EVS30 Symposium
Stuttgart, Germany, October 9 - 11, 2017

Development, Implementation (Pilot) and Evaluation of a Demand Responsive Transport System

Mascha Brost[1], Matthias Klötzke[1], Gerhard Kopp[1], Oliver Deißer[1], Eva-Maria Fraedrich[2], Katharina Karnahl[3], Tim Sippel[4], Alexander Müller[5], Stefanie Beyer[5]

[1]*German Aerospace Center, Institute of Vehicle Concepts, Pfaffenwaldring 38-40, 70569 Stuttgart,* *mascha.brost@dlr.de*

[2]*German Aerospace Center, Institute of Transport Research*

[3]*German Aerospace Center, Institute of Transportation Systems*

[4]*University of Stuttgart, ZIRIUS, Stuttgart, Germany*

[5]*Hochschule Esslingen, University of Applied Sciences, Faculty of Automotive Engineering*

Summary

Within the framework of the project "Bürgerorientierte Optimierung der Leistungsfähigkeit, Effizienz und Attraktivität im Nahverkehr (BOOLEAN)", demand responsive transport and operating systems as well as vehicle concepts are developed and implemented in a "real-world laboratory" in Schorndorf. An inter- and transdisciplinary approach integrates perspectives from the social, technical and computer sciences and various local stakeholders (operators, municipality, politics and citizens of a medium sized town in Southern Germany). Transformative processes are induced, supported and scrutinized in a one-year pilot phase. Vehicle concepts specifically designed according the needs of demand responsive transport systems are based on automation technologies and electric propulsion.

Keywords: demand responsive transport, real-world laboratory, trans- and interdisciplinary research, autonomous driving, barrier-free vehicle concepts

1 Introduction

Transport systems in urban areas are facing increasing challenges regarding congestion, air quality, greenhouse gas emission, noise emission and individual motorized traffic's enduring persistence. Public transport should be further improved in order to meet these challenges. While the development of innovative transport systems has often focused on areas with very high population densities (i.e. inner city centers), it often neglects medium and small municipalities and their specific challenges regarding fluctuating passenger numbers and commuter traffic to urban centers. And even where on-demand systems were introduced beginning in the 1970s, they often failed for several reasons and were withdrawn [1]. Rural-urban commuter traffic today is mainly conducted by private motorized vehicles [2], [3], whereas public transport means are less used and often perceived as inflexible. The possibilities for improving conventional public transport by increased temporal and spatial availability are limited by economical and ecological constraints resulting from low occupancy factors. Occupancy tends to be low in sparsely populated areas, especially in off-peak periods. Frequency of public transport is usually accordingly low, being adapted to passenger numbers, which can highly fluctuate throughout the day. For some areas passenger demand per route is generally low throughout operating time. Definition of operating period, schedule intervals and routing is a compromise between customer convenience on the one hand and economical and ecological requirements on the other hand. Additional to the described conflict of objectives, requests from passengers opposite those of local residents, as increased service frequency results in higher emission of noise and pollutants.

To address these conflicting requirements, new demand responsive transport and operating concepts as well as innovative vehicle concepts must be considered. In particular with new, demand-oriented vehicle concepts and application of digital solutions, the requirements in terms of time, comfort, safety and environmental conditions can be addressed. Increased availability of public transport might induce a self-energizing effect by enhancing attractiveness and passenger numbers, which results in the possibility to further increase availability.

2 Development of the Demand Responsive Transport System

We present the development of a demand responsive transport system operating without fixed routes, timetables and stations. Project scope comprises the evaluation of local conditions and user requirements, development of an operating system including a smart phone application and a telephone order system, implementation and operation of the transport system in the municipality of Schorndorf for one year, evaluation of the pilot operation and derivation of task-specific vehicle concepts, Fig. 1.

	Participation	Operation Concept	Vehicle Concept
1	Initial position	Specification analysis	Specification management
2	User perspective	Architecture	Drafts/Sketches
3	Expert perspective	Implementation	Concepts
4	Monitoring pilot phase	Testing/pilot phase	Construction
5	Public dialogue	Evaluation	Installation of demonstrator
Knowledge Management			
Project Coordination			

Figure 1: project structure

Differing from existing similar approaches for demand responsive transport systems, the system developed for Schorndorf will replace parts of existing public transport at certain operating times. This implies fundamental impacts on the complete system specification, as a heterogeneous user group must be considered with special attention to elderly and mobility restrained persons. The innovative demand responsive transport concept must not exclude any part of the population. Effects concern parameters for operation (e.g. operation area and time span), user interaction and information (e.g. integration of a telephone service supplementing a smart phone application) and vehicle concept (special focus on barrier-free accessibility). The system will be integrated into the pricing system of Stuttgart's Transport and Tariff Authority (VVS), meaning that conventional tickets (e.g. commutation tickets) can be used without additional charge.

The demand responsive transport system is developed in the format of a real-world laboratory. Real-world laboratories address existing problems connected to transformation processes by an inter- and transdisciplinary approach that involves permanent interaction of the engaged expert groups (scientific disciplines and practical actors), dissolving borders between specialist fields, integrating knowledge, methods and mindsets to a common understanding ([4], [5], [6]).

