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A highly innovative on-the-road modular vehicle and operation concept to solve today traffic issues

Christian Ulrich[1], Prof. Dr. Horst E. Friedrich[2], Jürgen Weimer[2], Dr. Stephan A. Schmid[2]

[1]*German Aerospace Center (DLR), Institute of Vehicle Concepts, Pfaffenwaldring 38-40, 70569 Stuttgart, Germany, Christian.Ulrich@DLR.de*

[2]*Same affiliation*

Summary

Technology trends, like automated driving, electro mobility, and digitalization amplify each other and lead to a transformation of the mobility sector. A possible approach to support this process, are modular vehicle concepts. However, only truly on-the-road modular concepts have the potential to change the mobility system in a disruptive way. Our proposed solution focuses on an autonomous, electrified and connected vehicle which's drive module is separated from a transportation capsule. After analyzing the current traffic situation, our vehicle concept will be described in detail. Subsequently, possible use cases and operation strategies are explained.

Keywords: Business model, city traffic, freight transport, mobility concepts, public transport

1 Situation

Currently, major technological trends have an impact on the transportation system, especially in urban regions. The technological trends autonomous driving, electrification, and digitalization amplify each other, thereby initiating a transformation process in the mobility sector. Intensive research and public awareness in these technology areas increase the speed with which new technologies are market ready and accepted in the society. For instance, battery prices are decreasing while energy density and the mileage are increasing [1]. The intensified contribution to the electrification of vehicles has been reflected in a growing market for electric vehicle: according to the ICCT[1], there have been 60% more sales of electric vehicles worldwide in 2017 than the year before [2]. Further, legislative questions for autonomous and highly connected vehicles are clarified and safe and reliable technological solutions are being developed [3].

Action plans to reduce transport induced environmental pollution

Apart from the technological trends ("push-factors") which enable new vehicle concepts, current traffic issues demand for new solutions ("pull-factors"). Worldwide, urban regions are challenged with air pollution and traffic congestions. Continuing with the status quo this issue will become even more severe in the future, as urban regions are massively growing: as of today, 55% of the global population lives in urban regions and it is expected that two thirds of the whole population will live in "global cities" by 2050 [4]. In

[1] ICCT: The International Council on Clean Transportation

order to tackle issues induced by urban transport and to comply with legislative emission limits such as the Paris 2° target [5], nations as well as municipalities react with action plans while simultaneously looking for new transportation concepts. Action plans include e.g. the “Roadmap Towards a single European Transport Area” by the European Commission which’s target is to reduce the greenhouse gas emission of transport by 60% (compared to 1990) and no more conventionally-fueled vehicles in cities until 2050 [6]. Fig. 1 shows the impact of the “roadmap” on CO_2-emissions from the transport sector.

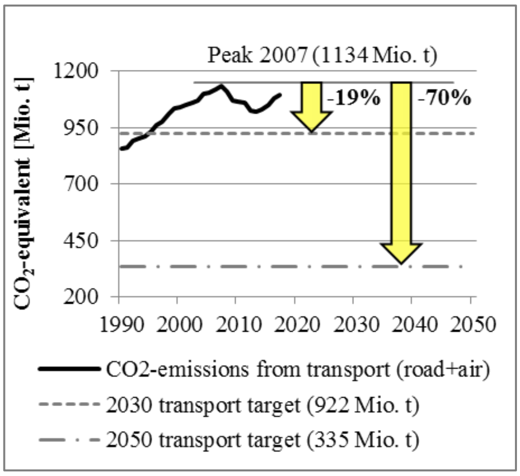

Fig. 1: CO_2-emissions of the transport sector in the EU28 (own visualization, data from [7]).

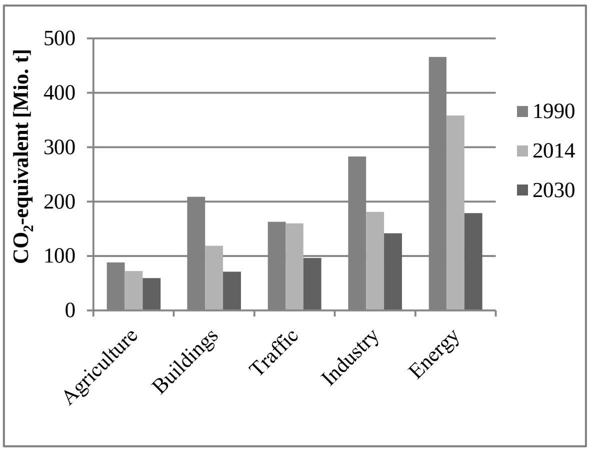

Fig. 2: Greenhouse gas emissions per industry in Germany; values for 2030 are target definitions to achive the 2016’ action plan (own visualization, data from [8]).

