Next Generation of Virtual Stops for Future Mobility Solutions

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Abstract.
The growing demand for mobility of people and goods poses major challenges for the inner-city transport infrastructure. At the same time, the increased volume of commuters increases the need for demand-oriented local public transportation (LPT) as well as more flexible connections to rural areas. In the long term, therefore, a shift in individual vehicle traffic toward intelligent, modern, low-emission and sustainable mobility solutions is necessary. Flexible, demand-oriented stops will be of increasing importance for new sustainable mobility solutions in the future.
In this paper, the concepts for new virtual stops as an integral part of the roadside infrastructure for future mobility solutions are presented. The paper gives the answer to these questions: which criteria does a public transport bus stop, on-street parking or parking bay have to meet so that it can act as a virtual stop or chosen by the end user like on-demand passenger of demand responsive transport?
This paper also illustrates the most significant mobility uses cases involving virtual stops.

Keywords: next generation virtual stop, on-demand oriented stops, future mobility solution, stop recognition, stop management, stop selection criteria, stop placement criteria

1 Introduction

The demand for mobility of people and goods is growing due to the increasing number of large cities and global economic growth [1]. This poses major challenges for the inner-city transport infrastructure. At the same time, the increased volume of commuters increases the need for demand-oriented local public transportation (LPT) as well as more flexible connections to rural areas. If there will be no change in the mobility system, the emissions caused by the traffic will increase more and more. In the long term, therefore, a shift in individual vehicle traffic toward intelligent, modern, low-emission and sustainable mobility solutions is necessary [2].

The contribution presented in this paper describes the activities of the German mobility research project KoKoVi [3], founded by the German Federal Ministry for Digital and Transport. The project started in January 2022 with a duration of two years (2024). The objective of this project is to connect traffic infrastructures and automated driving functions to central traffic nodes in order to develop building blocks for innovative and sustainable mobility solutions. New functions of automated networked vehicles and roadside infrastructure are being developed. This includes automated and connected driving functions that can use distribution functions for virtual on-demand stops in a complex urban traffic network and communicating with the traffic infrastructure. Flexible, demand-oriented stops will be of increasing importance for new sustainable mobility solutions in the future. Therefore, the concept of new virtual stops (VS) as an integral part of the traffic infrastructure is developed, implemented in road traffic and evaluated in the context of future mobility solutions.

In this paper the focus is on the next generation of virtual stops and the future mobility solutions involving virtual on-demand stops.

2 Next Generation of Virtual Stops.

A concept for a virtual stop was developed as part of the project KoKoVi, implemented in road traffic and finally evaluated. In the following sections, the requirements for virtual stops in terms of technical, legal feasibility, acceptance, traffic safety and efficiency are described. A distinction is made between legal, technical and user requirements.

2.1 Virtual and physical stops

In principle, any safe and feasible location in the road network can be defined as a “virtual” or “unconventional” stop. The possible location for a virtual stop can also be mapped to the “physical” existing stop, for example, a “conventional” bus stop. The virtual bus stop can also be viewed as a special form of parking space.

Fig. 1 shows possible realizations of virtual stops (VS) such as ordinary bus stops, on-street parking or parking bay. In Germany, buses are not allowed to reverse in public spaces without further ado, so the only option is to stop along the road.

(a) VS as bus stop (b) VS as on-street parking (c) VS as parking bay

Fig. 1. Example of different categories of virtual stop (Google Map).

2.2 Goals and approach

The following two main goals are described in detail in the next sections.

- Goal 1: Criteria for the placement/localization of a virtual stop on the road: which criteria does a public transport bus stop, on-street parking or parking bay have to meet so that it can act as a virtual stop?
- Goal 2: Criteria for the selection of a virtual stop for mobility solutions: Which criteria make the virtual stops comparable so that the preferred one can be selected by the mobility user or services?

Different categories are introduced in order to obtain as complete a picture as possible of the criteria for placing and selecting a virtual stop.

