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# Deployment Scenarios for First/Last-Mile Operations With Driverless Shuttles Based on Literature Review and Stakeholder Survey

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**ABSTRACT** Driverless shuttles are a new automated road-based means of transport, small in size and capacity and with a relatively low operational speed. Classified as high-automation vehicles, these shuttles are capable of driverless operations in specific operational design domains. Given their characteristics, driverless shuttles have been studied as a first/last-mile complement to main public transport lines, serving the access and egress parts in multimodal trips. Currently, driverless shuttles are mostly operated as pilots testing their technical capabilities and measuring passengers' willingness to use them. To reduce the gap between pilots and implementation, this study formulates a set of deployment scenarios for driverless shuttle integration in transit. A four-step approach is followed. First, the scenario field is identified. Second, key factors that support the future integration of driverless shuttles are defined based on a literature study. Third, these key factors are analysed through a stakeholder survey, in which experts in the field of transport define possible development directions. Fourth, survey respondents combine these factors to create plausible future scenarios. Through the formulation of three scenarios, the results of this study show the best combinations of vehicle characteristics, type of supervision, operational characteristics, and type of infrastructure for future integration of driverless shuttles.

**INDEX TERMS** Driverless shuttles, first/last-mile, literature review, scenario, shared automated vehicles, survey.

## I. INTRODUCTION

AUTOMATED Vehicles (AVs) are one of the largest innovations in transportation research [1], with private automated cars envisioned as the future of passenger transport, promised to reduce traffic congestion [2] and increase traffic safety [3]. In the past decade, several studies have investigated the opportunities and implications of AVs for the private sector, focusing on travel behavior research, network design, cost/benefit analysis and infrastructure development (examples can be found in [4], [5], [6], [7]).

The public transport sector has already seen an introduction of automation technologies in its daily operations. Rail-bound transport systems are the pioneers, due to the controlled Operational Design Domain (ODD), with separate infrastructure and/or prioritized intersections [8]. In train operations, first pilots are taking place with the implementation of the ERTMS, the European Rail Traffic Management System (for a detailed explanation the reader can refer to [9]). On the other hand, metro operations have been driverless already for a long time (like the Lille Metro Line A in France, autonomously operated since 1983), with nearly all new metro lines designed to be fully automated without any attendant in the vehicle. For road-bound automated public transport systems, tests and pilots have started to take place in the form of automated buses and driverless shuttles [10], [11]. Driverless shuttles, sometimes referred to as shared automated vehicles (SAVs), are a completely automated road-based means of transport equipped with

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automation level 4, usually small in size and capacity, with a low operating speed and with no (regular) possibility for the user to engage in any of the driving tasks [11]. According to the definition of automation levels proposed by [12], vehicles equipped with level 4 are capable of ODD-specific driverless operations and are designed without user control features, such as braking, accelerating, steering and transmission gear selection input devices. For level 4, the ODD is limited to permitted areas within which the vehicle is designed to function, with specific traffic and road characteristics and environmental, geographical, and time-of-day restrictions.

Driverless shuttles are mostly operated as pilots and demonstrations [11], and often research is linked to these pilots to test vehicles technical capabilities and to measure passenger reaction and willingness to use [10], [13]. So far in Europe, 118 demonstrations were performed starting from 2004 and some more are planned for the upcoming years. Countries outside the European Union have also performed many tests and pilots involving driverless shuttles, mostly within corporate campuses [14]. Notwithstanding this substantial amount, only a few fully operative driverless shuttle systems have been integrated successfully into a public transport service (e.g., the Rivium ParkShuttle in Rotterdam). This means that most of the envisaged advantages, such as flexibility, cost reductions, decreased congestion, and reduction of traffic accidents, cannot be proven yet. Although pilots have not shown the aspired capabilities of driverless shuttles yet, it is nonetheless interesting to analyze the potential of these vehicles operated within a public transport system.

This study focuses on the deployment scenarios of driverless shuttles serving the first- and last-mile connections of main public transport lines. The concept of a feeder transit service was already introduced by [15] as a system that supports a main public transport line to increase accessibility. Following the work of Li and Quadrifoglio, further studies were recently conducted, extending the concept of feeder transit services to automated buses [16]. Based on the idea of using driverless shuttles as a feeder transit service for first- and last-mile operations, and considering the limited amount of such systems currently operating, with this study we aim to answer the following research question: What are the potential deployment scenarios involving driverless shuttles for first/last mile connections in a public transport network? To serve this purpose, we created a set of potential future deployment scenarios using a four-step approach. First, the scenario field is identified, with the definition of the problem statement and the research area. Second, key factors are defined based on a literature study. Third, key factors that support the future integration of driverless shuttles are analyzed through a stakeholder survey, in which experts in the field of transport define possible development directions. Fourth, survey respondents combine these factors to create plausible future scenarios.

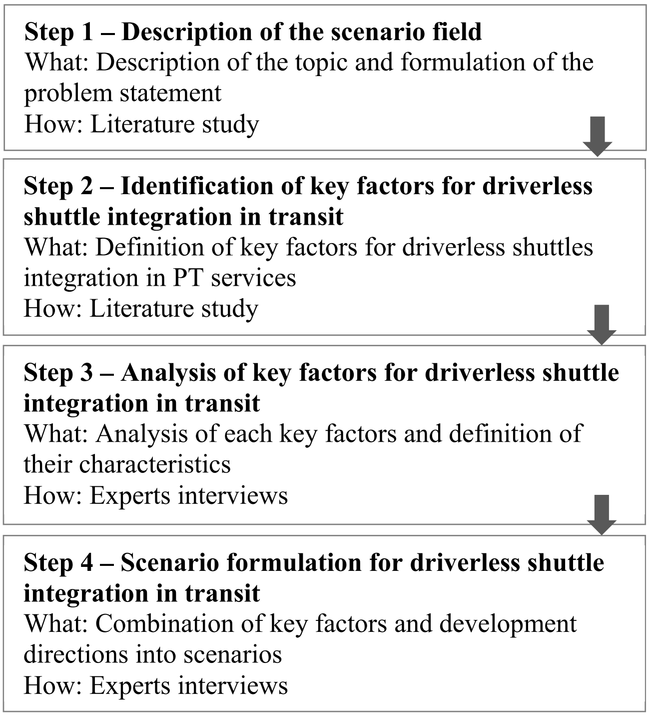
The remainder of this paper is organized as follows: Section II displays the methodology used for the scenarios formulation. Results are provided from Sections III–VI. Section VII provides a discussion of the methodology used and the obtained results and a contextualization within previous studies. Section VIII elaborates a conclusion of this study and directions for future research.

## II. METHODOLOGY

The main goal of this study is to formulate a set of deployment scenarios for the introduction of driverless shuttles as a first/last-mile option in multimodal trips. In this set of scenarios, driverless shuttles are included in the daily operations of public transport systems and function as an access and egress complement of main transit lines.

Scenario formulation, and the subsequent step of scenario analysis, are some of the most powerful tools to assess emerging transport modes like driverless shuttles. An understanding of the possible future of technology and operations is of the utmost importance to help develop policies and integration strategies, as well as to support planning, design and operations. Techniques for designing a proper set of scenarios are numerous and are based on the functions and goals that are to be achieved, the available data (qualitative and/or quantitative) and the basic assumptions from which the process begins. According to [17], three main scenario techniques are defined: trend analysis, systematic-formalized analysis and creative-narrative analysis. In the trend analysis, future developments are based on the extrapolation of existing situations. In the systematic-formalized analysis, key factors are defined, analyzed and combined in such a way that future situations are gathered in a wide scenario funnel, from which different scenarios are generated. Lastly, in the creative-narrative analysis, future developments are based on creative techniques, intuitions and implicit knowledge. For the specific nature of this research, the systematic-formalized analysis is chosen. This choice is based on the fact that driverless shuttles are a new transport mode, which do not have extensive previous research and developments, and which implementation depends on several adopting factors (i.e., key factors) and their mutual combination.

