COOPERATIVE R&D PROJECT

INDUSTRIAL RESEARCH OR EXPERIMENTAL DEVELOPMENT

PROJECT DESCRIPTION FOR PROPOSALS TO "BEYOND EUROPE" – PROGRAMME FOR INTERNATIONALISATION OF RTI PROJECTS

3RD CALL 2018

Version 17.12.2018

RTI Initiative:	Beyond Europe 3rd Call	
Full title of the project:	Open Simulation Environment for the Exploration and Evaluation of Autonomous Driving Functions	
Short title of the project:	OSE³AD	
Applicant:	AVL List GmbH (Austria) – **AVL**	
Project partner(s):	- Nanyang Technical University, Energy Research Institute (Singapore) – **NTU** - Graz University of Technology, Institute of Automotive Engineering (Austria) – **FTG**	
Research category:	Experimental Development (ED)	
Project duration:	From 09/2019	Duration in months: 24
Costs:	Total costs [€]: 1.150.846	Total funding [€] 490.661 (max. 0,5 Mio)

PROJECT GOALS:

Autonomous driving ("AD") – especially in the context of urban mobility – is **one of the main trends in the automotive domain.** AD is also expected to **impact various social challenges** such as the mobility behavior in general, safety, emission and air quality, or traffic congestion. With AD application, the complexity for design and validation of highly automated driving functions is **growing exponentially**; it is obvious that the validation can no longer be performed solely on a real vehicle. For that reason, a **new virtual approach** is required relying on simulation driven, **rule-based scenario evaluation** and **automated test execution.**

For that purpose, the OSE³AD project targets are as follows: (Obj 1) to develop an **open and integrated simulation framework for L4+ AD functions**, (Obj 2) to provide a **set of objective evaluation criteria for rule-based reasoning of complex scenarios**, and (Obj 3) to **deploy and evaluate the proposed methodology** for real L4+ AD functions.

The OSE³AD project has an **enabling character to deepen business relationships between Austria** (AVL, TU Graz) and **Singapore** (a leading location in the field of AD with NTU and other regional partners) for exploitation of autonomous driving vehicles used in public and private traffic.

CONTENTS

KURZFASSUNG

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Autonomes Fahren („autonomous driving“, AD) ist speziell im urbanen Bereich **einer der wesentlichen Trends in der Automobilbranche**. Neben den technischen Herausforderungen werden mit dem autonomen Fahren auch gesellschaftliche Fragen zur allgemeinen Verkehrssicherheit, zu Emissionen und Luftqualität oder zur innerstädtischen Staubildung zu beantworten sein; darüber hinaus wird sich das allgemeine Mobilitätsverhalten grundlegend ändern und die soziale Inklusion vorantreiben („mobility-for-all“). Die Komplexität hochautomatisierter Fahrfunktionen **wächst exponentiell**, was enorme Herausforderungen für die Entwicklung und Validierung dieser Funktionen mit sich bringt. Es liegt auf der Hand, dass die Absicherung nicht mehr ausschließlich im realen Fahrzeug stattfinden kann, sondern dass auf **neue, virtuelle Methoden** zurückgegriffen werden muss. Diese beinhalten eine simulationsgetriebene, **regelbasierte Szenarienauswertung** sowie eine **automatisierte Testabwicklung**.

Vor diesem Hintergrund stellen die **AVL List GmbH** (AVL), die **Nanyang Technological University** (NTU), und das **Institut für Fahrzeugtechnik** an der **Technischen Universität Graz** (FTG) den Antrag auf Förderung eines Forschungsprojekts namens OSE³AD (*Open Simulation Environment for the Exploration and Evaluation of Autonomous Driving Functions*) mit Fokus auf Stadtbussen zum Personentransport, welches die folgenden Ziele („objectives“) verfolgt:

Obj 1.: Bereitstellung einer **offenen und integrierten Simulationsplattform** zum effizienten Entwickeln, Testen und Validieren innovativer autonomer Fahrfunktionen, um die **Effizienz im Entwicklungsprozess durch Frontloading zu erhöhen** und um die **virtuelle Validierung zu ermöglichen**.

Obj 2.: Identifizieren **objektiver Bewertungskriterien** für den Anwendungsfall „Stadtbus“ zur Formulierung sowohl quantitativer als auch qualitativer Zielwerte für die regelbasierte Bewertung komplexer Szenarien zwecks **Ermöglichung automatisierter Auswertung von Szenarien**.

Obj 3.: Entwurf, Bewertung und Absicherung innovativer autonomer Fahrfunktionen für nach SAE-Level 4 zertifizierte Fahrzeuge mithilfe der bereitgestellten Simulationsplattform zum **Nachweis der Effizienzsteigerung**.

Das OSE³AD-Projekt hat einen **Befähigungscharakter („Enabler“), um die geschäftlichen Beziehungen zwischen Österreich** (AVL, TU Graz) **und Singapur** (mit NTU und anderen regionalen Partnern) im **wichtigen Zukunftsmarkt der autonomen Mobilität zu vertiefen**. Diese Kooperation wird darüber hinaus einer weltweiten Anwendung der Projektergebnisse die Tür öffnen, da Singapur ein globaler Hotspot für die **Implementierung autonomen Fahrens in den öffentlichen Verkehr** ist. Während sich die europäischen Aktivitäten im Bereich AD-Funktionsentwicklung derzeit eher auf die Autobahnfahrt konzentrieren, gehen urbane Szenarien angesichts ihrer enormen Komplexität **weit über den Stand der Technik hinaus**.

ABSTRACT

Autonomous driving ("AD") – especially in the context of urban mobility – is **one of the main trends in the automotive domain.** AD is also expected to **impact various social challenges** such as mobility behavior in general, safety, emission and air quality, traffic congestion, as well as social inclusion ("mobility-for-all"). With AD application, the complexity for design and validation of highly automated driving functions is **growing**; it is obvious that the validation can no longer be performed solely on a real vehicle. For this reason, a **new virtual approach** is required relying on simulation driven, **rule-based scenario evaluation** and **automated test execution.**

In this context, **AVL List GmbH** (AVL), **Nanyang Technological University** (NTU), and **Graz University of Technology - Institute of Automotive Engineering** (FTG) propose to conduct a research project called OSE³AD (*__O__pen __S__imulation __E__nvironment for the __E__xploration and __E__valuation of __A__utonomous __D__riving Functions*) for the specific use case of urban busses for people transport which is organized around the three following main objectives:

Obj 1.: Provide an **open and integrated simulation framework** for the efficient development, testing and validation of innovative autonomous driving functions to **increase efficiency through frontloading and to enable virtual validation**.

Obj 2.: Identify **objective evaluation criteria** with respect to the selected use case of urban busses to assess both quantitative and qualitative targets for rule-based reasoning of complex scenarios, thus **enabling automated scenario evaluation**.

Obj 3.: Design, evaluate and validate innovative autonomous driving functions for SAE level 4 using the provided simulation framework to **demonstrate the increased efficiency**.

The OSE³AD project has an **enabling character to deepen business relationships between Austria** (AVL, TU Graz) **and Singapore** (with NTU and other regional partners) for exploitation of autonomous driving vehicles used in public and private traffic. Such collaboration will also open the door for future application of the resulting procedures worldwide, since Singapore is a globally leading location in view of implementing **autonomous driving in urban traffic**. While current European activities focus on AD functions for highway driving, urban scenarios are far more complex to realize and thus **go substantially beyond the state of the art**.

1 QUALITY OF THE PROJECT

1.1 State of the art – current level of technology/knowledge

Rationale for OSE³AD: The Need for Virtual Validation

The introduction of autonomous driving functions implies an enormous increase in testing and validation demand which cannot be covered by physical testing and on-road validation any more. While around 10^5 km road driving was sufficient for appropriate scenario coverage of L1 / L2 systems, it is expected that an increase toward 10^8 equivalent road km and more will be required for proper validation of L4 / L5 systems. Figure 1 illustrates that the validation methods used today are not capable of covering validation demands introduced by SAE level 3 functions and above; frontloading and purely virtual validation will be a must[1].

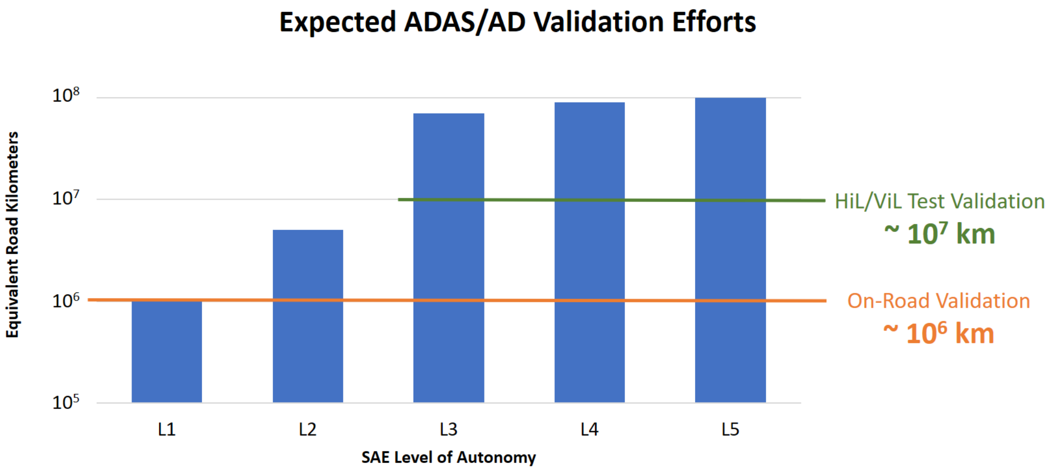

Figure 1: Expected ADAS and AD validation efforts

To tackle this challenge and to support the shift from in-vehicle validation to hybrid and possibly even purely virtual validation, the OSE³AD project (***O****pen* ***S****imulation* ***E****nvironment for the* ***E****xploration and* ***E****valuation of* ***A****utonomous* ***D****riving Functions*), has been designed around the three following main objectives:

Obj 1.: Provide an **open and integrated simulation framework** for the efficient development, testing and validation of innovative autonomous driving functions to **increase efficiency through frontloading and to enable virtual validation**.

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Obj 3.: Design, evaluate and validate innovative autonomous driving functions for SAE level 4 using the provided simulation framework to **demonstrate the increased efficiency**.

[1] Winner, H.: Absicherung automatischen Fahrens. 6. FAS-Tagung, München, 2013

ADAS in-vehicle architecture overview and related challenges

The development of AD functions and systems is a task of enormous complexity. Hence, in comparison to powertrain systems, where comprehensive environment modeling can be reduced to velocity and acceleration profiles together with wide-sense static environmental conditions (temperature, humidity and road resistance), ADAS functions need to appropriately model complex vehicle maneuvers, other road participants and their interactions, while taking into account highly dynamic environmental conditions which impact advanced sensing (e.g., radar, lidar) and dynamic driving behavior. The European Automated Driving Roadmap[2] lists safety validation and roadworthiness testing as being "one of the key challenges on the path to higher levels of automation", and also the Austrian Research, Development and Innovation Roadmap for Automated Vehicles[3] acknowledges the "difficulty of demonstrating and proving the reliability, safety and robustness of automated vehicles in all conceivable situations" as a key issue in the development of autonomous driving.

The functional architecture of autonomously driven vehicles, sketched in Figure 2, consists of four main components: sensing, perception, planning, and control. None of these components can be developed in isolation from the others, so a reasonable number of simulated components is involved in early development phases (X-in-the-loop).

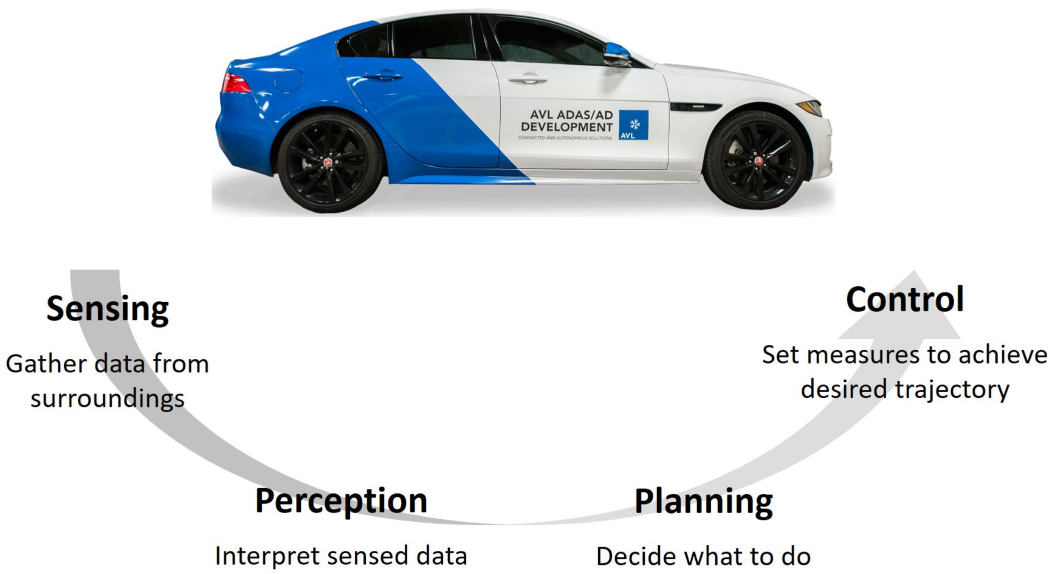

Figure 2: Functional architecture of autonomous vehicles

While vehicle simulation as such is well established in today's vehicle development processes, validation and release tasks are still carried out on real vehicles in most cases, mainly due to the lack of appropriate and mature validation solutions for high-level AD functions. Autonomously driven vehicles will be the game changer here, as the number and complexity of the diverse scenarios to be tested and validated require these tasks to be executed faster than real-time.