On the one hand, there are criteria that make it impossible to place or select a virtual stop. For example, a stopping ban is a general exclusion criterion for the placement of a virtual stop. On the other hand, there are criteria that are only relevant for special use cases, such as a barrier free access for a pram. Comparable criteria, such as walking distance from or to the virtual stop, are most important when selecting a virtual stop for a flexible mobility service.

2.3 Goal 1: Criteria for the placement of a virtual stop on the road

Research questions:

- Which general criteria does a stop have to meet in order to act as a virtual stop on the road?
- Which specific criteria should a stop meet in order to fulfil the needs of different user groups and stakeholders?

There are different strategies for placing virtual stops. A summary of three possible approaches can be found in Harmann et.al [4]. The placements at street lamps, at intersections and at regular intervals (grid) are examined. Some criteria for the placement of virtual stops have already been named in Harmann et.al [5]. However, these are mixed with attributes of virtual stops and are incomplete. A complete list of all relevant criteria will be provided in this chapter. The criteria for the placement of virtual stops are usually mandatory, but some are always relevant and others only for certain use cases, such as using autonomous vehicles or handling with users with large luggage.

2.3.1 Legal requirements

The legal requirements describe the legal basis for "stopping" in road traffic, which takes place at virtual stops. In the legal sense, "stopping" is understood according to the German road traffic regulations (StVO) under §12 paragraph. 2 as the " intentional" interruption of the journey, i.e. the standstill of the vehicle, during which the driver remains in the vehicle and which does not last longer than 3 minutes, otherwise it is referred to as parking. In this context, stopping is generally not allowed under the conditions stated in **Table 1**. Some criteria may be time-dependent and thus only relevant in certain applications. All other criteria must always be fulfilled.

Table 1: Legal requirements for a stop. (found in [Harmann, et.al. [5]])

No	Criteria	Description
1	Parking or stopping restriction / prohibited	- Absolute stopping prohibition (also with time restrictions) - Cycling infrastructure on the roadway - Speed limit higher than 50 km/h - Railroad crossing - Entrance or exit lanes - Fire department access road - Taxi rank - In the running space of rail vehicles - Traffic roundabout - In unclear road sections - In the area of sharp curves

2.3.2 Technical requirements

Technical requirements for virtual stops can be divided into basic requirements of the stops, such as required dimensions of the stop to guarantee enough space for the shuttle/vehicle, and communication requirements of the dispatching system to guarantee the correct management of the stop (see **Table 2**).

If we talk about the basic requirements, it is important to meet the requirements of the shuttle to the virtual stop. This includes, as mentioned above, the dimension of the stop (total length and width), the corner points of the stop, the geo-coordinates, access/admission restrictions, such as availability only on certain days and/or times or only for certain vehicle types of vehicles, and the type of stop (i.e. a bus stop or a parking bay).

Table 2: Overview about the technical requirement of virtual stop.

No	Criteria	Description
1	Form of stop	Autonomous driving Manual driving
2	Type of stop	Bus stop, Shuttle stop Parking bay On-street Parking
3	Dimension of the stop	Total length and width Corner point of the stop Geometry as shape
4	Availability of communication infrastructures on the stop	To guarantee the correct management of the stop E.g. Car2Infrastructure (C2I)
5	Location/position	Geo-coordinate
6	Location type	on-street virtual stop

		off-street virtual stop
7	Parking Capacity	In term of number of vehicles
8	Street name	The name or address of the street
9	Operating time	Information about the opening days and hours

