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Integrating Autonomous Shuttles: Insights, Challenges, and Strategic Solutions from Practitioners and Industry Experts' Perceptions

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Abstract: Integrating autonomous shuttles into public transportation systems holds immense potential to revolutionize urban mobility and enhance accessibility. This paper focuses on a comprehensive analysis of the perceptions of practitioners and industry experts and proposes best practices for effectively integrating autonomous shuttles into public transportation systems. Perceptions of stakeholders have been collected, and a two-fold analysis was performed. Critical barriers for the adoption of autonomous shuttles were identified using the Garette ranking method and principal component analysis (PCA). Recommendations covering different aspects, including underutilization, safety concerns, seating arrangements, reliability, data security, operational aspects, sensor technology, and lane use, are provided. They encompass operational adjustments, infrastructure enhancements, safety measures, policy considerations, and economic foresight. The findings emphasize the importance of extending pilot deployment trial periods, improving autonomy, strategically positioning sensors, enhancing road signage, and providing dedicated lanes for autonomous shuttles. Data-security policies, operator training, and stakeholder responsibilities are also highlighted to build trust and facilitate a seamless transition to autonomous shuttles. This paper concludes by providing recommendations to ensure the successful integration of autonomous shuttles, fostering widespread acceptance and shaping the future of urban transportation.

Keywords: autonomous shuttle; perception; principal component analysis; stakeholders; best practices

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1. Introduction

Autonomous shuttles are driverless micro-transit vehicles operating at slower speeds than traditional transit buses. The initial deployments of autonomous shuttles took place in Australia, Switzerland, France, and the USA, marking the beginning of a transformative journey in urban mobility [1]. Autonomous shuttles offer a unique and promising solution for short-distance travel needs within urban and rural areas with a capacity of 12 to 15 passengers [1]. They are designed to run on pre-defined routes at speeds ranging from 3 to 20 miles per hour, serving as a reliable and efficient mode of transportation. Autonomous shuttles can be more attractive to riders with efficient planning and management. These shuttles are crucial in addressing public transportation system users' first- and last-mile (F&LM) connectivity gaps. Therefore, autonomous shuttle technology is an additional component to the existing long-route transit systems, enhancing overall transportation accessibility and efficiency.

The Society of Automotive Engineers (SAE) International defined six levels of automated vehicles (AVs), ranging from Level 0 (no automation) to Level 5 (complete automation) [2]. As per the vehicle design, autonomous shuttles can fall under Level 4 autonomous vehicles as there are no manual controls like steering wheels and pedals, and they rely entirely on the autonomous system for driving tasks. Operation-wise, they could be currently categorized as Level 3 or Level 4 autonomous vehicles. A safety operator should be present on board for safety and security purposes, particularly in the case of Level 3 autonomous shuttles.

Autonomous shuttles hold immense promise in transforming urban mobility, easing traffic congestion, and playing a pivotal role in fostering sustainable transportation systems within the framework of mobility as a service (MaaS) [3]. They were deployed in the USA in different environments, such as public roads, closed campuses, and airports, to assess their real-world performance [4]. Despite these trials, there has been no permanent deployment of autonomous shuttles yet in the USA.

Numerous challenges, such as safety, regulatory compliance, public acceptance, and technical reliability, need to be addressed before the permanent deployment of autonomous shuttles. Therefore, it is imperative to thoroughly evaluate all aspects of the technology before proceeding with permanent deployment. One practical approach to addressing these challenges is by assessing the perspectives of practitioners and industry experts. It is crucial to capture stakeholders' perceptions in identifying necessary updates, replacements, or key focus areas before large-scale shuttle deployments. By analyzing stakeholders' perspectives, potential barriers and positively influencing factors can be identified, which can help in enhancing the adoption of autonomous shuttles among road users.