[2] https://www.ertrac.org/uploads/documentsearch/id48/ERTRAC_Automated_Driving_2017.pdf
[3] https://www.bmvit.gv.at/innovation/publikationen/ikt/downloads/austrian_roadmap_automated_vehicles.pdf

Integrated and open development platform for virtual validation of autonomous functions

The vehicle development process is a source of incredible know-how, information, and capabilities, but often inefficiencies occur because these assets are not connected. This is especially true when it comes to the interconnection of virtual and real elements. To master this complexity, AVL has developed an Integrated and Open Development Platform (IODP) which integrates all elements in the vehicle development process, blurring the lines between the virtual and the real worlds. Simulation models, test environments, devices, data and automation solutions interlock and accelerate the development of the overall system.

Based on an open co-simulation platform, AVL has a comprehensive suite of software products for the simulation and validation of engine and powertrain elements as well as software functions available[4]. Starting with a purely virtual testing environment, it is possible to successively replace virtual components by real components without modifying the overall framework. This ensures consistent methods and results throughout the vehicle development process.

The following tools are relevant for the OSE³AD project:

- AVL CRUISE M is a multi-disciplinary vehicle system simulation tool[5]. It can be used in the office for powertrain concept analysis, sub-system design and virtual component integration. Office models can then be reused in a real-time MiL (Model-in-the-Loop), SiL (Software-in-the-Loop) or HiL environment as well as plant models on engine, powertrain and chassis dyno testbeds which is perfect for controller validation and component testing.
- AVL VSM is a comprehensive vehicle dynamics simulation package that predicts vehicle behavior precisely and enables improvement of various vehicle attributes from the initial concept to the testing phase[6].
- AVL DRIVE is a solution package for drivability assessment and development. It consists of comprehensive services, such as objective vehicle benchmarking and target-setting, comprehensive vehicle analysis, drivability calibration, integration of OEM-specific criteria and system integration in the customer's test field. An ADAS-specific package is available for applications with regard to drivability, handling, ride comfort and ADAS function validation up to SAE level 3.
- Vires VTD offers the creation of complex driving environments with built-in editors, but also the option to import digital environments in OpenDRIVE format. The realistic visualization allows not only for a good interpretation of the driving scenario but also the implementation of automotive cameras for HiL testing. It offers interfaces to implement complex sensor models with and without ray tracing and brings along simple sensor models for conceptual investigations. The software allows the user to define different environmental conditions, which is crucial for the machine recognition of the environment.
- SUMO is a free and open microscopic traffic flow simulation software provided by DLR that allows modelling of intermodal traffic systems including road vehicles, public transport and pedestrians. It is possible to create deterministic and stochastic traffic

[4] AVL Team Suite: https://www.avl.com/-/powertrain-development-is-a-team-sport
[5] AVL CRUISE M: https://www.avl.com/-/avl-cruise-2
[6] AVL VSM: https://www.avl.com/web/guest/-/avl-vsm-4-

for virtual testing and validation of ADAS and AD by online external control of the traffic objects. Complex urban road networks including traffic lights can be modelled without limitations of the network size.

- AVL Model.CONNECT is an integrated and open co-simulation platform which interlinks simulation models into a consistent virtual prototype, regardless of the tool they were created with. Simulation and hardware components can be easily integrated into a complete virtual/real system to facilitate continuous, model-based development over different testing environments.

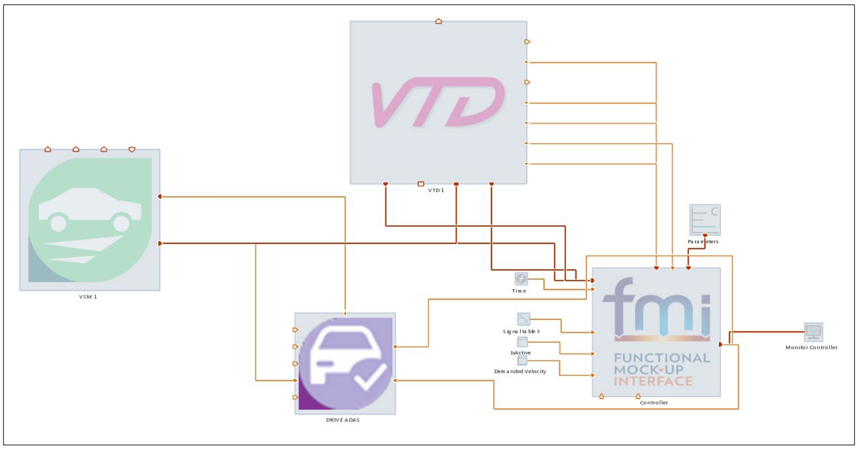

Figure 3: Example for the seamless integration of a function to be developed with Vires VTD, AVL VSM and AVL DRIVE-ADAS in AVL Model.CONNECT

Rule-based reasoning for automated evaluation of L4+ scenarios

Driveability assessment is typically performed by professional test drivers, who analyse the different driving manoeuvres in a systematic way and assess the vehicle behaviour accordingly. The drawback of this approach is the subjectivity of the assessment and the lack of reproducibility. In this context, AVL-DRIVE has been introduced as an objective tool for driveability assessment and development. As described above, an ADAS-specific package is available for applications with regard to drivability, handling, ride comfort and ADAS function validation up to SAE level 3. The working principle of AVL-DRIVE is described in Figure 4.

This means that virtual validation is already possible with existing tools such as AVL-DRIVE ADAS which offers objective ratings on how well automated driving functions are performing. However, in its current release version, only driving functions and selected scenarios up to SAE level 3 are considered. To be best of the authors' belief, no other commercially available products for objective driving function validation beyond L3 are available on the market, so these functionalities need to be developed. Starting with an already mature solution, the main challenge during the OSE³AD project will be the further development of AVL-DRIVE ADAS towards the validation of level-4 functions.

As a matter of fact, evaluation criteria for autonomous driving scenarios will heavily depend on the scenario itself. While drivability attributes can be seen as global in this context – or at least as a function of the chosen driving mode in a modern vehicle – since they describe the general dynamic behavior of the vehicle, the decisions of autonomous driving control strategies are subject to the options allowed by the scenario. This means that scenario generation implies not only the creation of a certain setting and possible events, but also suitable evaluation criteria for the successful accomplishment of this very scenario.

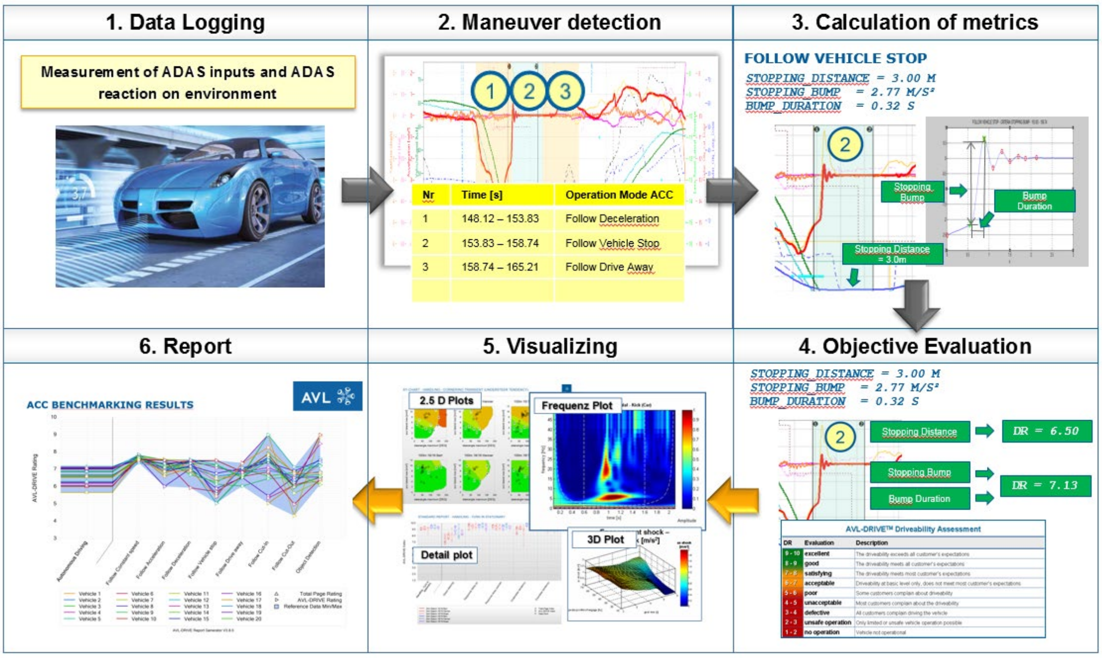

Figure 4: AVL-DRIVE approach for objective drivability assessment of automated driving functionalities

Scenario creation and development – migrating real scenarios to virtual environments

Innovative test and validation processes of ADAS based on X-in-the-loop methods have been the focus of research of the Institute of Automotive Engineering, Graz University of Technology (FTG) ever since the large European project PROMETHEUS. A simulation framework for virtual test and validation of Adaptive Cruise Control (ACC), Lane Keeping Assist (LKA) and Autonomous Emergency Braking (AEB) was developed within the scope of the research project *VDC-DAS*, (part of *NETI,* FFG headquarter strategy). The main challenges were the definition of relevant test cases, evaluation metrics[7] and the enhancement of vehicle simulation models with respect to environment recognition sensors[8] [9] and advanced controllers for automated driving [10] [11].

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[7] Bernsteiner, S., Holl, R., Lindvai-Soos, D., & Eichberger, A. (2013). Subjective Evaluation of Advanced Driver Assistance by Evaluation of Standardized Driving Maneuvers. in Proceedings of SAE 2013 World Congress (S. 1-11). DOI: doi:10.4271/2013-01-0724

[8] Bernsteiner, S., Magosi, Z. F., Lindvai-Soos, D., & Eichberger, A. (2015). Radarsensormodell für den virtuellen Entwicklungsprozess. *ATZ-Elektronik*, *10*(2), 72-79.

[9] Eichberger, A., Markovic, G., Magosi, Z. F., Rogic, B., Lex, C., & Samiee, S. (2017). A Car2X Sensor Model for Virtual Development of Automated Driving. International Journal of Advanced Robotic Systems, 14(5). DOI: https://doi.org/10.1177/1729881417725625

[10] Samiee, S., Azadi, S., Kazemi, R., & Eichberger, A. (2016). Towards a Decision Making Algorithm for Automatic Lane Change Maneuver Considering Traffic Dynamics. Promet - traffic & transportation, 28(1).

[11] Samiee, S., Azadi, S., Kazemi, R., Eichberger, A., Rogic, B., & Semmer, M. (2015). Performance Evaluation of a Novel Vehicle Collision Avoidance Lane Change Algorithm. in Advanced Microsystems for Automotive Applications 2015 (1 ed., S. 103-116). (Lecture Notes in Mobility). Springer.

In the research project IAFA, also part of *NETI* (FFG headquarter strategy) and HiLITe (FFG EFREtop), FTG enhanced the simulation framework for automated lane changes. Already this enhancement drastically increased the number of test cases as well as the evaluation criteria[12]. Parameters for the driving strategy (i.e. decision for initiation of a lane change and lane change duration) were derived from naturalistic driving studies and tested for human factors in a driving simulator. To account for the complexity of the test cases, the performance of the lane change function was tested with an innovative method for **deterministically** varying the parameters of the target vehicles (i.e. traffic) starting on a straight highway. Human factors were tested in the driving simulator using a co-simulation of vehicle dynamics (AVL-VSM), environment (Instant Reality player) and traffic simulation (PTV-Vissim). This procedure offered the possibility of **stochastically** created test cases by the microscopic traffic flow simulation.[13]

Currently, the deterministic and stochastic approach is combined in a holistic co-simulation framework, where the behavior of the traffic is controlled by **simultaneous** traffic flow simulation and **separate control** of individual target vehicles. This allows for identification of critical test scenarios that can be re-used for fast improvement of the "driving robot" whenever failures are detected. The crucial research topic is the definition of the evaluation metrics, since not only collisions are relevant but other criteria such as human factors including safety, comfort and trust, energy efficiency and traffic flow. Also, systematic investigation of critical parameters (such as corner radii) are needed for efficient test and validation which is based on the reduction of test cases, duration of individual test cases and computational efficiency of the models. [14]

Similar to objective evaluation of driver comfort, human factors with respect to acceptance, safety and trust in automated driving, and objectivation of subjective human evaluation are key factors. In the research project *MueGen Driving* (FFG FemTech Forschungsprojekte), these human factors were investigated for 96 test persons for ACC and AEB in naturalistic driving studies as well as driving simulator studies. Main parameters such as vehicle speed, distance to the target vehicle, driving strategy and road conditions were investigated considering gender and age aspects [15] [16].

In the research project Enable-S3, FTG currently contributes to validation of radar sensor models and radar target stimulators, as well as a virtual co-simulation framework to test and validate vehicle platooning in traffic jams. Modelling active sensors include a number of

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12 Rogic, B., Bernsteiner, S., Samiee, S., Eichberger, A., & Payerl, C. (2016). Konzeptionelle virtuelle Absicherung von automatisierten Fahrfunktionen anhand eines SAE Level 3 Fahrstreifenwechselassistenten. Postersitzung präsentiert bei VDI/VW-Gemeinschaftstagung, Wolfsburg, Deutschland.

13 Eichberger, A., Rogic, B., Quinz, P., Koglbauer, I. V., Payerl, C., Haberl, M., & Malic, D. (2017). Evaluation of Human Acceptance and Comfort of Automated Highway Driving at Different Levels of Automation. in Transportation Research Procedia (TRPRO) Elsevier Ltd..