2.3.3 Non-technical requirements

The non-technical requirements for virtual stops are mainly user requirements. However, there are also requirements from the vehicles, the providers and the municipalities. The general criteria have been divided into nine categories and subdivided into further specifications. The category "accessibility" describes the unhindered access to the virtual stop under different circumstances. The "safety" category includes both subjective and objective requirements. For example, the presence of street lighting may contribute to a greater sense of safety and security for the user, but it may also reduce the risk of stumbling. "Accessibility" describes requirements on the way to or from the virtual stop. For example, the vehicle must not only be able to reach and travel to the virtual stop, but there must also be access to public transport if needed. "Convenience/Comfort" is more relevant to the selection of the virtual stop. "Uniqueness/findability" indicates how well the virtual stop can be found and identified by the user or the vehicle. POIs are suitable for this purpose. "Costs" can be reduced if possible, parking fees are estimated at the time of the placement of the virtual stop and, e.g., contracts are concluded with the operators of parking facilities. Especially for electric vehicles, it is a good idea to integrate the charging infrastructure and bundle waiting times. "Privacy" is not relevant to the placement of virtual stops. Sometimes it is necessary to include less attractive virtual stops in the system to achieve adequate "coverage". "Impact on traffic flow" may be relevant to the municipalities responsible for the traffic system. Excessive negative impact on traffic flow, e.g., due to high frequency, may result in the prohibition of certain potential virtual stops.

An overview of the specific requirements for the placement of virtual stops can be found in **Table 3**.

2.4 Goal 2: Criteria for the selection/ choice of an operative virtual stop for mobility solutions

Research question:

- What criteria must a virtual stop fulfil in order to meet the specific requirements of different users or vehicles?
- Which virtual stops can be used at the service time?
- What criteria make the virtual stops comparable so that the optimal one can be selected?

The criteria required to select a virtual stop should consist primarily of evaluative criteria. The mandatory criteria are either special needs of the user or time restrictions regarding the possible use of the virtual stop, such as enough space for the disability vehicle to fold out the ramp used by the wheelchair user, or temporary halting restrictions. A duplication of the criteria for the placement of a virtual stop is possible. In addition to the criteria described in section 2.3.3, „privacy / data protection" can be relevant, if a door-to-door service is offered and thus includes private addresses that become traceable. „Convenience / comfort" includes the existence of infrastructure elements such as shelter or seats, but also low traffic. Some criteria are hard to evaluate and need more research to make them measurable.

An overview of the criteria for the selection or choice of the virtual stops on public roads is also described in **Table 3**.

Table 3: Overview of the criteria for the placement (Goal 1) or choose (Goal 2) of virtual stop.

No	Criteria	Parties concerned				Specification	Measurement	Description	Relevant for	
		User	Vehicle	Provider	Municipal-ity				Placement	Choose
1.a	Barrier-free	☑				Disabled access [12]	Is available (yes or no)	• Can be very specific depending on the nature of the disability (e.g. walking impediment, visual impairment)	☑	☑
1.b		☑				Space for loading/unloading luggage or strollers	Is available (yes or no)		☑	☑
1.c		☑				Direct access from/to the footway available	Is available (yes or no)	• There is no bike lane or grass verge	☑	☑
1.d			☑			Space to fold out the ramp of the vehicle	Is available (yes or no)	• Depends on the available ramp of the vehicle (lateral or at the back)	☑	☑
2.a	Safety	☑				Electrical lighting is available	Is available? (yes or no)	• When getting in and out of the vehicle	☑	☑
2.b		☑				Surveillance camera are available	Is available? (yes or no)		☑	☑
2.e		☑				Low traffic area	Is the virtual stop located at the low traffic area? (yes or no)	• E.g. Low traffic area consists of road with speed limit 30 km/h	☑	☑
2.f		☑				Pedestrian crossing is available	Is a pedestrian road crossing available? (yes or no)	• E.g. pedestrian road crossing	☑	☑
2.g		☑	☑			Compact road surface	Surface of the road allows a stable stop	Can be affected by: • Potholes • Inclination • Slippery ground	☑	