This paper focuses on specification of system requirements and the development of vehicle concepts tailored towards future demand responsive transport systems.

2.1 Specification of System Requirements

System requirements are derived in an inter- and transdisciplinary process that integrates expert knowledge from scientists of the social sciences as well as the technical and computer sciences, various local stakeholders comprising a municipality, a transportation company, a bus operating company, the local citizenship and a vehicle manufacturer. Specifically, the project consortium consists of The German Aerospace Center (DLR), the Hochschule Esslingen University of Applied Sciences, the University Stuttgart, Stuttgart's Transport and Tariff Authority (VVS), Knauss Linienbusse, Daimler AG, and the City of Schorndorf. Citizens of Schorndorf act as co-designers in the development process in several workshops and provide input for the requirement assessment within a structured citizen participation concept that accompanies the complete development process. Participation of citizen includes inter alia public information events, weekly citizens' consultation by the municipality of Schorndorf and a project homepage. In order to methodologically include the heterogeneous requirements of local citizens, the approach of Design Thinking [7] was applied in several workshops. Four personas [8] developed within the workshops represent local target groups: senior citizens, mobility-restricted persons, persons regularly using buses, and persons regularly using cars. They allow derivation of requirements of passengers and local residents. The interaction of methods, further including Requirements Engineering [9], is described in detail in [10].

Besides requirements gained in the citizen participation process, interests of various stakeholders must be assessed. Conflicting goals are evaluated by the project consortium and adequately considered when determining system specifications (Fig. 2). Legislative and regulatory approval aspects must be fulfilled and constitute additional requirements.

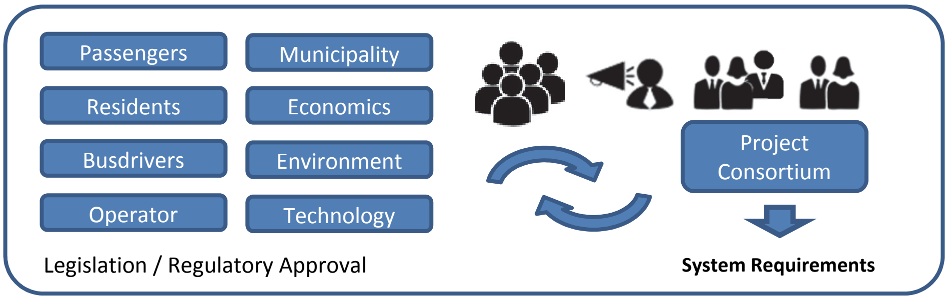


Figure 2: derivation of system requirements under consideration of affected stakeholders' interests

Differing from conventional participation processes, stakeholders' requirements are not collected simultaneously without referring to one another. Instead, discourse of the engaged expert groups is promoted, creating synergies by the interaction between science, economy, municipality, politics and society [11]. The final determination of the system requirements comprises the transfer into technical parameters and hence incorporates results of this cooperative development process.

In order to evaluate the service of public transport and support the decision process for systems parameters, quality criteria listed in the DIN EN 13816 (2002) are considered. The criteria which are taken as a basis are: operational availability, accessibility, information, time, customer support, comfort, safety, and environmental conditions. These criteria are addressed by the complete system of operation, operability and the vehicle concept.

Besides application of the described methods, determination of system specification with involvement of numerous stakeholders correlated to the characteristics of a real-world laboratory requires extensive communication. Information exchange within the interdisciplinary project consortium is supported by a „specification book". Due to the research character of the project, system requirements are not described in a tender specification and accordingly defined in a technical specification document as described in DIN 69 901-5. Instead, development of system requirements and respective technical solutions is a dynamic process within the project and is continuously updated in a central document accessible to all project partners.

System requirements described in the specification book comprise spatial and temporal system boundaries, operation and operability parameters and vehicle requirements. In the following, we exemplarily describe derivation of selected parameters.

2.1.1 Determination of Operation Area and Period

Schorndorf is a medium-sized major district town 26 km east of Stuttgart within the catchment area. It consists of the actual urban core of Schorndorf with 25,000 inhabitants and seven incorporated communities with further 15,000 inhabitants. Schorndorf's structure is typical for Baden-Württemberg, hence results gained in the real-world laboratory can be applied to other communities. The population density of 681 inhabitants/km² is well above the average of 142 inhabitants/km² living in on-demand operation areas with rural structures that were analyzed. Different to many of them, the presented system is not aiming at providing a basic, rudimentary public transport system, but to enhance the attractiveness of an existing, well developed system.

In order to define an adequate operation area for the on-demand transport system, prevailing traffic conditions were examined. Analyses included spatial distribution of points of interest, road traffic situation (congestion), passenger car occupancy rate, commuter flows, existing public transport (e.g. frequency, route alignment, number of passengers and isochrones regarding accessibility of main station, Fig. 3) and characteristics of transport user groups (public and individual transport). Research on legislative framework completed analysis of as-is state conditions.

