

# Use Cases for Autonomous Driving

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by:

Walther Wachenfeld and Hermann Winner

as a joint outcome of the coreteam Villa Ladenburg Kolleg „Autonomes Fahren“:

Barbara Lenz, Eva Fraedrich  
Chris Gerdes, Sven Beiker  
Markus Maurer, Thomas Winkle  
Hermann Winner, Walther Wachenfeld

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## 1. Motivation for the Consideration of Use Cases

Although autonomous driving is characterized through the definition for „fully automated“ according to BAST<sup>1</sup> as well as through the quote by E. Feil<sup>2</sup> “self-determination within the scope of an higher (moral) law”, it is possible to come up with a large variety of usage scenarios and specifications for autonomous driving. In order to grasp this variety, proxies are sought, which on the one hand make use of distinguishing characteristics, and on the other hand describe typical usage scenarios for autonomous driving. In the following, these will be called use cases for autonomous driving. Besides the nomenclature, the use cases are defined through the distinguishing characteristics, so that a common understanding can be reached for all project partners. In addition, the use cases are supposed to serve as reference scenarios for further discussion. It is not intended to exclude other examples. However it is recommended to use the defined use cases to avoid misunderstanding or oversight. The following definitions and assumptions can additionally be expanded for the different

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<sup>1</sup> Gasser, T. M.; et al.: Rechtsfolgen zunehmender Fahrzeugautomatisierung. Berichte der Bundesanstalt für Straßenwesen, Heft F 83, 2012

<sup>2</sup> Based on the understanding of autonomy according to Immanuel Kant interpreted by Feil, E: Autonomie und Heteronomie nach Kant. Zur Klärung einer signifikanten Fehlinterpretation, in: Freiburger Zeitschrift für Philosophie und Theologie, 29/1-3, 1982, S. 389-441 (Abgedruckt in Feil, E. Antithetik neuzeitlicher Vernunft. „Autonomie – Heteronomie“ und „rational – irrational“, Göttingen 1, Teil I, S.25-112.)

work packages with detailed descriptions. As for the different work packages, definitions and assumptions are relevant in different ways. For instance the owner relations are less important for a technical point of view than for taking a look at the market impact. Thus, definitions and assumptions are to be examined critically. Desired results from working with these use cases are a founded change of definitions and assumptions as well as possible controversy, which arise in between the different topics (different parameter sensitivity).

The following description of the use case is structured in 4 parts. Part 2, general definitions, proposes definitions, which facilitate a unique description of the use cases. Part 3, general assumptions, describes the limitations and assumptions that are used and are supposed to apply for all use cases. Part 4 explains the selection and the level of detail for the characteristics describing the use cases. Part 5 introduces the four selected use cases and defines the specific characteristics.

## 2. General Definition

Some basic terms, which will be used in the following sections, are defined as follows:

**navigation** – according to Donges<sup>3</sup>, navigation includes choosing an appropriate driving route from the available road network as well as an estimation of the expected time requirement. If there is information about current interferences, such as accidents, road works or traffic jams, a change in route planning can be necessary.

**guidance** – according to Donges<sup>3</sup> the guidance task is basically to derive the advisable command variables like the intended track and the set-point speed from the road situation ahead as well as from the planned route. Part of the guidance is also to anticipatorily intervene the open loop control to create favorable conditions for the lowest possible deviations between set and actual values.

**stabilization** – to fulfill the stabilization task according to Donges<sup>3</sup> the driver has to ensure with corrective actions that the deviations in the closed loop control are stabilized and compensated to a level for which the driver is capable of handling.

**driver only** – ground (0) level of automation according to BAST<sup>1</sup>: “the driver continuously (throughout the complete trip) accomplishes longitudinal (accelerating/braking) and lateral (steering) control.”

**assisted** – first (1) level of automation according to BAST<sup>1</sup>: “the driver continuously accomplishes either lateral or longitudinal control. The other/ remaining task is accomplished by the automating system to a certain level only.

- The driver must permanently monitor the system
- The driver must at any time be prepared to take over complete control of the vehicle”

**fully automated** – fourth (4) level of automation according to BAST<sup>1</sup>: “the system takes over lateral and longitudinal control completely within the individual specification of the application.

- The driver does not need to monitor the system
- Before the specified limits of the application are reached, the system requests the driver to take over with sufficient time buffer.
- In absence of a takeover, the system will return to the minimal risk condition by itself

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<sup>3</sup> Donges, E.: Fahrerverhaltensmodelle. In: Winner, H.; et al.: Handbuch Fahrerassistenzsysteme. 2. Auflage, S. 15-23, Vieweg+Teubner Verlag, Wiesbaden, 2012.

- All system limits are detected by the system, the system is capable to return to the minimum risk condition in all situations.”

**autonomous driving** – for autonomous driving, the driving task<sup>3</sup> is performed in a way that is called “fully automated” (level 4 automation according to Bast<sup>1</sup>). This definition is extended by the assumption that the machine behavior stays within an initially set behavioral framework.

**machine driving capabilities** – the machine (driving) capabilities are capabilities related to perception, cognition, behavior decision as well as behavior execution.

**driving robot** – a driving robot is the implementation of the machine (driving-) capabilities. The driving robot consists of hardware components (sensors, processors, and actuators) and software elements. It acts as the hard- and software, equally to the role of a driver in today’s vehicles as subject<sup>4</sup>. (The definition term for this system is not completed yet, so alternative suggestions are welcomed.)

**autonomous vehicle** – an autonomous vehicle is equipped with a driving robot and therefore has the possibility to drive autonomously. The area that is covered with the autonomous vehicle isn’t defined (see below).

**fully autonomous vehicle** – a fully autonomous vehicle is a vehicle, which can drive almost all routes autonomously, on the same level as “driver-only” vehicles. This definition is beyond the BAST<sup>1</sup> definition as it defines the vehicle and not the degree of automation.

**exclusively autonomous vehicle** (autonomous-only vehicle) – an exclusively autonomous vehicle is a vehicle, which can drive all routes, for which the vehicle has been specified, autonomously from start to destination. This definition is beyond the BAST<sup>1</sup> definition as it defines the vehicle and not the degree of automation.

**transportation task** – the driving task describes a defined transportation object (vehicle, cargo, passenger etc.) that is transported from one start location to a destination location. Examples for the transportation task are “park vehicle” or “get passenger to the requested destination”.

**driving mission** – the driving mission describes the journey from start to destination in execution of the transportation task.

**safe execute** – the safe execute is a special driving mission. It leads the vehicle in the fastest way to a system status, which allows the passengers to safely exit the vehicle.

**driver** – a driver is the human operator of a vehicle not further specifying the driving capability. This means within a range of humans who have a driver license. The driver is the subject of autonomy in case of non-fully automated driving.

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<sup>4</sup> “A system which is capable of taking decisions depending on sensor data processed internally has additional degrees of freedom as compared to one with direct sensor data to actuator feedback or one without any capability of control actuation. The former one is termed a 'subject', the last one an 'object'...” Dickmans, E.D.: "Subject-object discrimination in 4D dynamic scene interpretation for machine vision," Proc. IEEE-Workshop on Visual Motion, 1989.