								• Material of the surface		
2.h					☑	Increased risk of accidents with the vehicle [14]	Is the typical traffic flow disturbed? (yes or no)	E.g., caused by stop • At crossings • In the second row (next to parking vehicles)	☑	☑
3.a	Accessi-bility	☑				(Maximal) Distance (Length) of the footway / distance from the user actual position to the pickup virtual stop	Distance [in meter]	• Maximal Distance that the user has to travel from his actual position to location of the virtual stop • Measurement by pedestrian routing • Depending on the season, mobility and baggage or total travel time		☑
3.b		☑				(Maximal) travel time to the virtual stop	Time [in minute]	• The time that the passenger needs to reach the virtual stops		☑
3.c		☑				Complexity of the pedestrian route to the virtual stop (small detour)	Number of intersections / turns, curve, road category	• The necessary steps to find the way to the given stop. E.g., how often does the user have to turn, are there main roads or intersections that the user has to cross		☑
3.d		☑				Maximal duration of waiting time at the virtual bus stop until pickup	Time [in minute]	• The time that the passenger has to wait for the shuttle to arrive after arriving at the virtual stop • Define the maximum time a passenger should wait at the virtual stop until the vehicle arrives		☑
3.e		☑				Accessibility of virtual stop using public transport is possible	Number of train stations, tram stations, bus stops, and taxi stations at the virtual stop area	• Set the maximum value • Connection to the bus rail, tram, taxi transport services	☑	☑
3.f		☑				Pedestrian road crossing is possible	Is available at the virtual stop area? (yes or no)	•	☑	☑

3.g			☑			Vehicle has enough space to stop at the virtual stop	Vehicle fits into the virtual stop? (yes or no)	• Depends on the lengths of the used vehicles	☑	☑
3.h			☑			Vehicle has the right to reach the virtual stop	There are (currently) no restrictions such as taxi stand or one-way street which does not impede the driving on of the virtual stop (yes or no)	• Provider dependent contracts can affect these restrictions • Can depend on the characteristics of the vehicle as the weight	☑	☑
3.i			☑			Vehicle has the right to stop at the virtual stop	There are (currently) no restrictions specified by traffic regulations (yes or no)	• see **Table 1**	☑	☑
3.j			☑			Near to main roads	Time to access the superordinate road network [in minutes]	• Relevant for long trips especially in rural areas to reduce the detour	☑	☑
3.k			☑			Avoid typical areas of congestions	Time depending on the current traffic situation the vehicle can reach and/or leave the virtual stop [in minutes]	• Traffic situation can also be derived from historical data		☑
3.l			☑			Virtual stop is empty	The virtual stop can be used at the time of the request or an alternative stop is available (yes or no)	• The virtual stop can be shared with public transport • Virtual stop should be booked/blocked, if possible		☑
4.a	Convenience / comfort	☑				Shelter facilities are available	Is available at the virtual stop area? (yes or no)			☑
4.b		☑				Seats facilities are available	Is available at the virtual stop area? (yes or no)			☑
4.c		☑				Toilet is available	Is available at the virtual stop area? (yes or no)			☑
4.d		☑				Paid or free parking is available for own vehicles	Is available at the virtual stop area? (yes or no)	• Prefer low parking fees or free of charge		☑
4.e		☑				Low traffic area	Is available at the virtual stop area? (yes or no)		☑	

4.f				☑		High acceptance of the user	Are all criteria relevant for the user fulfilled? (yes or no/ how many?)			☑
5.1	Uniqueness / findability	☑				At intersection	Is near an intersection? (yes or no)	• The precise point of stop must be clear	☑	
5.b		☑	☑			POIs for identification of virtual stop available	Is near a POI? (yes or no)	• The street site must be clear	☑	
6.a	Costs			☑		Parking fees	Cost if the virtual stop is used [in EUR or similar]	• Contracts with the supplier of the parking place can reduce the costs	☑	☑
6.b				☑		Near charging infrastructure	Is charging currently needed? (yes or no)	• Reduce costs to combine charging with the stop or at least shorten the way to the charging infrastructure	☑	☑
6.c				☑		Short entire route	Is there another virtual stop that can be used near the current route? (yes or no)	• Use virtual stops near the current route • Prefer virtual stops of the current route ("common meeting points")		☑
7.a	Privacy / data protection	☑				Address not traceable	Is available at the virtual stop area? (yes or no)	• Stop at POI or minimum distance to address		☑
8.a	Coverage			☑		Density of the virtual stops within the service area	Is there at least one virtual stop near all potential requests? (yes or no)	• Important especially for public providers • Three different strategies of commercial providers are described in [Harmann et.al. [2]]	☑	
9.a	Impact on the traffic flow				☑	No negative impact on the traffic flow	Does a stop at the virtual stop causes a congestion? (yes or no)	Is influenced by: • The current traffic flow • Sufficient wide road • Main or side road • Stop on the lane or parking bay		

