



# Evolution and Safety Concept of the Modular U-Shift Vehicle for Sustainable Mobility of People and Goods

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**Abstract.** At the German Aerospace Center (DLR), new transport and vehicle concepts for sustainable and user-friendly mobility are being researched. The Institute of Vehicle Concepts of the DLR developed a concept study of a modular and fully automated transport system. The so-called U-Shift enables the transport of different capsules as load carriers and changing them during operation without requiring additional infrastructure. This paper describes the vehicle concept and its project landscape developed in cooperation with other partners in order to picture the evolution towards real life testing. The latest prototype, U-Shift IV, was presented in April 2023 as a new research platform. The first active use case of the U-Shift was decided to be within a public area, in which a research operation is implemented over half a year. Testing prototypes in public areas brings new challenges for DLR in applying legal safety requirements as well as following new processes of assigning automated vehicles in Germany. Due to its interfaces and interactive research, the U-Shift concept of the DLR strongly addresses several TRA themes like user-centered transport or transport safety.

**Keywords:** Automated Driving · Modularity · User-centred Development · Real-life Testing · Prototype · Safety Concept

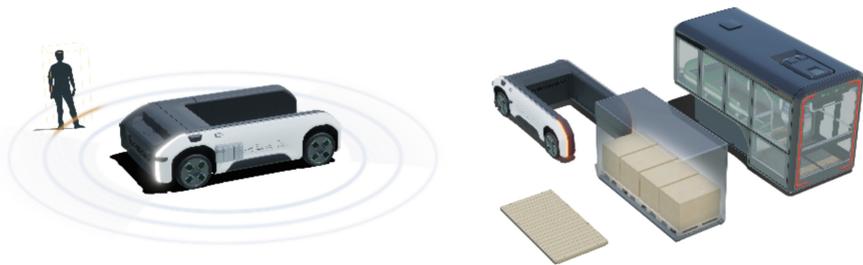
## 1 Introduction, Goals and Methodology

Due to the constant increase in commercial traffic in large cities, especially delivery vehicles and small trucks, there is a great load on the traffic system, particularly at peak times. This is accompanied by a pollution of the air and burdening residents through emissions, traffic jams and noise. This is further intensified by additional passenger traffic with buses and other individual transport. This is where U-Shift comes in, by combining these two essential business areas and offering a new transportation solution. At the German Aerospace Center (DLR), transport researchers are developing vehicle concepts with the aim of devising sustainable and user-centric mobility solutions [1, 2] to face European and global development goals. Within the DLR, the Institute of Vehicle Concepts has developed a concept study for a modular and automated transportation system, the U-Shift (see Fig. 1). Specific use cases are public transport, inner-city store

deliveries, parcel logistics or other services. By addressing these main issues and with its zero-emission drivetrain, the automated U-Shift is meant to contribute to reach mobilities sustainability goals and help decarbonating the cities. The overall goal of this research in DLR is to develop and test this modular vehicle concept and find out requirements for user-friendly and cost-effective transport solutions. Therefore, the DLR is facing particular research topics in separate projects (see Sect. 2). By increasing the technology readiness level (TRL) a public testing is made possible (see Sect. 3). This is an enabler for participative development, which is a main goal in this project. To allow the U-Shift prototype for public research, a state-of-the-art safety concept is being developed and introduced in Sect. 4. The results of the research operation itself is not in the scope of this paper.

## 2 The Vehicle Concept U-Shift and TRL Improvement

The automated *Driveboard* integrates all components and systems necessary for driving. In addition to the electric engines, battery and automation components, it has an integrated lifting system for the simple and quick exchange of different capsules. The capsules are changed “on-the-road”, i.e. during operation at designated areas, to enable new transport and mobility services without additional assistance.



**Fig. 1.** Graphic of Driveboard with sensors and computers for object detection (left side). Different capsule types (right side) for persons (right) or goods (middle) and a bottom structure (left) with same interface structures (Source: DLR).

The U-Shift *capsules* are only equipped with the most necessary technical equipment and can be produced cost-efficiently. This is an important design principle, especially for use in freight transport. U-Shift freight capsules can have a modular design and serve a wide range of applications. The integrated *lifting system* enables the quick and easy exchange of different capsules: First, the Driveboard is sliding under the rail of the capsule bottom. It then raises vertically upwards and lifts the capsule. A locking mechanism centers and locks the capsule. An electrical coupling can be connected to transmit signals or energy. The vehicle is now ready for use.

There are different projects within the U-Shift ecosystem with various research and development goals, covering different development stages and TRLs (see Table 1). The very first version of the vehicle concept was created during the U-Shift I project [3] to define main technical details and build a real scale demonstrator. The U-Shift II project

followed and achieves to improve the technology and create an automated Driveboard as a research platform focussing on citizen participation for research questions [4].

