Cost-Benefit Analysis of an Innovative and Modular Autonomous Vehicle: The Case of “U-Shift”

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1. U-Shift Vehicle Concept
1.1 U-Shift: An on-the-road modular, autonomous vehicle concept

- On-the-road modular
- Autonomous
- Shared / Pooling

Background

• Since 2017, U-Shift has been developed by the German Centre for Aerospace

• In 2020, a first prototype has been completed

• In addition to technical R&D activities, the institutes conducts analysis to evaluate the proposed technology

→ Quantification of costs and benefits of U-Shift with a focus on CO₂-emissions, air pollution and road safety

→ The CBA was undertaken in 2019-2020 as part of a feasibility study funded by the German Ministry for Economy
2. Cost-Benefit Analysis Framework
2.1 Cost-Benefit Analysis Framework

Assessment of 3 different future autonomous vehicle scenarios in Stuttgart in 2040:
2.1 Cost-Benefit Analysis Framework

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price Year</td>
<td>€2019</td>
</tr>
<tr>
<td>Study Year</td>
<td>1 year (2040)</td>
</tr>
<tr>
<td>Base Year</td>
<td>2040</td>
</tr>
<tr>
<td>Study Area</td>
<td>Stuttgart</td>
</tr>
<tr>
<td>Scenarios</td>
<td>Base Case (Business-as-usual)</td>
</tr>
<tr>
<td></td>
<td>U-Shift Managed Automated Driving (MAD);</td>
</tr>
<tr>
<td></td>
<td>U-Shift Automated Driving (AD);</td>
</tr>
<tr>
<td>Cost quantification</td>
<td>Opex: 2040</td>
</tr>
<tr>
<td></td>
<td>Capex: apportioned to 2040 based on asset life</td>
</tr>
<tr>
<td>Benefit quantification</td>
<td>2040</td>
</tr>
<tr>
<td>Quantified benefits</td>
<td>Road safety, CO₂ emissions, air pollution</td>
</tr>
</tbody>
</table>

→ CBA is undertaken in accordance with Australian infrastructure appraisal practice and methodology developed in eIMPACT (2006). Input values based on German guidance and local data.
3. Cost-Benefit Analysis
Results
3. Headline Results

<table>
<thead>
<tr>
<th>Standalone, in €</th>
<th>Base Case</th>
<th>U-Shift: Managed Automated Driving</th>
<th>U-Shift: Automated Driving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road Safety</td>
<td>-398 M</td>
<td>-317 M</td>
<td>-332 M</td>
</tr>
<tr>
<td>CO₂ Emissions</td>
<td>-153 M</td>
<td>-107 M</td>
<td>-110 M</td>
</tr>
<tr>
<td>Air Pollution</td>
<td>-96 M</td>
<td>-73 M</td>
<td>-75 M</td>
</tr>
<tr>
<td>Total Benefits</td>
<td>-647 M</td>
<td>-496 M</td>
<td>-517 M</td>
</tr>
<tr>
<td>CAPEX</td>
<td>958 M</td>
<td>837 M</td>
<td>860 M</td>
</tr>
<tr>
<td>OPEX</td>
<td>721 M</td>
<td>927 M</td>
<td>919 M</td>
</tr>
<tr>
<td>Total Cost</td>
<td>1.680 M</td>
<td>1.765 M</td>
<td>1.779 M</td>
</tr>
<tr>
<td>Benefit-Cost Ratio</td>
<td>1,8</td>
<td></td>
<td>1,3</td>
</tr>
</tbody>
</table>

Driver: Reduction in average emission factor (g/km)

Largest benefit: improvement in road safety

Driver: large maintenance costs of U-Shift (conservative approach)

CAPEX: infrastructure based automation less costly than vehicle based automation!
4. Main Inputs
4. Main Inputs
Road Safety

- High expectations regarding road safety improvements from automated vehicles

- Technology is not mature, extent of future road safety benefits are unknown. For estimates, different approaches are used:
  