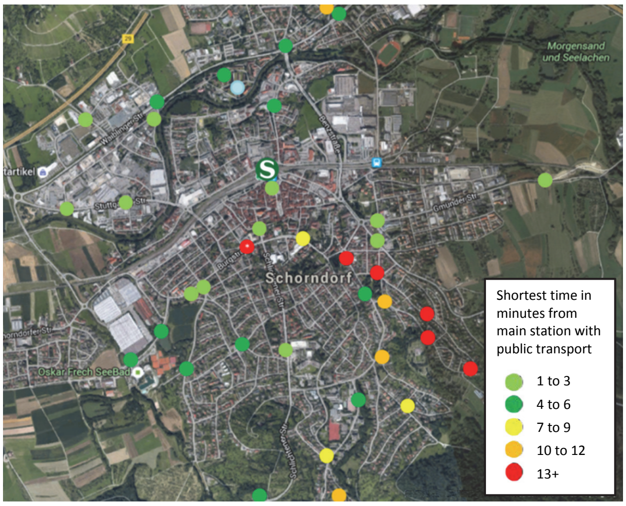


Figure 3: reachability analysis – isochrone map showing travelling time from main station

Analysis of data served as preparation for a co-creation workshop applying the methodology of design-thinking [7], where scientists, vehicle manufacturer employees and citizens developed together system requirements including parameters for operation area and span of service. Four target group related personas were developed within the workshop. Requirements regarding span of service varied widely according to different user profiles of the four diverse personas.

Results of the co-creation workshop were evaluated by the consortium under close interaction of municipality, transportation authority, bus operator company and science. Conflicts of objectives were evaluated in continuous inter- and transdisciplinary dialogue. Limiting constraints like number of deployable busses (personnel availability and cost), operable area size, and integration of certain points of interests (hospital, graveyard, swimming pool) led to the decision of defining the southern part of the urban core of Schorndorf as operating area. This area is also appropriate regarding existing public transport with two urban bus routes and four trans-regional bus corridors served in this area. The two urban bus routes will be replaced in the initial phase only after Fridays' afternoon peak (3 p.m.) until Sundays midnight. This period might be extended in the course of the pilot phase. The trans-regional bus routes stay unaffected.

Scientific aspects regarding the determination of this operations period are inducing considerable impact on mobility behavior, while limiting irritations caused by the innovative mobility experiment by avoiding periods when travelling is particularly time-sensitive (peak hours). Replacement of bus routes is a particular objective for the real-world laboratory in order to create considerable impact with the innovative transport concept and evaluate the acceptance of a heterogeneous user group.

Part of the heterogeneous user group are elderly people without access to smartphones. Hence provision of a telephone service covering the complete span of service is mandatory in addition to input options via smartphone app or web interface. Financial expenses for telephone service constitute one boundary condition for definition of the operating period.

2.1.2 Definition of Pick-up Areas / Stopping Points

Application of discrete stopping points versus continuous pick-up areas was evaluated with consideration of legislative, route planning, operational, and customer convenience aspects. Advantages connected to discrete stopping points like more efficient routes, simplified passenger identification, local stopping restrictions and dissociation from "Ruftaxi" (legislative aspect) predominate the advantage of minimizing walking distances for passengers and hence the system will operate with discrete stopping points. Targeted walking distance to stopping points is 150 m within the operation area. A maximum distance of 200 m should not be exceeded.

Digital maps were analyzed to evaluate local conditions (e.g. grass verges between road and footpath which prevent boarding and alighting, stopping restrictions). On-site visits complemented digital analyses for missing data or unclear situation [12]. Details like roadwise accessibility with busses as in Fig. 4 were defined in close accordance with scientists, municipality and bus operator and consideration of the citizen workshop results.