A significant research gap exists in understanding the perspectives of practitioners and industry experts regarding the adoption and deployment of autonomous shuttles. While past studies have focused on general perception and adoption, little attention has been given to key stakeholders' perceptions toward integrating autonomous shuttles into transportation systems. This gap hinders a comprehensive understanding of barriers and the potential for enhancing the permanent deployments of autonomous shuttles. Addressing this research gap through the specific analysis of practitioners and industry expert's perceptions will help identify obstacles and reasons why users are less willing to adopt autonomous shuttles, offering insights into decision-making. Potential enablers to enhance existing deployments can also be identified, providing valuable recommendations for improved effectiveness and acceptance. The findings will also assist in making informed decisions in the future, bridging the research gap, and facilitating the successful integration of autonomous shuttles into transportation systems. Overall, the perceptions of stakeholders such as practitioners and industry experts will provide a more holistic understanding of factors influencing the successful implementation of autonomous shuttles.

This study, therefore, focuses on capturing and analyzing the perceptions of practitioners and industry experts on autonomous shuttle adoption and deployment. A well-structured questionnaire was used to capture the perceptions of practitioners and industry experts on various operational and safety aspects of autonomous shuttles. An explanatory factor analysis (EFA) was employed to model the perceptions of practitioners and industry experts to identify potential barriers hindering the widespread adoption of autonomous shuttles. Further, critical reasons for the underutilization of autonomous shuttles and suggested areas of improvement before permanent deployment were identified using the Garrett ranking method. Valuable recommendations are provided to aid stakeholders in making informed decisions and in formulating a robust framework for autonomous shuttle deployments and integrating them into transportation systems. Overall, the contributions of this study are two-fold. Firstly, it systematically investigates the perceptions of practitioners and industry experts to identify potential barriers to the widespread adoption and implementation of autonomous shuttles. Secondly, it provides recommendations for successfully implementing and integrating autonomous shuttles into transportation systems.

This paper is organized into five sections. Following this introduction (Section 1), Section 2 summarizes the past literature on the perceptions of users and stakeholders on autonomous shuttles and AVs. The research design and methodology are explained in Section 3. Section 4 summarizes and discusses the results obtained from this study. The recommendations from this study are presented in Section 5, followed by conclusions and future research directions.

2. The Literature Review

A robust framework to address the challenges related to safety, public acceptance, operations, and policies in both short- and long-term scenarios is essential for successfully deploying AVs and autonomous shuttles [5]. An autonomous shuttle is a type of AV designed to improve accessibility in public transportation. Therefore, the deployment of autonomous shuttles may be related to the deployment of private AVs. As AV's are soon to be integrated into the current transportation system, there is an urgency for long-term planning and a collaborative approach from various sectors to streamline the transition toward AVs. Insights from the early stages of AV development provide a crucial foundation for evaluating future innovations and their implications [6]. Since autonomous shuttles are not yet widely deployed, road users are not very familiar with these vehicles. Therefore, in the early stages, it is beneficial to include the perspectives of practitioners and industry experts on this technology in transportation planning.

Autonomous shuttles are designed to optimally connect origin and destination with the nearest public transportation stop [7]. Autonomous shuttles' operational pathways, road certification concepts, essential infrastructure elements, and factors influencing safe operations have been examined previously [1,4,8]. However, the stakeholders' views on operational constraints on road networks are still being determined as they swing between waiting for technology to mature or seeing proven societal benefits before dealing with infrastructure needs [9].

In the MaaS landscape, autonomous shuttles can serve as a flexible and convenient mode of transportation. Emberger and Pfaffenbichler observed that total vehicle miles can be reduced by 14.6% with a consequent increase in public transportation usage by improving F&LM connectivity [7]. Although there are many positive aspects of autonomous shuttles, there are also several barriers to their adoption. Public–private cooperation, business support, service coverage, shared vision, data security, and demand-side barriers like appeal, digital platform attractiveness, and user willingness to pay are some barriers to adopting AVs and autonomous shuttles [8].

The introduction of autonomous shuttles has consistently highlighted a common issue: adjusting distance and timing [10–13]. Adjusting distance involves the fine-tuning of spatial positioning for safety and efficiency, while adjusting timing refers to synchronizing its movements with traffic flow and schedules. Legal, regulatory, and guideline-related hurdles emerge as primary barriers, while customer acceptance and labor shortage rank lower. The unpredictability of these systems, especially when they need to anticipate the action of other road users' behavior, requires them to effectively manage spatial context and real-time road space negotiation [14,15]. Flexible policymaking for private AVs is critical to match global technological advancements [16]. While optimistic about Level 4

AVs becoming publicly available within the next decade, stakeholders are only planning to deploy them on specific road sections [17].