For the scenario formulation, several approaches are found in the literature, among which are the step-wise approach from [18], the sequential step for AVs scenarios from [19] and the general five-phase scenario formulation from [17]. The aim of our study fits the first step of Milakis's approach, the identification of key factors and driving forces. Kosow's approach continues with the analysis of the aforementioned key factors to lead to scenarios generation and scenario transfer. The scope of this research is limited to the formulation of future scenarios and not to the further application and processing of scenarios, as mentioned in the scenario transfer phase of Kosow's methodology. It was decided to combine the two approaches of Milakis and Kosow, to generate this four-step procedure that best fits our research question: 1) description of the scenario field, 2) identification of key factors and driving forces that support the future integration of driverless shuttles, 3) analysis of these key factors and development directions, 4) formulation of scenarios. An overview of the research methodology can be seen in Figure 1.



**Step 1 – Description of the scenario field**
What: Description of the topic and formulation of the problem statement
How: Literature study

**Step 2 – Identification of key factors for driverless shuttle integration in transit**
What: Definition of key factors for driverless shuttles integration in PT services
How: Literature study

**Step 3 – Analysis of key factors for driverless shuttle integration in transit**
What: Analysis of each key factors and definition of their characteristics
How: Experts interviews

**Step 4 – Scenario formulation for driverless shuttle integration in transit**
What: Combination of key factors and development directions into scenarios
How: Experts interviews

**FIGURE 1.** Methodology for scenario formulation. Based on [17] and [19].

For the description of the scenario field and the identification of key factors and driving forces, a literature review approach is followed, using the most common searching websites such as Google Scholar and Scopus. The research was restricted to studies published between 2016 and 2021, peer-reviewed and published in English. The choice of the time span is based on the observation that in Europe the number of pilots and tests regarding driverless shuttles has considerably increased starting from late 2015 and early 2016 [10]. Articles containing any combination of the following keywords in their title, abstract or keywords were considered for the review: Driverless Shuttle, Shared Automated Vehicles, Self-driving Vehicles. The words automated and autonomous were treated as synonyms, and searches were performed with British English spelling. To narrow down the review, the keywords travel behavior, network design, cost analysis, willingness to share and willingness to pay were subsequently added. Besides peer-reviewed articles from Scopus, additional searches were performed using Google and Google Scholar Web pages as a result of backward and forward snowballing, for which the search criteria were extended regarding the publication year and the peer-reviewed prerequisite.

For the analysis of key factors and driving forces, a survey is prepared and specifically tailored for experts in the field of transport and stakeholders. When designing the questions, the following target groups were considered: public transport operators, autonomous shuttles operators, autonomous shuttles manufacturers, government authorities, consultancy firms and researchers. The survey was shared via email to research partners and transport operators (Keolis Nederland, HTM Personenvervoer and members of the STAD project [20]) and via LinkedIn to reach a broader and international audience. To underline potential trends and patterns among different categories, respondents were filtered based on their self-declared level of knowledge on the technology (ranked from 1 – not at all familiar, to 5 – completely familiar) and on their background and expertise. The survey was created using Google Form. Questions were formulated based on the factors and driving forces identified in the literature review and are presented in Section IV.

## III. DESCRIPTION OF THE SCENARIO FIELD

The first step of the scenario building process concerns the description of the scenario field, with the formulation of the problem statement based on the identification of research gaps. For this phase, a literature review was performed, with the searching criteria described in Section II. The analysis focused on practical research findings and results from pilots and tests implementations, aiming for an understanding of what are the links between operational characteristics and future integration of driverless shuttles into public transport networks.

Driverless shuttles are vehicles designed to be operated exclusively by a level 4 or level 5 automated driving system (ADS), with a relatively low operational speed (between 15 and 25 km/h), small passenger capacity (usually 8 to 12 passengers) and designed without users interfaces, such as braking, accelerating, steering and transmission gear selection input devices. When performed with a level 4 ADS, operations can be carried out within a geographically prescribed area or on all mapped roads, where passengers are picked up and discharged along a specific route. In the case of a level 5 ADS, no operational restrictions are in force [12].

In this study, scenarios concern the use of driverless shuttles for first- and last-mile operations in multimodal trips. As the name suggests, multimodal trips are defined as trips being performed with more than one mode. For public transport, three different stages are usually observed: access, main part and egress [21]. The access and egress parts serve as a complement to the main mode, in which passengers travel to and from bus and rail stops. Application cases involving driverless shuttles for first- and last-mile trips are restricted to pilots and test demonstrations, with research conducted on the technical capabilities of vehicles and on passenger willingness to use. Oftentimes, these pilots are not supported by any research and performed only as showcases. Therefore, it is important to understand the links between behavioral aspects, operational characteristics and implementation strategies, so to promote the integration of driverless shuttles into public transport operations.

### A. BEHAVIORAL ASPECTS

The reviewed articles were mostly based on stated-preference choice experiments, linking explanatory variables (or predictors) to the (choice) behavior of users, expressed in response variables. Referring to the MAVA model proposed by [6], we gathered insights on driverless shuttle acceptance based on socio-demographic characteristics and travel behavior patterns.

Past research focused on the willingness of travelers to use automated vehicles and the likelihood to switch to automation once the technology is ready (examples can be found in [4], [5], [6], [7]). Several studies linked the intention to use driverless shuttles to socio-demographic characteristics of potential users, such as age [21], [22], [23], [24], [25], [26], [27], [28], [29], gender [21], [22], [29], [30], [31], [32], [33], [34], [35], [36] and income level [22], [23], [26], [30], [32], [36]. According to the reviewed articles, a target user group of medium/high-income individuals between 26 and 65 years of age is identified, with no substantial differences between male and female travelers.

For what concerns travel behavior and willingness to share a driverless shuttle, stated preference studies show that potential users would mostly use the new shared service for commute trips home-work and vice-versa [37], [38]. The prospect of sharing such a small vehicle (considered smaller than a traditional bus but with enough capacity to potentially share a trip with strangers) is somehow controversial, with different studies focusing specifically on the willingness to share a driverless shuttle. According to qualitative interviews conducted by [25], 59% of respondents would prefer to own an automated vehicle, meaning that only 41% prefer to share one. This distinction was made between owned and shared automated cars and not automated shuttles per se, so it is not fully representative of people preferences towards driverless buses. More positive results were found by [33], who investigated the likeliness of using driverless buses amongst members of the Norwegian Automobile Federation. More than 56% stated that they are somewhat likely or very likely to use a shared automated shuttle in the future, especially in combination with other public transport modes. When asked about their expectations regarding driverless buses benefits, 58% of respondents agreed that shared automated vehicles will increase mobility for the elderly and people with disabilities, 50% agreed on fewer cars in traffic and pollution and around 30% recognized possible fewer traffic accidents and shorter travel time. This is in line with several studies linking the provision of automated shuttles as a first/last-mile solution with an increase in accessibility and inclusiveness (examples can be found in [27], [39], and [40]).

### B. OPERATIONAL AND INTEGRATION STRATEGIES

The literature study continues with a review of the different operational and integration strategies that could lead to the implementation of driverless shuttles into public transport services. For this purpose, operational characteristics were included in the analysis, with aggregating factors such as potential areas of usage, impact on traffic congestion, travel time and travel costs, presence of personnel in the vehicle and service type and driving context.