**scenery** – the term scenery according to Geyer et al.<sup>5</sup> refers to the static environment of the vehicle. That considers the geometry of pre-defined road types, number of lanes, curvature, position of traffic signs and traffic lights, as well as additional stationary objects such as for example construction areas as well as natural (e.g. bushes and trees) or man-made objects (e.g. buildings, walls).

**dynamic elements** – dynamic elements according to Geyer et al.<sup>5</sup> are temporary and spatially variable elements such as other road users, states of traffic lights, light as well as traffic conditions.

**scene** – the scene according to Geyer et al.<sup>5</sup> is built by the scenery, dynamic elements and optional driving instructions. A scene starts with the end of the earlier scene or - in case of the first scene - with a defined starting scene. Within a scene the elements, their behavior as well as the position of the autonomously driving vehicle are defined. The dynamic elements change their states within a scene.

**Situation** – a clear definition of the term situation for the use case description is still to be determined. Especially an “objective, complete situation (-description)” has to be distinguished from a “subjective, projective situation (-description)”.

**operating area** – a spatial and / or temporal area, specified explicitly through the scenery and implicitly through the velocity, in which the vehicle can be moved autonomously through the operation of the driving robot.

**operating limit** – the operating limit is specified explicitly through the scenery and implicitly through the velocity and is therefore a predictable boundary, at which the driving task is handed over.

**functional limit** – a condition that appears in the permitted operation range but is not predictable in detail, which contradicts with continuing the autonomous journey. Even if the limit is not foreseeable, the driving robot recognizes it at an early stage.

### 3. General Assumptions

Besides the characteristics, which distinguish the use cases, and which are listed in the following section, there are additional attributes, which apply to the chosen use cases as well. The following general assumptions describe these attributes.

One basic assumption is that the use cases are deployed at the considered time in a mixed operation of transportation systems with different levels of automation. Road traffic consists of vehicles with all levels of automation ranging from “driver-only” to “assisted” to “fully automated”. During the stepwise introduction of automation, human vehicle operation and simultaneously driving robot operation is probable.

Hardware shutdowns or software failures can of course happen with autonomously driven vehicles. However it is assumed that a vehicle designed according to ISO26262 is, with regard to the mentioned shutdowns, at least as reliable and safe as today’s vehicles.

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<sup>5</sup> Geyer, S; et al.: Concept and Development of a Unified Ontology for Generating Test and Use Case Catalogues for Assisted and Automated Vehicle Guidance. IET Intelligent Transport Systems. Accepted to publish. 2013

The description of the use cases is not a detailed specification. Instead of a detailed description of weather conditions, light conditions, road surface conditions etc. the following simplification is assumed. The quality as well as the success rate with which the driving robot performs the driving task is similar to the human quality and success rate. For example, heavy rain leads only to transition to the safe state and the discontinuation of the transportation task, when a driver would discontinue the journey as well. In this document the question remains not dealt with, if this assumption from the user's point of view, the society's point of view etc. is sufficient. Furthermore in this document the question remains unanswered, how this quality and success rate is quantified and proved.

For all use cases it is assumed that the autonomous journey is performed compliant with the set of rules of the respective jurisdiction (federal / national level, state level in the United States), in which the driving actually takes place. From this assumption the question about the action in dilemma-situations directly arises. Is the driving robot permitted to or is it possible to disregard rules in order to prevent major damage? For this use case it is assumed that a legally valid set of rules, respectively meta-rules, exists, which the driving robot follows. In order to do so, the respective authority has granted permission to perform autonomous driving, while it is not further contemplated how such permission can be obtained and what respective rules might be.

## 4. Selected Characteristics to Describe the Use Cases

In this part, the characteristics and its values are introduced, which will later describe the use cases. Besides the (in the authors' mind) few number of characteristics, which will characterize the autonomous driving in the following, it is possible to define further distinguishing attributes, for example regarding the business model or market position. This will be disregarded for now because of the yet little knowledge in this area.

The characteristics, in alphabetical order A to I, were derived from the three-level-model for the driving task according to Donges<sup>3</sup> and chosen for the description. In that model, the driving task is divided into the three levels "navigation", "path tracking", and "stabilization".

### Characteristic A: Type of Occupant

#### Motivation

For today's individual mobility with a vehicle, a human is required to be permanently in the vehicle and to control it under all circumstances<sup>6</sup>. This constraint could change with the automation of the driving task. Thus the vehicle concept and the safety concept depend on the **type of occupant**.

#### Values of Characteristic

Here, the values

1. *no cargo and no person*, therefore no specific occupant or cargo protection interests,
2. *for transportation approved cargo*,

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<sup>6</sup> Kempen, B.: Fahrerassistenz und Wiener Weltabkommen; in 3. Sachverständigentag von TÜV und DEKRA: Mehr Sicherheit durch moderne Technologien, 25./26. February 2008 in Berlin

3. *person/s with agreed destinations,*
4. *persons with non-agreed destinations,*

are distinguished.

One use case can be covered by several values of this characteristic. The distinction between value 3 and 4 is made in order to distinguish between individual and public transportation. A vehicle of **individual transportation carries persons with agreed destinations**. In contrary, a vehicle of public transportation carries multiple persons, who have not previously agreed upon a destination. However, persons reach their destinations with public transportation, because a schedule with destinations and via points is established.


## Characteristic B: Maximum Permitted Gross Weight

### Motivation

The **maximum permitted gross weight** influences the safety considerations via the kinetic energy. Besides safety considerations, the contemplation of the gross weight extends the discussion beyond individual transportation to public transportation, freight transportation as well as road infrastructure. In addition, this characteristic addresses the question of vehicle types on a high level, which potentially don't fit with the current vehicle types because of the autonomous driving functions and changing requirements. Instead of considering the boundaries of often country-specific vehicle classes, four mass attributes are chosen. They range in values from ultra-light vehicles to heavy trucks and each step spans a factor of 4 between types.

### Values of Characteristic

The discrete distinction is established, in order to describe the fictitious use cases and to roughly categorize their mass. An exact determination of the mass is possible for existing use cases and specified deployment. The characteristic B covers the values

1. *ultra-light vehicles* around 500 kg
2. *passenger vehicle* around 2 t,
3. *light commercial trucks and vans* around 8 t,
4. **trucks** around 32 t. 

## Characteristic C: Maximum Deployment Velocity

### Motivation

The characteristic **maximum deployment velocity** (to be precise the square of the velocity) determines multiplied with the mass the kinetic energy of a vehicle and therefore also needs to be distinguished. In addition, the stopping distance is calculated using the square of the velocity. Accordingly, with the velocity square the requirements for the autonomous system grows regarding a risk-minimal state in case of failure or when reaching functional limitations.

Besides the safety consideration, the travel time and conclusively the temporally passable range as a result of the deployment velocity are values that influence individual mobility. In addition, the deployment velocity defines directly the road type, which can be used if a minimum velocity is required for using it.