14 Prialé Olivares, S., Rebernik, N., Eichberger, A., & Stadlober, E. (2015). Virtual Stochastic Testing of Advanced Driver Assistance Systems. in Advanced Microsystems for Automotive Applications 2015 (1 Aufl., S. 25-35). (Lecture Notes in Mobility). Heidelberg, Deutschland: Springer Verlag.

15 Koglbauer, I. V., Holzinger, J., Eichberger, A., & Lex, C. (2018). Autonomous emergency braking systems adapted to snowy road conditions improve drivers' perceived safety and trust. Traffic injury prevention, 19(3), 332-337. DOI: 10.1080/15389588.2017.1407411

16 Koglbauer, I. V., Holzinger, J., Eichberger, A., & Lex, C. (2017). Drivers' interaction with the Adaptive Cruise Control on Dry and Snowy Roads with Various Tire-Road Grip Potentials. Journal of Advanced Transportation

complex issues for research and development[17], mainly due to the complex wave propagation of radar sensors. Physical modelling of high frequency electromagnetic wave propagation usually results in complex models which will not run in real time. A test and validation framework with co-simulation based on Model.CONNECT has been developed using VIRES VTD, AVL VSM and Matlab/Simulink[18]. Currently this framework is enhanced with microscopic traffic flow simulation (SUMO) in order to add stochastic test cases to the previously deterministic test cases.

Pilot site for development, evaluation and validation of autonomous driving functions – an industrially relevant environment for the evaluation of OSE³AD outcomes

NTU runs a test facility designed for autonomous vehicles at its Centre of Excellence for Testing & Research of Autonomous Vehicles (CETRAN). It replicates various elements of Singapore's urban road conditions, such as traffic signals, multiple bus stops and pedestrian crossings, and tropical conditions such as driving through heavy rain and partially flooded roads. Operated by NTU scientists, CETRAN is located on the NTU Smart Campus in the Jurong Innovation District. This test track helps on the one hand to validate the designs of various AV types for first/last mile transport and public transport; it also serves as a platform to certify AVs for various applications through carefully selected test cycles and simulations.

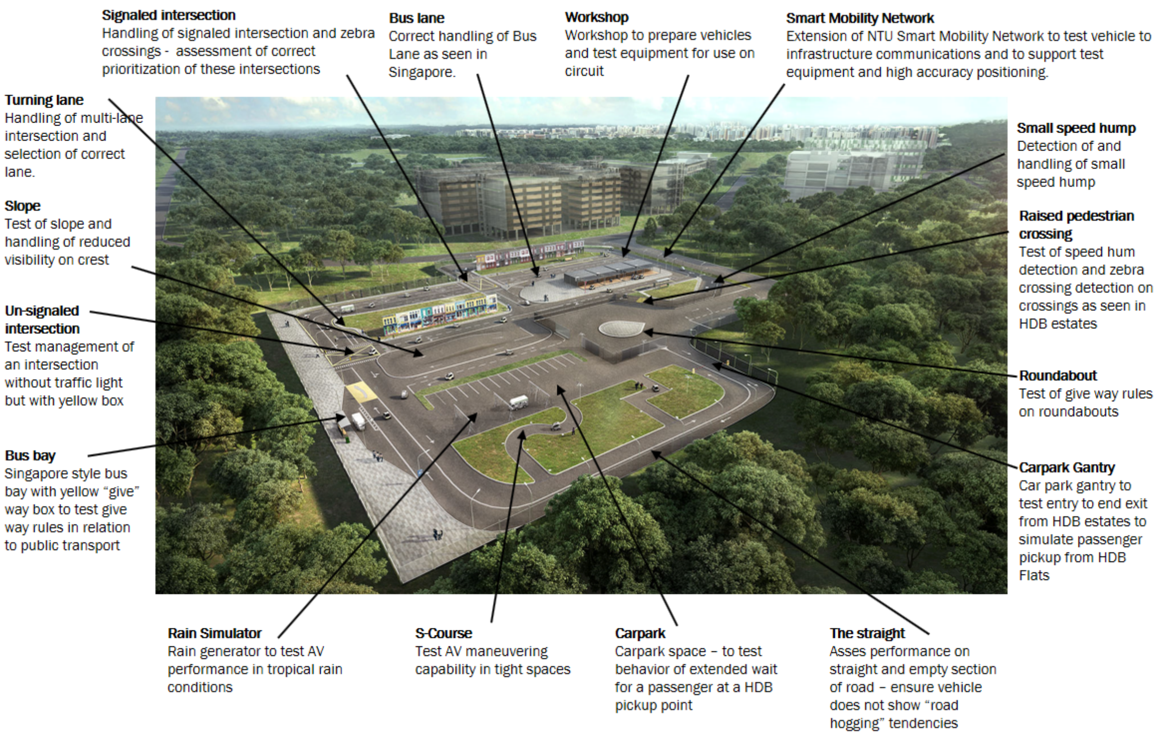

Figure 5: NTUs Centre of Excellence for Testing & Research of AVs

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[17] Holder, M., Rosenberger, P., Winner, H., D'hondt, T., Makkapati, V. P., Maier, F. M., ... Rosenstiel, W. (2018). Measurements revealing Challenges in Radar Sensor Modeling for Virtual Validation of Autonomous Driving. In 2018 21st International Conference on Intelligent Transportation Systems (ITSC) (pp. 2616 - 2622). DOI: 10.1109/ITSC.2018.8569423

[18] Kastner, R. Modellbildung und Simulation eines kooperativen Stauassistenten über ein Co-Simulationsframework. Master thesis. Graz University of Technology. 2017

The Energy Research Institute at Nanyang Technical University is developing autonomous functions for the use case of a full-sized electric bus which is classified to have near Level 4 autonomy. In March 2019, a launch ceremony was held for the bus and showcased to the media. The on-the-road trials will start later this year, with one bus to be tested at the university without any passenger pick-ups. Another, identical bus will be trialed at an SMRT depot to check if it can navigate itself into washing bays and park at charging stations. One goal for the NTU-Volvo team is to be one of the successful tenderers for the Singapore Government's plans to have autonomous vehicles in Punggol, Tengah and the Jurong Innovation District from 2022 for commuter use.

Figure 6: The autonomous bus tested at NTU

Roundabouts are one of the most complex urban scenarios

To reach full Level 4 autonomy, the bus will have to be tested in residential areas and in mixed traffic conditions with other vehicles. In order to receive the approval for real-life testing, the autonomous bus will have to prove its ability to handle a series of highly complex urban traffic scenarios.

One of the most complex urban traffic scenarios is the roundabout (also known as traffic circle). Contrary to simple intersections, roundabouts have multiple exits, and the traffic is flowing constantly which makes it difficult to predict the behavior of other vehicles. When entering a roundabout, a yield-or-merge decision must be made in a short amount of time. This makes high demands on sensing and perception as well as on the prediction of the movement of other vehicles, and the decision-making on maneuver execution and planning is extremely complex.

Therefore, roundabout scenarios are seen as being a perfect fit for testing full AD systems[19]. In the course of the OSE³AD project, NTU will develop AD functions for the decision-making in roundabout scenarios which are tested and validated using the open and integrated simulation framework.

[19] B. Okumura et al., "Challenges in Perception and Decision Making for Intelligent Automotive Vehicles: A Case Study," in IEEE Transactions on Intelligent Vehicles, vol. 1, no. 1, pp. 20-32, March 2016.
doi: 10.1109/TIV.2016.2551545

1.1.1 Activities and Results from other projects

The Austrian industrial and research partners, AVL and FTG, have an excellent position in the European research landscape (ECSEL-Austria) and are leaders or participants in numerous European (ARTEMIS, ECSEL, FP7, Horizon 2020 etc.) and Austrian national R&D projects.

Existing results and deliverables obtained from publicly funded projects that provide the basis of or feed into the proposed project

Table 1: OSE³AD related projects

Funding provider	Project-number	Title	Description of results already obtained and relevant deliverables (verifiable results / products of R&D work) in terms of the basis for / differentiation from the proposed project	Location and type of documentation (e.g. link to homepage, publication, conference proceedings, interim report, final report, …)
EU-ECSEL	692455	ENABLE-S3	Highly automated and autonomous systems in different application domains, coverage-oriented test selection methods, to enable certification of automated systems with reasonable efforts. **AVL** as overall coordinator and **FTG** as partner; will transfer project-related knowhow and results for integration and testing of autonomous driving components.	Project Website: http://www.enable-s3.eu/
H2020 ART-04	723324	TrustVehicle	Identification and evaluation of critical scenario for level-3 autonomous driving functions. An enhancement of **AVL**'s products VSM and DRIVE is intended for the evaluation of level-3 AD functions. This development will provide a solid basis for OSE³AD.	Project Website: http://www.trustvehicle.eu/
H2020 ART-07	769033	AVENUE	Design and realization of full-scale demonstrations of urban transport automation by deploying fleets of autonomous mini-buses in low to medium demand areas of four European demonstrator cities. **AVL** provides a controlled environment vehicle safety evaluation to assess that performance targets are met before evolution are deployed. This development will provide a solid basis for OSE³AD.	Project Website: https://h2020-avenue.eu/

EU-ECSEL	783190	PRYSTINE	Realization of fail-operational surround perception based on robust Radar and LiDAR sensor fusion and control functions in order to enable safe automated driving in urban and rural environments. **AVL** is a major contributor over the whole project and leads one of ten supply chains for the application of the developed technology into a passenger vehicle. This supports OSE³AD by providing experience on relevant architecture and scenarios for L4+ systems.	Project Website: https://prystine.automotive.oth-aw.de/
EU-ECSEL	826653	NewControl	Development of virtualized platforms for vehicular subsystems that are essential to highly automated driving (functions such as perception, cognition and control), so as to enable mobility-as-a-service for next-generation highly automated vehicles. **AVL** will be WP leader on validation and testing and will deliver significant technological contributions throughout the project.	(no information available yet – project will start as of May 2019)
ICT-01	732242	DEIS	The DEIS project addresses the challenge of assuring dependability of collaborative CPS by developing technologies that enable a science of dependable system integration. **AVL** is the overall project coordinator; knowledge of collaborative functions will be important for the development of L4+ functions.	Project Website: http://www.deis-project.eu/
FFG	841539 847834 852409 822934 831362 835504	NETI, HiLite	**FTG**'s contributions to these projects is a virtual test and validation framework up to SAE level 3 based on the software package IPG CarMaker. The work included also sensor models and automated driving controllers as well as the investigation of human factors in a driving simulator. Recent extensions include co-simulation to microscopic traffic flow simulation (PTV Vissim) and a combination of deterministic and stochastic generation of test cases.	(see publications in the state-of-the-art section)
FFG	860875	WACHsense	The project focusses on artificial intelligence to classify driving behavior (drowsiness) based on vehicle responses and bio-signals of the human driver. This development will provide a solid basis for scientific innovation in OSE³AD.	(no information available yet – project started)

1.2 Degree of Innovation

1.2.1 Problem and research need

Challenge 1: Efficient Vehicle Testing
The testing effort in vehicle development has been growing significantly over the last decades. Not only the diversity of vehicle variants is growing, but also the complexity of powertrains thanks to their electrification and hybridization. At the same time, advanced driver assistance systems (ADAS) and automated driving (AD) functions are conquering the market and are adding their contribution to the overall testing efforts. Figure 7 exemplarily illustrates the number of equivalent road kilometers to be tested before the start of production (SOP) of an ADAS-equipped vehicle, depending on the different SAE levels. Compared to a non-autonomous vehicle, testing efforts are increased by factors of several hundreds[20].

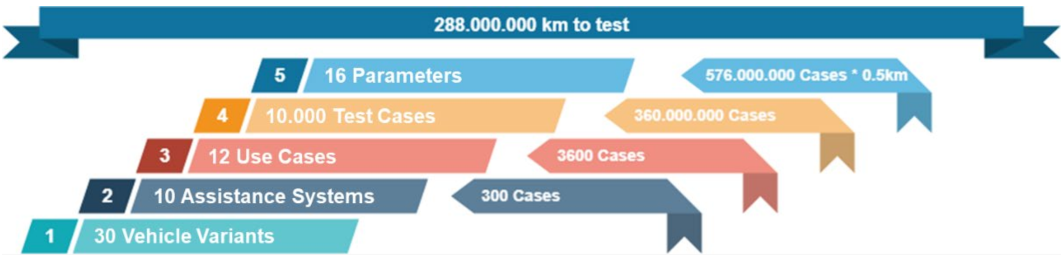

Figure 7: Example for the number of equivalent road kilometers to be tested for an ADAS-equipped vehicle

Depending on the testing environment, different levels of simulation are present in the vehicle development process, as shown in Figure 8. The quality of the models used has rapidly improved over the last years, not least due to the ever-growing amount of computational power available. This allows for the frontloading of development tasks, which has several advantages: first, the testing time incorporating the real vehicle is minimized which saves costs. Second, valuable hardware testing resources are freed which allows engineers to handle this increasing testing effort with existing equipment. Third, tasks accomplished in pure simulation can be executed faster than real-time which is an additional issue in mastering complexity.

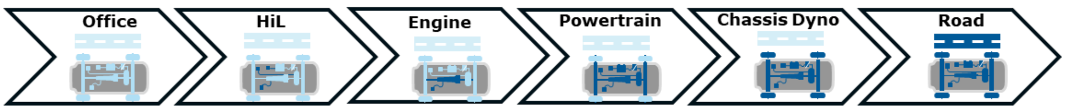

Figure 8: Simulated (light blue) and real (dark blue) parts in different testing environments used during powertrain development.

When migrating a development task from one testing environment to another, it is crucial to implement a general methodology for both testing and validation in order to obtain meaningful results.

[20] Nidhi, K., Paddock, S. (2016): Driving to safety: how many miles of driving would it take to demonstrate autonomous vehicle reliability? Transp. Res., Part A, Policy Pract., 94, 182–193.

