An Approach for a Requirement Analysis for an Autonomous Family Vehicle *

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***Abstract*— Various manufacturers have presented concepts for autonomous vehicles in recent years. However, none of these concepts were designed specifically for the needs of a multi-generation family. A vehicle that meets these requirements can be used independently even by those who are dependent on an accompanying family member when using a conventional car. Furthermore, an autonomous family vehicle, as discussed in this paper, is intended for private use. The basis of the requirements of such a vehicle are the physical and mental abilities of its users. This paper pursues the approach of deriving initial functional requirements by considering examples of accompanied rides in a conventional car. Additionally, an outlook is given on the derivation of non-functional requirements necessary for the safe operation of the autonomous family vehicle.**

I. INTRODUCTION

There are various reasons why people might not be able or allowed to use a car on their own. If their need for mobility cannot be satisfied by public transport, they are dependent on a accompanying person who is able to drive a car. In many cases, this accompanying person is a family member [1]. For example, children are driven to school by their parents or the elderly are driven to a doctor's appointment by their adult children. These dependencies can be restricting for the daily life of all family members. A family car that can be used independently even by those who are not able to drive a conventional car would increase the autonomy of every family member. The basic prerequisite for such a car is the automation of the driving function. However, there are additional tasks that are accomplished by an accompanying person. These secondary tasks enable the accompanied person to use the vehicle safely. In an autonomous family car, these tasks must be fulfilled by the vehicle itself as no accompanying person may be available. The automation of the driving function of a vehicle can offer significant benefits, especially for those who use a conventional private car as an accompanied or accompanying person. However, none of the concepts of driverless vehicles known to the authors is aimed specifically at this group of users.

* This research was carried out as part of the UNICAR*agil* project (FKZ 16EMO0285). We would like to thank the Federal Ministry of Education and Research (BMBF) for its financial support of the project and all members of the consortium for their contribution to this publication.

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This contribution describes a first approach for deriving the requirements for such an autonomous family vehicle. An overview of the vehicle concepts presented to date is given in Section III. Section IV outlines the abilities of potential users of an autonomous family vehicle. The users, who cannot drive a conventional vehicle themselves due to their limited abilities, are of particular importance in this context. In Section V, the use cases of two accompanied rides in a conventional car are examined as as examples to explore the degree of support given by an accompanying person to an accompanied person. In Section VI, possible functional requirements for an autonomous family car are derived on the basis of the use cases described before. Suggestions for an implementation - which is planned in the project UNICAR*agil* - are made in Section VII. Section VIII provides an outlook on the derivation of non-functional requirements.

An early stage of this paper has been published in German [2].

II. Project Context

The prototypical realization of an autonmous familycar is part of the research project UNICAR*agil*. The project is funded by the German Federal Ministry of Education and Research. It is carried out by different institutes of seven German universities and six industrial partners. The aim of the project is to implement four driverless cars prototypically by 2022. Although all these cars are based on the same modular platform, they are aimed at completely different usecases. Besides the aforementioned autonomous family car, called AUTO*elfe*, an autonomous taxi, the AUTOtaxi, an autonomous shuttle, the AUTO*shuttle* and an autonomous delivery vehicle, the AUTO*liefer*, are planned. A detailed description and a presentation of all research contents was made by Woopen et al. [3].

III. COMPARISON TO OTHER CONCEPT CARS

In recent years, various manufacturers have shown concepts for driverless vehicles. Although these concepts are very diverse, none of the concepts known to the authors meet the requirements for an autonomous family vehicle in the sense outlined in this contribution.