### Values of Characteristic

The maximum deployment velocity, characteristic C, has five proxy-values, one for walking speed, and four in steps with a factor of two (= factor 4 related to kinetic energy and stopping distance). For concrete use cases the values and regulations need to be adapted to the respective deployment. The discrete distinction is established, in order to describe fictitious use cases and to roughly categorize their velocity. An exact determination of the velocity is possible for existing use cases and defined deployments.

1. up to 5 km/h
2. up to 30 km/h
3. up to 60 km/h
4. up to 120 km/h
5. up to 240 km/h



## Characteristic D: Scenery

### Motivation

Which spatial areas, which are accessible to the driver through the “driver-only” automobile, will also be made accessible with the described use case of autonomous driving? The characteristic **scenery** describes the spatial deployment, in which the vehicle drives autonomously. For instance, do standardized structures exist, how many lanes are available, and do other markings exist?

The static scenery can already be diverse and present a challenge for the driving robot. One example for this is the often-mentioned lanes, which can be covered with snow, or traffic signs, which can be hidden by bushes or trees. These, at the beginning of the journey potentially unknown and non-changeable scenery settings, will not be considered with this characteristic. It is determined through the assumption that the quality and success rate of the driving robot in dealing with the driving task is similar to that of a human driver to what extent the driving robot can manage the scenery settings.

This characteristic therefore describes scenarios that are predictable and that follow existing rules on a high level (location, environment and function of the road).

### Values of Characteristic

The characteristic scenery has 9 values (the sceneries from the German guide line for integrated network design<sup>7</sup> were expanded):



1. *Terrain (off-road)*:- is without standardized or known structures like lanes or other markings and without apparent traffic coordination.
2. *Non-standardized road*: This covers rural roads and similar roads with a simple pavement. Traffic rules apply. The road is public and the respective traffic rules (e.g. StVO in Germany) apply.
3. *Parking lot or parking structure*: This is explicitly designated and marked for parking vehicles. Markings are not always present for lanes, but standardized marking of the area for the coordinated parking of vehicles exist. Especially in urban areas parking structures with

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<sup>7</sup> Kategorien der Verkehrswege für den Kfz-Verkehr (3.4.1) out of Richtlinien für integrierte Netzgestaltung edition 2008 . Distinguished are Autobahn, Landstraße, anbaufreie Hauptverkehrsstraße, angebaute Hauptverkehrsstraße and Erschließungsstraße. The definitions are translated freely.



several levels have at times narrow ramps and little space for maneuvering. The respective traffic rules (e.g. StVO in Germany) apply.

4. *Access road (Erschließungsstraße)*: “[These] included developed roads within developed areas, which primarily serve direct access to the developed properties or serve for general accommodation. Furthermore these roads access neighborhoods characterized by residential, commercial and business. These roads are generally single lanes and connected by intersections without traffic lights. The connection with...” developed main traffic roads “...are realized through intersections with or without traffic lights or roundabouts. In special cases they serve public transportation; they are mainly open and used by inner-community bike traffic. Not least due to the fact that the posted speed limit is 30 km/h in many cases.” The respective traffic rules (e.g. StVO in Germany) apply.
5. Developed *main traffic roads* – “[These] include developed roads within developed areas, which primarily serve as connections and to collect traffic from access roads. They normally also serve public transportation. They can be part of connection roads used by several communities (thoroughfares). These roads might be single or double lane. The connection with roads of the same category is generally realized through intersections, traffic lights or roundabouts. Because the road directly accesses adjacent premises, these roads are characterized by areas of low traffic. The posted speedlimit is 50 km/h in Germany.” The respective traffic rules (e.g. StVO in Germany) apply.
6. *Urban arterial road*. “[These] include roads without direct connections or within developed areas. These roads generally serve a connecting function (connection roads). Within developed areas, these roads are the continuation [of country roads] as an approach to larger continuously developed areas. Widely spaced buildings often characterize the sides of these roads with facilities for tertiary use, which is why the development remains low. The roads are single or double lane, which are mainly connected by intersections with traffic lights or roundabouts to the remaining road network. The posted speed limit within suburban areas is generally 70 km/h and within intra-urban areas 50 km/h.” The respective traffic rules (e.g. StVO in Germany) apply.
7. *Country road*: “[These] include single lane roads situated outside developed areas. This category also includes short road sections with two lanes, which are single lane roads in the regular case. The connection with roads of the same category is generally realized through intersections or interchanges of different kinds. These roads are predominantly for general transportation [...]. The general posted speed limit is 100 km/h or less. [...] The roads have a connecting function and serve only in few cases as access to adjacent buildings. If this type of road is used more often as an access to adjacent buildings, it may be appropriate to characterize this type of road in the category [urban arterial road]”. The respective traffic rules (e.g. StVO in Germany) apply.
8. *Interstate*: “[These] include non- developed, two-lane roads that are connected with interchanges of different kinds. These roads run outside, in the perimeter of, or within developed areas and are exclusively used by fast road traffic. Access is only possible by special connecting elements like onramps. [...]Also included in this category are roads that are marked with the sign 331 of the Road Traffic Act (StVO) in Germany with two lanes and interstate-like roads general with yellow - for city interstates - or white instruction signs in Germany (other jurisdictions might use different signage). Only for the city interstate the posted speed limit is 80 km/h or 100 km/h in Germany.” The respective traffic rules (e.g. StVO in Germany) apply.

9. *Special areas*: These are not open to the public, their geometry is unknown and general public traffic rules (e.g. StVO in Germany) do not apply. This can be for example an extensive private terrain or industrial facility both indoor and outdoor. The area can have additional infrastructure for autonomous driving, like for example a container port with autonomous systems for loading and unloading as well as commissioning.

Besides this value that describes the scenery within which a specific use case can be performed, the characteristic has a second dimension, which is the condition whether the scenery has to be permitted explicitly or not. The respective values are the following:

- a. *Without permission allowed*: All scenarios of this kind are permitted for driving robot operation.
- b. *Only with permission allowed*: Only selected and permitted sceneries of this kind permit a driving robot to operate autonomously in this area.

For now, it is left open who grants this permission and whether that is a private or public administration. In that sense, the type of permission is not further specified, for example the infrastructure could be in maintenance mode or a map could be provided, enriched with additional information. And also, the permission could include a temporary component and statistical or dynamical cutoff times for specific scenery areas.

## Characteristic E: Dynamic Elements

### Motivation

The complexity of a scene depends besides the scenery largely on the dynamic elements. The dynamic elements, which find themselves in the scene in addition to the autonomously driving vehicle, extend the requirements on the driving abilities of the driving robot. Therefore this characteristic describes to what extent the use case can be deployed in the current traffic situation and if limitations or exclusions for the dynamic elements are considered.

### Values of Characteristic

Four values of the characteristic are distinguished.

1. The value *without exclusion* describes the most complex scene. Animals, pedestrians, cyclists, vehicles, law enforcement, etc. meet the autonomously driving vehicle in the scene.
2. **Only motor vehicles**. This value describes the interaction of autonomous vehicles and human controlled motor vehicles. Animals, pedestrians, cyclist etc. are excluded (see below).
3. *Only autonomously driving* vehicles describes a scenery exclusive for autonomously moving vehicles.
4. *No other dynamic elements*, the area of the scenery is exclusive for ONE autonomously driving vehicle.