Many studies on automated vehicles and driverless shuttles focus on the impact that these vehicles could have in urban areas, underlying the benefits in terms of congestion and pollution [27], [34], [41]. The report of Roland Bergen from 2018 suggests a change of perspective [42]. They push for more research on the use of automated public transport feeders in rural environments, envisioning a great contribution to mobility, helping elderly, young and physically impaired people to access public transport. A survey conducted for the website Accenture shows that in Europe, 42% of people would consider moving from urban to suburban or rural areas in case that their daily commute would be eased with the introduction of automated public transport services [43]. Therefore, they suggest paying more attention to suburban and rural areas, and evaluate their potential for the integration of automated public transport services. This line of reasoning is also shared by [33], who suggested that research should focus on the market potential of driverless shuttles in rural areas, and by [44], who predicted that rural areas could profit more from an automated public transport system compared to urban areas.

For a feeder transit service, two types of operation have been discussed in recent literature: either an on-demand system or a fixed-schedule system. On-demand systems, sometimes also called demand-responsive systems, are operated based on the requirements of their users, with the possibility to book a trip without adhering to a specific timetable. Fixed-schedule systems, on the other hand, operate as a traditional bus system, with a predefined timetable. Benefits of on-demand systems such as improved mobility and lower generalised journey time [45] have been contrasted with some limitations due to demand density and size of operational areas [16]. On-demand systems are better deployed when combined with door-to-door services, a business model that otherwise could not be implemented in a fixed-schedule system. Based on the work of [15] and [46], the research of [16] studied the performances of a feeder transit service operated with automated vehicles, comparing an on-demand door-to-door system with a fixed-route system. Based on their model, a fixed-schedule system proved to be more efficient on average. They also set the conditions for on-demand systems to have a better impact compared to fixed-schedule: low hourly operating unit costs, small areas of service, short trip lengths and high value of time, with a demand density threshold of 1000 pax/km$^2$ h. These results suggest that the choice of the service type is highly related to the driving context and its costs, i.e., whether the shuttles are operated in urban or rural areas, on which type of infrastructure and under which type of supervision.

Almost all the pilot demonstrations conducted so far had personnel on board (oftentimes called *stewards* or *operators*), replacing some of the tasks that drivers have on traditional buses. Their role is to guarantee passengers' safety inside the vehicle but also traffic safety at crossings and in the case of a vehicle's malfunction they are responsible for the emergency brake procedure. Studies regarding operational costs [21], [34], [35], [47], [48] have shown that the cost savings are maximized when vehicles are remotely supervised from a control room, and therefore no personnel is present on-board. On the other hand, studies regarding trust in technology and willingness to share [21], [24], [35], [47] linked to the presence of on-board personnel [34], [49], [50], have brought some drawbacks of remotely supervised driverless shuttles – e.g., lack of trust on vehicle technology and perceived safety [51], low willingness to share and fear of not having an on-board operator.

Based on the review of existing pilot projects, some operational issues were found, in relation to the challenges of this new feeder system. Some examples are reported in [52], which pointed out the issues of vehicle capacity connected to different demand patterns, the possible disruption of the current public transport service, the complex routing and operational constraints related to different network designs. Another important challenge is defined in [53], regarding the difficulties of coordinating a driverless shuttle system with a bus or train schedule, because of the different speeds of the vehicles.

### *C. RESEARCH NEEDS*

Although much research has been performed concerning the behavioral aspects of driverless shuttle adoption, this study aims to formulate future deployment scenarios and understand how to fit this new service into a public transport system from an operational perspective. Therefore, we decided to focus on the research needs in terms of operational and integration strategies, taking into account the impacts that this new service might have on public transport services. In support of this, the findings from [54] suggest that the current threats to a successful driverless shuttle system are not so much related to passengers' willingness to use but rather to technological and operational challenges, with the open question of how to integrate this feeder transit service in the existing urban mobility.

What results from the literature study is the need for further research on the application areas, focusing on the different strategies for urban, suburban and rural areas. Moreover, a detailed analysis on the service type should be conducted, with particular attention to concepts like on-demand, door-to-door, fixed-schedule and fixed-routes systems. Consequently, operational decisions should be coupled with adequate infrastructure design, to evaluate the feasible combinations of service types and infrastructure configuration. Based on the inventory of existing pilots [10], one can notice that they were mostly operated on dedicated infrastructure. Oftentimes, local arrangements provide designated lanes, fully independent tracks or dedicated spaces for the pilot projects, which might not be the case for fully-fledged systems operating in mixed environments. Although there is some literature regarding the different infrastructure configurations, most information can be found on websites or scientific outputs not subjected to the peer review process, underlying a need for proper scientific research on the topic. Lastly, as deduced from the conclusion of [16], studies on the different operational strategies should also include analysis on the type of supervision, which is one of the main components of the operating costs.

This first step of scenario formulation concludes with a description of the main system components (driverless shuttles, multimodal system, first/last-mile operations) and with the formulation of research gaps based on the literature review of relevant research. These gaps are then used in the next step to identify key factors and their possible development directions.

## IV. IDENTIFICATION OF KEY FACTORS AND DEVELOPMENT DIRECTIONS FOR DRIVERLESS SHUTTLE INTEGRATION IN TRANSIT

The second step of scenario formulation builds on the findings of the literature study. Key factors for driverless shuttle integration in transit are identified based on the research needs previously formulated. For each of them, possible development directions are defined.

The *first knowledge need* relates to the application area of driverless shuttles, distinguishing between urban, suburban and rural areas. In association with this first aspect, the following key factor is formulated:

a) Area of operation: given the operational features, where is it best to operate a driverless shuttles service? Urban areas to improve mobility, reduce congestion and decrease waiting time or rural areas to improve accessibility and enhance public transport connection?

The *second knowledge need* concerns the operational characteristics of a driverless shuttle service, specifically related to the differences between on-demand and schedule-based operations. Related to these aspects, the following key factor is formulated:

b) Service type: what are the best operational conditions on which a driverless shuttles system should be operated, concerning traditional schedule-based operations and on-demand operations?

The *third knowledge need* relates to the personnel inside the vehicles and how their absence or presence can affect driverless shuttles integration. In association with this aspect, the following key factors are formulated:

c) On-board personnel: what is the role of personnel inside the vehicle? Under which conditions would it be possible to operate a fully automated driverless shuttle without the presence of an on-board operator?
d) Control strategies: how to guarantee that the vehicle works as expected? What are the different strategies concerning both personnel aboard and remote control supervision?

The *fourth knowledge need* is about the strategic infrastructure design, linked to the decisions about the best infrastructure configuration (e.g., mixed or dedicated lanes) and the consequences of allowing for interactions with other manually driven vehicles. On this matter, the following key factors are formulated:

e) Strategic infrastructure design: considering several points of view (e.g., passenger safety, infrastructure investment and service integration), which is the optimal strategic infrastructure design between a mixed infrastructure and a dedicated lanes configuration?
f) Vehicle characteristics: what are the features of driverless shuttles that are most important when used in a fully operational system?

In this study, the term dedicated infrastructure refers to a system operated on a segregated space, with limits defined either with physical barriers (e.g., flowerbeds) or with road signage. Interactions with other road users are avoided or limited to specific categories (e.g., when shuttles are operated on bicycle lanes, as seen in previous pilots [10]). Examples of dedicated infrastructure can be found in many pilots [10], operating on enclosed campuses or bicycle infrastructure. An example of a fully-fledged system operating within a dedicated infrastructure is the Rivium ParkShuttle operating in Rotterdam, The Netherlands. It has a dedicated route that works with its own right-of-way, allowing for safe crossings with cars, cyclists and pedestrians.

