automation

Vehicle in control in
special conditions

Taxibots, platooning,
automated highways

Comfort, efficiency, safety,
costs

Mode choice, location choice,
urban and transport planning
Personal Estimates of Market Introductions *(based on technological feasibility)*

**Everywhere**

- **Some** urban streets
- Campus or pedestrian zone
- Limited-access highway
- Fully Segregated Guideway

<table>
<thead>
<tr>
<th>Level 1 (ACC)</th>
<th>Level 2 (ACC+ LKA)</th>
<th>Level 3 Conditional Automation</th>
<th>Level 4 High Automation</th>
<th>Level 5 Full Automation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Now</strong></td>
<td>~2020s</td>
<td>~2025s</td>
<td>~2030s</td>
<td>~2075</td>
</tr>
</tbody>
</table>

Color Key: **Now** ~2020s ~2025s ~2030s ~2075

TU Delft

Workshop Ruimtelijke effecten automatisch rijden in Gelderland, 8 maart 2016
Knowledge urgently lacking

Much progress short term and small scale impacts on driver behaviour and traffic flow.

Research on longer term, indirect, wider scale impacts on mobility, logistics, residential patterns and spatial-economic structure in its infancy.
Fundamental changes in driving behaviour

Driver in control  \iff  Vehicle in control

Driver supervision

Workload, driving performance, attention, situation awareness, risk compensation, Driver Vehicle Interface, acceptance, mode transition, purchase and use
Potential impacts on traffic

- Solve traffic jams by increased outflow
- Prevent traffic jams by better stability
- Better distribution of traffic over network
- Decreased throughput by larger headways
- Decreased stability by lack of anticipation
- Less congestion delay
- Increased risk of congestion

Non connected
Large penetration
General findings on motorway capacity

- 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?

(Shladover, Su, & Lu, 2012)

<table>
<thead>
<tr>
<th>Percentage of CACC Vehicles</th>
<th>0%</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>2%</td>
<td>4%</td>
<td>8%</td>
<td>12%</td>
<td>18%</td>
<td>22%</td>
<td>32%</td>
<td>47%</td>
<td>68%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>2%</td>
<td>5%</td>
<td>8%</td>
<td>12%</td>
<td>18%</td>
<td>22%</td>
<td>32%</td>
<td>48%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20%</td>
<td>3%</td>
<td>5%</td>
<td>8%</td>
<td>12%</td>
<td>18%</td>
<td>23%</td>
<td>34%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30%</td>
<td>3%</td>
<td>5%</td>
<td>9%</td>
<td>12%</td>
<td>15%</td>
<td>25%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40%</td>
<td>4%</td>
<td>6%</td>
<td>8%</td>
<td>11%</td>
<td>17%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50%</td>
<td>4%</td>
<td>6%</td>
<td>6%</td>
<td>11%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60%</td>
<td>5%</td>
<td>3%</td>
<td>7%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70%</td>
<td>3%</td>
<td>4%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80%</td>
<td>2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90%</td>
<td>2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100%</td>
<td>97%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Many micro simulation studies
- Difficult to compare
- Focus on ACC and CACC
- Hardly any bottlenecks
A20: bottleneck motorway, no more space to expand

How can AVs relieve congestion here?

3+2 cross weaving

Short on-ramp
Automated roads?

- Implication of changes in traffic load? Platoons, bridges, rutting?
- Automated driving under adverse roadway and weather conditions?
- Implications for traffic management? Opportunity or thread?
- eHorizon: automated driving cloud for real-time positioning, maneuvering and safety?
- Level 4 certified roads?
- Geometric design, transition zones?
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
DEPLOYMENT RATES - EU27
BY MEMBER STATE

PS3
OBSTACLE & COLLISION WARNING

PASSENGER CARS
NEW REG. IN 2012

Workshop Ruimtelijke effecten automatisch rijden in Gelderland, 8 maart 2016
Car driving more attractive!

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

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

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

**Spatial**
It will take some time …

Mobility Impacts Questions

- More trips satisfied by each car?
- More willingness to travel by car?
- Lower Value of Time?
- Lower car ownership?
- Less trips by car?
- More or less traffic congestion?
- More or less parking demand?
- More public transport demand?
- Used as public transport? How will these be operated?
- Substitution of private conventional vehicles for automated ones?
- More or less parking demand?
- More or less traffic congestion?
- More trips satisfied by each car?
- More willingness to travel by car?
- Lower Value of Time?
- Lower car ownership?
- Less trips by car?
- More public transport demand?
- Used as public transport? How will these be operated?
- Substitution of private conventional vehicles for automated ones?
- More or less parking demand?
- More or less traffic congestion?
- More trips satisfied by each car?
- More willingness to travel by car?
- Lower Value of Time?
- Lower car ownership?
- Less trips by car?
- More public transport demand?
- Used as public transport? How will these be operated?
- Substitution of private conventional vehicles for automated ones?
- More or less parking demand?
- More or less traffic congestion?
- More trips satisfied by each car?
- More willingness to travel by car?
- Lower Value of Time?
- Lower car ownership?
- Less trips by car?
- More public transport demand?
- Used as public transport? How will these be operated?
- Substitution of private conventional vehicles for automated ones?
- More or less parking demand?
- More or less traffic congestion?
- More trips satisfied by each car?
- More willingness to travel by car?
- Lower Value of Time?
- Lower car ownership?
- Less trips by car?
- More public transport demand?
- Used as public transport? How will these be operated?
- Substitution of private conventional vehicles for automated ones?
- More or less parking demand?
- More or less traffic congestion?
- More trips satisfied by each car?
- More willingness to travel by car?
- Lower Value of Time?
- Lower car ownership?
- Less trips by car?
- More public transport demand?
- Used as public transport? How will these be operated?
- Substitution of private conventional vehicles for automated ones?
- More or less parking demand?
- More or less traffic congestion?
- More trips satisfied by each car?
- More willingness to travel by car?
- Lower Value of Time?
- Lower car ownership?
- Less trips by car?
- More public transport demand?
- Used as public transport? How will these be operated?
- Substitution of private conventional vehicles for automated ones?
- More or less parking demand?
- More or less traffic congestion?
- More trips satisfied by each car?
- More willingness to travel by car?
- Lower Value of Time?
- Lower car ownership?
- Less trips by car?
- More public transport demand?
- Used as public transport? How will these be operated?
- Substitution of private conventional vehicles for automated ones?
- More or less parking demand?
- More or less traffic congestion?
- More trips satisfied by each car?
- More willingness to travel by car?
- Lower Value of Time?
- Lower car ownership?
- Less trips by car?
- More public transport demand?
- Used as public transport? How will these be operated?
- Substitution of private conventional vehicles for automated ones?
- More or less parking demand?
- More or less traffic congestion?
- More trips satisfied by each car?
- More willingness to travel by car?
International Transport Forum Model