At national level, governments adopt additional action plans, such as Germany’s climate protection plan from 2016. It regulates the amount of greenhouse gas German industries need to reduce in order to comply with the overall aim of being greenhouse gas neutral by 2050. As an interim goal, 40% less greenhouse gases are to be emitted by 2030 compared to 1990. Fig. 2 depicts the current development the greenhouse gas emissions of different industries in Germany. The required target values for the sectors to achieve the 40%-reduction by 2030 are included as well. Specific measures such as the increased expansion of public transport, the promotion of alternative propulsion systems, or industry coupling shall help to reach the goals. Fig. 2 reveals, however, that the traffic-induced CO_2-emissions stayed almost constant from 1990 to 2014. This is due to the fact that the transport volume increased while the vehicles became more efficient. A further increase in the transport volume can be expected in the future. Gains in vehicle efficiency will not be able to compensate for this rise. In addition to a consistent electrification of the fleet, the transport concept and thus also the vehicle concepts have to be fundamentally reconsidered. Otherwise urban access restrictions for specific engine types – currently the ultima ratio[2] – might become the new status quo.

Motorized individual transport remains main means of transport

Fig. 3 combines the data from the statistics series "Mobility in Germany" from 2002, 2008, and 2017. It becomes apparent that in most cases (regardless of the regional type) the car continues to be the main means of transport. Only in metropolises less than 50% of all journeys are performed by car (driver or passenger). Presumably, this is because public transport in urban regions is better developed than in the countryside and that in cities the mindset is often more oriented towards public transport (due to issues related to MIT[3] such as lack of parking space, traffic jams or particulate pollution). Averaged over all regional types and grouped according to the main travel purposes, the development shown in Fig. 4 results. Except for educational purposes, where PT[4] is equally used, over 50% of all travel purposes are done by MIT. Unfortunately, MIT is very inefficient in terms of assets (cars etc.) standing idle. In fact, studies have

[2] E.g. Stuttgart (Germany) denies vehicles with diesel internal combustion engines (≤ Euro 4) access to the city since January 2019.
[3] MIT: Motorized Individual Transport, including car (driver and passenger) as well as motorcycle and moped
[4] PT: Public Transport (local)

shown that individually owned cars are parked more than 95% of their lifetime (e.g. [9], [10]). Hence, it would be better to have autonomous, connected cars, which could relocate themselves (more parking spaces) and could be called on demand in a shared model (higher efficiency).

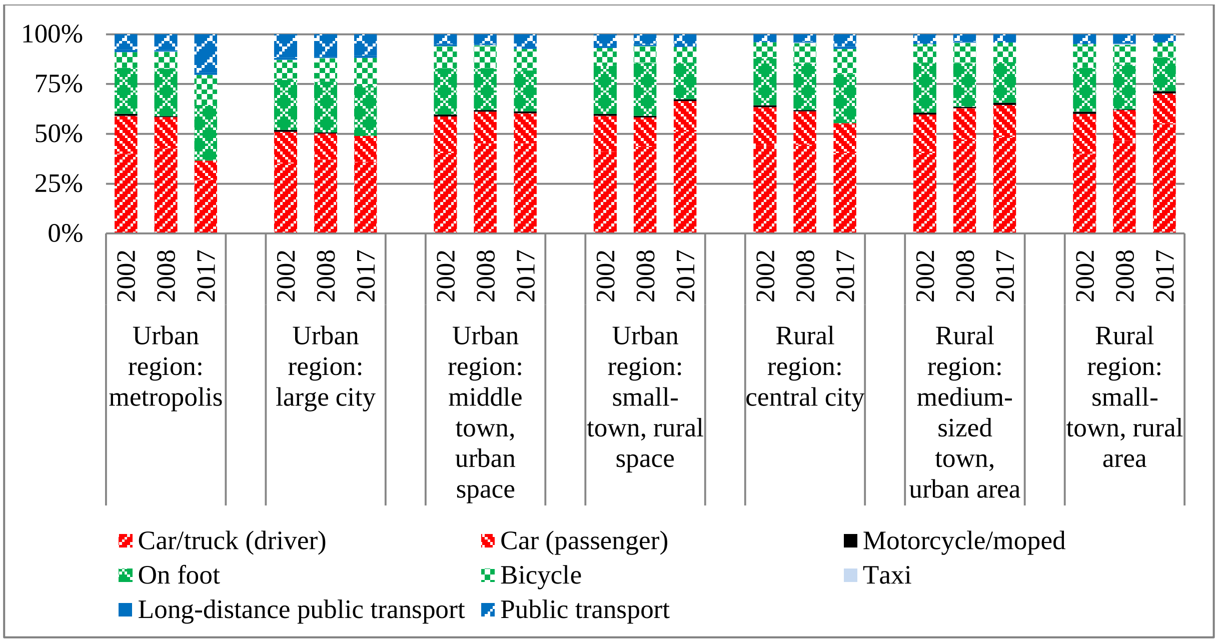

Fig. 3: Development over time (2002-2017) of the modal split according to main means of transport in Germany, sorted according to regional types (own visualization, data from [11]–[13]).

Last but not least, the statistics "Mobility in Germany" ([13]) give evidence that there is no such thing as a "standard" car (neither for urban nor for rural regions). While compact class cars have been sold most in Germany in 2017, there prevail cars from "mini" class (mostly in cities) to SUVs and luxury cars. The statistical evaluation indicated that travel purpose optimized vehicles would be best for the consumer, choosing the perfect car for each trip. Similar results have been derived from an internal project of the German Aerospace Center on urban mobility: On the basis of stakeholder analyses, different user groups (personas) have been created. Apart from the personas group "urban bike lovers", all others perceived vehicles with adaptable dimensions ideal as this facilitates a high flexibility in purpose-optimization during everyday application [14].