3 Future Mobility Services related to the Virtual Stop

In the project KoKoVi the research activities are focused on the five mobility use cases described in **Fig. 2**. This section introduces these use cases and describes them in detail. These use cases, more specifically “Demand Responsive Transport (DRT)”, “Autonomic Identification”, “Automatic Occupancy Status Detection”, “Augmented Reality (AR) Recognition” and “Management Assignment”, use virtual stops in some form.

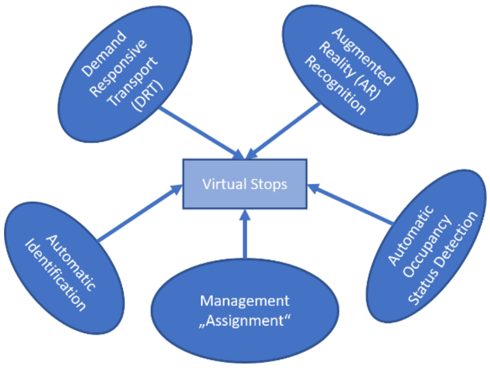

Fig. 2. An overview about mobility uses cases in the context of virtual stops.

The architecture of the KoKoVi sub-system, which covers the five use-cases above, is depicted in **Fig. 3**.

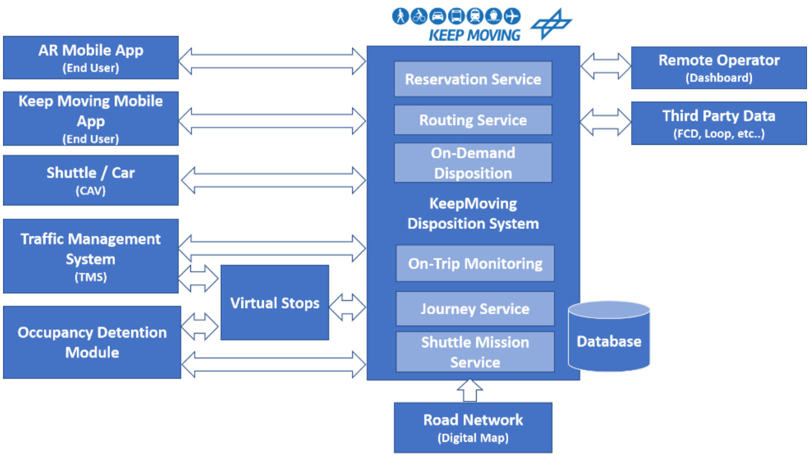

Fig. 3. KoKoVi sub-system architecture for future mobility solutions in the context of virtual stops.

The Following players and stakeholders are involved in the five used cases implemented in the project KoKoVi (see **Fig. 4**)

1. End-User (EU): Who requests passenger transport from a disposition system via end-user device (e.g. mobile app) and allows himself to be transported by a shuttle
2. End-User Device (EUD): That transmits communication between the end user and the dispatching system. Two DLR end user devices are the Keep Moving app [6] and the augmented reality AR app.
3. Dispatching/Disposition System (DS): That manages a shuttle fleet, receives the end-user's passenger transport request from the end-user's device, instructs a shuttle with passenger transport and initiates the creation of virtual stops in the traffic management system. This is realized by the Keep Moving software from DLR [6].