For instance, people with a physical disability cannot access some of these concept cars as the seating position might be too sporty. This concerns, for example, the

F105, realized in 2015 by Daimler [4], the *EVE*, shown by *NIO* in 2017 [5] and the *Symbioz*, presented in 2018 by Renault [6]. Furthermore, a step has to be passed to access the car. This also applies to some concept cars with larger door openings and relatively high roof lines. Examples are the *Cedric* which was presented by Volkswagen in 2015 [7] and the vehicles that are manufactured by Navya [8]. In addition, a person with physical disability cannot load and safely stow away larger items in any of the above mentioned vehicles. For example, a rollator or a baby buggy must be lifted into these vehicles manually.

However, there are some concept cars developed for use in public transport that provide a barrier-free access. Examples are the *EZ-GO* [9], presented by Renault in 2018 and the *Accessible Olli* [10], shown by IBM in 2015. Both of these vehicles are equipped with an automated ramp. Further concepts for autonomous shuttle vehicles are versions of the *e-Pallete* platform presented by Toyota at CES 2018 in Las Vegas [11] and the *IoT* presented by Bosch at CES 2019 in Las Vegas [12]. Comparable functions could also be achieved with the *Schaeffler Mover* platform presented by Schaeffler [13].

Due to their intended use, the interiors of these barrier-free cars do not meet the expectations of a private family vehicle. For example, in some of the vehicles mentioned above benches are used instead of single seats, storage options for personal items are missing, and the overall interior seems to be very robust. Functions to coordinate the vehicle within a specific user group are not shown in these concepts. In addition, the needs of children - for example in regards to usability - were not taken into account in the design of the driverless vehicles presented so far. Therefore, children are not able to use them safely and independently [14].

Waymo claims to have a similar target group with its *Early Rider Program*, but has not yet presented a systematic approach to derive the requirements for a family vehicle [15]. In addition, the vehicles used by Waymo for the *Early Rider Program* are based on conventional cars.

IV. USER DESCRIPTION

The central feature of an autonomous family vehicle is the possibility that it can be used by all family members without the support of another person. Therefore, the requirements for an autonomous family vehicle must be based on the individual user's abilities. According to Wirtz [16], abilities form the basis for learnable skills. A person carries out tasks with his or her skills, which can be differentiated between motor, perceptive, cognitive, linguistic, social skills, or a combination of different categories [16]. The abilities are different for each person. Limitation of abilities, for example in perception, can be expected especially from those who are not able to drive a conventional car. The effects of limited abilities and therefore the lack of driving skills, in particular of elderly people, were presented by Stelmach and Nahom [17].

One reason why people cannot drive a conventional vehicle are restrictions on information reception. An example mentioned by Stelmach and Nahom is the decreasing eyesight of elderly people.

Restrictions in the processing of information can also mean that a person cannot drive a vehicle. For example, older persons may be overwhelmed with the necessary recognition of unexpected situations during vehicle driving [17]. In addition, it must be considered that everyday cognitive competence - that a young human develops - decreases significantly in old age [18]. Furthermore, young people, especially children, can be overwhelmed with the correct recognition of traffic situations due to a lack of experience [19].

According to Stelmach and Nahom [17], restrictions in motor abilities are possible reasons why a person does not have the required skills to drive a vehicle. Safe driving of a vehicle requires a minimum degree of agility from the driver in order to have an overview of the surroundings. Furthermore, driving a vehicle especially in critical situations requires coordination skills, which, for example, can decrease due to age. In addition, certain motor abilities are required to enter and leave a car independently. The stowage of luggage also requires a specific degree of motor abilities. Especially for persons with walking disabilities, the independent stowage of a walking aid in the luggage compartment of a conventional vehicle can be problematic. In particular, the required motor abilities for the use of a conventional car strongly depend on its design. This applies, for example, to the entrance of the vehicle and the seat position.

During the development process, for ensuring the usability of an autonomous family vehicle by certain persons, the representation of their abilities is a suitable option. A consideration is made in the context of this contribution, which allows a definition of requirements for a vehicle suitable for a specific set of users. A strong individualization of an autonomous family vehicle enables an independent usage by a wide range of family members because it can be designed for individual needs.