## V. ANALYSIS OF KEY FACTORS AND DEVELOPMENT DIRECTIONS FOR DRIVERLESS SHUTTLE INTEGRATION IN TRANSIT

To analyse the key factors for scenario development, a survey was created, specifically tailored for experts in the field of transport. The survey was designed according to the factors identified in the literature review and listed in Section IV, and was based on the following assumptions:

a. Vehicle automation technologies have developed to such an extent that it is possible to guarantee safe and reliable driverless shuttles operations;
b. Policymakers have agreed to a set of regulations that allow the integration of driverless shuttle into public transport services, with the possibility to choose between on-board and remote supervision;
c. Prospective passengers have acquired a certain knowledge of vehicle automation technologies, with the growing market of automated cars and the extensive pilots and demonstrations of driverless shuttles.

The formulation of the aforementioned assumptions is important to set the framework in which the questions are formulated. The survey was not intended to assess the technical feasibility of a driverless shuttle system, but rather to identify and assess potential *what-if* situations.

Being the survey intended for experts in the field, the first questions related to their level of expertise, their current role and how it is related to the transport sector. Even though the survey was carried out anonymously, this first part allowed for the categorization of respondents with different knowledge and expertise, to understand the needs and interests of different categories. Of the total 24 respondents (N = 24), more than 96% stated that they are familiar or completely familiar with the concept of automation technologies and driverless shuttles. Respondents' background was somewhat heterogeneous with the vast majority belonging to research institutes (42%), government authorities (25%) and consultancy firms (17%) followed by public transport operators, autonomous shuttles manufacturers and operators and independent networks for smart mobility (Figure 2).

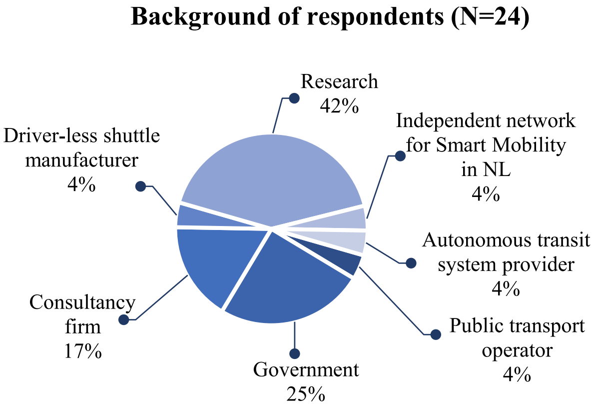


**FIGURE 2.** Background of survey respondents (N=24).

After the first round of questions about their background, respondents were asked to identify potential barriers and drivers that might hamper or boost driverless shuttles adoption. This part is relevant for identify weak points and strong points of driverless shuttle systems, so to improve the formers and leverage the latter. Respondents were faced with five characteristics of a hypothetical driverless shuttles service and had to define whether these characteristics were perceived as a barrier or a driver for the future implementation of the system. The decision of which characteristics to include in the survey was based on literature and previous pilots. The following aspects were considered:

- *Remote supervision:* According to [50], the operational costs of self-driving buses are almost four times smaller than the operational costs of traditional buses. These cost savings are only achieved in case that all human driving costs can be saved, otherwise, if a steward is present on board, operational costs can be twice as high.
- *Low fares:* The lack of personnel inside the vehicle (in the form of drivers and/or supervisors) might reduce ticket fares and subscriptions, and make a driverless shuttle service an attractive feeder transit system.
- *Shared vehicles:* Past research focused on the willingness to share a driverless shuttle for commute and leisure activities [21], [24], [35], [47]. Some may

argue that public transport is already shared, therefore what stands for a traditional bus should be valid also for an automated minibus. But driverless shuttles are a new, automated means of transport, with no personnel on board to check the safety of passengers inside the vehicle. Consequently, some concerns have been raised concerning the willingness to share this transit service.

- *Low operational speed:* Due to technology and policy limitations, driverless shuttles are now allowed an average operational speed of 15 to 25 km/h. Past research showed some conflicting results on this topic. On one hand, the low speed is seen as a hindrance to the integration of driverless shuttles, perceived as being too slow compared to other vehicles and not enough to compete with other active modes like cycling. On the other hand, surveys among users have shown that passengers feel comfortable and safe inside an automated shuttle partly because of its slow speed and therefore might encourage more people to use the service [55], [56].
- *Automation level 4:* Driverless shuttles are equipped with L4 automation technology, an innovation not yet implemented in private vehicles. Consequently, it is worth investigating whether this might be perceived as a barrier or a driver to a driverless shuttle integration.

The biggest driver for shuttles adoption is the possibility of reducing fares due to the lack of personnel inside the vehicle, followed by the automation technology itself, which, according to the respondents, are believed to be an attraction for potential users. Respondents working in consultancy firms overall feel that the fact that the vehicle is shared and the possibility of reducing fares have the highest market potential and could therefore be the main driver for implementation. Members of government authorities agree with the benefit of low fares, which may attract more users and therefore define a useful service. Respondents from research institutes also agreed on the importance of low fares but did not allocate the shared nature of the vehicles within the drivers cluster. A reason behind this is that researchers have first-hand experience in travel behavior research, which for the past years has pointed out that passengers tend to prefer not to share small confined spaces. This result could have also been biased by the current pandemic situation of COVID-19, which increased the reluctance of sharing public vehicles.

The highest barrier for driverless shuttles adoption is the low operating speed of vehicles, which in most cases it is not greater than 15∼20 km/h. The possibility of remote supervision (i.e., without a human operator on board) produced mixed responses, with members of consultancy firms seeing it as a barrier, researchers seeing it as a driver and the government authorities feeling neutral towards it.

Following this set of general questions, the remaining part of the survey focused on the key factors elaborated in Section IV. Results are provided in the following paragraphs.

### A. KEY FACTORS ANALYSIS

#### 1) TYPE OF VEHICLE FOR A DRIVERLESS SHUTTLES SERVICE

The survey continued with an analysis of the different types of vehicles that have been used so far in pilots and demonstrations. The inventory of pilots from [10] showed that the most used vehicles are the Navya Arma from the Navya company, the EZ10 from EasyMile, the GRT vehicle from 2GetThere and the Olli from Local Motors. Respondents were provided with information about the vehicles capacity, autonomy, operational and maximum speed and purchase and operational costs. Information was retrieved from vehicles websites and technical reports [13], [57], [58], [59] and are updated as of November 2020. Subsequently, respondents were asked which of these vehicles has the highest potential to be integrated into a public transport system as a first/last-mile option and to motivate their choice. According to the respondents, the most important characteristics to consider when selecting a vehicle were vehicle capacity, operational speed and the number of previous experiences and test operations. Members from consultancy firms and government authorities value more the capacity and operational speed of the vehicles, together with the total costs of ownership. Researchers, on the other hand, opted for the vehicle brand with a more realistic combination of technological advancement and the trustworthiness derived from the many and diverse test operations.

#### 2) ON-BOARD PERSONNEL AND CONTROL STRATEGIES

As the type of supervision, respondents were asked to rate some statements based on the extent to which they agree with them. Although the vast majority (75%) agreed that the presence of an on-board operator increases passengers' sense of security, they also agreed that for the correct functioning of the vehicle, it is not always mandatory (63%) and that passengers would be willing to use a driverless shuttle system even if an operator is not present on board (83%). As for the different business models with or without on-board personnel, the vast majority (67%) chose the option of having a mandatory operator present only during the first few months of operations, to let users get properly acquainted with the new automated service. The remaining 33% opted for a business model without an operator since the very beginning, meaning that no respondent indicated that on-board personnel should be made mandatory for the whole duration of the operation. Concerning the different backgrounds of respondents, members from consultancy firms and government authorities were slightly more prone to implementing a remotely supervised compared to members from research facilities, due to the prospect of reduced costs.

