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

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Contents

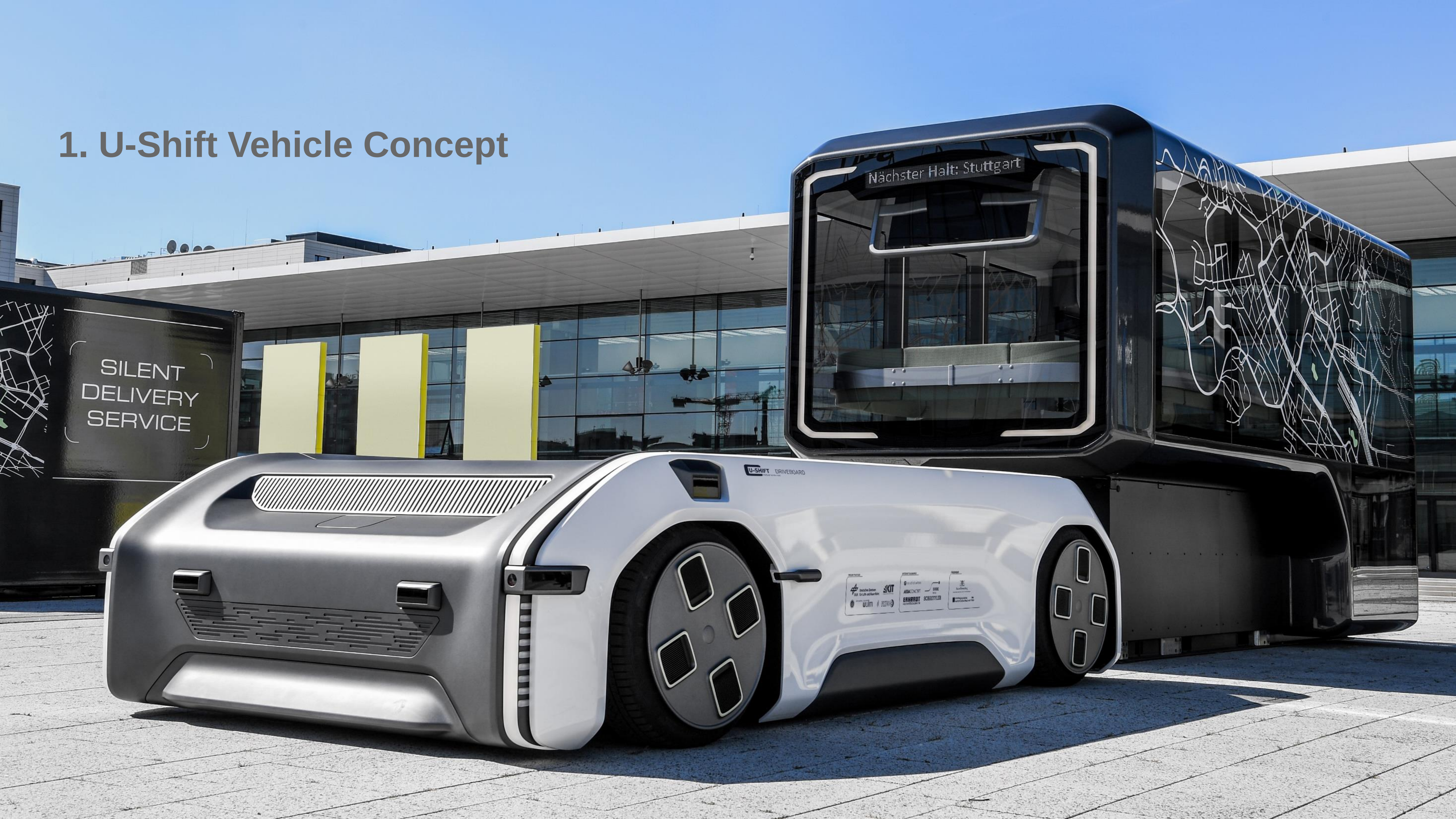
1. U-Shift Vehicle Concept

Cost-Benefit Analysis

2. Framework
3. Results
4. Main Inputs

5. Conclusions

1. U-Shift Vehicle Concept



1.1 U-Shift: An on-the-road modular, autonomous vehicle concept

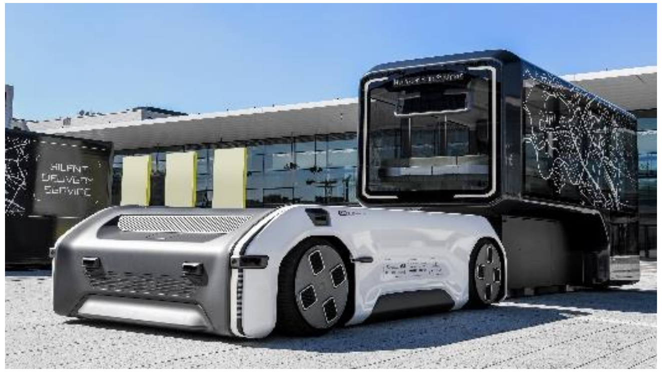
On-the-road modular

Autonomous

Shared / Pooling

Electric – Durable – Energy Efficient Design – Disabled-Accessible – Intermodal – Multi-Functional

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

Cost-Benefit Analysis

→ Quantification of costs and benefits of U-Shift with a focus on **CO_2-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

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2. Cost-Benefit Analysis Framework

2.1 Cost-Benefit Analysis Framework

Assessment of 3 different future **autonomous vehicle scenarios** in Stuttgart in 2040:

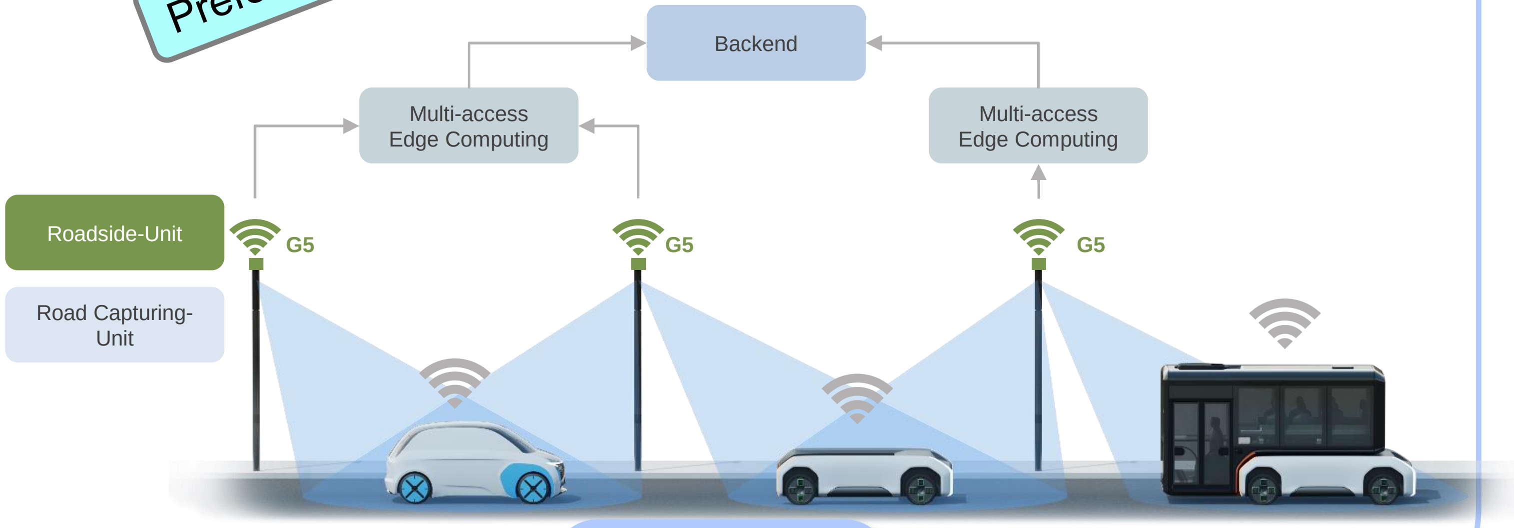
Business-as-usual

SAE 3

Vehicle-based automation

U-Shift: Managed Automated Driving

Preferred Option



Infrastructure-based automation

SAE 4

U-Shift: Automated Driving

SAE 4

Vehicle-based automation

2.1 Cost-Benefit Analysis Framework

Item	Description
Price Year	€2019
Study Year	1 year (2040)
Base Year	2040
Study Area	Stuttgart
Scenarios	Base Case (Business-as-usual) U-Shift Managed Automated Driving (MAD); U-Shift Automated Driving (AD);
Cost quantification	Opex: 2040 Capex: apportioned to 2040 based on asset life
Benefit quantification	2040
Quantified benefits	Road safety, CO_2 emissions, air pollution

→ 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.

1 eIMPACT (2006) Socio-economic Impact Assessment of Stand-alone and Co-operative Intelligent Vehicle Safety Systems (IVSS) in Europe Report type Deliverable D3

3. Cost-Benefit Analysis Results

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3. Headline Results

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

Largest benefit: improvement in road safety

Standalone, in €	Base Case	U-Shift: Managed Automated Driving	U-Shift: Automated Driving
Road Safety	-398 M	-317 M	-332 M
CO_2 Emissions	-153 M	-107 M	-110 M
Air Pollution	-96 M	-73 M	-75 M
Total Benefits	**-647 M**	**-496 M**	**-517 M**
CAPEX	958 M	837 M	860 M
OPEX	721 M	927 M	919 M
Total Cost	**1.680 M**	**1.765 M**	**1.779 M**
Benefit-Cost Ratio		1,8	1,3

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

CAPEX: infrastructure based automation less costly than vehicle based automation!

4. Main Inputs

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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[2]

  – Isolation of effect of driver assistance systems on safety