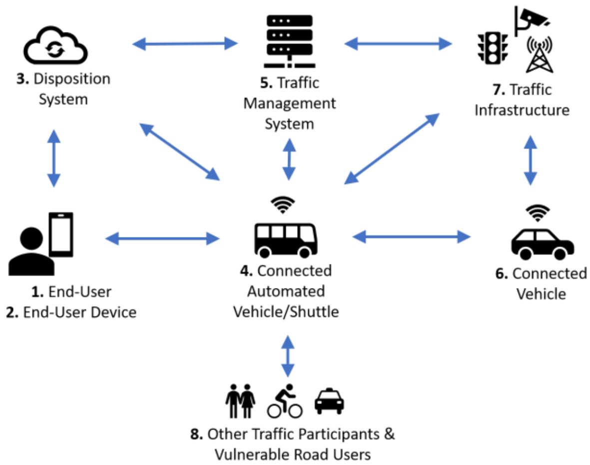

Fig. 4. Actors and stakeholders for the KoKoVi mobility use cases.

4. Connected Automated Vehicle (CAD)/Shuttle (SH): That takes the order for passenger transport from the disposition system and transports the end-users from one virtual stop to the next (e.g. from pickup to drop-off virtual stop).
5. Traffic Management System (TMS): Its role is the management of virtual stops. It decides on the requests for virtual stops made by the disposition system and creates/reserves/books virtual stops by informing connected traffic participants and, if available, also the road side infrastructure in the area of the planned virtual stops.
6. Connected Vehicle: In the area near of one of the virtual stops, who (if present) are informed of the stop and adjust/adapt their behavior accordingly.
7. Traffic Infrastructure (TI): In the area near one of the virtual stops, which (if present) is informed of the stop by roadside units and adapts its behavior accordingly.

8. Other Traffic Participants & Vulnerable Road Users (VRU): Play a role as obstacles, especially for autonomous shuttles as used in the KoKoVi project.

3.1 Demand responsive transport (DRT)

DRT refers to a form of mobility in which routes and stopping points are not fixed from the outset, but are flexibly adapted to current mobility needs [7, 8, 9, 13, 15]. It supplements scheduled services in areas with lower mobility needs and will become economically relevant in the future in combination with autonomous shuttles. **Fig. 5** shows the storyboard of a DRT scenario where two passengers for a journey of the same shuttle are involved with two different pickup and drop up locations, which are implemented as virtual stops. The shuttle requests a dispatching system (e.g. disposition system - DS) to choose a virtual stop at the shuttle's destination. After the stop location is confirmed by the traffic management system (TMS), automated vehicles in the vicinity of the stop are informed that the corresponding virtual stop is reserved for the arriving shuttle.

In KoKoVi, this scenario was carried out with an autonomous shuttle from DLR.

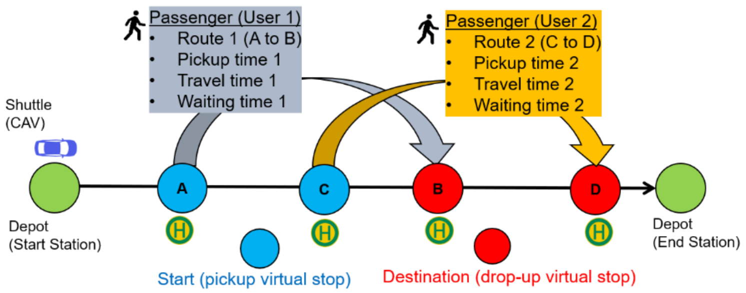

Fig. 5. DRT Scenario using two passengers with different pickup and drop-up virtual stops.

3.2 Automatic identification, detection and mapping of virtual stops on the road

Basically, a distinction can be made between the detection of possible virtual stops ("identification") and the determination of their occupancy status ("status determination"). Under certain circumstances, both can be done in one step, e.g. if the stop is identified for the first time, or if the identification should not be permanent. The following section provides an overview of existing technologies and procedures for the identification and detection of virtual stops.

Virtual stops can be regarded as a special form of parking space, because the basic conditions are very similar: the short-term or long-term parking of conventional vehicles in public traffic areas must be designed with minimal disruption to flowing traffic and other road users or participants, and for this reason takes place in designated (parking) areas. The same applies to virtual stopping points, which is why the following section describes procedures for identifying parking and stopping possibilities. The identification is achieved by different approaches of mapping.

In Germany, as in most other countries, the designation and management of parking and stopping zones, as well as prohibited zones, is a municipal task. These zones are also subject to constant change due to changing conditions, construction activity, transport policy initiatives, demographic change or a change in modal split (distribution of transport volume between different means of transport).