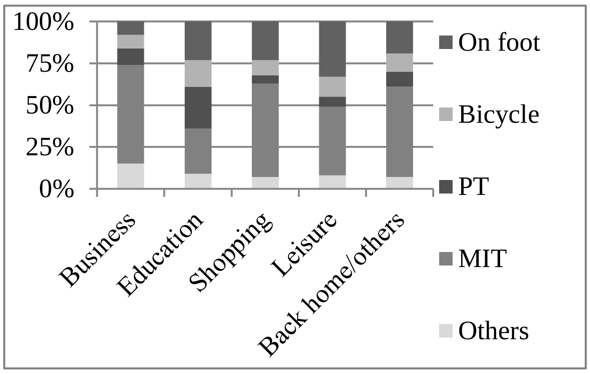

Fig. 4: Modal split by travel purpose in Germany (own visualization, data from [13]).

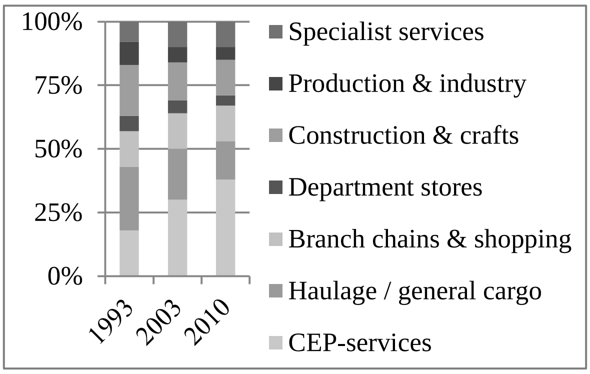

Fig. 5: Share of commercial vehicle trips by industries in urban areas in Germany (own visualization, based on internal analyses).

Commercial transport

However, not only has the passenger transport to be enhanced, but also the transportation of goods. As shown in Fig. 5, a wide variety of operational purposes prevails for urban commercial transport, with the share of parcel service providers (CEP[5]) increasing significantly. In Germany alone, the CEP industry was growing by 98% from 2000 until 2017 (with regard to the number of shipments). Another 5.2% increase per annum is expected from 2017 until 2022 [15]. Compared to the B2B shipments, especially the B2C segment grew in the last years, which is mainly due to the increase of e-commerce [16].

For every purpose other requirements have to be met: parcels, construction materials, other goods, and persons possess different formats, dimensions, and weights. New vehicle concepts, which can adapt to specific, application-optimized needs (such as variable vehicle length or interior), may prove suitable for commercial freight- as well as passenger-transport. The next chapters introduce modular vehicle concepts which are designed for purpose-optimization.

2 Modular road vehicle concepts

Modularization ex-factory is a common production strategy of automotive manufacturers already for decades. This approach separates the car in different standardized components during the manufacturing process. The benefits of this approach are a high variety of vehicle derivatives and lower costs for production and development at the same time (see [17], [18]). This way, use case optimized vehicles, like people mover with different lengths, cargo movers, or a combination, can be produced on the same platform. An example is the vehicle concept “Urban Modular Vehicle” by the German Aerospace Center [19]. However, while being optimized for one specific application it is not possible to change their dedication after leaving the factory.

On-the-road (otr) modular vehicle concepts use a similar modularization strategy as ex-factory modular concepts, but they remain modular even after leaving the factory, that is during operation. Here, the strategy is to divide the vehicle in two parts: a driveboard (chassis, including all components and functions for driving) and a transportation unit (capsule / hat) which is designed application optimized in terms of equipment for the interior as well as the external dimensions. Depending on the upcoming task, the required capsule is attached to the driveboard and when finished, the capsule is changed. While there are otr-modular vehicles on the market which do not drive autonomous[6], recently presented otr-modular vehicle concepts utilize an autonomous, highly connected driveboard, as this improves the efficiency of the costly driveboard (24/7 operation). Fig. 6 shows a compilation of published otr-modular vehicle concepts. Table 1 at the end of the following chapter and [17] compare (the most relevant) concepts in detail. We propose another otr-modular vehicle concept (next chapter), which was developed at the German Aerospace Center, Institute of Vehicle Concepts, which solves key functions differently than competing concepts.