The exclusion of other dynamic elements for the values 2-4 is not determined in an absolute way. The scene on a contemporary interstate is described for instance through value (2) *Only motor vehicles*. However, while the situation that one person or cyclist steps on the interstate applies in theory, it is neglected due to the respective probability of occurrence. According to the assumption in Part 3 that most likely there will be a mixed operation, only the values 1 and 2 will be used for the use cases.

## Characteristic F: Information Flow between Driving Robot and Other Entities

### Motivation

As described in Part 2, the driving robot fulfills the tasks perception, cognition, behavior decision and behavior execution. To do so, information about the state of the vehicle driven by the robot is required, such as for example position and velocity, but also information about the environment and occupants. This information is derived either from sensors, reading from memory systems, or through communication. How and which information is exchanged between the driving robot and respective entities, is defined through the purpose of the information flow. In order to describe the information flow for one use case, the purposes of information exchange are assigned to the use cases.

The availability of the information, the transmission, as well as the communication partner has to meet the deployment purpose. As already mentioned, it is additionally assumed that the technology is only deployed in the market slowly. Therefore not all dynamic elements in the vicinity are able to participate in the information exchange, so that a mixed operation has to be assumed.

The information flow of the driving robot considered herein is a subset of the entire information flow of the vehicle. For the consideration at this point, purposes are neglected, which are part of infotainment and convenience systems. Current news, the access to social networks, or music streaming may as specific services increase the additional benefit of the autonomous journey, however the information flow of these services is not primarily relevant for autonomous driving. Therefore only purposes, which impact traffic safety, traffic efficiency as well as purposes that are potentially prerequisites for the autonomous journey, are described as distinguishing attributes.

### Values of Characteristic

Eight purposes of the information flow are distinguished:

1. *Navigation optimization.* Information like current position, route destination, flow velocity, weather, etc. are exchanged with an inter-regional traffic center. The goals of the optimization are for example low energy consumption and CO<sub>2</sub>-emission, a travel time or travel distance that is as short as possible. Inter-regional in this context means, that the information relevant for navigation lies within the coverage area (several hundred kilometers) of the traffic central unit.
2. *Path tracking optimization.* Extensive information about the state (x, v, a, ...) and intention of the vehicle driven by a robot as well as information of the vehicles in direct vicinity are exchanged. In addition, information regarding weather, road condition, congestion, road closures, and phase timing of traffic lights are shared with a local traffic center. Local in this context means a coverage area of a few kilometers around the vehicle. The goal is for example the synchronized drive in lateral as well as longitudinal direction (platooning, intersections without signage, or adaptive lanes...).
3. *Stabilization optimization.* Selected vehicle states as well as intentions of the driving robot, the road users, and further elements in direct vicinity of the vehicle are exchanged. The goal is collision avoidance in lateral and longitudinal direction with one or several vehicles in the direct vicinity according to already existing V2X concepts.

4. *Provision of environmental information.* Information about the vehicle environment, which is perceived by the driving robot, is shared with road users as well as with a traffic center in direct vicinity. The goal is to serve an optimized map with information as a source for positioning, hazard recognition, navigation, etc.
5. *Updating the driving robot's capability.* The manufacturer provides an update, which improves the (driving-) capabilities of the driving robot.
6. *Monitoring the driving robot.* Information about the status, the capabilities, and the intentions of the driving robot are shared with authorized entities. The goal is to secure evidence (event data recording) to reconstruct the course of an accident, similar to a black box in aviation. In addition, malfunctions and hazardous situations that are identified through self-diagnosis are transmitted to the manufacturer.
7. *Monitoring occupants.* Information (video, audio, heart rate...) about the occupant, which characterize his / her condition, are shared with an emergency call center or a service provider. The goal is to monitor health and safety of the occupant. This information will be forwarded to authorized receivers without the intention and action of the occupant.
8. *Occupant emergency call.* If the occupant experiences an emergency, which is either related to him-/herself or the autonomous journey, it is possible to contact an emergency call center or the service provider of the autonomous journey. The occupant initiates contact and shares information voluntarily.

The first three values can also lead to interactions, which relate to negotiations about the temporal or spatial usage of the traffic infrastructure. For now this interaction is not considered.

## Characteristic G: Availability Concept

### Motivation

During normal operation the driving robot controls the vehicle within the permitted area. If the driving robot realizes a generally non-predictable functional limitation, the driving robot **hands over to a specified availability concept**. This availability concept defines how to continue the driving mission. Such functional limitations can be **unknown obstacles** on the road, which no longer permit a continuation within the autonomy of decision-making. An example for such an obstacle is a branch, which extends to the road, so that the vehicle needs to touch the branch in order to continue the journey. To what extent the availability concept takes over the entire driving task or just takes over the decision-making, is left open intentionally.

### Values of Characteristic

The following **availability concepts** are distinguished:

1. *No availability addition*, the driving robot waits until, through external influence, the scene becomes negotiable again and is covered by the specification of the driving robot.
2. *Availability through driver*, one occupant supports the driving robot negotiating the scene (left open, if by taking over the driving task or through maneuver commands).
3. *Tele-operated driving*, a service provider supports the driving robot negotiating the scene via a remote control.
4. *Pilot service*, an especially trained person proceeds to the vehicle and supports the driving robot negotiating the scene.

5. *Electric towing*. If the hardware necessary for the stabilization task is operational, a tow vehicle with a direct connection can operate it, in order to support the driving robot in negotiating the scene.

The handover from the driving robot to the alternative availability concept is to be implemented risk-minimally. The driving robot transfers the vehicle for the handover to that risk-minimal state, which is suitable for the transfer to the availability concept.

The respective interfaces for the availability through driver, the remote control, a pilot, or the towing need to be available.

## Characteristic H: Extension Concept

### Motivation

With the help of autonomous driving not necessarily all areas that are necessary for the transportation task will be covered, especially not at the beginning of the introduction. Subdomains will remain, which cannot be controlled autonomously. Nevertheless, in order to fulfill the mobility needs of customers, portions outside the regime of automated driving can be covered with **extension concepts**. The extension concept describes, if and with what aid it becomes possible to perform the vehicle control outside the area that is specified for autonomous driving.

### Values of Characteristic

The characteristic H has 5 values:

1. *No substitute* beyond the operating area, i.e. the autonomous driving area covers the specified transportation tasks completely. The vehicle with this value is an exclusive-autonomous vehicle. If the deployment also covers the entire deployment of current vehicles, it is a fully autonomous vehicle.
2. *Driver, a human takes over the driving task*.
3. *Tele-operated driving*, the driving task is performed by an external operator.
4. *Pilot service*, an especially trained person takes over the driving task in a specific regime.
5. *Extra transportation device*, at the boundaries of deployment the driving robot coordinates the handover of the vehicle to an extra transportation device so that this transportation device can continue the transportation task. Possible examples would be the long-distance transport of urban vehicles with the help of a “road train” or a concept similar to an electronic towbar.