Nevertheless, it can be assumed that even a strongly individualized autonomous family vehicle cannot meet the needs of every person. On the one hand, meeting every person's needs may not be technically feasible. On the other hand, it seems not sensible to leave some kind of people, such as infants, without an accompanying person.

V. USE CASE DESCRIPTION

To create initial requirements for an autonomous family vehicle, the rides of two persons who are dependent on an accompanying person in a conventional vehicle are considered as examples. One of these rides is that of a person who is dependent on an accompanying person when using a conventional vehicle due to his or her advanced age. The other ride is that of a minor person who cannot use a vehicle independently, too. By this means,

a consideration of two critical and contrary common use cases for an autonomous family car can be reached and in the following a wide range of possible requirements for an autonomous family vehicle can be derived. Nevertheless, these are only examples of use cases, so that there may be major deviations in requirements, in particular due to special user restrictions.

First, the older person's ride is represented using a use case diagram according to the standards of the OMG Unified Modeling language [20]. For better clarity, the use case is divided into two individual diagrams. The first diagram which is depicted in Fig. 1, describes activities that happen before and after the ride. The second diagram which is shown in Fig. 2, describes all activities that may occur during the ride.

The considered system is a conventional vehicle. The primary actor is the elderly accompanied person who initiates the ride. The secondary actor is the accompanying person who is able to drive a car.

It is assumed, that the older person requests a drive. However, it has to be taken into account that the elderly person forgets an appointment due to the decrease in everyday cognitive competence with advancing age [18]. After receiving the request for a ride, the accompanying person checks their schedule and the availability of the car. In consultation with the accompanied person, the driving person picks up the accompanied person at a suitable location for an entry. Due to lack of physical abilities of the older accompanied person, the vehicle's doors are opened and closed by the accompanying person. If necessary, physical assistance is provided to the accompanied person when he or she enters the vehicle. The luggage and a possible walking aid are lifted into the vehicle and stowed in a safe way by the accompanying person as well. When all passengers have taken their seats and the restraint systems are in place, the actual ride begins. Meanwhile, the driving person reacts to the behavior and expressions of the accompanied person. For example, he or she changes the destination if desired by the accompanied person. The driving person also observes the state of health of the passenger. In case of a medical emergency, the car has to be stopped, first aid has to be provided, and help has to be called. At the destination, the accompanying person provides the same physical support as at the beginning of the ride.

In contrast to the older accompanied person, it is assumed that the younger accompanied person does not always want to take a ride or could also forget it. Therefore, the accompanying person reminds to take the ride to school for example. Moreover, requests for a ride that are made by the younger person might be refused by the driving person. No physical support is required to enter the vehicle, except for very young children. However, the driving person ensures a safe entry by choosing a suitable place for entry and warning of passing road users if necessary since the minor person might not be able to recognize such hazards. In the vehicle, the accompanying person ensures that the minor sits in a suitable seat and restraint systems are correctly applied. Care is taken to avoid luggage items, such as school bags, lying loose in the passenger compartment. During the ride, it is prevented that a minor leaves the car without permission by a child safety lock. The driving person reacts to a possible misbehavior of the accompanied person and warns them if necessary. When leaving the vehicle, the accompanying person chooses a safe place and forbids to open the doors in situations in which, for instance, another road user drives past the vehicle. Moreover, the accompanying person reminds the accompanied person of forgotten luggage. If it is planned that another person takes care of the accompanied minor at the destination, the accompanying person does not leave until this person is actually there. If the minor is to be picked up for a return trip and does not appear, the driving person will try to contact the minor via mobile phone and, if necessary, initiates further measures.

VI. FUNCTIONAL REQUIREMENTS

A set of functional requirements for an autonomous family vehicle can be derived from the use cases above. Without claiming completeness, the following list contains solution-independent requirements which an autonomous family vehicle must feature in order to order to compensate for the absence of an accompanying person.

The autonomous family vehicle ...