For the different control strategies, the option of not having on-board personnel was investigated. In the case that an operator is not in the vehicle, other strategies must be applied to guarantee passenger safety and the correct functioning of the vehicle. One solution proposed in the survey was to use

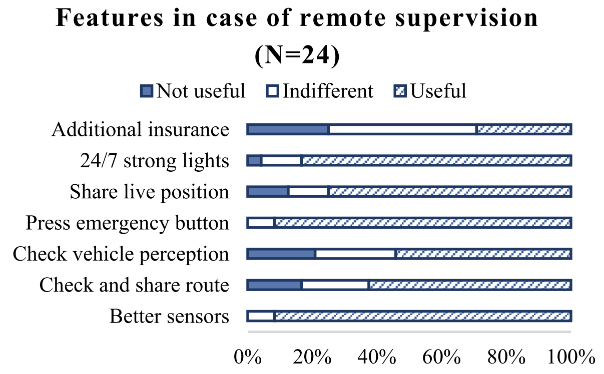


**FIGURE 3.** Features to be included in a remotely supervised service according to the panel of experts (N=24).

a control room in which an operator can remotely control one (or more) vehicles. Figure 3 shows the features that can be included in a driverless shuttles system in case of remote supervision from a control room and thus without any personnel aboard the vehicles. The introduction of better sensors was the one voted most useful together with the introduction of an emergency button which passengers can press to stop the vehicle and call the authorities in case of accidents and/or dangerous situations. For both features, only a few respondents proved to be indifferent to it and no respondent rated it as not useful. The introduction of strong lights inside the vehicle was also rated useful by many respondents, believed to increase passengers' sense of security, especially during nights trips. Respondents found useful also the possibility to check the live position of the vehicle using a specific app and the option to share this position with other people, to increase somehow perceived safety. Although fourth for usefulness, the live sharing position of vehicles met some sceptical respondents, who rated it as indifferent or even not useful. The possibilities for passengers to check the planned route and to check how the vehicle perceives the environment and to communicate eventual mismatches observed showed mixed answers, with half respondents leaning towards their usefulness and the other half ranking them as indifferent or even not useful. Lastly, the least useful feature was found to be the possibility of including, upon payment, extra passenger insurance for the duration of the trip. More than 70% of respondents found this extra insurance indifferent or not useful, with some claiming that additional insurance is not necessary, since oftentimes the operator is already liable for any harm caused to passengers.

### 3) AREA OF OPERATION

Respondents had to choose between different application areas (urban, suburban, rural) and come up with the benefits and challenges of a driverless shuttles system operated in each environment. Results showed that 75% of respondents believe urban areas to be more suited for this type of operations, 17% prefers rural areas and the remaining 8% is in favor of synergism of implementation in both areas (Figure 4).

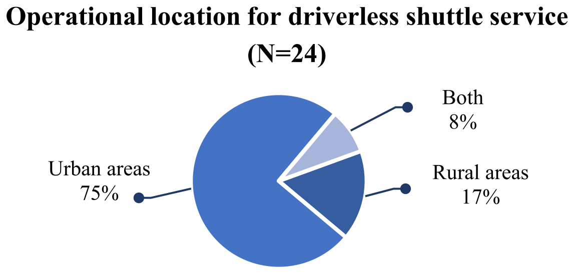


**FIGURE 4.** Preference for the operational location according to the panel of experts (N=24).

According to respondents, the main benefits of integrating driverless shuttles in urban areas were found to be a more flexible service with increased accessibility, especially for disabled people and elders. Respondents agreed that offering a first/last-mile automated minibus service in densely populated areas might become an attractive alternative to cars, leading to a mode shift towards public transport and a consequent congestion reduction and fewer accidents due to human errors. The integration of such a system in urban areas was also found beneficial in terms of costs, believed to provide a strong business case with reduced costs, more users and cheaper vehicle/km and seat/km ratios when assumed to be implemented in a mixed traffic configuration. Challenges appointed by the respondents concerned mainly the complicated traffic situation of urban areas and how to integrate an efficient multimodal node in an already sophisticated and intricate public transport system. Another challenge linked to urban areas was social safety, with some respondents saying that a highly utilized system might lead to potentially risky situations, especially at stops. Due to the low speed of vehicles, respondents identified a potential user target in the people that are currently traveling using active modes (i.e., walking and cycling). A driverless shuttle system in an urban area that attracts pedestrians and cyclists provides increased comfort in poor weather conditions, offers a valid substitute for those trips that would require a long-distance walk or a medium/long-distance cycle and presents a good alternative especially for the egress part of the trip (for which a bicycle is not always available). Some respondents, however, used the same arguments to question the attractiveness of driverless shuttles, as they felt that the competition of walking and cycling is (too) strong, especially when the vehicle speed is below 20 km/h. For the 17% who believe that a driverless shuttle system should be operated in rural areas, the main benefit was the increased accessibility and connections to the existing public transport lines, especially for the elder population. The increased connection is also believed to enhance the liveability of rural areas. Among other benefits, respondents pointed out how the low capacity of vehicles might be a perfect combination with the lower demand (in comparison with urban areas) and how it might be easier from a technical point of view to implement this system in remote areas rather than in densely populated areas. The low demand of rural areas was also identified as a potential challenge, with a lack of ridership leading to many empty trips, low revenues and the need for public grants. Other challenges related to rural areas related to the combination of low speed and long-range trips. Respondents argued that in rural areas first- and last-mile trips have usually a longer range compared to their urban areas counterparts. Providing a system with a low operational speed might not be attractive for users, who have to face longer trips. The longer ranges and longer trips pose also the problems of how to optimally distribute charging stations and how to provide reliable operations

### 4) TYPE OF OPERATION

For what concerns the types of operation, respondents were provided with two options: a fixed-schedule system and an on-demand system. The vast majority (67%) preferred the on-demand system (Figure 5), saying that it combines higher flexibility with a more personalized approach, increasing thus the willingness to use and creating a new market of on-demand automated systems. Although the many benefits of on-demand systems, challenges were identified in the fleet management, the complexity of the system and digital literacy (e.g., for the use of online booking operations). On the other hand, 33% of respondents opted for a traditional schedule-based system, valuing its predictability, simple logistics, reliability and possibility of synchronization with higher levels of the public transport network. Challenges for the schedule-based system were identified in the possibilities of denied boarding (especially in urban areas and/or during peak hours) and empty rides (in rural areas and/or during off-peak hours) and the lack of flexibility.

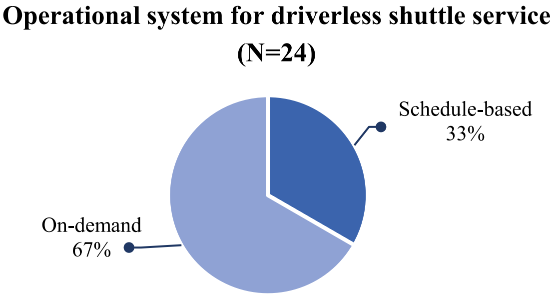


**FIGURE 5.** Preference for the operational characteristics according to the panel of experts (N=24).

Similar responses were identified across the respondents' backgrounds, with members of research facilities being slightly more in favor of schedule-based systems compared to members of consultancy firms and government authorities.