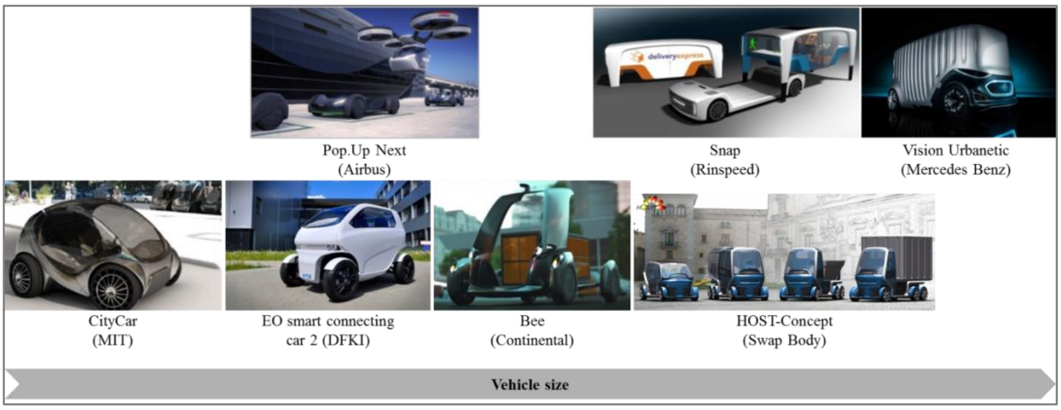

Fig. 6: Demand-oriented, flexible vehicle concepts - examples from previous concepts and prototypes (own compilation, picture source: vehicle manufacturers and Wikipedia).

[5] CEP: Courier, Express, Parcel
[6] E.g. the “Hubi 55” by “Heimann Fahrzeugbau” (https://heimann-fahrzeugbau.de/hubi-55-en)

3 MAUDE: an on-the-road modular vehicle concept

Following the on-the-road modularization strategy, our proposed vehicle concept MAUDE[7] consists of a driveboard and various capsules (Fig. 7). In the following sections, first the driveboard and then the capsules will be described in detail. Sections regarding automation and energy management succeed, while a comparison of different otr-modular concepts sums the chapter up. Ulrich et al. [20] provides more detailed information on the technological background of the otr-modular vehicle concept MAUDE.

Driveboard

The driveboard is an electric, standardized, autonomous, and highly connected platform comprising all functions for driving. Further, the lifting system to attach the capsules is integrated into the driveboard, as this reduces the capsules' costs and avoids additional infrastructure cost. This is a major difference to competing concepts which integrate the lifting system in the capsules or use handling robots. The driveboard is shaped in form of a lying "U" with the capsule between the "U-limbs". This structural design requires a sophisticated packaging since the space for chassis, power unit, battery pack, automation sensors, computational hardware, and lifting system is very limited. Moreover, the additional components for the modularization reduce typically the payload. For a Sprinter-sized[8] MAUDE vehicle (consisting of driveboard and capsule), the payload is reduced by approximately 10% (depending on the battery dimensioning) compared to equally sized electric light commercial vehicles without otr-modularization. Extra-large as well as large and maybe medium sized capsules are intended to operate on the same driveboard size. While this increases the complexity of the driveboards' structural design, it offers the required flexibility for various use-cases. The "U"-shape with the rear opening enables the transportation of capsules with different lengths, allowing for even more flexibility in applications. Last but not least, the lifting concept has the benefit that the capsules are discharged on ground-level. This facilitates the loading and unloading of the capsules for urban applications and reduces conceptual payload shortcoming.

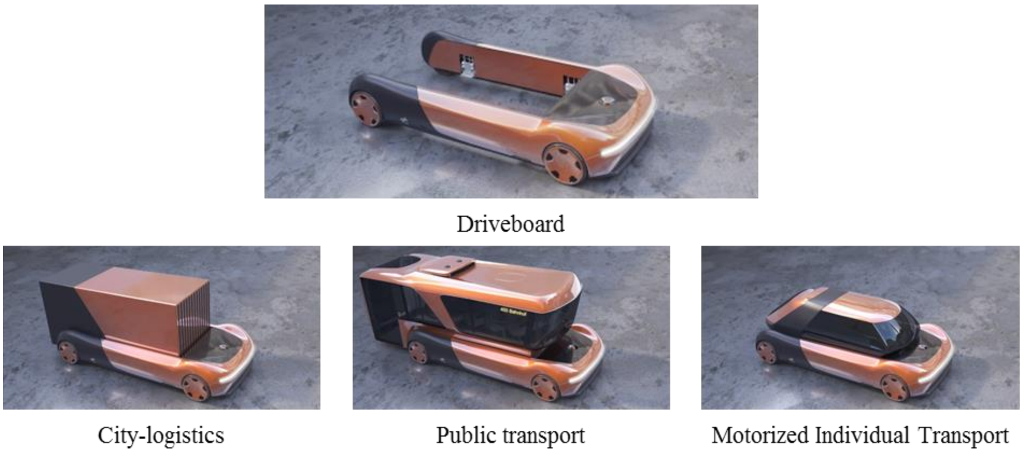

Fig. 7: Driveboard and selected application-optimized capsules (own visualization)

Capsule

The capsules are application-optimized, have standardized interfaces for the lifting system, and can be produced in light-weight and cost-efficient as they do not need an own integrated lifting system. They can be designed multi-purpose for 1) the transportation of goods (cargo mover), 2) the transportation of people (people mover for public transport), and 3) optionally for individual mobility. Detailed use-cases are discussed in chapter 4. The capsules are shaped like a basic rectangular box with a thin and lightweight

[7] MAUDE: Modular, Autonomous, Updateable, Disruptive, Electric
[8] Mercedes-Benz Sprinter: a N1-class vehicle (https://www.mercedes-benz.com/en/mercedes-benz/vehicles/transporter/mercedes-benz-presents-the-third-generation-of-the-sprinter/, accessed 15.03.2019)

frame. A major gain of this simple capsule design is that it could become a standardized format. In the future, they might be normed transport units similar to ISO containers. ISO containers are not applicable to MAUDE as their width of 2.438m is too large to fit between the “U-limbs” and still comply with the regulatory maximal width of road vehicles (2.55m in Germany). For freight transportation the utilizable capacity is limited by the base (which is defined by the area between the “U-limbs”). E.g. for a pallet transport application, an extension of the capsule’s width above the limbs does not make sense. For other use cases, however, such as public transport or the delivery of parcel boxes a side extension increases the applicability.