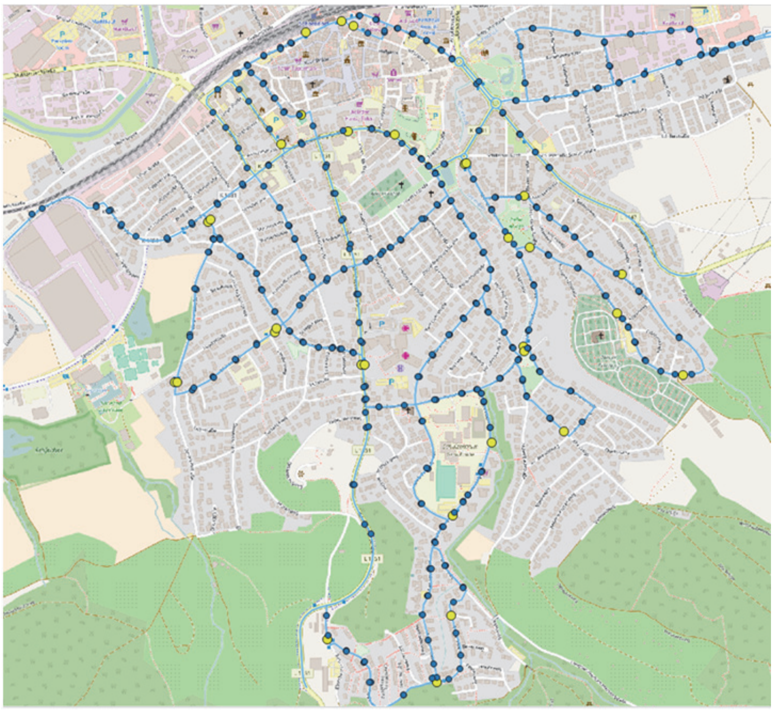


Figure 4: distribution of planned stopping points

According to the flexible concept without fixed routes and no restriction to existing bus stations, additionally introduced stopping points (dark blue dots) will not be equipped with physical infrastructure. This imposes an obstacle for some mobility-restricted persons. During the pilot phase, affected persons must continue to use existing stopping points (yellow dots). For future regular demand responsive systems, where barrier-free public transport has to be provided from 2022 onwards according to the law PBefG [13], vehicles themselves must provide adequate layout. This means that measures for barrier-free public transport would transfer from stations into busses.

2.1.3 Routing – Disposition Algorithm

Ride requests collected via smartphone app, web interface, and telephone service will be processed and combined to an optimized route by an algorithm specifically developed for the application in the demand responsive transport system in Schorndorf. Optimized route computation is a function of parameters like number and spatial distribution of destinations, maximum walking distances for passengers, availability of other transport options (trans-regional bus routes), cycle time, connections to the half-hourly S-Bahn departures/arrivals, and number and type of deployed busses.

Quality and constraints to route optimization are evaluated by simulations. A route factor that represents the ratio of ride time with on-demand system versus a direct route is computed and can be adjusted for route optimization.

Passengers will receive updates with route information via push messages and will also be able to check the status of their trip via smartphone or web interface. Passengers using the telephone service will receive a fixed departure time when they book their trip. In this case, announced departure time includes a waiting buffer that still allows route disposition according to trip requests received after the telephone booking.

2.2 Derivation of Vehicle Concept Requirement and Constructive Implementation

For the pilot phase starting in December 2017, existing vehicles of the Mercedes-Benz Sprinter model range will be used. However, future optimized operation of demand responsive transport systems requires vehicle concepts tailored to the system. In the sub-project "vehicle concept", an innovative vehicle concept is developed by scientists of Hochschule Esslingen and DLR together with social scientists and the later users. Rising technologies like automated driving offer new possibilities in vehicle design and will be considered.

Deployment of small and agile vehicles increases the flexibility of demand-oriented systems. However, this would presently result in high operating costs as vehicles are controlled by human drivers. Personnel cost in public transport constitutes a share of app. 40% to 70% ([14], [15], depending on boundary conditions). Personnel cost would even increase, if many small vehicles would be used simultaneously. With regard to personal costs and progress in automated driving systems, we assume that the use of autonomous vehicles provides advantages both regarding user requirements (e.g. spacious interior, small vehicles, flexibility of fleet) and economical needs.

Considering todays' air quality and noise pollution situation in urban areas, the vehicle concept will possess an environmentally friendly propulsion concept that does not locally emit air pollutants and generates only low noise emission. Reducing noise emission is part of the motivating factors for the project and is a requirement repeatedly expressed by local residents in the operation area. According to the population structure of Schorndorf and the addressed target groups, barrier-free access to the bus and user-centric design are additional central development issues.

As previously described, inter- and transdisciplinary research and development processes represent a central element of real-world laboratories. Accordingly, vehicle design requirements are derived involving a group of Schorndorfs citizens. In a workshop, personas defined in preceding citizen workshops were used to organize citizens, municipality and scientists (social sciences and engineers) in four groups. Each group discussed vehicle requirements according to specific needs (e.g. design elements for barrier-free access) and developed simple, but conclusive hardware prototypes in scale 1:10. Various craft materials such as seat or wheelchair patterns and materials allowing for free shape design (e.g. modeling clay, pipe cleaners) were used. An empty Mercedes-Benz Sprinter was available to help workshop participants to gain a feeling for size ratio. The scale 1:10 models showed differences such as importance of appealing interior design and privacy (persona of regular car users) and possibilities to store and secure luggage, or walking aids (persona of senior citizens and mobility-restricted persons). The prototype of the persona of regular bus users included a bicycle transport option at the rear of the bus. Barrier-free access was of central importance for all of the four groups, as passengers with small children, buggies or shopping trolleys profit as well as wheelchair users or persons with walking disabilities. Space and securing options for two wheelchairs (instead of one) were elaborated as requirement by the personas of senior citizens and mobility-restricted persons.

Citizen workshop results are complemented by expert interviews and analysis of existing vehicle concepts as well as legislative and normative requirements (e.g. DIN EN 13816:2002-07). Conflicts of objectives are evaluated using the “House of Quality” which is part of the Quality Function Deployment (QFD) method [16], [17], [18]. Customer requirements are correlated with functional and technical options in a matrix structure that includes weighting and provides support for conceptual decisions. Relevant issues like environmental effects, safety, comfort, availability and information provision are addressed.

Development of the vehicle concept is organized in four thematic areas "complete vehicle", "body", "interior / exterior" and "drive and suspension" that will be described in the following.