Consequently, the first research objective is the capability to manage the complexity of validating L4+ AD functions. The proposed validation environment shall support the seamless transition from pure virtual to full physical environment

Challenge 2: Comprehensive Validation of Autonomous Driving Functions
Autonomous driving introduces two major challenges to the vehicle development process. First, not only the complexity of the vehicle itself, but also the complexity of the vehicle's environment becomes part of the vehicle development process. A multitude of test cases must be validated which target the behavior of the autonomously driving vehicle in a certain situation under certain circumstances. When testing an ACC system, the creation of test scenarios is limited to the preceding target vehicles, usually in a comparably simple motorway environment. This is multiplied several times for an automated lane change when taking into account traffic in 360° view. In urban scenarios, the complexity grows drastically with additional objects such as vulnerable road users with difficult prediction of their behavior. The more complex the environment, the more critical the aspect of user acceptance becomes– both of passengers and of other road users – which is itself a complex criterion which needs to be assessed in an objective way.

Second, "customer acceptance" is a highly subjective attribute which is challenging to evaluate in an objective manner. The additional challenge brought in by AD vehicles is the fact that not only vehicle dynamics need to be assessed, but also the autonomous driving control strategies which decide on and execute the driving maneuvers; customers will not only judge the vehicle's response to operational commands, but also its *driving style*. Furthermore, the vehicle attributes identified need to be consistently broken down to component or control strategy level, in order to enable proper development and validation of single components and control strategies to finally fulfill the targets at the vehicle level.

Depending on the vehicle brand, customers will make demands on the general behavior of the vehicle. Decisions on vehicle attributes are made at the very beginning of the design phase and have a strong impact both on product development and business acceptance.

This means that, next to the mere number of cases to be tested, short validation loops are of the essence in order to save valuable time for the relevant cases. Testing faster than real-time allows this, but is only available in virtual test environments.

Consequently, the second research objective is the capability to automate reasoning on the outcome of a scenario in order to enable automation of the full process, finally reducing efforts and enabling faster execution.

Virtual validation is the key to master these challenges:

- The validation of AD functions is possible without existing vehicle prototypes.
- Thanks to short validation loops, a higher number of test cases and scenarios can be covered in the same amount of time.
- Both testing effort and risk are minimized in real-vehicle operation.
- Automated validation procedures allow intelligent parameter space exploration using advanced statistical test design methods such as design of experiments (DoE).
- The virtual development, testing and validation environment can be re-used for later phases of the product lifecycle.

The results of this project will help in solving the following development challenges which are seen by the project partners as prerequisites before fully-automated vehicles can be introduced into the mass market:

- **Passenger acceptance**: the passengers of fully-automated vehicles need to trust the automation system and have a positive driving experience.
- **Reliability and safety** (including functional safety, active safety): In contrast to classic passive safety, where relevant laboratory tests (such as Euro NCAP crash tests) have been developed based on accident research, the traffic scenarios which must be tested for a reliable functional proof are virtually inexhaustible. The literature reports up to 5 billion equivalent road kilometers needed to experience a sufficient number of critical events and to demonstrate the functional safety of an assistance system according to ISO 26262. The proposed framework shall enable frontloading of part of the test campaign in the simulation.
- **Legal framework, liability, and ethics**: internationally varying basic principles of law, national legislations, standards and norms are a challenge for both legislators and developers. The proposed framework shall facilitate a dedicated analysis of the impact of a specific driving scenario on a specific legal framework.

1.2.2 Goals

The overall target of the OSE³AD project is **to increase efficiency for the validation of L4+AD functions** through the use of a **virtual environment and automated evaluation** supported by **rule-based reasoning**.

The OSE³AD consortium attaches importance to clearly formulated project objectives to allow valuation of the degree of target attainment. To illustrate the intended step beyond the state of the art, technology readiness levels (TRLs) are given in Table 2.

Table 2: OSE³AD targets

Obj. ID	Objective and Quantification	TRL
Obj1	**Objective:** Provide an open and integrated simulation framework for the efficient development, testing and validation of innovative autonomous driving functions to increase efficiency through frontloading and to enable virtual validation. **Quantification**: The capability to integrate relevant elements – modeling of environmental conditions, other road participants – for holistic L4 evaluation is increased from 20% to 80%. ***Baseline:*** *Current development process for level-4 AD functions using different tools which are not interconnected; the interdependencies between elements as well as dynamic interactions cannot be efficiently analyzed*	TRL 3 → TRL 6
Obj2	**Objective:** Identify objective evaluation criteria to assess both quantitative and qualitative targets for rule-based reasoning of complex scenarios, thus enabling automated scenario evaluation. **Quantification**: The capability to comprehensively evaluate L4 scenarios in an automated way will be facilitated by provision of objective evaluation criteria around roundabout scenarios and autonomous parking. ***Baseline:*** *Current evaluation criteria for complex dynamic scenarios which are not standardized and do not allow automated validation.*	TRL 2 → TRL 4
Obj3	**Objective:** Design, evaluate and validate innovative autonomous driving functions for SAE level 4 using the provided simulation framework to demonstrate the increased efficiency. **Quantification**: The time-to-validation is reduced by 30% through the usage of purely virtual validation methods. ***Baseline:*** *Current development process for level-4 AD functions including on-road validation.*	TRL 3 → TRL 5

1.2.3 Degree of innovation and associated risk

It is meanwhile of common understanding that large alliances will be required to tackle the challenge of development and validation of ADAS systems[21]. Through the integrated and open platform for development and evaluation of L4+ systems proposed in this project, the OSE³AD consortium will provide an environment-enabling ecosystem reorganization toward efficient and cooperative L4+ virtual development and validation. The OSE³AD project covers tool integration as well as application of domain knowledge such as attribute engineering, multi-disciplinary vehicle system simulation, automotive development process, development standards, and calibration methodology.

Improvements are expected with respect to the efficient import of environmental information for automated vehicles into the simulation and validation framework – and thus mapping the required knowledge between classical automotive engineering and advanced automation into the automotive context. Furthermore, methods for efficient analysis of application scenarios (e.g., different driving maneuvers and scenarios) as well as data management (e.g., supplementary environmental data) are expected. Main improvements are related to mutual compatibility and information consistency between the development steps and related tools, therefore improving development efficiency by minimizing the manual (and error-prone) handover of information between the tools and increasing the degree of automation between the single development steps. Figure 9 depicts the gain in consistency across the vehicle development process.

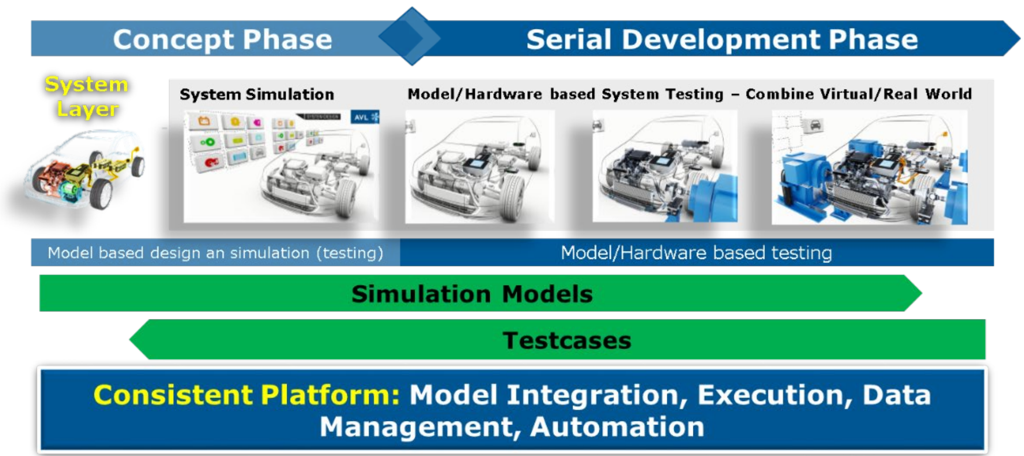

Figure 9: Underlying philosophy for AVL's integrated and open development platform (IODP)

Figure 10 provides an example of rule-based reasoning for automated cruise control. In this example, different physical parameters are measured and later mapped to high level KPI. This approach enables full traceability between a dedicated maneuver and its assessment, finally enabling objective evaluation. The challenge in OSE³AD will be to identify relevant criteria for L4+ functions, focusing on roundabout scenarios.

[21] https://www.bloomberg.com/news/articles/2019-02-28/daimler-bmw-deepen-cooperation-with-self-driving-car-venture

Especially, it is expected that because of the high dynamics of the scenarios and degree of interactions among the road participants, the complexity of the criteria (in terms of calculation and number of parameters) will strongly increase.

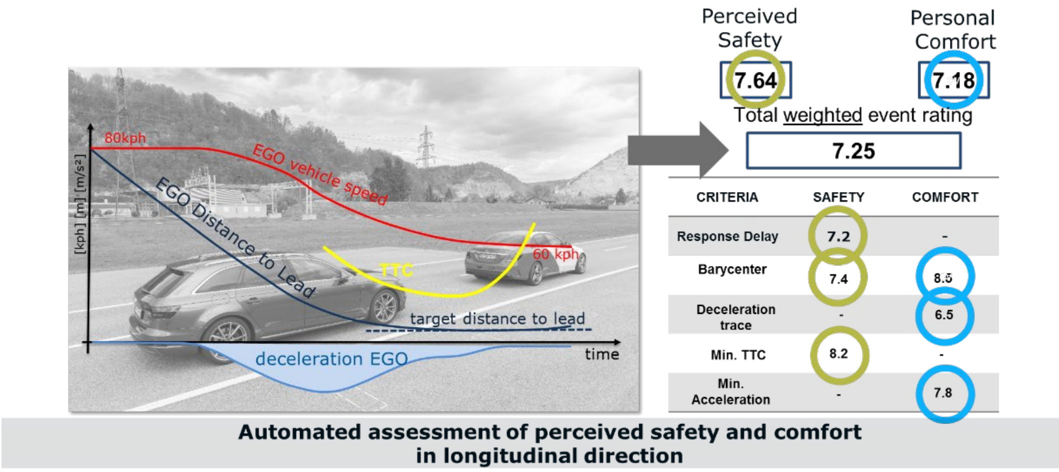

Figure 10: Example of rule-based scenario assessment for automated cruise control

Starting with an already mature solution, the main challenge during the OSE³AD project will be the further development of AVL-DRIVE ADAS towards the validation of level-4 functions. The technology readiness levels (TRLs) in Table 2 justify the classification of OSE³AD as being “experimental development”.

Scenario generation for test and validation of automated driving is part of intense worldwide research and can only be mentioned exemplarily. Ulbrich et al. [22]reviewed existing literature for the terms *scene*, *situation* and *scenarios,* which are the basis for creating a common understanding to build test cases for automated driving. Althoff[23] et al. presented an approach for online estimation of the safety of automated vehicles during operation by the use reachability analysis to capture all possible future scenarios. Rocklage et al.[24] presented an approach to automatically generate test scenarios for regression testing of autonomous vehicle systems in a virtual simulation environment. A backtracking algorithm was used to deal with the constraint satisfaction problem between combinatorial interaction testing and motion planning of traffic participants. Vishnukumar et al.[25] used artificial intelligence (machine

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[22] S. Ulbrich, T. Menzel, A. Reschka, F. Schuldt and M. Maurer, "Defining and Substantiating the Terms Scene, Situation, and Scenario for Automated Driving," *2015 IEEE 18th International Conference on Intelligent Transportation Systems*, Las Palmas, 2015, pp. 982-988.
doi: 10.1109/ITSC.2015.164

[23] M. Althoff and J. M. Dolan, "Online Verification of Automated Road Vehicles Using Reachability Analysis," in *IEEE Transactions on Robotics*, vol. 30, no. 4, pp. 903-918, Aug. 2014.
doi: 10.1109/TRO.2014.2312453

[24] E. Rocklage, H. Kraft, A. Karatas and J. Seewig, "Automated scenario generation for regression testing of autonomous vehicles," *2017 IEEE 20th International Conference on Intelligent Transportation Systems (ITSC)*, Yokohama, 2017, pp. 476-483.
doi: 10.1109/ITSC.2017.8317919

[25] H. J. Vishnukumar, B. Butting, C. Müller and E. Sax, "Machine learning and deep neural network — Artificial intelligence core for lab and real-world test and validation for ADAS and autonomous vehicles: AI for efficient and

learning and Deep Neural Networks) that was based on available scenarios and created new scenarios for efficient testing. Heinz et al. [26]presented a scenario -based trajectory generation based on OpenScenario descriptions from real test drives. Rogic et al. [27]presented a deterministic approach to generate test scenarios for motorway lane change by defining basic scenarios and limiting the resulting number of test cases by applying requirements-based constraints in the parameter variation. Prialé et al.[28] presented a method for generating test scenarios for a Camera-HiL test bench for testing Lane Keeping by introducing feedback loops that on-line modifies the road network on occurrence of failures. A more general overview of methodologies for automated test case generation (not particularly focused on automated driving) was done by Anand et al. [29], which summarizes existing methods that will be the basis for the research in OSE³AD.