Automation

Recently introduced urban cargo- or people-mover usually aim for SAE5-level of automation, which means that the vehicles are driverless, autonomous robots, i.e. without human drivers. This is an advantage not only from a financial point of view (human drivers are the main cost factor in e.g. parcel delivery) but also from a demand vs. supply perspective. Companies in the logistic as well as the public transport industry are desperately looking for new drivers. A decreasing number of people is applying for the job because it is often poorly paid and the working conditions are comparatively unfavorable to other industries [21], [22].

The MAUDE concept will be SAE5 as well, however, following a different automation strategy. Instead of a “conventional” vehicle focused strategy we pursue an automation based on the infrastructure. Most car companies, as well as companies promoting people mover such as Navya or EasyMile, integrate all necessary sensors, communication hardware, and computation power in the vehicle itself. This increases the costs and energy consumptions of the vehicle significantly. There are other approaches, though, which follow an automation strategy based on vehicle control within the infrastructure. E.g. Bosch already introduced Valet Parking based only on sensors in the infrastructure [23], while China follows the infrastructure-based strategy on a national level in their project “Intelligent Connected Vehicle” [24], [25]. From a financial perspective, it makes sense to outsource the sensors to the infrastructure as far as possible and thus distribute the costs among many different vehicles/users. In addition, the fleet can be coordinated more efficiently and controlled like a swarm via a central traffic control center. Of course, the concept only works in defined, fully developed spaces. City districts are therefore more suitable than rural regions. Probably a compromise between the two strategies is required for MAUDE in order to provide maximum safety. Ulrich et al. [20] discusses this question in-depth.

Energy management

In Ulrich et al. [20] the drive system of delivery van-sized MAUDE vehicle is defined with 2*45 kW and 1600 Nm. These are sufficient values for urban applications with maximum speed of 70 km/h and a gradeability of 8%. As for the energy supply concept MAUDE follows a modular strategy, too. The central battery is installed in the driveboard and in addition, some capsules will be equipped with additional batteries. Capsules for the transportation of passenger as well as specific energy consuming capsules like for refrigerated goods are a logic choice for an extra battery. The driveboard should be in operation close to 100% for maximum workload of the costly components. However, the battery in the driveboard alone cannot be designed effectively for 24h operation (let alone the time for charging). Further, fast charging affects the battery’s lifetime. When the capsules stand idle for a longer time they can be charged battery friendly with lower currents. During operation, the capsule’s battery will be used to charge the driveboard’s battery. Despite the significantly more complex design consideration (e.g. high-volt interface between capsule and driveboard), the modular battery approach is promising. First battery designs have been specified in [20].

Analysis of different otr-modular vehicle concepts

In Table 1, selected otr-modular vehicle concepts including MAUDE (rows) are compared on the basis of four factors (columns). The table is adopted from [17], which also explains the comparison in more detail.

Table 1: Juxtaposition of on-the-road modular vehicle concepts (from [17]).

	Use	**Standardization**	**Loading**	**Module change**
Snap (Rinspeed)	Flexible (various purposes)	Individual solution	Lateral	Vertical, lifting system in the capsule
microSNAP (Rinspeed)	Flexible (various purposes)	Individual solution	Lateral	Vertical, auxiliary robots needed
Vision Urbanetic (Mercedes Benz)	Flexible (various purposes)	Medium potential	Back, at ground	Forward (gauge actuation)
BEE (Continental)	People- and Cargo-Mover	Individual solution	Front	Auxiliary robots needed
Pop.Up Next (Airbus, Audi, Italdesign)	People-Mover	Individual solution	Lateral	In the high, lifting done by a drone
MAUDE (DLR)	Flexible (various purposes)	High potential	Back or side, at ground	Forward, lifting system integrated in the driveboard

4 Business models and operational concepts for MAUDE

The key to a successful market penetration of a new transportation solution is ease-of-use, cost-effectiveness, and improvement of today traffic issues. There are two major differences to today concepts for the transportation of passengers and cargo: (1) MAUDE is autonomous and (2) MAUDE is otr-modular. Electrified commercial transporters are already on the market[9]. Electrification (and automation) allows for night deliveries even in residential areas and complies with possible future urban access restrictions. (1) Autonomous driving at SAE level 5 is the key element of MAUDE's fundamental business model: Mobility-as-a-Service (MaaS). Instead of a possessive model (status quo), within MaaS vehicles or rides are shared, thus increasing the fleet's efficiency. Particularly, the driveboards should be used to capacity, as they account for the most costs in the concept. Moreover, high personal costs can be reduced by automation. (2) The otr-modularization is ideal to increase the utilization of investment goods (driveboard) while equipment that stands idle (capsules) are designed particularly low-cost. This should also encourage small and medium enterprises to design or buy their own capsules tailored to their individual needs. Due to the low acquisition costs of the capsule and the pay-per-use model for the use of the driveboard, this is an ideal business model for a variety of different stakeholders. Possible applications are illustrated in Fig. 8. Of course, many more are conceivable.