- Scale up the concept of public transport with automatic vehicles:

  Taxibots (Shared taxis): till 6 pax and 5 min waiting; or
  Autovots (Individual carsharing): 5 min waiting as well.

Source: Luis Martinez, analyst at the ITF

Workshop Ruimtelijke effecten automatisch rijden in Gelderland, 8 maart 2016
## International Transport Forum Model

### Cars travelling at peak hours \% of current max. flow

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>100% shared self-driving fleet</th>
<th>50% private car use for motorised trips</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ride sharing (TaxiBot)</td>
<td>Car sharing (AutoVot)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No high-capacity public transport</td>
<td>No high-capacity public transport</td>
</tr>
<tr>
<td></td>
<td></td>
<td>With high-capacity public transport</td>
<td>With high-capacity public transport</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25 867 % 43.1</td>
<td>46 011 % 76.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21 105 % 35.2</td>
<td>33 975 % 56.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ride sharing (TaxiBot)</td>
<td>Car sharing (AutoVot)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No high-capacity public transport</td>
<td>No high-capacity public transport</td>
</tr>
<tr>
<td></td>
<td></td>
<td>With high-capacity public transport</td>
<td>With high-capacity public transport</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13 173 % 117.8</td>
<td>22 768 % 133.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 890 % 90.9</td>
<td>18 305 % 103.4</td>
</tr>
</tbody>
</table>

* = shared + private cars

### Car-kilometers (millions) \% of baseline

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>100% shared self-driving fleet</th>
<th>50% private car use for motorised trips</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ride sharing (TaxiBot)</td>
<td>Car sharing (AutoVot)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No high-capacity public transport</td>
<td>No high-capacity public transport</td>
</tr>
<tr>
<td></td>
<td></td>
<td>With high-capacity public transport</td>
<td>With high-capacity public transport</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.62 % 122.4</td>
<td>7.15 % 189.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.01 % 106.4</td>
<td>5.44 % 144.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ride sharing (TaxiBot)</td>
<td>Car sharing (AutoVot)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No high-capacity public transport</td>
<td>No high-capacity public transport</td>
</tr>
<tr>
<td></td>
<td></td>
<td>With high-capacity public transport</td>
<td>With high-capacity public transport</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.04 % 160.2</td>
<td>7.20 % 190.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.90 % 129.8</td>
<td>5.69 % 150.9</td>
</tr>
</tbody>
</table>
Policy relevance

- Congestion and accessibility
- Safety
- Travel patterns
- Freight transport
- Public transport
- Socio-economic development
- Urban design
- Spatial structure
- Investment policies

Automated cars can improve traffic efficiency and safety

Netherlands to facilitate large scale testing of automated cars

National, regional, city authorities, public transport operators, Multimodal hubs (ports, airports)
### Exploration using LMS

#### Automated Autonomous

5% capacity decrease on primary road network

<table>
<thead>
<tr>
<th>Mode</th>
<th>Index km travelled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train</td>
<td>100.3</td>
</tr>
<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>
</tr>
<tr>
<td>Cycling</td>
<td>100.1</td>
</tr>
<tr>
<td>Walking</td>
<td>100.1</td>
</tr>
<tr>
<td>Total</td>
<td>99.98</td>
</tr>
</tbody>
</table>

Index congestion: 115.7

#### Automated Cooperative

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

<table>
<thead>
<tr>
<th>Mode</th>
<th>Index km travelled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train</td>
<td>98.8</td>
</tr>
<tr>
<td>Car driver</td>
<td>100.8</td>
</tr>
<tr>
<td>Car passenger</td>
<td>101.4</td>
</tr>
<tr>
<td>Bus, tram, metro</td>
<td>99.2</td>
</tr>
<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

Workshop Ruimtelijke effecten automatisch rijden in Gelderland, 8 maart 2016
Scientific challenges: understanding the spatial and transport changes

Regional spatial and transport system

- Automated Driving
- Infrastructure service networks
- Spatial structure and economy
- Urban design and traffic safety
- Travel and location choice behaviour
- Freight and Logistics applications

Accessibility
- Economy
- Traffic Safety
- Urban quality
STAD: Spatial and Transport Impacts of Automated Driving
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