### 5) STRATEGIC INFRASTRUCTURE DESIGN

To elaborate on the best strategic infrastructure design, respondents were asked to rank different parameters that could potentially be relevant when deciding upon infrastructure changes. Figure 6 shows the results according to survey respondents. The safety of road users proved to be the most important parameter, with all respondents rating it as important. Integration with existing infrastructure and cost savings are the second and third most important parameters with only 8% and 16% of respondents respectively saying that they do not contribute to the decisions concerning strategic infrastructure design. Potential profit generated mixed responses; although the majority rated it as an important parameter in strategic infrastructure decisions, 25% considered it neutral and 17% not important. The least important parameter is the innovation and technological aspect, rated as neutral or not important by almost 70% of respondents. Respondents from different backgrounds gave similar answers for each factor, with members from consultancy firms and government authorities attributing slightly more importance to cost savings, potential profit and innovation, suggesting that they are looking for a profitable, attractive and new market for automated public transport.

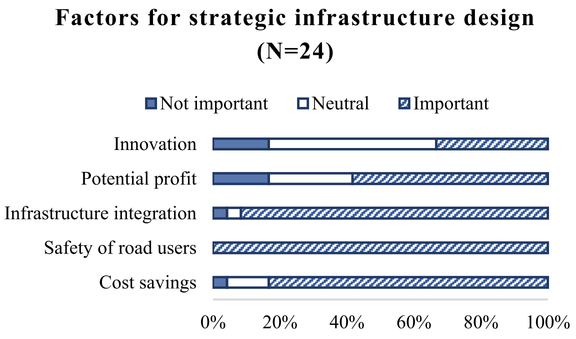


**FIGURE 6.** Relevance of factors for strategic infrastructure design according to the panel of experts (N=24).

For what concerns the different types of infrastructure design, two options were given: a mixed infrastructure configuration or a dedicated lane configuration. The first allows driverless shuttles to travel in the same lane like any other manually driven vehicle. The second restricts the operations of driverless shuttles to dedicated lanes, separated from other vehicles avoiding any possible interaction. From the results (Figure 7), one can see that there is a clear predisposition towards a mixed infrastructure configuration, with around 70% of respondents preferring the idea of driverless shuttles sharing the road with other (motorized) users. The arguments in favor of a mixed infrastructure configuration concerned mainly the lower costs and investments required, with no or little infrastructure changes needed and the flexible route allocation in the existing system. Flexibility was also a big benefit in terms of disruption management, with shuttles able to be reallocated in a different lane in case of accidents or congestion.

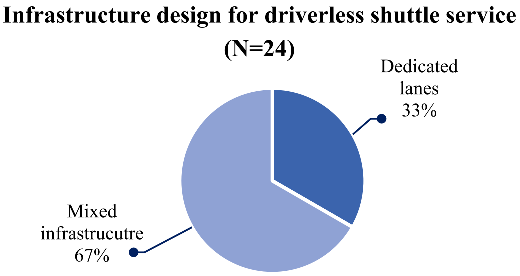


**FIGURE 7.** Preference for the infrastructure design according to the panel of experts (N=24).

The main challenges of mixed infrastructure were the collaborations and interactions with other road users, with many respondents finding it hard to guarantee security especially for more vulnerable users such as pedestrians and cyclists. Safety and security, on the other hand, were classified as benefits in favor of a dedicated lane configuration. With very limited interactions, vehicles can travel at a higher speed increasing their usage potential, guaranteeing at the same time safety for passengers and other road users. To ensure this increased safety though, heavy investments are necessary. The majority of respondents found indeed challenging to create a solid business case around dedicated lanes, with many challenges arising. Among the most cited challenges, there was space allocation, seamless integration in the existing environment, delays at intersections, low flexibility in case of disruptions, difficulties to scale up the system in an effective way and further segregation of road users.

### *B. DEVELOPMENT DIRECTIONS*

In this first part of the survey, stakeholders were asked to analyze the key factors. The results provided some insights in terms of supervision strategies, location areas, operational characteristics and infrastructure design, defining what will be, according to experts' opinion, the development directions of the selected key factors (Table 1).

**TABLE 1.** Key factors and selected development directions according to the panel of experts (N=24).

| Key factor | Selected development direction |
|---|---|
| Supervision | Remote supervision, with a business model that includes on-board operators for the first months of operations |
| Location | Urban areas |
| Operations | On-demand with booking options |
| Infrastructure | A mixed environment with shuttles sharing the lanes with other road users |

## VI. SCENARIO FORMULATION FOR DRIVERLESS SHUTTLE INTEGRATION IN TRANSIT

In the previous step, respondents have defined the most likely development direction for each of the factors. However, not all combinations might lead to a feasible service (e.g., a door-to-door system on dedicated lanes might be unfeasible in certain areas). This fourth and last step aims to evaluate the potential market for driverless shuttles and understand the trade-offs in terms of operations and infrastructure design.

Stakeholders were presented with three different situations in which one attribute was fixed and the others were open to stating a preference. Then, based on the preference distribution, final scenarios were derived. The three different design dimensions proposed in the survey are created based on the key factors identified in Section IV, and involved type of supervision, type of operation and type of infrastructure. The scenario situations proposed in this step are formulated based on the assumptions made for this specific study.

### *A. SCENARIO SITUATIONS*

#### 1) REMOTELY SUPERVISED VEHICLES

For the first case, it was proposed a situation in which vehicles are remotely supervised from a control room. The assumption is that there is no operator/steward in the vehicle during the trips and vehicles are remotely supervised from a control room. Table 2 shows the distribution of preferences for this first proposed situation. Respondents are highly in favor of integrating a driverless shuttles system with remote control supervision in urban or suburban areas (74%) using dedicated lanes (61%). Respondents justified the choice of dedicated lanes saying that they expect this infrastructure configuration to be safer and therefore more appropriate for vehicles running without an operator on board. For the operational characteristics, respondents were slightly in favor of fixed operations (48%), having thus a predefined timetable and route to follow, whereas 39% preferred on-demand operations and 13% opted for a combination.

**TABLE 2.** Preference distribution in case of remotely supervised vehicles, according to the panel of experts (N=24).

| Operations | | Infrastructure | | Area | |
|---|---|---|---|---|---|
| Schedule | 48% | Dedicated | 61% | Urban | 74% |
| On-demand | 39% | Mixed | 35% | Rural | 13% |
| Both | 13% | Both | 4% | Both | 13% |

#### 2) ON-DEMAND OPERATIONS

The second situation involves on-demand operations, in which vehicles operate on an on-demand basis, with passengers able to book a trip choosing the origin, destination and time slots. Results of the preference distributions are shown in Table 3. The majority opted for a remotely supervised vehicle (70%) operating in a mixed environment (74%). For the area of operation, respondents did not have a clear preference between urban areas and rural areas and saw potential opportunities for on-demand first/last mile operations in both environments.

**TABLE 3.** Preference distribution in case of on-demand operations, according to the panel of experts (N=24).

| Supervision | | Infrastructure | | Area | |
|---|---|---|---|---|---|
| Steward | 21% | Dedicated | 17% | Urban | 43% |
| Remote | 70% | Mixed | 74% | Rural | 35% |
| Neutral | 9% | Both | 9% | Both | 22% |

#### 3) MIXED INFRASTRUCTURE

The third situation relates to the strategic infrastructure design, for which a mixed infrastructure configuration is considered. Small infrastructure investments are assumed and driverless shuttles share the road with traditional manually driven vehicles. Table 4 shows the distribution of preferences for this third situation. Respondents were noticeably in favor of on-demand operations (74%) implemented in urban or suburban areas (74%). As for the type of supervision, results show

**TABLE 4.** Preference distribution in case of mixed infrastructure, according to the panel of experts (N=24).

| Supervision | | Operation | | Area | |
|---|---|---|---|---|---|
| Steward | 43% | Schedule | 17% | Urban | 74% |
| Remote | 48% | On-demand | 74% | Rural | 9% |
| Neutral | 9% | Both | 9% | Both | 17% |

that respondents gave diverse reactions, with 48% preferring remote-controlled supervision against 43% who prefer a steward on board.