[9] E.g. Streetscooter's „Work“ (https://www.streetscooter.eu/models/work/, accessed: 10.03.2019)

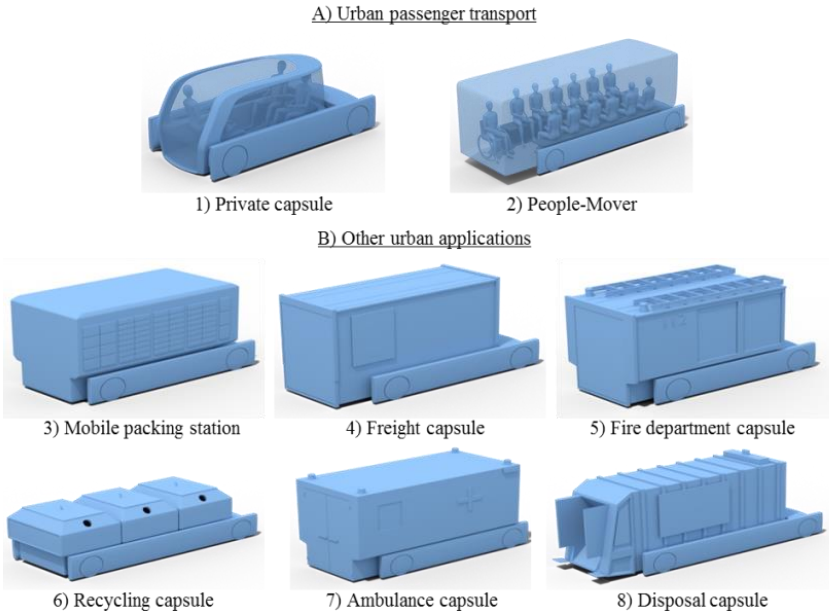

Fig. 8: A selection of capsule designs for possible applications (own visualization in a former design).

Preliminary considerations on the current supermarket and parcel delivery situation

Currently, most supermarkets are served only once per day (in the morning). With otr-modularization the refrigerator capsule is deposited at the supermarket autonomously in the night and unloaded by the supermarket employees in the morning. During the day delivery perishable goods can be restocked.

Parcel lockers have the benefit that the recipients do not have to be present to receive the parcel. Instead they are informed via smartphone when their parcels are ready for collection. According to [26], parcel lockers should be switched twice a day: once in the night and once during early afternoon. Not collected parcels stay in the capsule and can be fetched in the next turn. A survey and analysis done by McKinsey on last mile delivery models in 2016, claims that “in the next ten years” automated guided vehicles with parcel lockers will deliver more than 80% of regular parcels (not same-day, courier, etc. and no groceries) [16]. They base their assumption on their cost model with the (not surprising) key finding that personal costs have the biggest impact on delivery-costs. With most of their survey-respondents mentioning the price as the biggest decision factor and 40% of the respondents already open minded to parcel lockers, their conclusion seems to be coherent. For the MAUDE concept, we assumed a 2750x1350x1250mm³ parcel capsule as one possible locker solution. Based on standardized parcel sizes and the statistical distribution between large, medium and smaller parcels, an optimization algorithm was used to calculate the possible number of packet boxes per capsule: the assumed capsule can contain one very large, 22 medium and 100 small sized parcel boxes as well as one service terminal.

Parcel lockers are a suitable choice to deliver standard parcels (not express or courier) to recipients who are closely located to the locker (e.g. ideal for apartment high rises). If these two requirements are not fulfilled, other delivery concepts need to be pursued. For less dense populated areas within the city, micro hubs offer a viable alternative. Micro hubs for parcel delivery are small mobile depots. Other vehicles, such as small electric vehicles ([27]) or city cargo bikes can deliver the parcels on the last mile to the final customer. For the MAUDE concepts ultimately a whole family of different vehicle sizes is planned. Thus, the most suitable vehicle can be used for the respective specific task. For the last mile delivery a very small version should be utilized. Projects, e.g. in Hamburg or in Barcelona, analyzed the potential benefits of micro hub implementation for the last mile [28], [29]. They found out that for their individual set-ups this new logistic concept results in a significant reduction of emissions and travelled ton kilometers.