In our proposed work, we will develop an enhanced method for scenario generation tailored to the targeted **use-cases**. After creation of the static environment using digital maps, laser-scans or other sources, the dynamic environment will be modelled using **traffic flow simulation** calibrated on measured traffic of the selected road network. In urban areas this includes **vulnerable road users** such as pedestrians, bicycles, mopeds and motorcycles, which adds huge complexity by their individual behavior patterns. In addition, **weather and road conditions** will be varied in VIRES VTD together with sensor models (radar, lidar video, ultrasonic and C2X) taken from other projects or commercially available. A combination of **statistical** methods for automated test case generation and **deterministic** modelling of individual target vehicles in certain environments such as roundabouts and junctions will provide a suite of test cases that will be optimized to balance the requirements of **coverage** (traffic and environment conditions) and **computational effort**. Taken into account the complexity of urban traffic, environmental conditions, Level 4+ driving functions, and the complex evaluation metrics, the simulation framework will be clearly beyond published research.

quality test and validation," *2017 Intelligent Systems Conference (IntelliSys)*, London, 2017, pp. 714-721. doi: 10.1109/IntelliSys.2017.8324372

[26] Heinz, Aaron, Remlinger, Wolfram and Schweiger, Johann: Track- / Scenario-based Trajectory Generation for Testing Automated Driving Functions, in: 8. Tagung Fahrerassistenz, 2017

[27] Rogic, B., Bernsteiner, S., Samiee, S., Eichberger, A., & Payerl, C. (2016). Konzeptionelle virtuelle Absicherung von automatisierten Fahrfunktionen anhand eines SAE Level 3 Fahrstreifenwechselassistenten. Postersitzung präsentiert bei VDI/VW-Gemeinschaftstagung, Wolfsburg, Deutschland.

[28] Prialé Olivares, S., Rebernik, N., Eichberger, A., & Stadlober, E. (2015). Virtual Stochastic Testing of Advanced Driver Assistance Systems. in Advanced Microsystems for Automotive Applications 2015 (1 Aufl., S. 25-35). (Lecture Notes in Mobility). Heidelberg, Deutschland: Springer Verlag.

[29] Saswat Anand, Edmund K. Burke, Tsong Yueh Chen, John Clark, Myra B. Cohen, Wolfgang Grieskamp, Mark Harman, Mary Jean Harrold, Phil McMinn, Antonia Bertolino, J. Jenny Li, Hong Zhu, An orchestrated survey of methodologies for automated software test case generation, Journal of Systems and Software, Volume 86, Issue 8, 2013, Pages 1978-2001, ISSN 0164-1212, https://doi.org/10.1016/j.jss.2013.02.061.

Project risks

The following table shows the main technical, commercial and other relevant risks.

Table 3: Risk management and contingency (Severity scale 1-5 [1-low / 5-catastrophic], Probability scale 1-5 [1- once in the project / 5 - every week], risk priority number (RPN) = Severity x Probability)

Risk ID	Risk Item	Effect	Severity	Probability	RPN	Measures
1	[*Commercial Risk*] Major change in legislation or disruptive show stopper leading to decreased interest in automated driving	No or reduced needs for automated driving functions	5	1	5	Systematic analysis of markets, stakeholders' rationales, end-user needs, and legislation
2	[*Technical Risk – Process and tool*] Proposed OSE³AD framework not mature enough for evaluation and validation of relevant L4+ functions	Additional major efforts required for tool and method enhancement	4	2	8	Regular feedback within OSE³AD consortium and with external partners to assess this risk
3	[*Technical Risk – objective assessment method*] Low acceptance of proposed integrated development platform due to compliance problem with existing tools or low acceptance of assessment method	Stagnant or delayed rollout	4	2	8	Regular feedback within OSE³AD consortium and with external partners to assess this risk
4	[*Technical Risk – Vehicle demonstrator*] Demonstrator vehicle not available or insufficient for testing of ADF	No or reduced in vehicle validation of ADF	4	1	4	Systematic analysis of needs and redesign necessary

1.3 Quality of planning

The three central objectives of OSE³AD have been broken down to tangible tasks within the project, as illustrated in Figure 11:

- An appropriate route for a geo-fenced L4 autonomous vehicle driving on NTU's CETRAN test track is defined from which the most relevant scenarios are identified.
- For each of these relevant scenarios, requirements for both scenario creation and evaluation criteria engineering are specified.
- The simulated scenarios are built and integrated into the co-simulation platform.
- The evaluation criteria are formulated as functions of objectively assessable quantities and integrated into the co-simulation platform.
- An autonomous driving function is designed and integrated into the co-simulation platform.
- Finally, the whole framework is tested and evaluated.

Doing so, each of the three central objectives has a dedicated work package with measurable results and defined milestones.

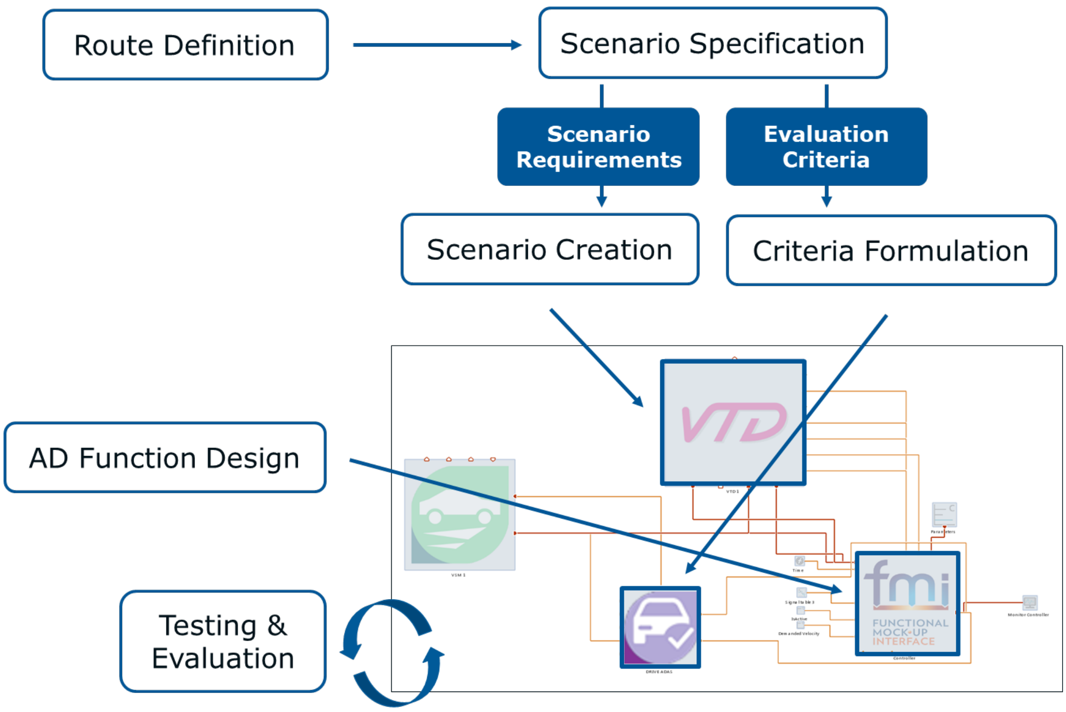

Figure 11: concept of OSE³AD project

1.3.1 Overview and description of work packages

WP No.	Work package title	Duration (month)	Start MM/YY	End MM/YY	Planned result
1	Project Management	24	09/19 (M1)	08/21 (M24)	Ensures monitoring and operational feasibility of the project and disseminates relevant results and innovations.
2	Requirements and Specifications	6	09/19 (M1)	02/20 (M6)	Delivers specifications of scenario setups and corresponding evaluation criteria along a predefined route.
3	Scenario Creation	21	12/19 (M4)	08/21 (M24)	Delivers virtual test scenarios and evaluation criteria according to specifications.
4	Environment for Simulation Execution and Objective Evaluation	21	12/19 (M4)	08/21 (M24)	Sets up the co-simulation platform for virtual validation, integrates necessary tools and prepares interface for AD function. Also implements specified evaluation criteria.
5	Autonomous Driving Function Development	21	12/19 (M4)	08/21 (M24)	Delivers an innovative AD function to be validated using the proposed framework.
6	Evaluation of Proposed Framework on Relevant Scenarios	12	09/20 (M13)	08/21 (M24)	Provides the proof-of-concept for the proposed framework.

Overview of milestones

Milestone No.	Milestone title	Work Packages involved	Expected date	Milestone is achieved when:
1	MS1: Project started	WP1	M1	Kick-Off Meeting executed (Minutes of meeting available) D1.1
2	MS2: Route definition and scenario specifications available	WP2	End of M6	Detailed specification of scenario setups available D2.2
3	MS3: Interim report available	WP1, WP2, WP3, WP4, WP5	End of M12	Interim project report available D1.2
4	MS4: Environment, traffic model and scenario generation tool available	WP3	End of M12	Environment, traffic model and scenario generation tool available D3.1 D3.2
5	MS5: Evaluation criteria implemented	WP4	End of M12	Evaluation criteria implemented D4.1
6	MS6: Virtual validation co-simulation platform available and ready for operation	WP4	End of M12	Co-simulation platform available and ready for operation D4.2
7	MS7: First Version of Autonomous function available as FMU	WP5	End of M12	Autonomous function available as FMU D5.2
8	MS8: Evaluation report available	WP6	End of M24	Evaluation report available D6.1
9	MS9: End of project	WP1, WP2, WP3, WP4, WP5, WP6	End of M24	Final project report available D1.3

1.3.2 Detailed description of work packages

WP No.	1	Title of WP:	Project Management
Participating organisation (A/Pn) and person-months per organisation:			
AVL (A): 6.6 PM | NTU (P1): 1.4 PM | FTG (P2): 0.6 PM			

Goals:
- Ensure the project is conducted on time, according to the budget and directed towards the overall project objectives - Communicate the project outcomes to selected audiences - Initiate a dialogue with relevant stakeholders for dissemination and future exploitation

Description of contents:
Task 1.1: Project Management (Lead: AVL) Ensures compliance of project execution with the goals of the program. Project management will maintain communication with all partners and with FFG. Project management is understood both on the coordinative and the administrative level with a distinctive person for each role. The coordinator and the administrative project leader will jointly work on managing the consortium and providing the necessary reports to FFG.
Task 1.2: Organization of Dialogues with Stakeholders (Lead: NTU) Manage dedicated communication to relevant stakeholders in order to disseminate relevant project outcomes to interested partners. Especially, the main outcomes of the OSE³AD project are primary targets for this dissemination activity.
Task 1.3: Coordination of Dissemination Actions (Lead: FTG) Plan and support the dissemination activities. This includes the planning of dissemination activities towards identified target groups and FFG reporting. Support for all project partners concerning documentation of project results.

Method:
The management will be based on established project management standards and project management organization. The progress of the work packages is measured through deliverables which are synthetic and can be evaluated with each WP leader. Discrepancies will be tackled by measures decided in the meetings which are regularly scheduled. Management risk meetings are planned on regular basis. As standard project management methods are accepted and established within the consortium, the management risk is foreseen as low.

Milestones, planned results and deliverables:

Milestones

MS1: Project start

MS9: End of project

Deliverables

D1.1 (MS1): Project handbook – summarizing main project processes, organization, templates

D1.2 (MS3): Interim project report

D1.3 (MS9): Final project report

WP No.	2	Title of WP:	Requirements and Specifications

Participating organisation (A/Pn) and person-months per organisation:

AVL (A): 17.3 PM | NTU (P1): 2.8 PM | FTG (P2): 3.3 PM

Goals:

- Definition of relevant SAE level 4 scenarios to be validated
- Specification of (a) scenario setups for the implementation in VTD, and (b) of the corresponding evaluation criteria

Description of contents:

Task 2.1: Definition of Intended Route and Relevant Scenarios (Lead: NTU)
From an intended route on NTU's CETRAN test track, 3-5 relevant scenarios will be defined to be evaluated subsequently.

Task 2.2: Specification of Scenario Setups (Lead: AVL)
For each of the relevant scenarios defined in Task 2.1, the scenario setup will be defined. This includes the scene settings as well as a specification of variable parameters for the scenario.

Task 2.3: Specification of Evaluation Criteria (Lead: AVL)
For each scenario, evaluation criteria for the successful accomplishment will be defined.

Method:

Selection of scenarios depending on frequency of occurrence over intended route. Internal workshop involving experts from different domains for the specification of scenario setups and evaluation criteria will lead to well-founded decisions.

Milestones, planned results and deliverables:

Milestones
MS2: Route definition and scenario specifications available

Deliverables
D2.1 (MS2): Intended route and relevant scenarios to be evaluated
D2.2 (MS2): Specification of scenario setups and corresponding evaluation criteria

WP No.	3	Title of WP:	Scenario Creation
Participating organisation (A/Pn) and person-months per organisation:			
AVL (A): 1.3 PM | NTU (P1): 0 PM | FTG (P2): 23.7 PM			

Goals:
- Modelling of environment, environmental conditions and traffic in specified use cases within the proposed urban scenarios

Description of contents:
Task 3.1: Environment and Traffic Modelling (Lead: FTG) Definition of road network based on the use cases. Environment modeling in VIRES VTD using available data (digital maps, OPEN Drive data, laser scans etc.). Modelling of the corresponding road network in SUMO traffic flow simulation. Definition of input volumes, vehicle and time gap distributions for a basic set-up.
Task 3.2: Scenario Generation (Lead: FTG) Definition of parameter space for scenario generation (traffic and environment condition parameters). Development of a mathematical tool for stochastic scenario generation. Implementation of automated evaluation for online detection of critical cases. Development of a procedure for storing critical cases in the scenario database.

Method:
Environment modelling using built-in Editors and parametric CAD tools for creating surfaces from point clouds, modelling and calibration of traffic flow models based on measured traffic, stochastic approaches for scenario generation, SW and database programming.

Milestones, planned results and deliverables:
Milestones MS4: Environment, traffic model and scenario generation tool available **Deliverables** D3.1 (MS4): Complex urban environment and traffic model, ready to use in VIRES and SUMO D3.2 (MS4): Software for automated generation of test cases in the defined parameter space

WP No.	4	Title of WP:	Environment for Simulation Execution and Objective Evaluation
Participating organisation (A/Pn) and person-months per organisation:			
AVL (A): 23.2 PM | NTU (P1): 0 PM | FTG (P2): 0 PM			

Goals:

- The extension and tailoring of the vehicle attribute engineering solution and its integration to existing development platforms for autonomous driving applications is target of this work package.
- Integrate relevant tools with appropriate configuration to manage the simulation and evaluation of the automated driving function application. Furthermore, solutions for automated data and model interfacing between the tools (e.g., Model.CONNECT) shall be provided to increase consistency during development.