2.2.1 Vehicle Concept / Package

As a combination of the thematic areas mentioned above, the derived concepts and designs were visualized and evaluated by ground planes, 2D-models, sketches and digitally configured conceptual in parameterized CAD models, allowing for efficient variation evaluation. The vehicle design was set up with respect to the predefined requirements and in this connection with different package arrangements. Customer and user-requirements as well as technical possibilities within the vehicle package and the operational concept were taken into account [19]. Conditions of the inner city area of Schorndorf, which serves as an exemplary target operation area are considered for definition of vehicle parameters.

Having regard to the above described conditions and requirements, an autonomous, fully electrically propelled, two-axle and low-floor vehicle concept will be developed. The maximum speed is expected to be between 50 and 80 km/h, adapted to the specific operation purpose of an on-demand system with short to medium distances, mainly in inner city surrounding. A customary inclination of app. 12% shall be possible to drive referring to [20], where a maximum of 12% is recommended for planning certain types of urban streets. The range for the vehicle and the electric energy storage are based on a typical operating day of a bus in Schorndorf and the currently assumed maximum operation duration of three hours (net driving time without recharging in urban surrounding with hilly topology). Drive dimensioning (see 2.2.3) and derivation of vehicle dimensions are based on analysis of existing infrastructure (local road system). A vehicle length of at most 5 m combined with a turning circle of max. 12 m is presently assumed to meet these requirements best.

2.2.2 Interieur / Exterieur

The vehicle interior is developed in a user-centered, centrifugal way, meaning that the overall vehicle length, width and height result in first order from the physical consideration of the vehicle users by applying the digital man model RAMSIS^{TM}. The model serves for evaluation of ergonomic aspects. Based on observations on today’s usage behavior, four different usage scenarios, which result from vehicle operations at different daytimes, were derived [19] and define the vehicle interior for different types of use. For example, in the case of vehicle operation during main traffic periods, it is assumed that the bus is used by professional commuters and the interior will be accordingly designed. Another scenario assumes that the bus is used mainly by so-called everyday users and occasional users, which requires different layout features. The four scenarios used for layout derivation are presented in Fig. 5.

Design parameters reflecting the needs of the specific target groups are for instance number and position of seats, layout of a multifunctional space (space for luggage, buggies, walking aids, wheelchairs etc.), provision of information or distribution and shape of handholds. The developed design solution takes into account conflicting and common requirements and provides convenient usability for many scenarios.

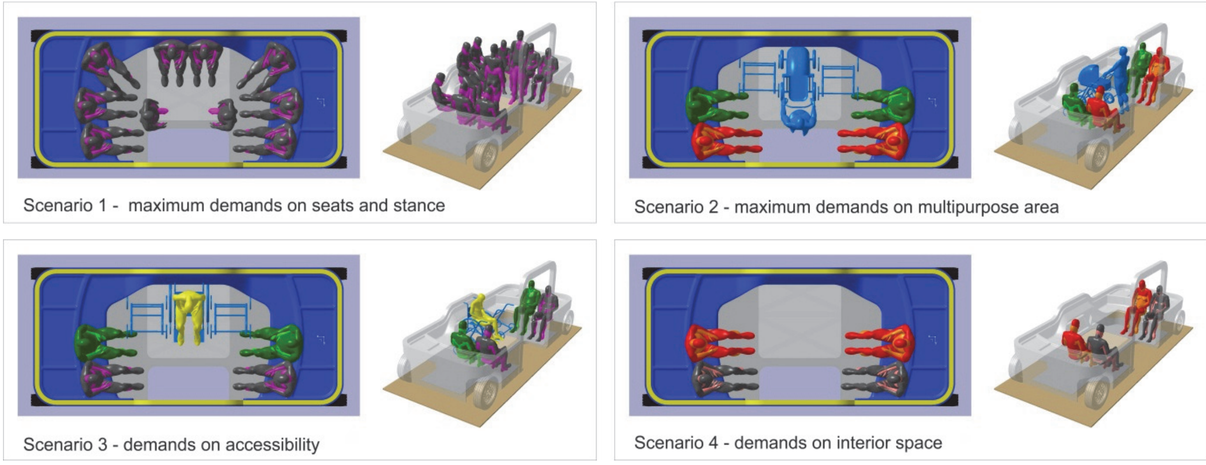


Figure 5: usage scenarios considered for layout derivation

Since autonomous public transport vehicles are not supported by a bus driver and full accessibility of the vehicle is also required for people with disabilities such as wheelchair users, the requirements relating to the accessibility, operating elements (for passengers) and information systems of the bus are expected to be far higher than in vehicles currently used in public transport. Placing of handholds, equipment with information systems and the interior dimension concept will consider these requirements.

The vehicle length, width and height takes into account the user-centered development of the interior, which is currently developed with 6 seats and 4 standing places with small luggage.