Collaboration and standardization among stakeholders are essential to ensure trust and safety in AV deployment. The current road infrastructure needs to be AV-friendly. New urban design discussions encourage transforming transportation infrastructure to enhance livability and sustainability, even though this may require some infrastructural changes and societal acceptance [3,17,18]. Infrastructure requirements for AVs include everything from the physical features of roads to secure digital communication systems. Ensuring equity in terms of accessibility and the funds to support them is a major challenge, requiring a well-planned approach to prepare for AVs [9].

Safety concerns rank highest among objectives, while ease of use and cross-border interoperability are ranked lowest [19]. From a manufacturing perspective, the designs of autonomous shuttles should prioritize smooth operation in complex traffic situations without substantial road infrastructure modifications. Several mitigation areas have been identified, including road infrastructure, weather-dependent operation, localization improvement, digital infrastructure, design, working conditions, and user experience for citizens [20].

The roles of stakeholders differ in the implementation of autonomous shuttles. Policymakers are encouraged to promote AV adoption through subsidies for shared AV usage and road testing permits for AV-sharing service providers. Manufacturers should strategize diverse business models to attract a wider customer base and partner with ride-hailing services to demonstrate AV utility through robotaxi type services [19].

Many researchers have previously explored road users' perceptions of autonomous shuttles [3,4,9,19–21]. User acceptance surveys indicate a generally positive outlook toward autonomous shuttles, underscoring the importance of safety measures and separate right-of-way [22]. However, public perception is impacted by concerns over the limited availability of regular service and potential private vehicle replacement [13].

Variability exists in levels of acceptance and satisfaction across different surveys. Environmentally conscious consumers are strongly influenced by the perceived drawbacks of AVs. Policymakers should promote sustainable development in the AV industry through energy-efficient standards and incentives for electric AV development [21]. Therefore, sensor technology enhancements and long-term user experiences are required to shape user acceptance.

The deployment of autonomous shuttles presents a range of known and unknown challenges, spanning vehicle performance, safety, security, traffic management, weather conditions, infrastructure, social justice, equity, legal considerations, and user acceptance. To effectively address these challenges and identify potential enablers for best practices, it is essential to capture the perceptions of stakeholders, such as practitioners and industry experts, to assess all the factors impacting the adoption of autonomous shuttles. These challenges can be overcome with continuous technological advancements, infrastructure upgrades, collaborative engagement among stakeholders, and the establishment of suitable regulatory frameworks, paving the way for the seamless integration of autonomous shuttles into our transportation landscape and unlocking their full potential for the benefit of society.

3. Research Design and Methodology

There are different methods to capture perceptions, such as interviews, focus group meetings and online survey questionnaires. Capturing perceptions through questionnaires is more cost-effective and provides more quantifiable data that can be easily analyzed. A well-structured questionnaire comprising multiple choice and scaling questions was used to gain insights into the perceptions of practitioners and industry experts toward autonomous shuttles.

3.1. Questionnaire Content and Participants

The web-based questionnaire was developed based on the potential factors identified from the literature. The draft questionnaire underwent internal review and modifications based on suggestions from the Institutional Review Board (IRB) to ensure comprehensive data collection regarding autonomous shuttle deployment and adoption. The questionnaire was divided into three parts. The first part focused on socio-demographic information. The second part focused on questions related to familiarity with autonomous shuttles. The third part focused on how practitioners and industry experts perceive the operation of autonomous shuttles and areas that require improvement, including vehicle, road infrastructure, safety, and security aspects. Overall, the questionnaire sought to gain insights into the barriers concerning the safety, comfort, and operational elements of autonomous shuttle deployment.