  - Analysis of crash data from prototype vehicles: e.g. data on Waymo vehicles include description of 16 rear-end accidents: Waymo was one time the back vehicle; 15 times it was the front vehicle
  
  - Isolation of effect of driver assistance systems on safety
    
  - Insurance Institute for Highway Safety (IIHS) (2020)\(^3\) study based on vehicle crashes in the U.S.: If crashes involving only sensing/perceiving factors or incapacitation would be prevented by autonomous vehicles, 34% of accidents could be prevented
4. Main Inputs
Road Safety

Assumption on road safety for this study: own *qualitative* assessment based on data in IIHS (2020)²

<table>
<thead>
<tr>
<th>Estimated reduction potential of accidents (by causes)</th>
<th>Managed Automated Driving</th>
<th>Automated Driving</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crashes (by Causes)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Only sensing and perceiving crashes</td>
<td>95%</td>
<td>75%</td>
</tr>
<tr>
<td>Incapacitation</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Unavoidable by driver</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Remaining crashes with multiple factors (average)</td>
<td>62%</td>
<td>62%</td>
</tr>
<tr>
<td>Planning and deciding</td>
<td>75%</td>
<td>75%</td>
</tr>
<tr>
<td>Execution and performance</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>Predicting</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td><strong>Crashes preventable by U-Shift compared to today</strong></td>
<td>1.569.076</td>
<td>1.439.913</td>
</tr>
<tr>
<td><strong>Crashes preventable by U-Shift %</strong></td>
<td>74%</td>
<td>68%</td>
</tr>
</tbody>
</table>

² Insurance Institute for Highway Safety (2020) What humanlike errors do autonomous vehicles need to avoid to maximize safety?

- Sleeping, heart attacks and drug&alcohol abuse are not known problems of machines.
- Difficult to project how well machine will perform in the future.
- Not possible to achieve 100% perception, e.g. due to view obstructions; infrastructure-based automation has advantage.
- 2% of accidents. Mainly technical failure. These issues will increase with autonomous vehicles.
4. Main Inputs
Energy Consumption of Automation

• Replacement of driver with machine requires electrical energy

• Today, automated vehicle prototypes require as much energy as needed for propulsion

• Future: Uncertain. Substantial energy efficiency improvements from technological advancements are possible; however, risk of rebound effect from increased focus on comfort/entertainment feature

→ Input values for average energy consumption of automation in CBA:

– Core Scenario: 3.5 kWh / 100 km (Source: Gawron et al. 2018)\(^3\)

– Sensitivity test with pessimistic case: 12.5 kWh / 100 km

4. Main Results and Conclusions
Main Results

Benefits of U-Shift

• Implementation of U-Shift may contribute to substantial reduction of road accidents

• CO₂ emissions and air quality can be improved because of shared approach and lower vehicle specific emissions compared to a Business-as-Usual Scenario

Opportunities

• Automated driving is less costly under the infrastructure-based automation approach compared to the vehicle-based approach because of less automation hardware required

Disbenefits (not quantified)

• Implementation of U-Shift in the scenarios considered leads to more congestion and road space required because average load is lower compared to today’s vehicles → need to identify adequate use cases (ongoing research activity)

Challenges

• Energy consumption of automated vehicles is higher compared to today’s vehicles, driving emissions and operating costs
Conclusions

• To harness opportunities from autonomous driving technologies, main principles for adoption should be:
  
  – Minimization of vehicles’ energy consumption (for propulsion, automation, comfort)
  
  – Integration into sustainable mobility concepts (no mode shift from public transport and walking/cycling; shared use of autonomous vehicles; high occupancy rate)
  
  – Prerequisite that machines should be better drivers than humans

• The study shows that Cost-Benefit Analysis for a future technology has proven adequate:
  
  – To identify possible drivers for costs and benefits for society
  
  – To identify opportunities and risks of automated driving
  
  – To provide evidence base to formulate policy recommendation
  
  – To inform implementation scenarios
Thank you for your attention.

QA

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