Exemplary use case “Urban PT operator with MAUDE vehicles offering LaaS”[10]

The following exemplary use case shows, how the MAUDE concept could go in operation in different applications. A local privately owned bus company operates in the public transport sector in an urban region. Currently, they need large articulated busses (typically 18m) in order to cope with peak passenger flows. However, these peaks occur only during the morning and the afternoon (commuter or school traffic). This means, that the bus is underutilized most of the day. These large busses could be replaced with smaller busses of about 8-12m lengths to reduce this inefficiency. The “small” bus is cheaper in acquisition as well as in consumption. In addition, MAUDE driveboards and passenger capsules are employed in order to assist the busses during peak hours. This way, the company still complies with the statutory duty towards the municipality to supply transportation – even in peak hours [30]. In “off-peak” phases, the driveboards unload the capsules at the main station or industrial area / airport (Fig. 9). The passenger capsules serve as bus shelters during this time.

The driveboards are free for other applications during these “PT off-peak” phases. Thus, the bus company signs contracts with a hauler specified in transporting goods for supermarkets (“HAUL”) and a parcel delivery operator (“PDO”). HAUL bought cargo capsules with refrigeration while PDO owns capsules in form of (a) parcel lockers and (b) micro parcel hubs. The driveboards deliver HAUL- and PDO-capsules in “off-peak” phases according to Fig. 9. The parcel company as well as the hauler pay the bus company per time and distance their capsules travelled on the driveboards (pay-per-use, LaaS[10]). As the driveboard will operate autonomously, they can deliver during the night. Night delivery is ideally applicable for CEP as well as for supermarket delivery. The PT- as well as the HAUL-capsules need a battery for their task. A bigger battery dimension and the modular battery strategy in chapter 0 enable an increased range of the driveboards for nearly 24h/day. Thus, potentially only shorts breaks for charging of the driveboards are sufficient.

The business model canvas (Table 2), according to the methodology introduced by Osterwalder [31], concentrates the key components of the use case while Fig. 9 illustrates how otr-modularization enables new operational concepts for urban logistics. Table 3 sketches a typical operation schedule of the driveboards in the exemplary business model.

Table 2: Business model canvas for the exemplary use case “Urban PT operator with MAUDE vehicles offering LaaS”

<table>
<tr>
<td colspan="2" rowspan="2"><u>Key Partners</u>
Manufacturers of driveboards and capsules; municipalities</td>
<td colspan="2"><u>Key activities</u>
Operate and maintain the fleet for PT[10] and LaaS[10] in B2B[11]</td>
<td colspan="2" rowspan="2"><u>Value proposition</u>
LaaS; Lower risk for B2B-partners; Increased efficiency; New time windows for delivery; Use case optimized capsules</td>
<td colspan="2"><u>Customer relationships</u>
B2C[11]: individual
B2B: contracts</td>
<td colspan="2" rowspan="2"><u>Customer segment</u>
B2C: people using PT
B2B: parcel service operators, haulers for supermarket goods</td>
</tr>
<tr>
<td colspan="2"><u>Key resources</u>
Fleet of drive-boards and PT-capsules; Fleet management skills</td>
<td colspan="2"><u>Channels</u>
B2C: Apps, Website
B2B: personal contacts</td>
</tr>
<tr>
<td colspan="5"><u>Cost structure</u>
Purchase costs for driveboards and PT-capsules; low personal cost (no driver, maintenance and operational staff); maintenance and operating costs; remote control equipment</td>
<td colspan="5"><u>Revenue streams</u>
B2C: Pay-per-ride for PT
B2B: cargo transport either on pay-per-use or on contractual basis</td>
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[10] LaaS: Logistic as a Service; PT: Public Transport
[11] B2C: Business to Customer; B2B: Business to Business