... can be ordered by all family members. (1)
... reminds its users of their appointments. (2)
... coordinates travel requests. (3)
... chooses a suitable place for entry and exit. (4)
... recognizes the identity of all passengers. (5)
... offers suitable seats. (6)
... opens and closes the doors automatically. (7)
... can be entered and exited by all family members independently. (8)
... enables all family members to stow their luggage independently. (9)
... ensures that no objects are left loose in the passenger compartment. (10)
... cannot be entered by unknown persons. (11)
... recognizes medical emergencies and initiates first aid. (12)
... recognizes misbehavior of passengers. (13)
... reacts to misbehavior of passengers. (14)
... prevents passengers from leaving without permission. (15)
... informs passengers about the vehicle's current status. (16)
... can be controlled by passengers, according to their permission (including comfort functions). (17)
... can be operated by family members from outside according to their permission. (18)
... ensures safe exit. (19)
... reminds users of forgotten luggage. (20)

Fig. 1. Activities before and after an accompanied ride of an elderly person

... initiates measures when the person to be picked up does not appear. (21)

... checks the presence of a person that has to take over care of the passenger at the destination if required. (22)

In addition to these functional requirements, there are further requirements that must be met. For example, the interior must have a certain appearance and offer comfort functions due to the private nature of the vehicle. It can be assumed that users' expectations of an autonomous private vehicle differ significantly from those of a conventional car. However, prior to the implementation, they need to be examined by suitable methods [21].

VII. PLANNING FOR IMPLEMENTATION

It is planned to prototype an autonomous family vehicle until February 2022 in parallel with three other vehicle versions in the context of the project UNICAR*agil*. A preliminary illustration of the planned vehicle is depicted in Fig. 3. Based on the requirements mentioned here, approaches for technical solutions are currently devised. The newly developed platform and the modular structure of the vehicles offer a relatively large freedom for interior design.

For example, it is planned to offer barrier-free access to the vehicle by installing an underfloor lift (8). The doors are to be actuated automatically (7), as is the underfloor lift. The interior must have sufficient space for moving and offer the possibility of stowing larger items of luggage at ground level of the passenger compartment (9). An appropriate holding device can be used to safely carry baby buggies, rollators or wheelchairs in the passenger compartment. Single seats with automatic adjustment offer each user a suitable seat which is appropriate for a private vehicle (6).