Description of contents:

Task 4.1: Specification of Necessary Components and Interface Definition (Lead: AVL)
Selection of project-relevant tools (as described in section 1.1) and creation of wiring diagram as a layout for the simulation environment.

Task 4.2: Integration into Existing Co-Simulation Platform (Lead: AVL)
Setup of the simulation environment by integrating required AVL TeamSuite tools as well as third-party components into Model.CONNECT. Preparation of an interface for the AD function developed in WP5.

Task 4.3: Implementation of Specified Evaluation Criteria (Lead: AVL)
Translation of evaluation criteria into mathematical formulas and integration into the simulation environment.

Method:

The AVL tools Model.CONNECT, VSM, CRUISE M and DRIVE-ADAS will be used, as well as VIRES VTD and SUMO (described in section 1.1). ISO 26262 on functional safety will be considered. The evaluation criteria will first be implemented in MATLAB and integrated into the framework as FMU to keep the flexibility.

Milestones, planned results and deliverables:

Milestones
MS5: Evaluation criteria implemented
MS6: Virtual validation co-simulation platform available and ready for operation

Deliverables
D4.1 (MS5): Mathematical formulation of evaluation criteria available
D4.2 (MS6): Co-simulation platform (hardware and software)

WP No.	5	Title of WP:	Autonomous Driving Function Development

Participating organisation (A/Pn) and person-months per organisation:

AVL (A): 1.7 PM | NTU (P1): 11.2 PM | FTG (P2): 0 PM

Goals:

- Implementation of innovative autonomous driving functions (not yet available on market) to enable an autonomous bus to handle roundabout scenarios.

Description of contents:

Task 5.1: Requirements Definition (Lead: NTU)
Gathering of requirements for the AD functions to handle the selected roundabout scenarios. The focus is on the decision-making for entering the roundabout in a safe way during flowing traffic.

Task 5.2: Software Implementation of the AD Functions (Lead: NTU)
Implementation of autonomous driving functions to operate a vehicle according to the requirements defined in Task 5.1. The result will be compiled to a generic functional mock-up unit (FMU) to ensure full compatibility with the co-simulation platform.

Method:

Model-based software development, Software-in-the-Loop (SIL) and Model-in-the-Loop (MIL) testing, as well as individual component testing on specific test equipment.

Milestones, planned results and deliverables:

Milestones
MS7: First version of autonomous function available as FMU

Deliverables
D5.1 (MS7): Description of autonomous function
D5.2 (MS7): Autonomous driving function, first version (FMU)

WP No.	6	Title of WP:	Evaluation of Proposed Framework on Relevant Scenarios
Participating organisation (A/Pn) and person-months per organisation:			
AVL (A): 39.6 PM | NTU (P1): 2.7 PM | FTG (P2): 5.0 PM			

Goals:
- Provide the proof-of-concept for the proposed framework by designing, evaluating and validating the innovative autonomous driving function from WP5 using the simulation environment from WP 4

Description of contents:
Task 6.1: First Simulation and Evaluation of Relevant Scenarios (AVL) All relevant scenarios are simulated with each proposed combination of parameters and the AD function from WP5 is validated using the criteria from WP4. Results are documented and shared with the consortium partners.
Task 6.2: Quality Assessment and Adjustments (AVL, NTU, FTG) Based on the results from T6.1, the scenarios and the AD function might be revised, and the automated simulation/validation process will be triggered again (1-2 iterations).
Task 6.3: Final Simulation and Evaluation of Relevant Scenarios (AVL) A final simulation/validation run will be performed; results and findings from T6.2 will be documented in the evaluation report.

Method:
Using the integrated virtual validation framework, prototypes of the deliverables from all previous work packages are brought together and interconnected. The validation process is retraced in order to demonstrate the capability and to understand the maturity of the system.

Milestones, planned results and deliverables:
Milestones MS8: Evaluation report available **Deliverables** D6.1 (MS8): Evaluation report

1.3.3 Work and time schedule (Gantt chart)

The work and time schedule for the OSE³AD project is given in Figure 12.

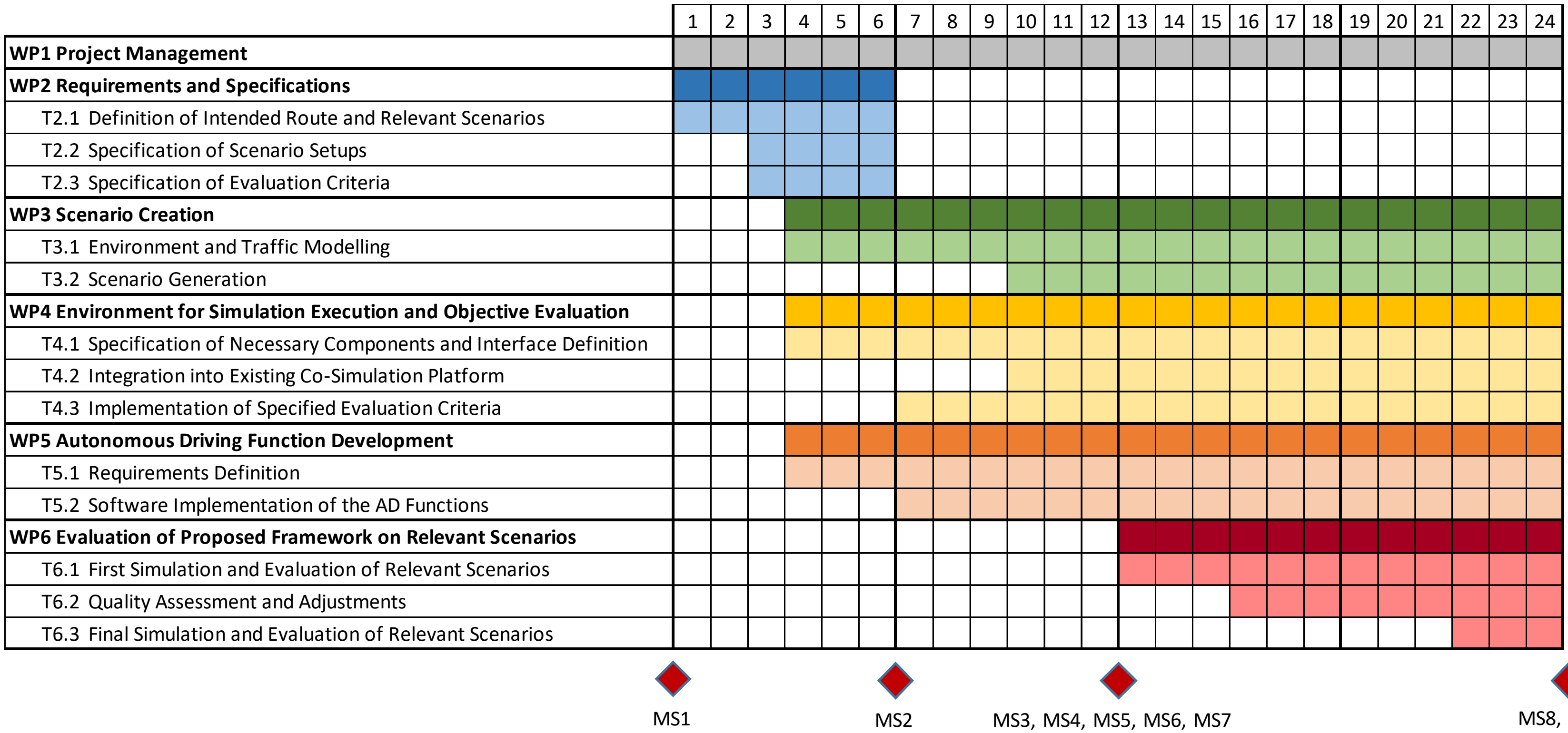

Figure 12: GANTT chart for the OSE³AD project

1.3.4 Description of cost plan

The requested funding corresponds well to both the expected amount of work and to the targeted results. The planned resources are adequate for meeting the overall objectives and for successful completion of individual tasks. The nature of the objectives and the focus of the project justify the composition of the consortium and the number of partners. The resource management in OSE³AD has been planned in a way that guarantees the successful achievement of its objectives.

Key facts at a glance:

- The project duration is 24 months.
- Three partners contribute a total effort of 140 person months to the project.
- The total budget amounts to 1,150,846 Euros;
- The requested funding from FFG amounts to 490,661 Euros.

AVL: The personnel costs for AVL, representing 92% of their total costs in the project, are related to the research activities described in section 1.3.2. Main activities carried out by AVL are the specification of relevant scenarios and corresponding evaluation criteria (WP2), the setup of the co-simulation platform as well as the implementation of evaluation criteria (WP3) and the proof-of-concept by testing and validation of the autonomous driving function developed in WP4 using the proposed framework (WP5). Material costs are related to project-specific hardware and software licenses; travel costs will cover technical workshops at NTU's CETRAN test track during scenario specification in WP2.

NTU: The personnel costs for NTU, representing 81% of their total costs in the project, are related to the research activities described in section 1.3.2. NTUs contributions to OSE³AD are the development of an innovative automated driving function (WP4) and to support the proof-of-concept activities (WP5) by bringing in their unique expertise. The remaining percentage will cover travel costs used for technical workshops within the project.

FTG:
Personnel costs: The work will be carried out by a PhD student in full employment. The PhD will be supported by Assoc. Prof. Dr. Arno Eichberger.
Asset Utilization: For set-up of the environment and traffic model as well as development of the scenario generation approach, a high-performance workstation for the co-simulation environment is needed.
Cost of Materials: Software licenses for academic use of Matlab/Simulink toolboxes as well as VIRES VTD are needed.
Third-Party costs: Costs for a single master student are provided.
Travel costs: Cost for dissemination of the research in two international conferences as well as one project meeting in Singapore are calculated.

1.3.5 Third-party costs (if exceeding 20% of total costs per partner)

There are no planned third-party costs exceeding 20% of total costs per partner.

1.4 Integration of gender-specific aspects

The technical aspects of the project such as the deployment of an open and integrated simulation framework, the choice and implementation of relevant scenarios or the development of an innovative autonomous driving function do not contain any gender-specific aspects.

The judgement and acceptance of AD functions, however, includes gender-specific aspects[30]. Due to the complexity of the scenarios to be evaluated, research within the OSE³AD project will be concentrating on "pass-or-fail" evaluation criteria for the respective scenarios. A next logical step would be to test passenger acceptance in a demonstrator vehicle; for the selection of volunteer drivers for such tests, a balance between men and women should be targeted.

[30] Koglbauer, I. V., Holzinger, J., Eichberger, A., & Lex, C. (2017). *Drivers' interaction with the Adaptive Cruise Control on Dry and Snowy Roads with Various Tire-Road Grip Potentials*. *Journal of Advanced Transportation*. Open access at https://www.hindawi.com/journals/jat/aip/5496837/

2 SUITABILITY OF APPLICANT / PROJECT PARTNERS

2.1 Description of the Expertise of project partners

2.1.1 Applicant (A)

a) Company Name
AVL List GmbH

b) Relevant expertise of organisation and staff involved in the project
AVL is the world's largest privately owned and independent company for the development of powertrain systems as well as simulation, instrumentation and test systems. AVL´s Powertrain Engineering division activities are focused on the research, design and development of various powertrains in the view of advanced driving functions and improved drivability. The Advanced Simulation Technologies division develops and markets the simulation methods which are necessary for the powertrain development work. The Instrumentation and Test Systems division is an established manufacturer and provider of instruments and systems for powertrain and vehicle testing. AVL supplies advanced development and testing solutions for conventional and hybrid vehicle components and systems like simulation platforms, development tools and system integration tools.
Involved Key Staff: Dr Theodor Sams (Head of R&D, Powertrain Engineering – advisory), Dr Herbert Schiffbänker (Account Manager, Powertrain Engineering Business – advisory), Johannes Jany-Luig PhD (Project Coordination), DI(FH) Rainer Vögl (Lead Engineer ADAS/AD Validation), DI Philipp Clement (Project Manager)

c) Description of know-how relevant to the project, e.g. market success, patents
In the past years, AVL has developed several prototype vehicles with advanced and alternative powertrains including fully electric concepts, various hybrid concepts, etc. As engineering partner of leading OEMs throughout the world, AVL is involved in various advanced vehicle function developments and is constantly seeking new capabilities and their exploitation. AVL is continuously carrying out R&D in the field of advanced automotive functionalities and applies for patents for a high number of new features, systems and design elements for potential commercialisation.

d) Description of existing infrastructure relevant to the project and other aspects indicating the applicant's ability to perform the project
As an engineering service provider, AVL has the know-how, the tools and the equipment available which is required within this project, so no project-related investment costs will be necessary. Most of the test equipment and simulation tools are developed and manufactured by AVL, which enables a very high flexibility in case new systems require updated test procedures.

2.1.2 Project partner 1 (P1)

a) Company Name

Energy Research Institute at Nanyang Technical University (NTU)

b) Relevant expertise of organisation and staff involved in the project

NTU was set up with the intention of building on NTU's existing research strengths, synergizing various research groups, and mobilizing resources in energy-related research. NTU plays a key role in developing a technology roadmap for electromobility in Singapore. The technology roadmap has given the team a broad overview on the existing state of the art on AVs. NTU's expertise in many key electromobility areas complemented with support from the MAE and EEE departments makes it well positioned to deliver to the adaptation of autonomous transport solutions.