**Table 1.** The table shows an overview over the completed and ongoing U-Shift projects [5]

Project	Objective	Runtime	Funding	Partners
U-Shift I	First demonstrator with remote control	2019–2020	DLR, WM-BW	DLR, KIT, FKFS, UULM
U-Shift II	Drivable automated prototype for research purposes	2020–2024	WM-BW	DLR, KIT, FKFS, UULM
U-Shift III	Remote operated drivable prototype with high performance and ability for MAD	2020–2022	BMWK	DLR, Industry
U-Shift IV	Drivable automated prototype for real-life testing with approval criteria	2022–2025	DLR, WM-BW, SDA	DLR

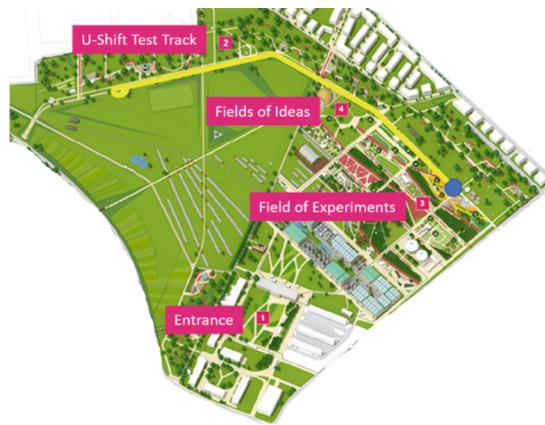
In the U-Shift III project, DLR and industrial partners built another Driveboard designed to operate remotely and provide a test vehicle for Managed Automated Driving (MAD). Currently, the U-Shift IV project is running with the goal to demonstrate automated driving in simple real-life environments. This real-life testing connects international research projects such as EU project “SHOW”. Also technology transfer activities are made to analyze and transfer the knowledge to the industry.

### 3 Research Operation at BUGA

The U-Shift is used to allow the public transparent insights into current mobility research. To do this, an intensive citizen dialog and citizen surveys are taking place at the National Garden Show (BUGA) in Mannheim, Germany. The DLR also conducts workshops with the prototype with potential users and operators for future deployments of autonomous movers. For example, an on-the-move survey was conducted. This means that guests were observed and interviewed during the trip and then invited to take part in in-depth discussions about their needs and expectations. In total, over 150 visitors of the garden show took part in this survey spontaneously and delivered in a transdisciplinary feedback. The driving operation takes place with the Driveboard and the passenger capsule to allow visitors to board the U-Shift.

The BUGA takes place from April 14 to October 8, 2023 with a total of about 2 million visitors inside the area. For the research operation, a 2,000 m long test track is available on the park site. The U-Shift is exhibited for seven days a week which results in a total exhibition time of about 1,500 h. Approximately 10 journeys can be made per

day, which means a total mileage of about 2,000 km with about 10.000 passengers in the entire testings.



**Fig. 2.** U-Shift test track at the National Garden Show with start and ending point (blue circle) and the 2.000 m test route (yellow line) inside the park area (Source: <https://www.buga23.de/die-parks/spinellipark/>. Accessed on 08.01.2024)

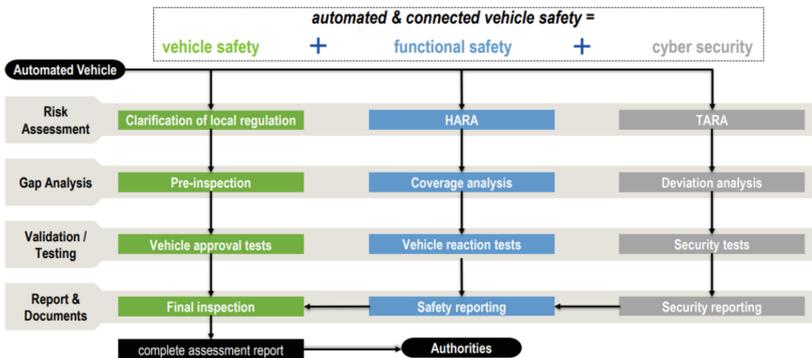
The test route is a 4.0–5.0 m wide asphalt road. The terrain is flat, but there is varying vegetation along the road. The exact route can be seen in Fig. 2. It contains several straight sections and curves, as well as a U-turn at the left end of the route. In addition to the U-Shift, Light Electric Vehicles are present on the road, as well as a trackless park train for the visitors. Pedestrians can move or cross the road along the entire track in a short distance, so there is no separate driveway for the U-Shift which is a challenge in forecasting road users' movements. For monitoring such interactions, the sensor system is able to record the field of view and provide information about quality and range of different sensor types. For communicating with pedestrians, the U-Shift is equipped with visual panels and sound systems to inform about its movement. Additionally, a safety operator is always on board to control the vehicle and act in critical situations.