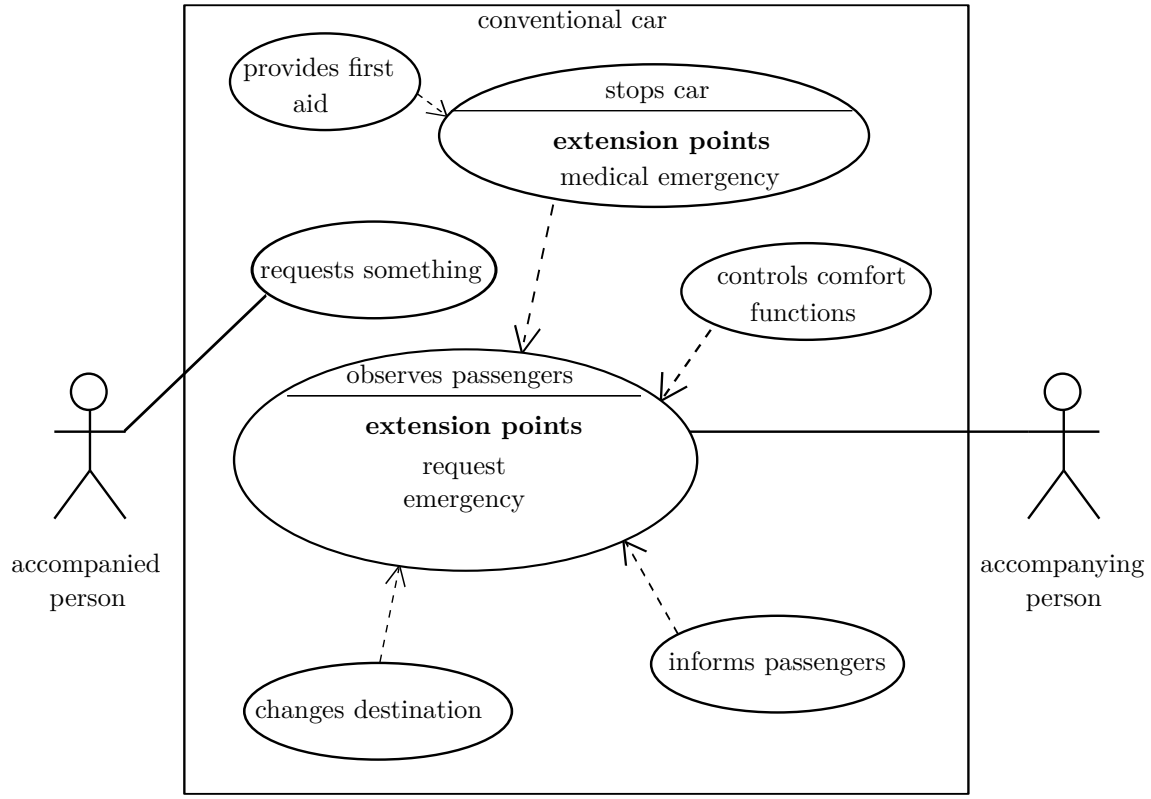

Fig. 2. Activities during an accompanied ride of an elderly person

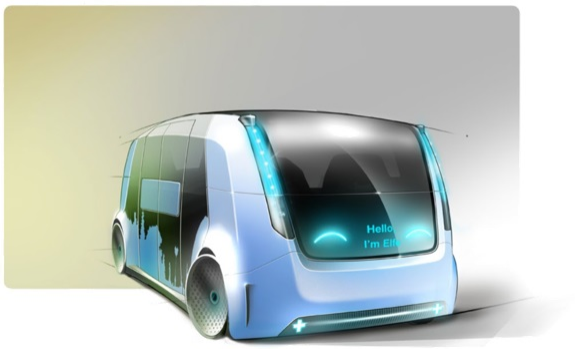

Fig. 3. Preliminary illustration of the autonomous family vehicle currently developed in the UNICAR*agil* project [3]

The vehicle can be called using a smartphone app with an individual interface for each user (1). This enables all users to operate the vehicle only in accordance with their individual permissions. It also allows family members to access the status of the vehicle from outside the vehicle (18). This could be important for parents whose children travel unaccompanied in the vehicle. Based on developments available up to this point in time, it can be assumed that the proportion of smartphone users will continue to rise even in older generations [22]. Thus, the vehicle can be coordinated online via a cloud service (3) provided for in the project [3]. Users' appointments can also be synchronized with the cloud and reminder messages can be sent to users' smartphones. If a minor misses a trip to school, a legal guardian can be informed.

The individual user can be identified via a smartphone or transponder (5). A possible redundancy in case of loss is a fingerprint sensor. Various sensors can be used to monitor the vehicle interior (14)(15). Comparable systems, for example for monitoring the state of health of a driver, have already been presented [23], [24]. The sensors for interior monitoring can be used to detect loose objects lying around or forgotten luggage (10)(20). If a medical emergency is detected, the vehicle can be stopped and an emergency call similar to the European *eCall* system can be made [25]. Alternatively, a control room provided in the project can be informed (13). The control room is a service center that can intervene in an emergency [3]. If a person who has to be picked up does not appear, the control room can also be informed after trying to reach the person via his or her smartphone.