  – Insurance Institute for Highway Safety (IIHS) (2020)[3] study bas[illegible] crashes in the U.S.: If crashes involving <u>only</u> *sensing/perceiving* factors or *inca*[illegible] could be prevented by autonomous vehicles, 34% of accidents could be prevented

→ Informs our approach

Automated vehicles are expected to be a game changer with respect to road safety
Magnitude of benefits are unknown

[2] Schwall et al. (2020) Waymo Public Road Safety Performance Data
[3] Insurance Institute for Highway Safety (2020) What humanlike errors do autonomous vehicles need to avoid to maximize safety?

4. Main Inputs
Road Safety

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

Estimated reduction potential of accidents (by causes)

Crashes (by Causes)	Managed Automated Driving	Automated Driving
Only sensing and perceiving crashes	95%	75%
Incapacitation	100%	100%
Unavoidable by driver	0%	0%
Remaining crashes with multiple factors (average)	62%	62%
Planning and deciding	75%	75%
Execution and performance	50%	50%
Predicting	50%	50%
Crashes preventable by U-Shift compared to today	1.569.076	1.439.913
Crashes preventable by U-Shift %	**74%**	**68%**

Sleeping, heart attacks and drug&alcohol abuse are not known problems of machines

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.

Difficult to project how well machine will perform in the future

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

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

→ Automated vehicles require energy for automation
Magnitude depends on technological progress and implementation

[3] Gawron et al. (2018) Life Cycle Assessment of Connected and Automated Vehicles: Sensing and Computing Subsystem and Vehicle Level Effects

4. Main Results and Conclusions

Main Results

Benefits of U-Shift

- Implementation of U-Shift may contribute to substantial reduction of **road accidents**
- **CO_2 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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