If the driver is considered (value *driver*), it is inevitably necessary that a vehicle control interface (“driver work place”) is available. In addition it is assumed that a capable and licensed person as an occupant accompanies the journey outside the autonomous driving area. For other cases, from today’s perspective futuristic values (*tele-operated driving* as well as *pilot service*), a necessary service / interface needs to be provided for these alternatives.

## Characteristic I: Options for Intervention

### Motivation

According to Donges<sup>3</sup> the three primary driving tasks, “navigation”, “path tracking”, and “stabilization”, need to be fulfilled in order to guide a vehicle to the desired destination of the journey.

According to the definition of fully automated driving, this driving task is transferred completely to the driving robot. If a destination is indicated to the driving robot, it fulfills the “navigation”, “path tracking”, and “stabilization” tasks and guides the vehicle to the desired destination.

In contrary, with the exclusion of hazardous situations (electronic stability control, anti-lock braking system, automated emergency braking), the driver is in control of current production vehicles (overwrite capability). The human fulfills the driving tasks at the driver workplace in the vehicle. Thus he/she currently has the option to correct the actions of assistance systems, i.e. to overwrite these.

Therefore there are two entities, the occupant as well as the driving robot, which basically have the capability to control the vehicle.

In addition, ideas and concepts for vehicle remote-operation (tele-operated) exist, in which entities external to the vehicle intervene into the vehicle guidance. If a communication link as well as a respective interface for the outside world of the vehicle exists, these external entities also have the capability to influence the vehicle control. Therefore, in total three groups of entities, *internal*, *vehicle*, *external* can be distinguished, which can intervene with the vehicle control during the autonomous journey.

To simplify the description of the characteristic, the occupants (adult, minor, people with limiting disability etc.) are summarized as the group *internal*, as well as influences outside the vehicle (law enforcement (e.g. police), registered vehicle owner (if not part of group *internal*), authorized agent etc.) summarized as the group *external*.

If the entities are considered independently, the following questions regarding its options for intervention apply:

1. On which level of vehicle control has the entity the **option** to intervene?
2. For which level of vehicle control has the entity the **authorization** to intervene?

The first is answered through the vehicle concept of the use case. If the entity is supposed to have the option for intervention, an appropriate interface in the vehicle concept is provided to the entity.

The second question requires a statutory rule that defines which authorization is assigned to entities according to their properties and responsibilities. At this point it will not be further elaborated who sets and checks these rules, if there is a driving test of some sort for the different levels, and if authorizations like driver’s license or access codes are needed.

From this, the following combinations of options for interventions, that the vehicle provides, and the authorization for intervention that the entity possesses result:

- a) The vehicle concept offers the option for intervention on one of the three levels (navigation, path tracking and stabilization) and the entity is authorized to intervene on the same level of the driving task. Therefore the entity can intervene.
- b) The vehicle concept offers the option, but the entity is not authorized to intervene on one level. This situation correlates to a child that is in the driver's seat. For the use cases, it is assumed for this situation that law for this situation regulates the intervention by the entity.
- c) The vehicle concept does not offer the option, but the entity is authorized to intervene on one level. This correlates to a driver in the back seat, who cannot intervene.
- d) The use case offers the option on one level, however the entity is authorized to intervene on a different level of the driving task. Also with this combination, the intervention is not permitted to the entity.

Only with combination a) the driving robot can be influenced and / or overruled by the entity on one level of the driving task.

For the description of the use cases it follows that those entities are listed, for which at least one authorization matches one available option of the vehicle concept.

In addition, it is assumed that statutory rule will punish and therefore preclude misuse. This assumption also applies to current vehicle concepts. For example, technology does not prevent children from driving a vehicle, but respective statutory rule in combination with required supervision.

If the entities are now considered simultaneously and the entities are therefore able to act simultaneously on the three levels, the third question applies.

3. Which entity is dominant and how is the hierarchy of the entities defined in case of a conflict because of simultaneous interventions (Figure 1)?

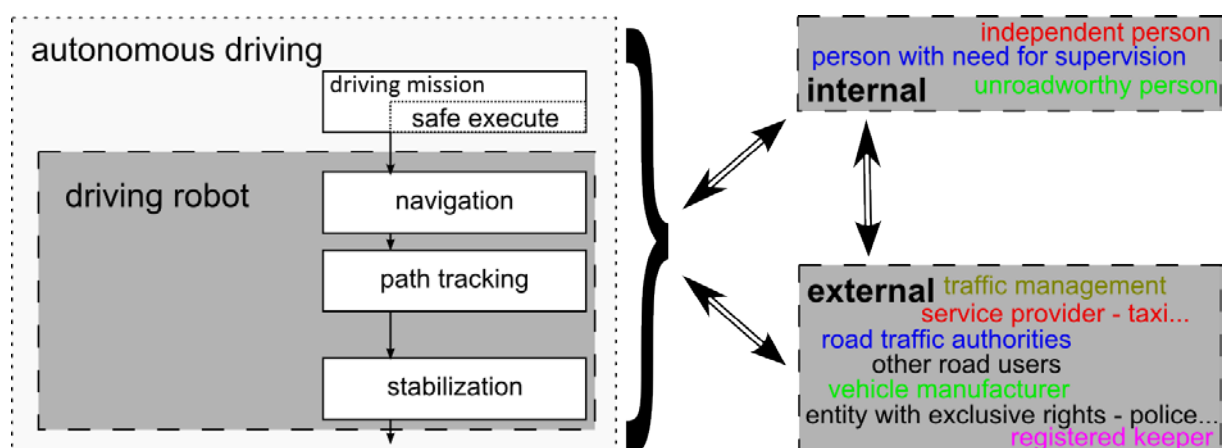


Figure 1: Driving task conflict of interventions between entities

In order to answer this question for the description of the use cases, the intervention of the entities has to be attributed with a certain hierarchy. Which entity dominates others and decides thereby the vehicle behavior on the different levels of the driving task? A hierarchy of the entities needs to be implemented in the vehicle design.

With this it needs to be acknowledged that in addition to the hierarchy of the entities, there also needs to be a hierarchy of the levels for the driving task. Stabilization always overrules path tracking and path tracking always overrules navigation. Therefore it is additionally defined that only on one level internal or external entities can intervene. The entity with the highest priority suppresses other interventions.

Through autonomous driving it is also possible to exclusively transport persons who are not able to perform the driving task or to change the driving mission. However, in order to provide occupants with the option to exit safely as fast as possible, the safe execute is introduced as a special driving mission. If the occupant gains access to the safe execute with the highest priority, he/she might not necessarily be able to change the destination of the journey, but can exit the vehicle as fast as possible.

## 5. Description of the Use Cases

The use cases were motivated, general assumptions were laid out, and the characteristics, which are considered for the description, were introduced. The combination of the characteristics and / or their values, respectively, lead to a very large number of use cases, which cannot be described in detail. The use cases that are described in the following serve, as mentioned in the beginning, as proxies for this multitude.