### B. TRADE-OFFS AND SCENARIO FORMULATION

From the scenario-making process, one can conclude that on-demand operations are better matched with a mixed infrastructure configuration, whereas fixed operations are paired only in the case of dedicated lanes. In the case of on-demand systems on mixed infrastructure, a fully door-to-door system can be implemented, with customers able to book not only the time slot but also pick-up and drop-off locations. On the other hand, a combination of on-demand and dedicated infrastructure should not be disregarded a priori. A hybrid business model consisting of predefined stops with time slot booking possibilities could provide an on-demand system while keeping the shuttles separated from the other road users.

Respondents agreed that remotely supervised vehicles should be preferred both in the case of dedicated infrastructure and mixed environments, showing that there is no preference concerning the infrastructure design. The trade-off identified by the respondents includes an on-board operator for the first months of operations, to get passengers acquainted with the technology, to switch to a remotely supervised system in the long term. Similarly, for the type of operations, respondents did not decide for one over the other in the case of remotely supervised vehicles.

The choice to operate a driverless shuttle system in urban areas was preferred by most respondents in all the proposed cases. In the case of on-demand operations (situation 2), coupled with remote supervision and mixed infrastructure, the experts' opinion suggests that this business model is applicable both in urban areas and rural areas. This shows that, although an urban service should always be preferred, in the case of a rural service it should be remotely operated, on-demand and on mixed infrastructure.

Based on these trade-offs and the development directions defined in Section V-B, three scenarios are proposed. All scenarios refer to feeder transit services, in which driverless shuttles are used as access and egress components of main public transport lines.

- Scenario A: Vehicles are operated with a fixed-route and fixed-schedule system on dedicated lanes and in urban areas. Vehicles are remotely supervised from a control room, with a business model that includes on-board operators for the first months of operations
- Scenario B: Vehicles are operated with a hybrid on-demand fixed-route system on dedicated lanes and in urban areas. Passengers can book a time slot for their trip but hubs are provided as pick-up and drop-off locations. Vehicles are remotely supervised from a control room, with a business model that includes on-board operators for the first months of operations.
- Scenario C: Vehicles are operated with a fully on-demand system in which customers can book a time slot for their trip as well as pick-up and drop-off locations. Vehicles drive in a mixed environment with other road users in the context of urban areas and are remotely supervised from a control room, with a business model that includes on-board operators for the first months of operations.

## VII. DISCUSSION OF METHODOLOGY AND RESULTS

Driverless shuttles are a system that is scarcely used in public transport, with many pilots and few real application cases, operating in closed environments or under specific conditions. The inventory of pilots from [10] shows that the average route length is between 150m and 1500m, with an average pilot duration of 6 months. As a consequence, all research conducted so far is based on unique assumptions formulated for the specific pilot to which they relate, and all experimental research findings relate to these specific conditions. Moreover, the pilot systems are not fully-fledged systems, but they are rather offered with optimal service, on optimal routes and with great reliability in terms of travel time, scheduling and even in the actual driving tasks. Although commonalities can be found in the results, the research is still at its early stages and it is difficult to provide an accurate picture of how the system will operate in the future, under which circumstances and what passengers' satisfaction will be.

In this study, the used methodology shows some strong points as well as some limitations. The structured approach with which scenarios were formulated, provides a validation of the obtained results. The research gaps found in the literature served as a starting point for the identification and analysis of the key factors. The survey was conducted in such a way that experts in the field of transport had the opportunity to elaborate on possible development directions of a hypothetical driverless shuttle service, resulting in the formulation of three deployment scenarios. However, the survey was designed based on the ideas of how a driverless shuttle system might operate in the future; respondents were faced with fictitious situations and were asked to evaluate a system that is not in use yet and estimate development directions based on assumptions and hypotheses. These circumstances might have potentially limited the outcomes of the survey, which are restricted to the evaluation of the proposed key factors. Although a different survey setup might have led to changes in the details of the scenarios, we are confident that the scenarios directions would have remained unchanged. Moreover, combinations of key elements are assumed to be always feasible. In the last step (i.e., scenario formulation), respondents were asked to evaluate the pros and cons of their desired combination of factors, without investigating the respective practicalities. For this reason, a more accurate study on the feasibility of different key factor combinations should follow this research, focusing on the practical aspects of each scenario. In this regard, future research directions are discussed in Section VIII.

As for the results, some interesting considerations can be elaborated. As one can expect, the totality of respondents agreed that the safety of passengers and road users is the most important aspect in many strategic decisions when it comes to new transport services. Safety is also the first basic need for a public transport service to be attractive according to the pyramid of travelers' requirements developed by [60]. One aspect often related to safety is the presence of a human component inside the vehicle in the form of a driver or, in the case of driverless shuttles, of an on-board operator. The definition of a self-driving bus entails that the driver is not present in the vehicle. Nonetheless, almost the totality of pilots has been performed with on-board personnel, helping out passengers to understand how the vehicle works and performing safety measures in case of emergencies [10]. From the stakeholder survey we can conclude that, although the presence of an on-board operator is assumed to increase passengers perceived safety, a system without on-board operators is considered possible, both from a technology perspective and a passenger perspective. This is in line with the findings from [54], who investigated the mobility factors that affect the acceptance of driverless shuttles. According to their study, 80% of respondents would use an automated shuttle bus without an on-board operator in the immediate time or in case of a future application. On the contrary, earlier studies showed that passengers felt less confident when no human component is present during their trip [61], resulting in a lower willingness to pay [49] and a lower perceived safety [34]. Given these discrepancies between earlier and later studies, it can be argued that with the advancement of technology, passengers will feel less reluctant to use a completely unmanned system and once the driverless shuttle system is fully understood by the prospective users, a remotely controlled vehicle with no operator on board will be easily achievable.

Another controversial aspect of driverless shuttle operations is the low speed of the vehicles. According to our survey, the low speed of vehicles is the biggest barrier when it comes to future integration. Previous studies on users' perception also linked a reduced willingness to use the service to the low speed of the vehicles [62], [63], [64], suggesting that for proper operations, speed must increase to at least 30 km/h to make it competitive with other transport systems [65], [66]. On the other hand, a lower (maximum) speed is considered as a positive aspect that increases the perceived safety. In our study, the prospect of a reduced speed was often mentioned as a benefit for choosing a particular operational location or infrastructure configuration, arguing that a lower speed might attract more users and increase the comfort and perceived safety of passengers. This finding is also in line with recent publications from [55] and [56] on the public perception of automated shuttles. In their studies, respondents agreed that after riding the shuttle for the first time, its low speed increased their perceived safety and enhanced their positive experience. However, when it comes to vehicle speed, studies are often biased by the fact that they rely solely on pilots, test drives and stated preference experiments. Respondents rely on current technology and fail to imagine how it will develop in the coming years. In a long term scenario, one can hypothesize that an improvement in technology will allow for smooth and safe trips even at higher speeds, eliminating the sense of discomfort felt by some passengers.