The participants surveyed included practitioners and industry experts interested in autonomous shuttles and AVs. Practitioners are employees from state and regional departments of transportation (DOTs), private consultants, and consulting firms, while industry experts are individuals involved in the manufacturing (including parts) and operation of autonomous shuttles. The participants were identified from a systematic review of public agencies with a transportation function, using publicly available contact information, relevant conferences, research papers, and organizations such as the American Association of State Highway and Transportation Officials (AASHTO), the Transportation Research Board (TRB), the American Society of Civil Engineers (ASCE), etc. Although users are one of the stakeholders, they were not considered, as the focus of the study is to comprehend the barriers related to the adoption and implementation of autonomous shuttles.

After receiving ethical approval from the IRB (IRB-23-0716), the questionnaire link was forwarded to the identified participants via e-mail and social media. Reminders were sent approximately two weeks after the original e-mail date. The online survey was left open for four months. Forty responses (36 from the practitioners and 4 from the industry experts) were received. Among these respondents, ten had actively participated in pilot deployments of autonomous shuttles.

3.2. Analysis Methods

A two-fold analysis was employed to gain insights from the collected data. In the first part, descriptive statistics were computed to analyze the general perception of practitioners and industry experts toward autonomous shuttles. It covered vital areas, such as the intended purpose of use, proposed trial durations for pilot projects, safety measures, crash liability, restricted operational zones, and necessary upgrades or replacements required before long-term deployment. Further, the Garrett ranking method was used to rank the factors responsible for the underutilization of autonomous shuttles and the areas needing improvement before permanent deployment. In the second part, the collected responses were analyzed using EFA to identify barriers to adopting and implementing autonomous shuttles.

3.2.1. Garrett Ranking

The application of Garrett's ranking technique allows the conversion of the preference sequence, changes in constraint orders, and benefits into numerical scores. This method provides an edge over primary frequency distribution by arranging constraints based on their intensity as the respondents perceive them. The formula to estimate the percentage position of a feature is shown in Equation (1).

$$P_i = (100 \times (N_i - 0.05))/N \quad (1)$$

where P_i is the percentage position of the ith feature, N_i is the number of cases that were ranked above the ith feature, and N is the total number of features.

These percentage positions are then converted into Garrett scores via a standard table correlating percentages to scores. The final Garrett score for each feature is obtained by aggregating the scores from all the respondents. The Garrett ranking method was used to determine the most influential reason for the underutilization of autonomous shuttles. Additionally, the Garrett ranking method was used to identify the aspects that need improvement before considering the permanent deployment of autonomous shuttles.

3.2.2. Exploratory Factor Analysis

In the second part, the collected responses were analyzed using EFA to identify barriers to adopting and implementing autonomous shuttles. EFA is a multivariate statistical approach to interpreting the underlying structure of relationships among various variables. A smaller set of latent variables (factors) is obtained from the original dataset [23]. The factor model is created, and adjustments are made through an iterative process, where variables are eliminated based on the suitability criteria of the method. The EFA was applied to assess the questionnaire data, utilizing the principal component analysis (PCA) methodology. The PCA method is employed to extract the factors, which are then represented by the set of original variables in the model, and to describe the behavior of the evaluated data. Latent variables from specific question sets are created per Equation (2).

$$y_q = \sum a_q \cdot x_q \quad (2)$$

where y_q = Factor; a_q = Factor loading; and x_q = Variable

The EFA approach was used to identify the influential factors and uncover the critical latent factors contributing to the resistance to adopting autonomous shuttles. It proved beneficial in comprehending relationships among variables and data aggregation for analyzing the factors involved. In general, EFA offers the advantage of uncovering the structure of variables influencing the problem and their correlations while extracting the latent factors that impact the phenomenon. IBM SPSS (version 28.0.1.1-14) statistical software was used for the EFA, employing PCA with Varimax rotation, a common practice in factor analysis.

The suitability of EFA for the problem was confirmed using the Bartlett sphericity test and the Kaiser–Meyer–Olkin (KMO) test. The model tuning was conducted by removing variables based on the suitability criteria of the anti-image correlation matrices (diagonals more than 0.5) and commonalities (extraction value over 0.6). The factors obtained via the PCA method were visualized using the total explained variance matrix, which reflects the total variance percentage defined by the retrieved factors. Variables related to the factors were pulled from the rotated component matrix. Factor loadings symbolize the variable's contribution to the factor; thus, variable identification for each factor was based on selecting those with the highest absolute values [24].