- Interstate Pilot with Availability through Driver
- Autonomous Valet Parking
- Full Automat with Availability through Driver
- Vehicle on Demand

Especially the partition of the driving task between human and driving robot, in which the four versions differ, has contributed to the selection of the use cases. The first two use cases are seen as introductory versions, while the two latter use cases present widely developed versions of autonomous driving.

### Interstate Pilot with Availability through Driver

#### **Benefit**

The driving robot takes over the driving task of the driver exclusively on interstates or interstate-like expressways.

The driver becomes during the autonomous journey just a passenger and can take his/her hands off of the steering wheel and pedals, and can pursue other activities.

#### **Description**

From the beginning when entering the interstate the driver can activate the driving robot, if he/she desires, while this happens sensibly in conjunction with indicating the desired destination. The driving robot takes over navigation, path tracking, and stabilization until the exit from or end of the interstate is reached. The driving robot is safely coordinating the handover to the driver. If the driver does not meet the requirements for safe handover, e.g. because he/she is asleep or appears to have no situation awareness, the driving robot transfers the vehicle to the risk-minimal state on the



emergency lane or shortly after exiting the interstate. During the autonomous journey, no situation awareness is required from the occupant; the definition for fully automated driving according to Bast<sup>1</sup> applies. Because of simple scenery and limited dynamic objects, this use case is considered as introductory scenario, even if the comparatively high vehicle velocity exacerbates accomplishing the risk-minimal state considerably.

Values of Characteristics			
Characteristic		Value	
<b>A</b>	Type of Occupant	<b>3.</b>	Person/s with agreed destinations
<b>B</b>	Maximum Permitted Gross Weight	<b>1.-3.</b>	500 kg to 8 t
<b>C</b>	Maximum Deployment Velocity	<b>4.</b>	Up to 120 km/h
<b>D</b>	Scenery	<b>8.   a.</b>	Interstate   Without permission allowed
<b>E</b>	Dynamic Elements	<b>2.</b>	Only motor vehicles
<b>F</b>	Information Flow between Driving Robot and Other Entities	<b>1.-4.</b>	Navigation optimization, Path tracking optimization, Stabilization optimization, Provision of environmental information
<b>G</b>	Availability Concept	<b>2.</b>	Availability through Driver
<b>H</b>	Extension Concept	<b>2.</b>	Driver
<b>I</b>	Options for Intervention	Figure 2: Interstate Pilot options for intervention	

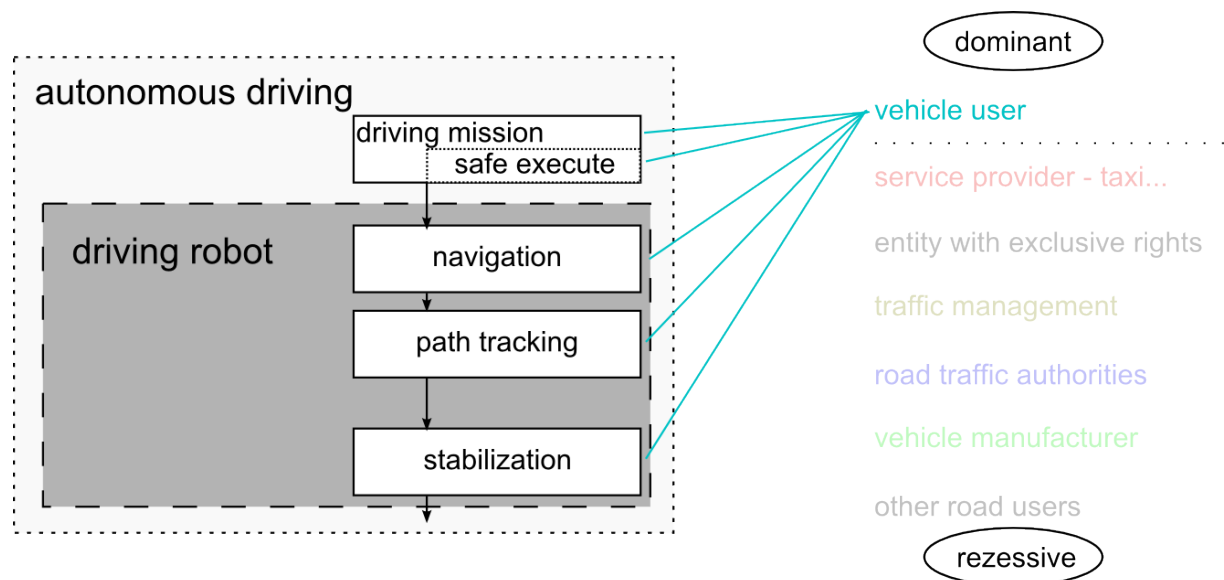


Figure 2: Interstate Pilot options for intervention

Figure 2 shows the intervention possibilities for instances on the levels of the driving task for the use case Interstate Pilot. The vehicle user is the only instance, which may intervene. It be emphasized again that the handover is managed in a safe manner through the driving robot. Potential service providers, police and ambulance with specific authority, a traffic coordinator etc. do not have any possibility to intervene with the vehicle control.

## Autonomous Valet Parking

### Benefit

The driving robot parks the vehicle at a remote location after the passengers have exited and cargo has been unloaded. The driving robot drives the vehicle from the parking location to a desired destination. The driving robot re-parks the vehicle.

The driver saves the time of finding a parking spot as well as of walking to / from a remote parking spot. In addition, access to the vehicle is eased (spatially and temporally). Additional parking space is used more efficiently and search for parking is arranged more efficiently.