The vehicle's environment perception - which is already available for automating the driving function - can be used to identify suitable entry and exit places for the individual user (4). The preferences for such places of each user can be stored in the profile of the app through which the vehicle is called. In addition, the vehicle's perception of the surroundings can be used to detect and

track road users driving along the length of the vehicle and to keep the doors of the vehicle closed temporarily if the passengers want to leave the vehicle (19). If a person has to take care of a passenger at the point of destination, it can be possible that this person confirms his or her presence on the vehicle (22).

VIII. OUTLOOK ON NON-FUNCTIONAL REQUIREMENTS

The approach presented here is mainly used to derive functional requirements. In the course of further development steps, a definition of non-functional requirements for an autonomous family vehicle is necessary in order to ensure the safe operation of the vehicle.

In comparison to conventional cars, new hazards arise from the extended use of automation throughout the vehicle. For example, the completely automated doors can open or close at the wrong time. A person can be crushed by a door or the doors can open in an unsuitable place for entry or exit. Moreover, the doors could be opened while the vehicle is moving. The same applies to the underfloor lift, which is also to be fully automated.

In addition to the new hazards which occur due to the extended automation, new hazards arise from to the extension of the user group. For example, minors could walk around in a moving vehicle without the presence of an adult which could lead to injuries in the event of emergency braking or an accident. Moreover, the autonomous family vehicle could offer the possibility for minors to go to places that they are not allowed to visit. Furthermore, hazardous scenarios mentioned by the Blue Ribbon Panel on Children in Autonomous Vehicles [14] are the arrival of a child at an unknown place or the absence of a person to meet the child at the vehicle's destination.

Another safety-critical aspect is the vehicle's usability. A particular challenge here is that the intended users must be able to operate the vehicle on their own all the time they use it. At the same time, the individual users abilities are very diverse, as may the requirements concerning the vehicles usability.

There are also security requirements for an autonomous family vehicle which go beyond the security requirements of conventional vehicles. For example, minors who travel on their own might need special protection from strangers. The appropriate security requirements depend not only on the users, but also on the region in which the vehicle is used.

Consequently, it is necessary to take into account the intended users skills and abilities for the further development of an autonomous family vehicle. A possible approach is to create segments of users. These segments can be described by attributes that are considered as relevant for the independent use of a vehicle, such as locomotor skills. In this way, the minimum requirements to be met by users for independent use of the vehicle can be formulated. At the same time, the use of the vehicle could be divided into different activity stages, such as entering the vehicle. In this way, the beginning and the end of the vehicle's operating range could be defined. The combination of a limited number of user segments with a certain number of activities results in a set of scenarios as depicted schematically in Fig. 4. In a further development step, the scenarios created by the combination of these divisions can be used as basis for the definition of further functional and non-functional requirements which are necessary for the safe operation of the vehicle.

user segment A	scenario AA	scenario AB
user segment B	scenario BA	scenario BB
	activity A	activity B

Fig. 4. Combination of user segments and their activities when using the autonomous family vehicle

IX. CONCLUSION

This paper presented an approach to derive first requirements for an autonomous family vehicle. The aim is for the range of family members who are able to use the vehicle independently to be as wide as possible. The highest requirements result from the users that are dependent on an accompanying person if they want to use a conventional car due to their limited abilities. For further derivation of the requirements for an autonomous family vehicle, it is important to define the abilities of the intended users. By representing the abilities of individual users, a comparison to the abilities required for the independent use of a particular vehicle would be possible. The derivation of requirements on the basis of two use cases provides an indication for the possible design of an autonomous family vehicle.

It is planned to realize a prototype for an autonomous family vehicle until 2022 in the context of the project UNICAR*agil*. A comparison to concepts for autonomous vehicles presented by different manufacturers shows, that no concept addressing the same use cases has been presented so far. The prototypical realization of such a vehicle offers the opportunity of gaining practical experiences of an autonomous family vehicle before autonomous vehicles become more common. In addition, the potential benefits of autonomous vehicles for everyday life of many people can be demonstrated to a certain extent.

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