The test track characteristics result in specific requirements for the safety concept and they are part of the DLR research. For example, the bus stop is used to investigate safe boarding and alighting. At intersections, communication between the vehicle and pedestrians as well as passengers can be investigated.

## 4 Safety Concept for Automated Vehicle Operation

The safety concept created applies exclusively to the single U-Shift IV vehicle, consisting of a Driveboard, a passenger capsule and a multi-use platform. Although the BUGA is a private area with no needs for official approval, the goal was to satisfy all legal safety requirements, especially the StVZO (German road traffic registration ordinance). This is intended to safeguard the demonstration operation at BUGA as well as other test fields and improve the vehicle's suitability for future road use.

The safety assessment follows the AV-Permit of TÜV Süd [6] as seen in Fig. 3. It is based on legal requirements and supplements these with an assessment of operational safety. The safety concept covers all driving modes (automated, remote-controlled and manual) as well as safety measures for the operating environment. The result of the AV-Permit is a comprehensive documentation of the vehicle, training concepts for the vehicle operators and the expert report for submission to insurance companies and authorities for final approval.



**Fig. 3.** Framework Details of the AV-Permit for automated and connected vehicles by TÜV Süd. The main assessment fields of Vehicle Safety, Functional Safety and Cyber Security are examined including a risk assessment, gap analysis and validating as well as reporting [6].

The *Vehicle Safety* contains a comprehensive system description of the vehicle. Here, legal requirements according to the German Road Traffic Licensing Regulations (StVZO) are clarified and the vehicle is physically inspected by an independent third-party organization. In *Functional Safety*, a hazard analysis (for the planned operating scenario, HARA), a fault analysis of the technical system (FMEA) and a reliability analysis (Fault Tree Analysis FTA) are carried out (e.g. according to the ISO26262 standard). To minimize errors and misbehavior, prerequisites and qualification measures for operators are defined. The *Cyber Security* includes a Threat Analysis and Risk Assessment (TARA) and a test plan for cybersecurity tests to secure all non-physical interfaces.

The U-Shift IV *Vehicle Safety*, together with the passenger capsule, was successfully approved by the TÜV as a special vehicle. With a few exceptions, U-Shift complies with German regulations, e.g. the vehicle has no steering wheel and no conventional driver’s seat. Based on this report, the authorities can issue an individual operating permit and exemption permit according to §21 and §70 of German StVZO.

In the HARA, all potentially dangerous situations occurring at the BUGA were systematically examined for the *Functional Safety*. Corresponding safety requirements and limitations were derived from the analyses such as limiting the maximum speed to 15 km/h along the test route. In designated slow zones, e.g. areas with dense traffic or at intersections the speed is limited to 6 km/h. The FMEA contains a complete system description of the U-Shift and possible (system) fault cases while the FTA shows the effects of simultaneous faults. The critical case here is the brake process. Redundancies

ensure that the vehicle is always able to brake to a standstill. An essential part of the safety concept is the driver training to qualify the vehicle operators. Due to the conditions at the BUGA and the prototype status, the safety concept defines the vehicle to be accompanied by a safety driver.

The remote control and the radio emergency stop are particularly relevant in the *Cyber Security*. These components communicate constantly with the vehicle and are a potential gateway for manipulation attempts. This risk was reduced by taking appropriate measures.

## 5 Conclusion and Outlook

Regarding user-centered transport, the research has shown that it is essential to involve all target groups in the requirements assessment and dialogue. In particular, groups that have doubts about new transportation solutions or that cannot be addressed using conventional methods can be reached by using a participatory approach to define important requirements and hence increase the chances of a successful market launch. In the field of road safety, it has been shown that it is essential to consider vehicle safety, functional safety and cyber security in each specific application. This includes both the operating environment and interactions with other road users or passengers. Unmistakable communication between the vehicle and pedestrians in particular is a prerequisite of safe automated transportation.

Within the U-Shift IV project the DLR successfully assigned the vehicle for the research operation according to legal requirements and the effectiveness of the safety concept was proven at the test area. For a fully road assignment further developments and a comprehensive approval are necessary, which is the next step and targeted for 2024. Further steps are also to research about the vehicle-to-vehicle communication as well as the communication between vehicle and passengers/pedestrians.

At the time of the paper submission, the test phase has not yet been completed and is therefore subject in further publications. The U-Shift IV project and its findings will serve as a blueprint for future DLR projects and further tests of similar vehicle concepts in public areas.

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