NTU has been carrying out research and technology advancement in driverless and self-sustained modes of transport for the first and last mile. NTU has been working on developing an integrated platform involving multiple sensors both on-board a vehicle and on the routes in which the vehicle will move. Trajectory mapping, positioning, initialization, embedded controls, and powertrain to communication links are being designed. NTU will bring its internationally recognized research expertise to the project in all important aspects of self-driving vehicles, such as its guidance and decision systems and inbuilt safety measures.

c) Description of know-how relevant to the project, e.g. market success, patents

NTU is committed to developing knowledge and innovative technologies to help achieve sustainable mobility for society. The research at NTU aims to focus on various core areas critical to the real-world adoption of smart mobility and to provide innovative and cost-effective solutions to meet current and future transport challenges. NTU Campus is being utilized as a smart mobility test area for developing and implementing V2X capabilities in autonomous vehicles. NTU's autonomous vehicles are being operated in specific regions in Singapore like NTU and CleanTech Campuses, DHL, Sentosa and One-North to study and develop (1) vehicle-to-cloud communication, (2) vehicle-to-vehicle communication, (3) self-wireless-charging, (4) vehicle-to-user interaction, and (5) vehicle's autonomy.

d) Description of existing infrastructure relevant to the project and other aspects indicating the applicant's ability to perform the project

The required infrastructure and software resources available at NTU provides:

a) power train test lab for electric vehicles,
b) CETRAN an autonomous vehicle test facility,
c) infrastructure sensor networks and integrations for context-aware automated vehicle testing, and
d) flash charging tram environment for prevailing first-mile and last-mile transportation problem.

2.1.3 Project partner 2 (P2)

a) Company Name

Graz University of Technology – Institute of Automotive Engineering

b) Relevant expertise of organisation and staff involved in the project

Assoc. Prof. Dr. Arno Eichberger, habilitated in the scientific field of Automotive Engineering, has worked in automotive R&D for more than 20 years. He has been working at the institute since 2007 and is responsible for the research area of Vehicle Dynamics, including lateral vehicle dynamics, tire technology, automated driving and advanced driver assistance systems.

c) Description of know-how relevant to the project, e.g. market success, patents

Since January 2004, the Institute of Automotive Engineering (FTG) has been an independent institute of the TU Graz. The institute focusses on teaching and research in the field of land vehicles, especially passenger cars and trucks. At present, about 50 employees work at the Institute of Automotive Engineering, dealing with aspects of new mobility concepts, virtual product development, E-mobility, vehicle dynamics and tire technology, automated driving and suspensions systems. Previous research projects of the Institute in automated driving dealt with a wide range of ADAS and AD functions, especially focusing on test and validation, sensor integration and human-machine interaction. We use different approaches for integration of AD on full vehicles, ranging from numerical simulation, test benches and on-road testing.

d) Description of existing infrastructure relevant to the project and other aspects indicating the applicant's ability to perform the project

Except for a new high-performance workstation for the co-simulation framework, the Institute of Automotive Engineering provides the complete infrastructure for the researchers and students to perform the assigned research tasks as well as all services for project administration.

2.2 Capacity of the consortium to achieve the project goals

2.2.1 Completeness and coordination of required expertise

Table 4: Main tasks of all project partners

Work package	Key expertise required for the work package	Name of partner contributing key expertise
1	Project management and controlling Document management and reporting	AVL
2	Expertise in preparation of technical requirements for various ADAS functions including testing catalogues for system evaluation	AVL, FTG, NTU
3	Expertise for scenario creation and test case derivation, possibly based on real measurements	NTU, FTG
4	Expertise in development of automated driving functions (e.g., ACC, AEB, LKA, LCA) including the decision making, path planning and track control	NTU, FTG
5	Expertise in development of integrated and open development environments for test and validation of ADAS	AVL
6	Expertise in rule-based reasoning for identification of relevant evaluation criteria in automated driving	AVL, FTG

If the consortium includes partners from outside Austria: explain why these partners are essential for the project and what advantage the participation of the non-Austrian partner/s brings as compared to an Austrian organisation. Describe the benefits for Austria as a business and research location. Describe the IPR regulations to be agreed with the partner/s from outside Austria.

The consortium consists of an automotive engineering company (AVL) and two scientific partners (FTG and NTU) highly active in the field of industry- and automotive domain- related research. Target is a research co-operation developing and instrumentalizing the necessary technological components and methodological approaches in the area of automated driving vehicle development and keeping these innovations reasonably economical for the fast-growing automotive markets in South East Asia (Beyond Europe).

Apart from representing top-level specialists in the field of interest, the industrial and academic partners have much experience in participating and leading national and transnational collaborative research & development projects. NTU and the Singapore government cooperate closely to quickly support regulations and certification requirements for deployment of autonomous vehicles. Together, the project partners form a unique team of excellence, uniting various innovative approaches with industrial applications of both generic and specific types.

The present **network partners** share the conviction that the eventual solution for automated driving vehicles will not only consist of technology, but also the preparation of proper methods for development and validation of the technologies and operation strategies into a holistic solution that goes beyond the knowledge and experience of a single project partner.

The **participation of NTU** in the OSE³AD consortium is essential in the project in order to (a) have a partner active in the development of testing requirements and homologation of autonomous driving vehicles and (b) better understand the South-east Asian market and thus increase the chances of business success for the solution being developed. Furthermore, the project targets are of key importance for future strategic collaboration between the partners. Hence the proposed project outcomes will serve as basis for future engineering services in the context of automated driving vehicles, relying on the proposed development environment.

IPR: As a general rule, knowledge will be the property of the partner generating it. In case of jointly generated knowledge, the property is shared as well, unless otherwise agreed upon. Before signing the Grant Agreement, the consortium will negotiate a Consortium Agreement to lay down the rules for knowledge management and protection. This Consortium Agreement will be based on the FFG model[31] in which (amongst other things) the following aspects are addressed and arranged:

- Background knowledge, specific limitations and/or conditions for implementation and for exploitation;
- Project Results, their (joint) ownership and the transfer of Results;
- Access rights to Background and Results, for consortium partners and their affiliates;
- Publications, procedures for dissemination of results and research data and open access hereto.

[31] https://www.ffg.at/sites/default/files/downloads/service/musterkonsortialvertrag_version_2015_englisch_0.pdf

2.2.2 Third-party expertise required

General information about subcontractor

Relevant WP(s)	4, 6	**Subcontractor of A/Pn**	AVL (A)
Name of subcontractor	I.K. Hofmann GmbH (or other temporary staff agency)		
Content of subcontract	Temporary staff employed in the departments working on the project will participate in the same manner as permanent staff. They will have similar qualifications but less professional experience. According to AVL's corporate human resources strategy, about 5% of overall staff is contracted via temporary staff agencies at all times, throughout all departments. This is part of our human resources strategy and gives us the possibility to grow quite rapidly. In practice, we do not make a distinction between temporary and permanent staff in a way that everybody works on all different kinds of projects in all kinds of positions. These temporary workers are usually (in 99% of the cases) taken over as permanent staff after 1-2 years of working with us.		

2.3 Composition of project team with regard to gender balance (gender mainstreaming)

In the course of this project, all participants are encouraged to increase the number of participating female staff. We place special emphasis on making the technical areas more attractive for women to be able to guarantee not only a gender-friendly work environment, but also to promote qualified female staff in general.

Note: For many years, the project partners have been striving to give women equal opportunities in research and technology through specific gender mainstreaming measures to increase the proportion of women in technical and scientific areas. Examples include internships for students and pupils, gender projects for managers, the establishment of a gender-oriented project management process, and special projects with the target to allow women a more flexible career development. Here, we refer to numerous FEMtech experts (www.femtech.at).

3 BENEFIT AND EXPLOITATION

3.1 User benefit and exploitation potential

The automotive industry is a key industrial sector for Europe[32] by securing 13.3 million jobs, producing 20% of all vehicles produced worldwide (which are 99 million vehicles per year), and generating a yearly trade balance over 99 billion EUR. At the same time, the automotive market impacts different major societal challenges such as reducing pollutant emissions[33], minimizing traffic fatalities[34], reducing congestion, or increasing mobility options for an aging population. Parallel to that, consumer habits are evolving, and new needs are emerging such as infotainment and connectivity, human-machine interaction and customization, as well as mobility-as-a-service.
Today, the automotive sector is facing four main trends:

- **Electrification[35]**, with the introduction of e-mobility (hybrid, pure electric vehicle) to optimize or even completely remove the internal combustion engine, finally reducing the resulting local pollutant emissions during vehicle operation.
- **ADAS and autonomous driving functions[36]**, with the purpose of providing more comprehensive information to the driver for better context awareness, up to taking over specific driving maneuvers – finally reducing the demands on the driver and reducing both the number and the severity of possible accidents.
- **Connected vehicles[37]**, enabling the optimization of vehicle operation or the emergence of new services while relying on external information, e.g. from other vehicles or from the infrastructure.
- **Diverse mobility[38]**, targeting the efficient movement of people and goods with respect to different factors such as time, energy consumption, or the ecological footprint.

These four trends all strongly rely on digitalization and connected control strategies; strong inter-relationships are predicted to unleash their respective potentials. At the same time, the complexity of the system – and the related validation efforts – are growing exponentially, which directly impacts quality and time to market.

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[32] European Automobile Manufacturer Association, „The Automobile Industry Pocket Guide 2018 - 2019“, available at http://www.acea.be/publications/article/acea-pocket-guide

[33] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL The Paris Protocol – A blueprint for tackling global climate change beyond 2020, available at https://ec.europa.eu/clima/sites/clima/files/international/paris_protocol/docs/com_2015_81_en.pdf

[34] European Commission, Mobility and Transport, Road safety in the European Union: Trends, statistics and main challenges, 2015, https://ec.europa.eu/transport/sites/transport/files/road_safety/pdf/vademecum_2015.pdf

[35] ETPs, 2017. "European Roadmap Electrification of Road Transport" jointly published by the three ETPs published in 2017, https://www.egvi.eu/uploads/Modules/Publications/ertrac_electrificationroadmap2017.pdf

[36] ERTRAC, Automated Driving Roadmap, 7th version, May 2017, available at http://www.ertrac.org/uploads/documentsearch/id48/ERTRAC_Automated_Driving_2017.pdf

[37] McKinsey & Company, Monetizing car data - New service business opportunities to create new customer benefits, Advanced industries, Sept 2016

[38] ERTRAC, Urban mobility Roadmap, final version, February 2017, available at https://www.ertrac.org/uploads/documentsearch/id45/2017%20ERTRAC%20Urban%20Mobility%20Roadmap%20-%20web.pdf

Consequently, the ***capability for efficient exploration, validation and reporting of L4+ AD functions will be a game changer for the market***. The OSE³AD project is designed in this context. The value proposition canvas (see Figure 13) illustrates the alignment between the customer needs (market view) and the value proposition (OSE³AD main objectives).

On the right part of the figure, the ***customer view*** is described. Two segments are identified for the ***efficient design, validation and deployment of L4+ AD functions*** (car manufacturers, suppliers), and for the ***increase in vehicle homologation efficiency*** (authorities). In both cases, the main pains are related to the efforts for exhaustive validation and reporting, while the gains are related to the capability to reduce innovation cycle duration through more efficient design, validation and testing.

On the left part of the figure, the ***value proposition*** ("products and services") is directly mapped to the main project objectives. The relationship between the objectives and the customer needs are made explicit with the "gain creators" and the "pain relievers" – mainly through the open and integrated simulation environment, its capability to frontload simulation and for scenario evaluation supported by automation, to ***finally speed up innovation cycles and to automate reporting***.

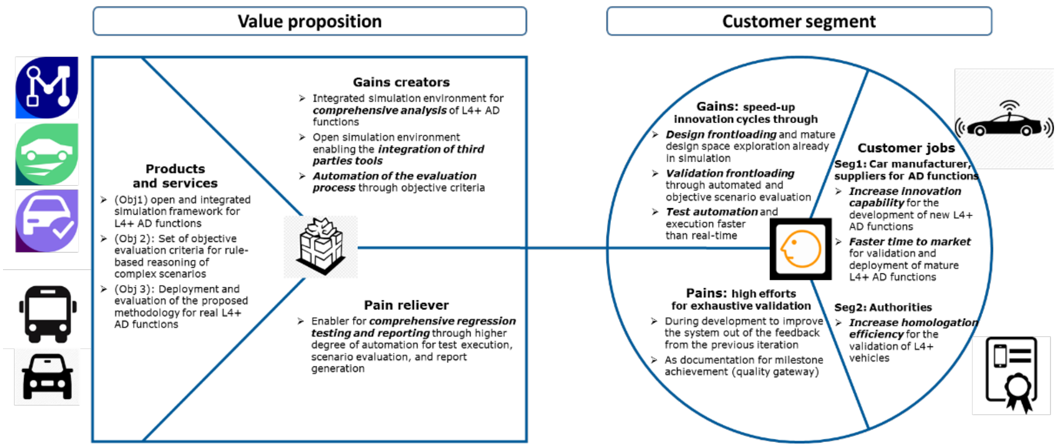

Figure 13: OSE³AD - value proposition canvas

The USPs of this proposal are directly related to the targeted OSE³AD objectives and value proposition, as listed in Table 5.

The specified users, markets and market segments are highlighted in Figure 13; the project targets car manufacturers and automotive suppliers as well as authorities. The market is clearly automotive, especially for the design, development, validation and deployment of autonomous driving functions.

Note that a link definitely exists to connected vehicles and to urban mobility. Regarding market size, the global market for autonomous vehicles is assumed to be worth \$54.23 billion in 2019 and to increase up to \$556.67 billion by 2026 with a compound annual growth rate of 39.47% during that period[39].