### Description

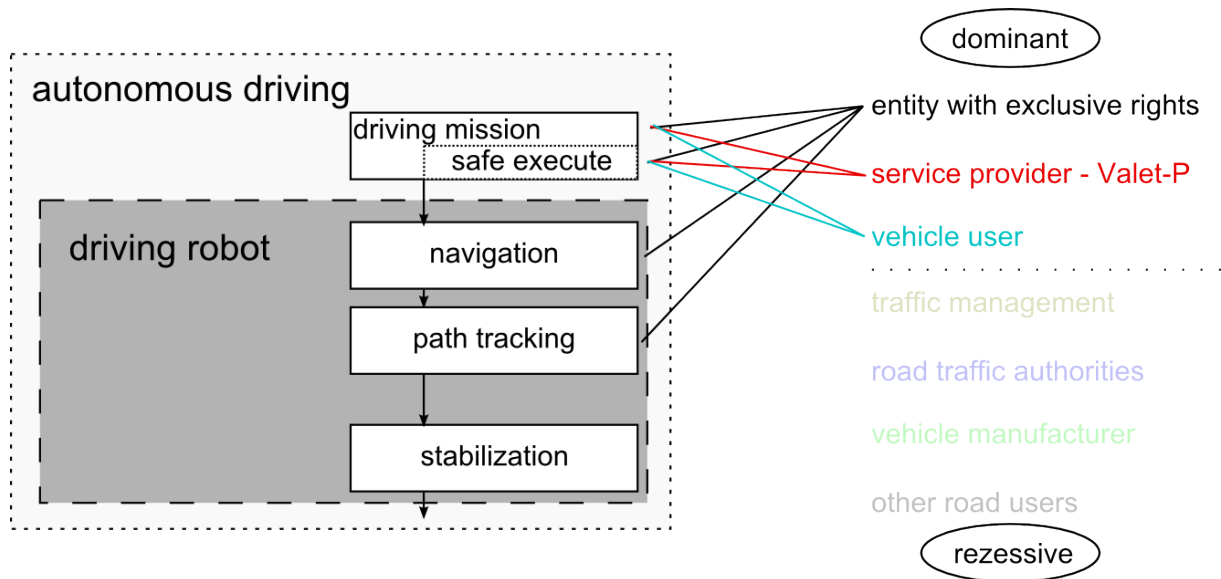
If a driver has reached his/her destination (for example place of work, gym, or home), he/she stops the vehicle, exits, and orders the driving robot to park the vehicle. The vehicle can be privately owned, but might be as well owned by a carsharing provider or similar business model. Therefore, the driving robot may now drive the vehicle to a private, to a public, or to service provider owned parking lot. It is important to assign a parking lot to the driving robot. The search for the respective parking lot by the driving robot is not considered. Therefore a defined destination for the driving robot is always given. Because of the low velocity and the light traffic situation, the deployment of Automated Valet Parking is limited to the immediate vicinity of the location where the driver left the vehicle. On the one hand this limitation reduces the requirements regarding the (driving-) capabilities of the driving robot significantly, because lower kinetic energy as well as shorter stopping distance results from lower velocity. On the other hand the use case could potentially irritate or frustrate other road users. However, this use case seems to be suitable as an introductory scenario.

An authorized user in the vicinity of the vehicle can indicate a pick-up location to the driving robot. The driving robot drives the vehicle to the target destination and stops, so that the driver can enter and take over the driving task.

If desired by the parking lot administration, the driving robot can re-park the vehicle.

### Values of Characteristics

Characteristic	Value	
<b>A</b> Type of Occupant	<b>1.</b>	No cargo and no person
<b>B</b> Maximum Permitted Gross Weight	<b>1.-5.</b>	Up to light commercial trucks and vans around 8 t
<b>C</b> Maximum Deployment Velocity	<b>2.</b>	Up to 30 km/h
<b>D</b> Scenery	<b>3.   a.</b> <b>4.   a.</b> <b>5.   a.</b>	Parking lot or parking structure, Access roads, built-up main traffic roads Without permission allowed
<b>E</b> Dynamic Elements	<b>1.</b>	Without exclusion
<b>F</b> Information Flow between Driving Robot and Other Entities	<b>1. &amp;</b> <b>3. &amp;</b> <b>6.</b>	Navigation optimization, Stabilization optimization Monitoring the driving robot
<b>G</b> Availability Concept	<b>1.</b>	No availability addition
<b>H</b> Extension Concept	<b>2.</b>	Driver
<b>I</b> Options for Intervention	Figure 3: Autonomous Valet Parking options for intervention	



**Figure 3: Autonomous Valet Parking options for intervention**

The instances, which can intervene into the driving task, are depicted on the right side of the hierarchy and are sorted from dominant at the top to recessive at the bottom. The vehicle user can change the driving mission from outside of the vehicle and instruct the driving robot to perform a safe execute. The service provider overrules the vehicle user and can also influence the driving mission and the safe execute. Both instances are overruled by the instances with exclusive rights. E.g. the police, ambulance can decelerate the vehicle on the path tracking, change navigation and driving mission, and order a safe execute.

## Full Automation with Availability through Driver

### Benefit

If the driver desires to do so, he/she hands over the driving task to the driving robot in permitted areas.

The driver becomes during the autonomous journey just a passenger and can take his/her hands off of the steering wheel and pedals, and can pursue other activities.

### Description

If the driver desires, he/she can always hand over the driving task to the driving robot, whenever the current scenery is cleared to do so. Almost the entire traffic area in the permitted country is approved for the vehicle, however the approval is subject to restrictions. If, for instance, the traffic flow is rerouted, a new parking structure opens, or similar changes are undertaken to the infrastructure, then the respective areas cannot be navigated autonomously until further approval. It also appears to be reasonable in this scenario that road sections are excluded from approval permanently or temporarily, e.g. roads with high frequency of pedestrian crossing. Here again, the handover between driver and driving robot has to be managed in a safe manner.

This use case might come as close as it gets to today's visions for autonomous driving, as it corresponds strongly with today's passenger vehicle usage and as the driving task is almost completely delegated to the driving robot while the traditional main user and driver are still participating in the journey.

### Values of Characteristics

Characteristic	Value	
<b>A</b> Type of Occupant	1.	Person/s with agreed destinations
<b>B</b> Maximum Permitted Gross Weight	1.-2.	500 kg to 2 t
<b>C</b> Maximum Deployment Velocity	5.	Up to 240 km/h
<b>D</b> Scenery	2.   b. - 8.   b.	Non-standardized road, Parking lot or parking structure, Access roads, Built up main traffic roads, Urban arterial road, Country road, Interstate Only with permission allowed
<b>E</b> Dynamic Elements	1.	Without exclusion
<b>F</b> Information Flow between Driving Robot and Other Entities	1. -6.	Navigation optimization, Path tracking optimization, Stabilization optimization, Provision of environmental information, Updating the driving robot's capability, Monitoring the driving robot
<b>G</b> Availability Concept	2.	Availability through driver
<b>H</b> Extension Concept	2.	Driver
<b>I</b> Options for Intervention	Figure 4: Full Automation with Availability through Driver	