2.2.3 Car Body

In order to address the requirements in terms of safety, comfort, accessibility, reduction of emissions and energy consumption, a systematic comparison of light-weight potentials was carried out. These potentials include different types of structure, different plastic applications and sandwich structures. In addition to the load-optimized frame structure, the main structural components e.g. floor, roof and side walls were designed with different plastic and sandwich configurations and then compared with respect to their lightweight potential. The three pictures in Fig. 6 show simplified the used three development stages. At first a topology optimization using a predefined maximum usable design space and different workloads was made. The result is shown in the first picture of Fig. 6. The middle picture is an example of the FEM models used for evaluating the different types of body architecture regarding the results of the topology optimization. The body architectures range from a pure space frame structure to the shown mixed body design with different grades of sandwich structures used. The last of the three illustrations is a conceptual design of the vehicle body without any further work on appearance. [21]

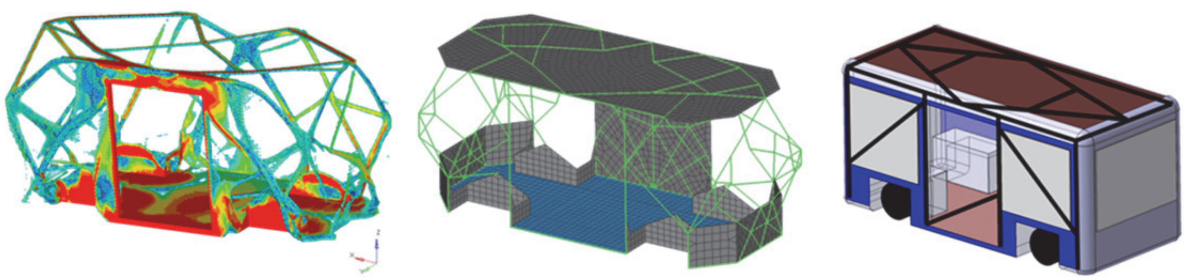


Figure 6: car body concepts -
left: topology optimization; middle: FEM model; right: construction concept *[21]*

2.2.4 Power Unit / Chassis

Due to a purely electric drive, the noise emissions are reduced significantly and the air pollution especially in the inner city area is avoided.

In order to define the drivetrain design, the inner city bus lines of Schorndorf were tracked with a GPS data logger (cp. Fig. 7). On the basis of the captured data a milage estimation was carried out analytically with the software application Matlab. Route length of considered bus routes in Schorndorf are around 10 km. As a result of logging data analysis, a suitable electric motor can be selected by considering the performance requirements resulting from top-speed rides on the flat and for hill-starting on the largest assumed gradient at full payload [19]. Battery pack parameters are accordingly defined and provide energy for a net driving time of three hours in urban surrounding and hilly topology.

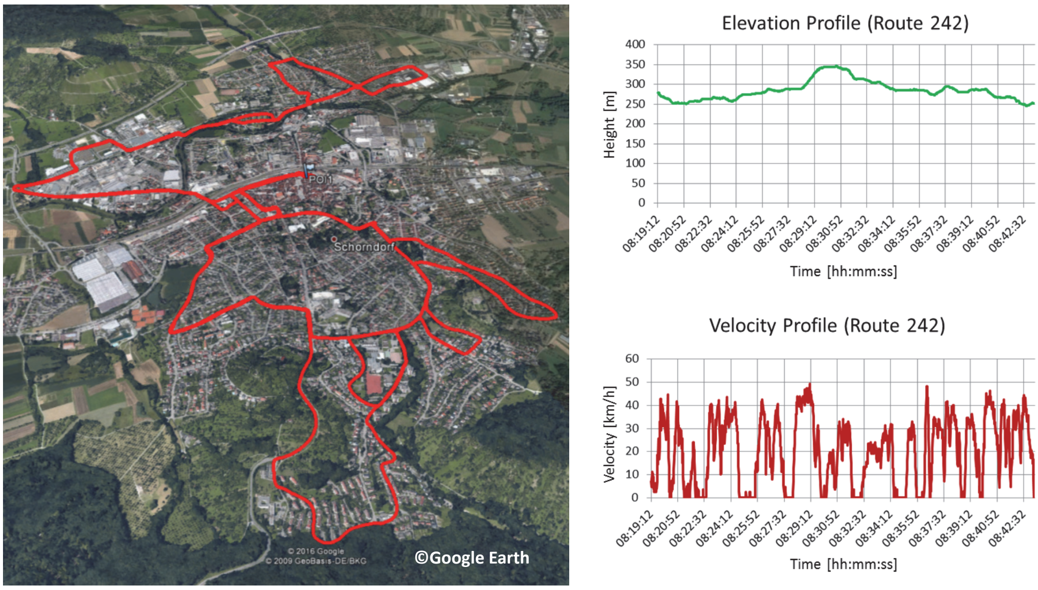


Figure 7: GPS-Tracked Inner City Bus Lines of Schorndorf –
route alignment (left, source: google Earth) and elevation and velocity profile (right)

Summary and Outlook

Within the first phases of the BOOLEAN project, local situation and boundary conditions in the municipality of Schorndorf were analyzed, system requirements were derived in an inter- and transdisciplinary process and implementation of the routing algorithm and smartphone application was largely completed.