OSE³AD objectives	USP
(Obj1) open and integrated simulation framework for L4+ AD functions	The uniqueness of this proposition is directly related to AVL's strategy on IODP[40] and related portfolio as described in Section 1.1.1. While single (monolithic) solutions do exist on the market, the capability to flexibly integrate proprietary and third-party tools in a single environment is unique for the automotive domain.
(Obj 2): Set of objective evaluation criteria for rule-based reasoning of complex scenarios	The uniqueness of this proposition is directly related to the AVL DRIVE-ADAS solution (see Section 1.1.1), strongly relying on expert knowledge accumulated over the years.
(Obj 3): Deployment and evaluation of the proposed methodology for real L4+ AD functions	This objective is directly linked to the activities in Singapore to support the deployment of AD-based urban mobility, ➢ relying on the Centre of Excellence for Testing & Research of AVs – NTU (CETRAN)[41], and ➢ supported by the Road Traffic Act (amendment 2017)[42]

Table 5: OSE³AD USP

In terms of Return of Invest: the overall budget of OSE³AD is below 1.2million € (with funding below 500,000€). At the same time, the turnover potential for the proposed development platform is in the range of several tens of millions € for the coming 5 years in terms of licenses and related engineering services. Similarly, the added value for CETRAN and for NTU (Singapore) is huge in terms of acceleration of the innovation process for development, validation and deployment of innovative L4+ AD functions in full vehicles.

It shall be noted that this activity is tightly embedded in the core strategies of the three partners; hence, long-term investments have been made in the past to develop the assets on which the OSE³AD project is relying (e.g., IODP and DRIVE-ADAS for AVL, Centre of Excellence for Testing & Research of AVs – CETRAN for NTU, and Innovative test and validation processes of ADAS based on X-in-the-loop for FTG). The resources for OSE³AD are mainly focused on human resources while relying on the lab and test infrastructure existing at the institutions, see Section 1.3.4.

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[39] https://www.alliedmarketresearch.com/autonomous-vehicle-market
[40] https://www.avl.com/en/integrated-and-open-development-platform
[41] https://media.ntu.edu.sg/NewsReleases/Pages/newsdetail.aspx?news=39308c90-536c-4c3a-be6d-b9c07041a442
[42] https://sso.agc.gov.sg/Acts-Supp/10-2017/Published/20170321?DocDate=20170321

Regarding impact creation and go-to-market strategy, all partners can rely on their existing channels:

- **AVL**: publishing the OSE³AD outcomes through existing business development and sales channels, which are based on tight relationships with OEMs worldwide and relying on 50 R&D centers, engineering and sales offices, as well as through the organization of and participation at major events such as SAE World Congress[43], AVL's Engine and Environment[44] conferences.
- **NTU**: supporting the development of AV through strong involvement in the Centre of Excellence for Testing & Research of AVs – CETRAN.
- **FTG**: relying on their network of excellence and through scientific publication as well as educational programs.

[43] https://www.sae.org/attend/wcx/
[44] https://www.avl.com/-/31st-international-avl-conference-engine-environment-

3.2 Impact and significance of the project results for the organisations involved in the project

From **AVL**'s point of view, the OSE³AD project and its objectives have been defined fully in line with the AVL core strategy with respect to simulation (IODP) and autonomous driving. The OSE³AD project is embedded in a group of internal and external R&D programs adding up to an investment of over one million € per year, see Table 1 for a list of the externally funded projects. Participation in the OSE³AD project will be the possibility to extend into two directions: (a) a technical direction by addressing L4+ AD functions, and (b) a geographical one, considering the close cooperation with NTU and therefore strengthening AVL's participation in the Singapore area specifically and the Asian market in general.

For **NTU**, the OSE³AD project has a strategic significance in order to identify and deploy efficient development, validation and assessment solutions for autonomous driving functions and components. This activity is tightly linked to the Centre of Excellence for Testing & Research of AVs – CETRAN. The main goal of NTU will be to proceed on the vision of Singapore´s government to implement environmentally friendly and safe automated public transport. This strategic cooperation with AVL and FTG is expected to improve NTU's innovation capacity and therefore to become more attractive on the Singaporean and Asian market.

From **FTG's** point of view, the close collaboration with AVL will illustrate their competences and their complementarity from a scientific point of view with the technical expertise of AVL. This cooperation shall increase long-term R&D capacities. Furthermore, it offers the opportunity to improve the theoretical methods by linking them with a practical implementation. The project will contribute to FTG's current ambitions to extend their research and education to SAE level 4+ vehicle automation. Also, the project will enrich our worldwide scientific network with NTU, especially in the field of electrified and autonomous busses for passenger transport in a complex urban environment. Insight into NTU's scientific approaches will clearly enrich our future expertise on automated driving.

3.3 Exploitation strategy

For **AVL** as an engineering partner, the path for exploitation targets the **increase of market share** for existing AVL tools and engineering solutions for the innovative design, development, validation and instrumentation of autonomous driving functions and systems. The approach is to strengthen competences and create success stories – respectively to apply these skills in cooperation with potential customers. In the context of the OSE³AD proposal, AVL's contributions towards integrated and open development platforms as well as objective scenario evaluation have been defined fully in line with the company business strategy, therefore maximizing the chance for successful exploitation based on their existing position of solutions and services in the market. Both markets, engineering solutions and tools, are complementary and lead to cross-fertilization. Furthermore, AVL's turnover was about 1.8 billion € in 2018, linearly increasing by 10% per year in the last decade. Assuming autonomous driving solutions impacting 20% of AVL's portfolio, then the **OSE³AD project might impact an overall turnover of 400 - 800 million€ for the 2022 to 2025 timeframe**. Consequently, the outcomes of OSE³AD could positively impact this very large and fast-growing market.

In terms of communication and marketing, AVL is active in many European interest groups such as **ARTEMIS** Joint Undertaking (member of the Steering Board), **ERTRAC**, **EARPA**, **European Green Vehicles Initiative**, **EUCAR**, etc. These channels will be activated to disseminate OSE³AD results and to **increase the visibility and impact** of the project. In terms of marketing and sales strategies, the approach will be to use existing business development and sales channels, which are based on close relationships with automotive OEMs worldwide and relying on 50 R&D centers, engineering and sales offices, as well as through the organization of and participation in major international events such as the SAE World Congress[45] or AVL's "Engine and Environment" conference[46]. As stated in the previous section, OSE³AD is integrated in R&D programs adding up to a one million € investment per year. AVL is the most successful Austrian company in terms of patent registration (155 patents in 2017[47]). This strategy will be followed in OSE³AD, with the target of 2-4 patents for this project.

NTU will use the results and the experience gained in this international project to collaborate in further research projects both regionally and on a wider international scale, and to perform consultancy work in the regional market. The synergies between industries and academia in NTU present a unique opportunity, both from a test bed and power management expertise perspective. Autonomous vehicles, alongside electric vehicles, represent new growth opportunities that will allow Singapore to build systems-level capabilities such as intelligent sensors and charging solutions. NTU campus as a testbed is also aligned with Singapore's position as a "Living Lab" where companies can develop, test and commercialize innovative urban solutions for global

[45] https://www.sae.org/attend/wcx/
[46] https://www.avl.com/-/31st-international-avl-conference-engine-environment-
[47] https://www.ots.at/presseaussendung/OTS_20180426_OTS0146/patentamt-zieht-bilanz-am-world-ip-day-oesterreich-bei-patenten-eu-weit-auf-platz-6-bild

markets. Key partnerships in this project will trigger new streams of R&D, test-beds and regulations of AVs in Singapore.

FTG will mainly exploit the research output for publications: we are targeting five scientific publications in relevant peer-reviewed journals and at least two contributions to national and international conferences. The project will provide a solid basis for a PhD candidate to achieve a doctoral degree. In addition, we will use the project's achievements to advance our educational program of engineers who are urgently needed in the field of vehicle automation Therefore we will aim at three master theses, employ a student and carry out about 5 bachelor projects. In addition, the research output will contribute to gain additional expertise and networks in an extremely dynamic field of research, enabling us to successfully continue in academic research.

4 RELEVANCE OF THE PROJECT

4.1 Relevance to the Call/Programme

According to the FFG Beyond Europe program[48], "*the present call aims at (1)* ***increasing the international RTI activities and collaborations*** *of Austrian companies and research institutions with partners outside Europe through research projects and (2)* ***facilitating access to international markets***". The OS³AD project is fully in line with these two goals by establishing a close and long-term cooperation between NTU in Singapore and AVL. Hence the proposed project outcomes will serve as a basis for future engineering services in the context of autonomous driving functions development, relying on the proposed development environment. The project will also allow AVL to further exploit its business in the Asian region, and particularly in Singapore which is one of the key and strategic locations in the fast-growing Asian market.

4.2 Incentive effect of funding (additionality)

The OSE³AD consortium was established so that the contributions and knowhow of the partners are fully complementary and lead to a maximum of added value from the cooperation, also in a longer perspective. The proposed project will serve as a basis to establish and deploy a technology platform creating the added value and to enable further exploitation. This project therefore has an enabling character for the strategic cooperation between AVL and NTU. The funding will have a strong impact on the quality, duration and size of the project, as well as the visibility of its outcomes (discussion with stakeholders) and the envisaged follow-up activities.

The incentive effects of the funding can be summarized as follows:

Enabling/Quality: The scientifically in-depth as well as personnel-intensive research and development activities entail high risks and costs which cannot be covered by the participating project partners alone from their own resources without public aid. Without that, the very ambitious project goals could not be tackled as a whole, but the project would have to be carried out on a much less scientific and, thus, more practical level. This implies that the transferability of the results can also be only guaranteed on the basis of a broader project supported by funding.

[48] "BEYOND EUROPE" programme for internationalization of RTI projects, call guideline, FFG, available at https://www.ffg.at/sites/default/files/allgemeine_downloads/thematische%20programme/be_call_guideline_call_3_2018.pdf

Duration: All consortium partners are well established in their areas. Without support, however, it would not be possible to implement these measures with the existing human resources within this time frame, with this intensive participation and, above all, in this quality. Without funding, the priorities would have to be shifted to short-term development activities which are directly commercially relevant. Furthermore, due to the increased number of researchers co-operating in the funded project, the results can be achieved in the rather short runtime of the funded project whereas qualitatively similar results could be obtained – if at all – in an extended project duration of at least +50%. This would reduce the competitiveness of the industrial research partner dramatically as well as the attractiveness of the research partners in the global research network.

Size: Through research funding, it is possible to align OSE³AD with a more comprehensive perspective and with considerably higher research expenditure, thus massively improving scientific quality. As already highlighted above, the extended project content due to the funding significantly contributes to a better, in-depth understanding of the related fundamental mechanisms and, thus, an easier transferability of the results. This is particularly important for the dissemination and exploitation of the project results.

Scope: The scope of the project can be increased, since the project

- focuses on a more long-term and research-intensive approach: by covering integrated and open development platform and L4+ AD functions.
- involves a higher technical risk: related to the modelling of L4+ AD functions and the respective design of objective evaluation criteria.
- involves a higher market risk: the impact of methods and development platforms is difficult to evaluate and is only indirectly related to primary customers of car manufacturers. These projects consequently have typically higher market risks.
- leads to new or more extensive collaborations: the proposed project outcomes will serve as a basis for future engineering services in the context of design, development, validation and deployment of L4+ AD functions, relying on the proposed development environment.

For FTG as a university partner, the requested funding of the project OSE³AD allows the participation of the institute in the first place, as academic budgets are very limited. Also, the project allows the institute to employ post-doc researchers as well as researchers in the middle and final phase of their PhD theses and beyond. This will strengthen the institute to keep key expertise of the involved excellent researchers in the field of autonomous driving. The cooperation with AVL will strengthen the already established cooperation. The involvement of NTU is an important incentive for cooperation, since new fields of cooperation are foreseen, not only limited to autonomous driving, but also in the field of urban mobility.

CALL-SPECIFIC SUPPLEMENTARY INFORMATION

Annex A: Major relevant publications of project partners

AVL

- Dr. Juergen Holzinger, DI Thomas Schloemicher, DI Erik Bogner; **Objective Assessment Of Comfort And Safety Of ADAS**. Autonomous Vehicle Test & Development Symposium 2016 Germany
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Annex B: Qualification Profiles

Qualification profile of PhD student to be employed at FTG

Competences

- Completed studies of Mechanical, Electrical Engineering or Computer Science. Preferably, the candidate has a solid knowledge in mechatronic systems by gradating in a related major.
- Excellent knowledge in Vehicle Dynamics and Control Theory.
- Advanced programming skills in Matlab/Simulink, Python and C++.
- Advanced knowledge in Statistics and Stochastics.
- Basic Knowledge in Machine and Deep Learning methods.
- Basic knowledge in scientific methods and paper writing, preferably scientific publications exist

Soft skills

- Team player
- Communicative
- Motivated and able to work under pressure

Languages

- English, C1 level minimum
- German, B2 level minimum

Qualification profile of doctoral candidate to be employed at NTU

- Master's degree in EE/automation engineering or related background.
- Expert knowledge of building automation and control systems, real-time closed loop control system design and implementation.
- Industry or research lab experience is required.
- Ability to develop control algorithms, quantitative evaluation of building energy systems.
- Knowledge and experience with real-time closed loop control system design and implementation-
- Experience with MATLAB, LabVIEW or similar control platform.
- Programming in C++/python-
- Strong analytical and conceptual abilities. Ability to work in a team as well as independently.
- Able to work under pressure and meet deadlines.

Qualification profile of ADAS simulation engineer to be employed at AVL

- Graduate of a university of applied sciences or university of technology in one of the following areas:
  - mechanical engineering
  - automotive engineering
  - telematics
  - electronics
  - control engineering
  - robotics
- Minimum of 2 years of professional experience in the development or application of automotive or automation technology
- Profound PC skills (including MS Office)
- Knowledge of the following tools desired: Matlab, INCA, CANape, CAMEO, DRIVE, ROS
- Pronounced communication skills
- High degree of self-motivation and project management skills
- High readiness to travel
- Driver's license (Austrian category B)
- Very good command of English