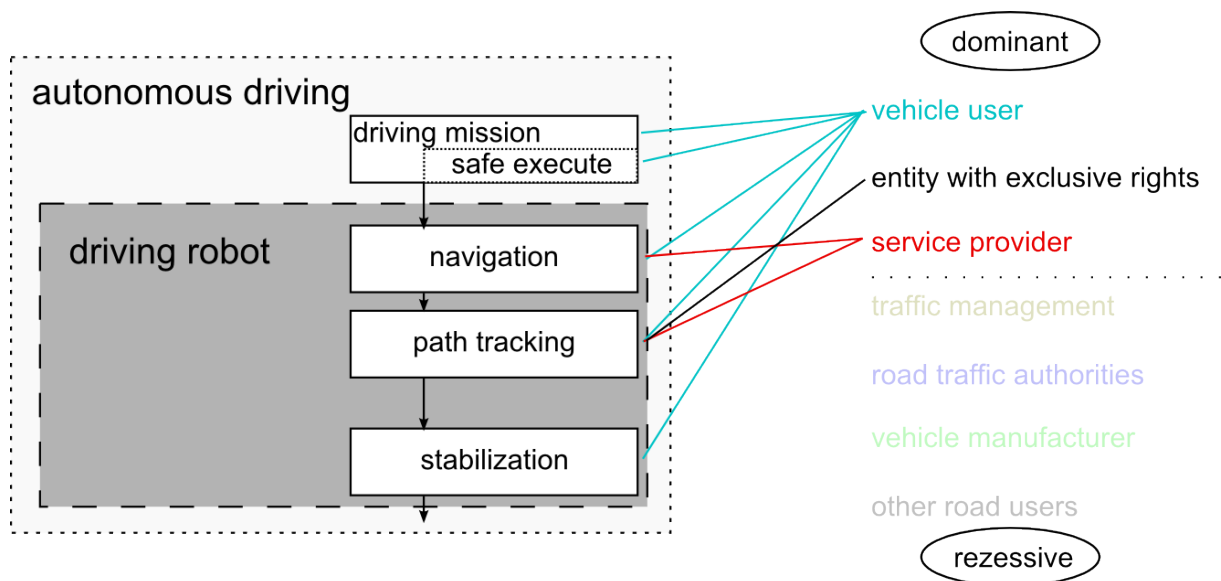


Figure 4: Full Automation with Availability through Driver

Figure 4 shows, which instance (right) intervenes with a certain driving task (left) on a certain level. If desired, the vehicle user can drive the vehicle the same way as driving a classic driver only automobile, provided that the driving task has been handed over safely from the driving robot. Furthermore, the vehicle user can intervene on the level of the navigation, path tracking and stabilization tasks. The vehicle user dominates the instances with exclusive rights. The vehicle user can therefore overrule police or ambulance, which could exclusively intervene on the path tracking level. The same is true for the service provider. The service provider could intervene on the navigation and path tracking level, as long as not overruled by the vehicle user. It is left open in this document for which services the service provider needs access. Some concepts propose services

where the service provider takes over the navigation for commercial use and partly pays for gas and travel expenses.

## Vehicle on Demand

### Benefit

The driving robot drives the vehicle autonomously in all scenarios with occupants, with cargo, but also completely without any payload. The driving robot makes the vehicle available at any requested location.

Passengers use the travel time completely independently for other activities than performing the driving task.

The compartment is designed completely independently from any restrictions of a driver workplace, whatsoever.

Cargo can be transported with the help of the driving robot continuously for 24 hours a day, as long as not restricted by the energy supply for driving.

### Description

The driving robot receives the requested destination from occupants or external entities (users, service provider, etc.), to which the vehicle proceeds autonomously. Humans do not have any option to take over the driving task. The human can only indicate the destination or activate the safe execute, so that he/she can exit the vehicle safely as quickly as possible. With this driving robot, a wealth of different business models is conceivable. A mix of taxi service and car sharing, autonomous cargo vehicles or even usage models that goes beyond the pure transportation task. One example could be a vehicle for social networks that uses information from the network directly in order to plan routes, match people or enables further services, which are not thought of today.

### Values of Characteristics

Characteristic	Value
<b>A</b> Type of Occupant	<b>1.-4.</b> No cargo and no person, For transportation approved cargo, Person/s with agreed destinations, Persons with non-agreed destinations
<b>B</b> Maximum Permitted Gross Weight	<b>1.-3.</b> From 500 kg to 8 t
<b>C</b> Maximum Deployment Velocity	<b>4.</b> Up to 120 km/h
<b>D</b> Scenery	<b>2.   a.</b> Non-standardized road, Parking lot or parking structure, Access roads, Built up <b>8.   a.</b> main traffic roads, Urban arterial road, Country road, Interstate Without permission allowed
<b>E</b> Dynamic Elements in the Scenery	<b>1.</b> Without exclusion
<b>F</b> Information Flow between Driving Robot and Other Entities	<b>1. - 8.</b> Navigation optimization, Path tracking optimization, Stabilization optimization, Provision of environmental information, Updating the driving robot's capability, Monitoring the driving robot, Monitoring occupants, Occupant emergency call
<b>G</b> Availability Concept	<b>3.</b> Tele-operated driving

<b>H</b>	Extension Concept	<b>1.</b>	No substitute
<b>I</b>	Options for Intervention	Figure 5: Vehicle on Demand options for intervention	

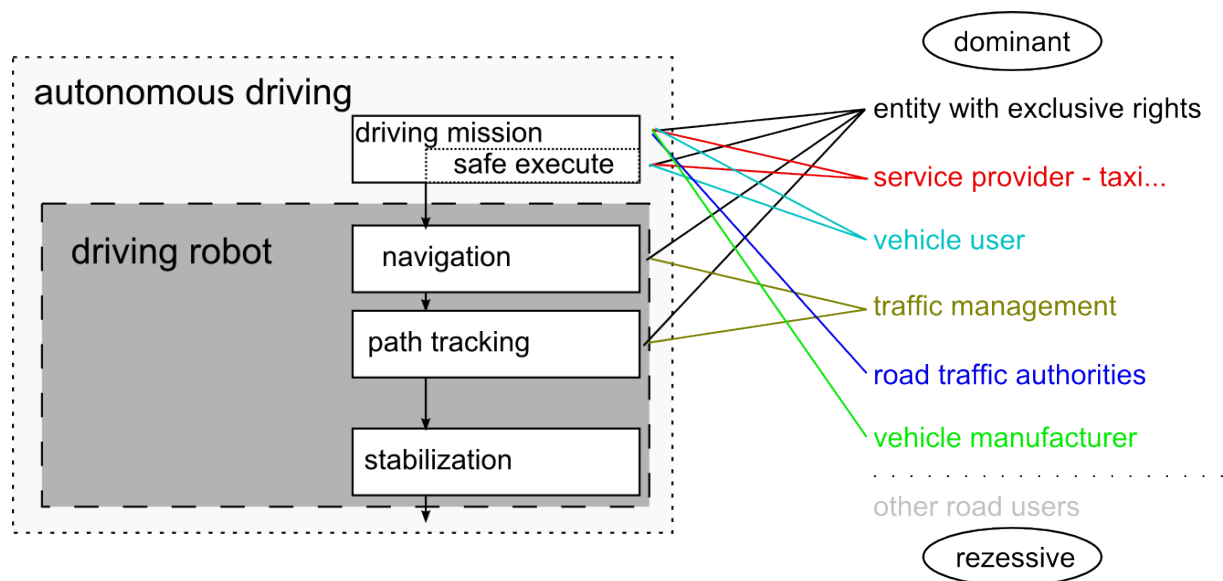


Figure 5: Vehicle on Demand options for intervention

The possibilities for intervention regarding the use case “vehicle on demand” are especially broad due to the enormous (driving-) abilities of the driving robot. The driving robot always carries out the stabilization level. The two instances the entity with exclusive rights (instance with the greatest dominance) and traffic management can intervene on the navigation and path tracking level. Vehicle users and service provider can influence the safe execute and therefore instruct the driving robot to a fast and safe stop in order for a passenger to leave the vehicle. It is especially noticeable that service provider and the authority with exclusive rights can overrule the vehicle user. If one authority overrules the user, he/she cannot perform the safe execute anymore and has to stay in the vehicle. This constellation is similar to that of current taxi-concepts. The taxi driver can stop as fast as possible, if the passenger so requests. Generally though, he (the taxi driver) also has the possibility to disregard this request and drive the vehicle at his/her own desire.