Testing of the smartphone application will be accomplished within the next weeks. In December 2017, the pilot phase of the demand responsive transport system will start. In the southern part of the urban core of Schorndorf, on demand service will be offered which can be booked by smartphone application, web interface or telephone service. Evaluation concept is presently elaborated in detail and will comprise collection and analysis of logged data and interviews.

Acknowledgements

The project “Bürgerorientierte Optimierung der Leistungsfähigkeit, Effizienz und Attraktivität im Nahverkehr (BOOLEAN)” is one of the real-world laboratories funded by the state of Baden-Württemberg by the Ministry of Science, Research and the Arts. Vehicles deployed within the project duration are kindly provided by Mercedes-Benz Vans (Daimler AG) and Hochschule Esslingen.

References

[1] M. Enoch, S. Potter, G. Parkhurst und M. Smith, „Why do Demand Responsive Transport Systems fail?,“ in *85TH ANNUAL MEETING OF THE TRB*, Washington D.C., 2006.

[2] U. Winkelmann, “Die Pendlermobilität steigt überall in Baden-Württemberg,” *Statistisches Monatsheft (2), Stuttgart,* pp. 25-28, 2012.

[3] HWWI (Hamburgisches Welt Wirtschafts Institut), “Pendeln in Hamburg,” *Policy Paper, http://www.hwwi.org/uploads/tx_wilpubdb/HWWI-Policy_Paper_83.pdf (23.06.2015),* 2013.

[4] A. Brandies, A. König, K. Viergutz, E.-M. Fraedrich, L. Gebhardt, F. Ulmer, T. Sippel und M. Dotzauer, *Transdisziplinäre Mobilitätsforschung unter Verwendung von Reallaboren: Integration von Stakeholderbedürfnissen und -anforderungen in die Entwicklung von Sys-temen bedarfsorientiert und vollautomatisiert fahrender Quartiersbusse,* AEET 2017, Braunschweig, 2017.

[5] P. Holm, M. Goodsite, S. Cloethingh, M. Agnoletti, B. Moldan, D. J. Lang, R. Leemans, J. Oerstrom Moeller, M. Pardo Buendia, W. Pohl, R. W. Scholz, A. Sors, B. Vanheusden, K. Yusoff und R. Zondervan, *Collaboration between the natural, social and human sciences in globale change research,* Environmental Science & Policy, 28. Aufl., S. 25-35, 2012.

[6] U. Schneidewind, *Urbane Reallabore: Ein Blick in die aktuelle Forschungswerkstatt,* pnd|online, Aufl. 3, Nr. 2, S. 19-27, 2014.

[7] T. Brown, „Design Thinking,“ *Harvard Business Review,* pp. 84-92, 2008.

[8] C. Mayas, S. Hörold and H. Krömker, “Meeting the Challenges of Individual Passenger Information with Personas,” *Stantin, N. (Hrsg.). Advances in Human Aspects of Road and Rail Transportation. CRC Press, Boca Raton,,* pp. 882-831, 2012.

[9] P. Zave, „Classification of Research Efforts in Requirements Engineering,“ *ACM Computing Surveys,* pp. 315-321, 1997.

[10] A. König, A. Brandies, L. Schnieder, M. Dotzauer und M. Jipp, *Zukunftsszenarien autonomer Fahrzeuge – Nutzungsorientierte Gestaltung eines individuell abrufbaren Personentransportsystems,* 5. interdisziplinärer Workshop kognitive Systeme, At Bochum, Volume: 5, 2016.

[11] T. Sippel, F. Ulmer, S. Alcantara, M. Klötzke, E.-M. Fraedrich und L. Gebhardt, *When citizens become experts. A new approach for an integrated project and participation management,* IST 2017, 2017.

[12] W. Niebel und A. Sauerländer-Biebl, „Challenges in static data acquisition for a bus-on-demand line,“ in *Workshop on Smart Mobility*, Burglinster (LUX), 2017.

[13] German Federal Government, *Personenbeförderungsgesetz (PBefG), § 8, paragraph 3,* 2013.

[14] E. Sax, *Wirtschaftlichkeit des elektrifizierten Busbetriebs. [PowerPoint presentation],* 8. ÖPNV Innovationskongress, Freiburg, March 14th - 16th, 2017.

[15] P. Frank, M. Friedrich und J. Schlaich, „Betriebskosten von Busverkehren schnell und genau ermitteln,“ *Der Nahverkehr, Alba Fachverlag, Düsseldorf, Heft 11,* pp. 15-22, 2008.

[16] M. Bors, Ergänzung der Konstruktionsmethodik um Quality Function Deployment – ein Beitrag zum qualitätsorientierten Konstruieren, München, ISBN 10: 3446180982: Carl Hanser Verlag, 1994.

[17] A. Schaaf, Marktorientiertes Entwicklungsmanagement in der Automobilindustrie – Ein kundennutzenorientierter Ansatz zur Steuerung des Entwicklungsprozesses, Wiesbaden, ISBN 978-3-8244-6846-1: Deutscher Universitäts-Verlag, 1999.