For what concerns the strategic infrastructure design, in our survey, the vast majority of the respondent opted for a mixed infrastructure configuration, in which driverless shuttles share the existing infrastructure with other road users. Besides being cost- and space-efficient, a mixed environment allows for easy and quick integration of a shuttle service in the existing public transport system. With the vehicles not bounded to a specific lane or road segment, logistics are more flexible in case of disruption and consequently, the service results to be more reliable. Previous studies showed similar results, with users valuing more a system in a mixed environment amongst regular traffic situations rather than dedicated lanes [67], [68]. Despite the many benefits, a mixed environment comes with some challenges. As suggested by [69], the current infrastructure may not be able to accommodate vehicles with automation level 4 or 5, in our case the driverless shuttle, due to their need for vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication. Physical and digital requirements must be met for driverless shuttles to operate, which may be more cumbersome in the case of mixed infrastructure configuration. The operational design domain (ODD) is more complex in case that driverless shuttles can access any traffic environment, which might limit the vehicles to only SAE level 5. Enhanced infrastructure with a sub-network for driverless shuttles can also be a solution, as firstly introduced by [70]. A mixed infrastructure configuration is also preferable when an on-demand door-to-door system is offered. When vehicles are bounded to dedicated lanes or road segments, the scalability of the system does not allow for a proper door-to-door system. A possible solution could be a hybrid fixed-route on-demand system, in which hubs or stops are allocated along the dedicated routes and passengers can book a vehicle at a preferred time, although this system does not represent the ideal situation, according to the stakeholder survey

Contrarily to what was stated in [71], two out of three scenarios have on-demand rather than fixed-schedule operations. This is because, from the operator perspective, on-demand systems are seen as a new market that might attract new customers and could easily be inserted as a transit feeder option in an already existing system. This prediction is supported by the work of [45], which analysis on-demand systems as a potential alternative to fixed transit. Their results show that a demand-responsive system provides improved mobility with a lower generalized journey time, matched with economic and social benefits. Moreover, the study from [72], showed that on-demand systems (especially when applied with a door-to-door service) are valid access and egress complements to main public transport lines.

## VIII. CONCLUSION AND FURTHER RECOMMENDATIONS

This study aimed to answer the research question: What are the potential deployment scenarios involving driverless shuttles for first/last mile connections in a public transport network? To do so, we formulated a set of scenarios following a four-step approach. The importance of this study lies in its aim to shorten the gap between research and implementation, providing a set of deployment scenarios based on experts' opinions.

Through a systematic review of available studies on driverless shuttles adoption, we focused on the research needs concerning the integration of these vehicles into an operative public transport service. The review showed that important aspects such as coverage areas, operational characteristics (e.g., type of supervision and type of operations) and driving contexts (e.g., type of infrastructure) are still lacking substantial research. When related to the many pilots that never reached the operational stage, filling these research gaps might help to understand the reasons behind this lack of implementation.

To address the research needs, a survey was shared among members of research facilities, government institutes, consultancy firms and other transport-related companies. In the survey, respondents were asked to analyze some key factors and define their development directions. Five main categories were proposed for elaboration in the survey: (1) drivers and barriers for future adoption, (2) vehicle characteristics, (3) type of supervision, (4) operational characteristics and (5) type of infrastructure.

The analysis of drivers and barriers for automated shuttles adoption showed opportunities for operations without on-board stewards and for shared vehicles and pointed out the need for technology and policy improvements in terms of operational speed. When choosing the preferred type of vehicle for future operations, operational costs and operational speed were also the two most important vehicle characteristics, as stated by the respondents. Members from research facilities value more a realistic combination of technological advancement and a substantial use in pilots and demonstrations, while members of government institutions and consultancy firms are more interested in the quality of the vehicle, its capacity, autonomy and operational speed. As for the prospect of remote supervision, respondents acknowledged that an on-board steward might increase passengers perceived safety but also agreed that their presence is not necessary for future integration, opting for an on-board steward during the first months of operation (to get passengers used to the technology), to switch to a remotely supervised system on the long term. In the case of remote supervision, respondents highlighted the need for better sensors, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. Similarly, a 24/7 strong illumination system inside the vehicle was considered a useful tool to increase personal safety, together with the possibility of checking and sharing with friends the live position of the vehicle at any instant and the possibility to access an emergency button. More than 75% of respondents agreed that urban areas allow for a more flexible and cheaper service, with the benefit of reducing congestion and emissions. For the type of operation, 67% of respondents preferred a system operated on-demand, in which customers request a vehicle and can select the pick-up and drop-off time and location. For the strategic infrastructure design, a mixed infrastructure configuration was preferred by the majority of respondents, saying that in a mixed environment it is easier to implement an on-demand system.

After having elaborated on possible development directions of key factors for driverless shuttle integration, respondents were asked to combine the key factors into deployment scenarios. From their responses, three scenarios for driverless shuttle adoption were formulated, each having a unique set of features (Table 5).

**TABLE 5.** Overview of potential deployment scenarios according to the panel of experts.

| | Scenario A | Scenario B | Scenario C |
|---|---|---|---|
| **Supervision** | On-board, then remote | On-board, then remote | On-board, then remote |
| **Area** | Urban | Urban | Urban |
| **Operations** | Schedule-based | On-demand | On-demand |
| **Infrastructure** | Dedicated lanes | Dedicated lanes | Mixed infrastructure |

The formulation of deployment scenarios based on experts' opinions provides an answer to the initial research question, setting the basis for further research on the topic. Following the scenario formulation, the next research step involves the identification of key performance indicators and the subsequent scenario assessment based on these indicators. Scenario evaluation can be carried out, among other ways, in a simulation environment.

Another important aspect worthy of further investigation is the role of stewards inside the vehicles and how to guarantee vehicle safety even in the case of remote supervision. As of today, travelers are not acquainted with driverless shuttle technology and therefore pilots usually provide an on-board steward, to guarantee both passengers' safety and traffic safety. With technological advancement, traffic safety can be ensured from a remote control room (as it is already done with the 2getthere GRT vehicle in Rotterdam). On the other hand, passengers' perceived safety is a more complicated aspect to address in the case of remotely supervised vehicles. Many prospective users may assume that an operator is needed for guaranteeing social security inside the vehicle, being used to the traditional driver and/or ticket inspectors. Consequently, future studies should focus on the role of on-board stewards and how to ensure safety, from a passengers' perspective, even when no human operator is in the vehicle and operations are remotely supervised from a control room.

One of the scenarios considers a dedicated infrastructure design combined with an on-demand system. An important aspect to investigate is therefore how to combine these two features feasibly. When vehicles travel in their dedicated infrastructure, a door-to-door system is not achievable and on-demand systems may lose the benefit of customized pick-up and drop-off locations, and other strategies should be applied. An example could be to provide a hub system in which travelers can book a ride for a chosen time slot in one of the predefined pick-up and drop-off locations. Future studies should focus on the feasibility of these *hub-like systems*, with simulation analysis and evaluation of performance indicators.

As for the operational areas, only urban areas were included in the scenarios, following the experts' suggestions. Nonetheless, some recent publications showed how rural areas require better connections to the main public transport service, and how driverless shuttle systems might be the solution. Future studies should focus on the cost functions of driverless shuttle operations in urban areas, rural areas or in the synergic implementation both in urban and rural areas. Cost analysis are a valuable addition to simulation studies, especially to provide business models to transport operators and government institutions.

Lastly, another possible direction for future studies is the assessment of current technology trends in the context of the requirements for an optimal driverless shuttle system. In this study, experts have defined some features and technologies that should be improved and guaranteed in this feeder transit service; further research is therefore required to match these needs with the technology advancements.

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