For the reasons mentioned above, parking or stopping zones are not yet a part of digital road maps, or only an incomplete one. There is a lack of both standards and scalable procedures for the area-wide and reliable mapping of parking and stopping facilities. A generally accepted data model could not be researched.

Digital map data on parking and stopping facilities offers a variety of benefits, including: 1. higher transparency for city and traffic planners regarding the available parking space 2. Enabling new navigation functions in the vehicle, such as navigation to the parking lot, 3. Optimized route planning for delivery traffic, 4. Creation of breakpoints for (automated) on-demand vehicles.

The development of current databases for parking space data began with the introduction of digital maps and geographic information systems (GIS). Although maps with parking garages or very large parking areas, e.g., in front of companies, are already available today, these parking areas only account for a small proportion of all parking spaces. The far larger share are so-called on-street parking spaces. These are parking spaces next to the street, as they often occur in residential areas. Public documentation on these parking spaces is currently only available in paper form from the individual city administrations.

Even though there are already some cities that digitize their plans, there is no uniform standard for this and also no central management system, so the information is only available on a city-by-city basis. Cross-city maps of parking and stopping facilities are nowadays only available digitally via the "crowdsourcing" platform OpenStreetMap or commercial providers.

OpenStreetMap (OSM): Today, OSM is the most comprehensive public digital map and the only GIS that contains significant amounts of parking information. The idea behind OSM is called "crowdsourcing" and describes the collaborative and voluntary collection of geographic information. This allows users to enrich OSM with additional geographic information. Among a variety of other geographic information, OSM also contains data about parking lots, including location, geometric shape, and, to varying degrees of completeness, meta-information. Through the OSM service, meta-information such as parking capacity, cost, opening hours or user group restrictions are made available. In Germany, just under 300,000 parking lot entries are mapped, with more than one million already recorded in OSM worldwide. About 50,000 parking lots contain additional meta information.

The first group of commercial solutions: In addition to OSM as an open source project, there are also a small number of commercial parking data providers. Companies such as INRIX [16], Streetline [17] or ParkingHQ [18] merge parking information from various sources such as car park operators, municipal traffic information systems or physical parking sensors into a single database for real time data. The problem here is that these platforms only contain data from managed parking areas, but not from parking spaces on the street or free parking spaces, which contain more than 85 percent of the city’s parking infrastructure.

The second group of commercial solutions: is aware of this issue and is trying to solve it with a different way of collecting data: Companies like Parkopedia [19] rely on data contributed by their own user base. Users of Parkopedia's mobile app can enter parking spaces into the database with locations, opening hours, restrictions and prices. Therefore, Parkopedia's data collection is also able to obtain data for free on-street or off-street parking. The data collection model is thus similar to OSM, with the difference that Parkopedia makes the data commercially available for purchase rather than free. However, data volume, timeliness, and spatial coverage depend heavily on the size of Parkopedia's user base.

3.3 Automatic occupancy status detection of virtual stops

As already explained, the detection of virtual stops refers to their time-dependent occupancy state and is in turn thematically very closely related to the state detection of parking spaces (determination of the occupancy state of a virtual stop ("state detection"). For this reason, the general state of the art for determining the occupancy status of parking spaces, especially in public spaces, will be discussed below.

If a vehicle leaves its parking space, this information is valuable for a person looking for a parking space, but also for other users of public parking and traffic space, such as delivery or on-demand vehicles. Nowadays, there are two approaches to detecting free parking spaces: via stationary sensors or crowdsensing systems, which are explained below.

Stationary detection systems: Stationary parking guidance and barrier systems are most commonly used for so-called off-street parking spaces such as parking garages. These systems consist of a mechanism for recording and counting the number of occupied parking spaces and a visualization that provides the user with information about the current occupancy. The measurement of the number of free parking spaces is usually carried out by cameras, ultrasonic or radar sensors, ticketing or barrier systems or ground sensors.