[18] H. Wildemann, Kundenorientierte Produktentwicklung in der Automobilindustrie. In E. S. Schwarz (Hrsg.), Nachhaltiges Innovationsmanagement, Wiesbaden, ISBN 978-3-409-12696-0: Springer Fachmedien, 2004.

[19] A. Müller, G. Kopp, S. Beyer und O. Deisser, *Reallabor Schorndorf - Bedarfsgerecht und Nutzerorientiert,* spektrum, Zeitschrift der Hochschule Esslingen 44/2017, ISSN: 18640133: http://www.hs-esslingen.de/index.php?id=95154, 2017.

[20] Forschungsgesellschaft für Strassen- und Verkehrswesen (FGSV), *Richtlinien für die Anlage von Stadtstraßen, RASt 06, Korrektur: 15. Dezember 2008,* 2008.

[21] G. Kopp, A. Müller, O. Deißer und S. Beyer, *Innovative Kunststoffanwendungen für ein kleines Stadtbuskonzept,* Düsseldorf: VDI Verlag GmbH, ISBN 978-3-18-234347-9, 2017.

Authors

Dipl.-Ing., M.Des. Mascha Brost studied mechanical engineering at the University of Stuttgart, Germany. After her studies, she worked for two years in the field of computational fluid dynamics She complemented her technical education with a Master degree of Integral Design Studies, an international, interdisciplinary program of the Stuttgart State Academy of Art and Design. The combination of technical and artistic product design contributed to the development of a small electric vehicle by a product design company in 2014, where she worked for two years. Since 2015, she is a research associate at the DLR Institute of Vehicle Concepts.

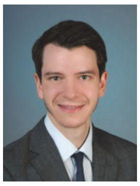
Dipl.-Ing. Matthias Klötzke is researcher and team leader road vehicles at the DLR Institute of Vehicle Concepts in the Department of Vehicle Systems and Technology Assessment since 2012. Since then Mr. Klötzke was involved in different research projects on technology assessment of future vehicle concepts. The focus within these projects was an the effect of future vehicle concepts on the fuel consumption, the greenhouse gas emissions, vehicle economics, future market potentials as well as the simulation of future drive trains and requirements for future vehicle concepts. Since October 2015, Mr. Klötzke is the team leader of road vehicles.

Dr.-Ing. Gerhard Kopp is team leader "Lightweight construction concepts and methods of road vehicles" within the department “Lightweight and Hybrid Design Methods”. His expertise is in the field of innovative lightweight structures, concept development and structural performance of vehicle bodies. In 2012 he got the Jec Europe Innovation Award with national project partners for an innovation sandwich structure. In 2014 Gerhard Kopp and members of his group won the “German High Tech Champion Award 2014” on the category “Urban-Move-T” from the German Federal Ministry of Education and Research.

Dipl.-Ing. (FH) Oliver Deisser is a research associate at the DLR Institute of Vehicle Concepts in the team "Lightweight construction concepts and methods of road vehicles" within the department “Lightweight and Hybrid Design Methods”.

Eva Fraedrich is team leader of the research group “Mobility and Spatial Structures” at the DLR Institute of Transport Research. She holds a Master of Arts in Educational Science from the Free University of Berlin and is currently finishing her PHD with a focus on sociotechnical transformation processes in the system of (auto)mobility using the example of autonomous driving. Before joining the DLR Eva Fraedrich worked at the Humboldt University of Berlin in the department of Transport Geography where she was involved in several research projects as well as policy platforms on autonomous driving. In her work she deals with socioscientific perspectives on autonomous driving, as well as questions of societal and individual acceptance, new mobility concepts, changing denotations of the automobile, or adequate and innovative research methodology in relation to user perspectives on and user needs for new technologies.

Katharina Karnahl is a research associate at the DLR Institute of Transportation Systems, department “Intermodality and Public Transport”. She participates in several thematic projects like “Bürgerorientierte Optimierung der Leistungsfähigkeit, Effizienz und Attraktivität im Nahverkehr (BOOLEAN)”.



Tim Sippel studied empirical political and social research at the University of Stuttgart. After completing his master degree, he worked in various projects for the Kommunikationsbüro Ulmer GmbH. Since November 2016 he has been a research associate at ZIRIUS. His main focus is on the scientific support of participation processes, stakeholder dialogues and the evaluation of public participation processes in infrastructure projects.

Prof. Dr. Alexander Müller researches and teaches at Hochschule Esslingen University of Applied Sciences, Faculty of Automotive Engineering. After he completed his doctoral thesis, which he conducted on the systematical derivation of dimensional layout concepts at the University of Stuttgart he worked in the automotive industry at last as head of the department “advance development, light and sight” at the EDAG Engineering GmbH in Munich. His areas of expertise are modularization in vehicle development, vehicle ergonomics, vehicle concepts, and chassis development.

M.Sc. Stefanie Beyer is research assistant at Hochschule Esslingen University of Applied Sciences, Faculty of Automotive Engineering and part of the project “Bürgerorientierte Optimierung der Leistungsfähigkeit, Effizienz und Attraktivität im Nahverkehr (BOOLEAN)”.