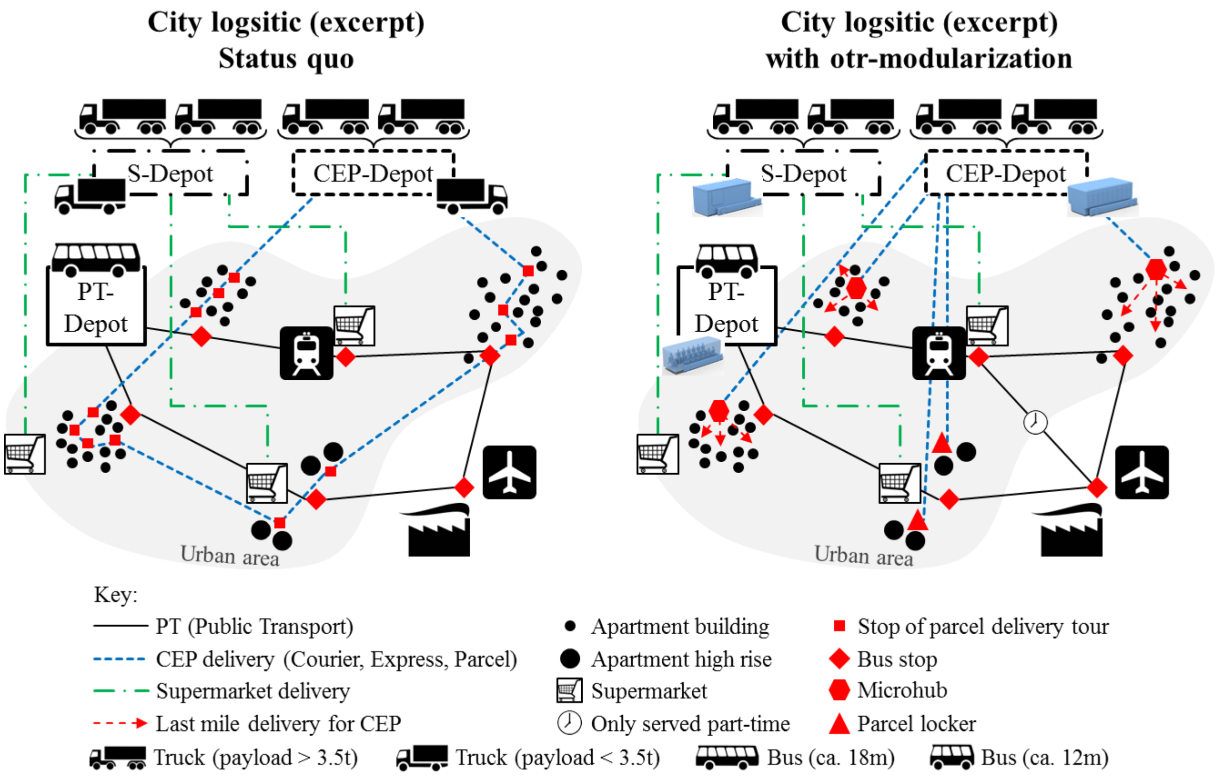

Fig. 9: Excerpt of the (left) current city logistic regarding public transport, parcel service, and supermarket delivery and (right) possible changes through otr-modular concepts. The urban area (grey) is filled with houses, stores, streets, etc. but they have been cut out for improved clarity (own visualization with symbols from Pixabay[12]).

Table 3: Typical operation schedule of the driveboards

Time vs. capsule type	Public transport	Supermarket delivery	Parcel delivery
00:00-05:00		X	
05:00-09:00 (peak)	X		
09:00-12:00			X
12:00-15:00		X	
15:00-19:00 (peak)	X		
19:00-24:00			X

This is an exemplary business model, while other concepts are viable as well and partly discussed in [17]. E.g. the fleet owner does not have to be the bus operator, and other stakeholder such as control unit operators or maintenance companies can benefit in the MAUDE environment as well.

5 Summary and outlook

In this paper, a new on-the-road (otr) modular vehicle concept has been presented. It consists of an electrified and autonomous driveboard and separated low-cost capsules which can be easily switched during operation. This enables new unique operational strategies for urban logistics. Further, a possible business model was described as an example.

However, there are still challenges on the way to realizing the vehicle concept: technical solutions are developed in a currently ongoing project. In addition, the business models have to be quantified for a real use case, respectively initial estimates have to be verified. This creates a reliable database that allows for meaningful comparison with existing concepts.

[12] www.pixabay.com (accessed: 10.03.2019). The symbols are used under the CC0 license.

For the otr-modular approach an open platform seems appealing: the capsule's external dimensions and interface requirements are predetermined, while stakeholders suggest designs and applications. Like with apps on smartphones this would be extremely beneficial for a successful and fast market penetration. In this thinking the driveboards would be the smartphones (hardware), while the capsules equal apps.

In the future, we envision a fleet of otr-modular vehicles which are closely connected to other urban transportation systems such as trains, ropeways, or drones for an ideal intermodal transportation of passengers and goods. For a maximal efficient transportation, new logistic concepts, specialized on autonomous carriers, need to be developed, e.g. tour planning based on artificial intelligence.

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Authors

Christian Ulrich (M. Sc.) received his diploma in Technology Management from the University of Stuttgart (Germany). He has profound knowledge in the fields of Technology and Innovation Management in the automotive industry. Since 2018, Christian Ulrich works at the German Aerospace Center (DLR), Institute of Vehicle Concepts in the department of Vehicle Systems and Technology Assessment as a Research Associate.

Prof. Dr. Horst E. Friedrich is Director of the Institute of Vehicle Concepts at the German Aerospace Center in Stuttgart. The institute develops concepts of road and rail vehicles of next generations. The research fields are Alternative Power Trains and Energy Conversion as well as Light Weight Design and Hybrid Construction methods. At the same time he became professor at the University of Stuttgart and he is lecturer at the Technical University of Berlin.

Jürgen Weimer is Project Manager at the Institute of Vehicle Concepts at the German Aerospace Center (DLR). He studied electrical engineering at the University of Kaiserslautern (Germany) and has a MBA in International Business from the German Graduate School of Business and Law in Heilbronn (Germany). Jürgen Weimer has a wide research and industrial experience as manager for carmakers and tier one suppliers in the field of electric and hybrid vehicles, drives and automotive electronics.

Stephan A. Schmid is Head of Department at the Institute of Vehicle Concepts at the German Aerospace Center (DLR). He is the National Scientific (Alternate) Delegate of Germany for the Implementing Agreement ‘Hybrid and Electric Vehicles’ of the International Energy Agency. Dr. Schmid served from 2011 to 2013 in addition as DLRs Transport Representative in Brussels. He holds a diploma degree in Mechanical Engineering from the Technical University of Karlsruhe, and received his doctoral degree (Dr.-Ing.) in Engineering from the University of Stuttgart.