More advanced stationary systems also stream their information to a server, making it accessible to third-party services, such as mobile apps. Although these systems are quite accurate, they are expensive to install and maintain, and of course only cover a very limited portion of the total parking spaces in an area, as they are usually only operated by property owners.

In public spaces, the systems described are practically not used due to the lack of cost-effectiveness due to the high investment and maintenance costs. In conclusion, it can be said that stationary systems do not allow extensive coverage of entire cities or countries.

Crowd sensing or distributed systems: On the other hand, try to use data from vehicles or users to track parking processes and inform other users about them. They are therefore not necessarily dependent on expensive hardware and, in addition, the costs incurred for hardware and connectivity are generally borne by the user. There are early attempts at mobile apps in which users enter free parking spaces on a map and thus inform other users about it. Due to the strong involvement of the driver and the fact that a critical mass of users was not reached, they could not achieve acceptable levels of accuracy. As a result, the systems did not offer sufficient added value. Even today's crowd sensing systems rely on a critical number of users, but they no longer require the manual entry of parking space. Nowadays, every mobile application can collect movement data in the background with user consent.

3.4 Augmented reality (AR) for the recognition of virtual stops

The automatic detection of a virtual stop as well as the reserved/booked vehicle (e.g., shuttle) arriving at the stop is useful and can help the mobility user to quickly find the virtual stop as a stop for the shuttle bus. Human Machine Interface (HMI) concepts using AR technology for the interaction of mobile devices with virtual bus stops and connected road users have proven to be very supportive for cooperative behavior. Using the AR application to automatically detect virtual bus stops and book a shuttle for on-demand traffic scenarios can help reduce the virtual bus stop and shuttle search time. Various research studies have been carried out in this area at DLR and other research institutions [10, 11]. **Fig. 6** shows an end user using an AR app developed by DLR to visualize the location of the virtual stop at the pickup position.

Fig. 6. DRT end user using prototype AR App for the localization of the virtual stop at the drop up location (DLR).

3.5 The management /assignment of virtual stops

The management of virtual stops for mobility purposes is complex and crucial to avoid conflict over the reservation and assignment of virtual stop to a single vehicle (e.g., shuttle by the DRT) for a certain time duration. Traffic management can play the role of management of virtual stops in the city for different mobility solutions [4]. The project KoKoVi deals with the topic of the management of virtual stops. To test and demonstrate the mobility use cases related to the virtual stops in KoKoVi, the mobility corridor as a test field in Brunswick, Germany has been used. **Fig. 7** shows the mobility corridor and the location of some selected virtual stops (blue) and the roadside infrastructures like traffic light (green) and roadside unit (RSU) elements (yellow).

Fig. 7. Overview of the mobility corridor as a test field for the demonstration and management of virtual stops in Braunschweig, Germany.

4 Conclusion and Outlook

In this paper, the concepts for new virtual stops as an integral part of the roadside infrastructure for future mobility solutions are presented. The paper gives the answer to these questions: which criteria does a public transport bus stop, on-street parking or parking bay have to meet so that it can act as a virtual stop or chosen by the end user like on-demand passenger of demand responsive transport? This paper illustrates also the most significant mobility uses cases where virtual stops are involved, such as demand responsive transport (DRT), automatic identification and occupancy status detection, automatic recognition using augmented reality for on-demand service users and management through effective assignment to the on-demand autonomous vehicle.

In the next step, the criteria for the placement and selection of virtual stops presented in this contribution will be evaluated in detail and the results according to the end user and vehicle expectation will be part of the next publication. In particular it is planned to combine several criteria into groups, which are always relevant for common use cases. These include, for example, mandatory criteria, criteria for users with large luggage, criteria for services with autonomous shuttles, etc. In order to strive for an automatic evaluation of the criteria for virtual stops, it will be investigated which information can be used from free sources like Open Street Map (OSM) and which criteria can be evaluated with it. In the best case, these criteria can be automatically queried for a selected area with a script. All research activities conducted in the scope of the German mobility project KoKoVi were founded by the German Federal Ministry for Digital and Transport.

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