4. Results and Discussion

4.1. Socio-Demographic Characterization of Responses

The majority of respondents were males (65%). Moreover, 62.50% belonged to the 25–54 age group, and 30% of respondents belonged to the greater than 55 years age group.

Further, 32.50% of the respondents had working experience of 5 to 10 years, whereas 20% of the respondents had working experience of 20+ years.

The survey responses provided valuable insights into the characteristics of the respondents and their familiarity with autonomous shuttles. Among the organizations that participated in the survey, the majority (42.5%) represented state DOTs, with additional contributions from regional transportation agencies (7.5%), city/town transportation agencies (5.0%), and industry experts (5.0%). A substantial portion (40%) fell under the "Other" category, demonstrating a diverse range of participants. Regarding departmental affiliations, respondents were associated with transportation planning (17.5%), road design (10.0%), traffic signals/intelligent transportation systems (22.5%), traffic safety (22.5%), and other areas (27.5%). Notably, 25% of the respondents had a direct role in deploying autonomous shuttles in their respective regions. This indicates that a notable percentage of respondents have direct experience and in-depth knowledge about autonomous shuttles. This level of direct engagement contributed to substantial first-hand insights into the operational aspects of autonomous shuttles, providing a richer context to the collected research data. Regarding their level of familiarity, 25% of the respondents referred to themselves as experts, while 70% of the respondents indicated that they knew little about autonomous shuttles. Overall, the response set is diverse and representative enough of practitioners with varying backgrounds and experiences to support the findings.

4.2. Perception Toward Autonomous Shuttles

4.2.1. Integration and Purpose of Autonomous Shuttles

The survey results revealed diverse views on the potential role of autonomous shuttles within public transport systems. Approximately 75% of the respondents supported the feasibility of integrating autonomous shuttles to enhance public transportation accessibility, while 15% of the respondents considered it unfeasible. This wide range of opinions reflects the varied perspectives on the impact and role of autonomous shuttles in shaping the future of public transportation systems. The debate extended to prioritizing longer routes with long-route automated transit possibilities. Approximately 37.5% of respondents leaned toward prioritizing long-route automated public transportation services, 47.5% of the respondents held the opposite view, and 15% of the respondents remained undecided.

Autonomous shuttles have proven helpful in diverse applications, most prominently in the context of F&LM connectivity. Autonomous shuttles extended their utility to community services, with a notable example being the Mayo Clinic using autonomous shuttles for COVID-19 sample collection during the pandemic [25,26]. Figure 1 presents the respondents' views on the most efficient application for autonomous shuttles.

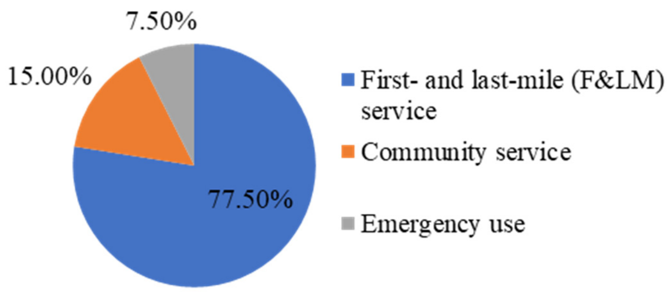

Figure 1. Best purpose of autonomous shuttles.

Brovarone et al. [5] indicated a potential reduction in the use of public transportation and activities like walking and cycling with the introduction of autonomous shuttles for F&LM service. Contrarily, 77.5% of the respondents from this study were optimistic that introducing autonomous shuttles, particularly as an F&LM service (connectivity), would increase the demand for public transportation. On the other hand, 15% of the respondents viewed community services as the best application, while 7.5% of the respondents perceived that autonomous shuttles could be best used for emergency services. The results indicate that autonomous shuttles are preferred to be deployed for F&LM connectivity.

4.2.2. Trial Period

Trial periods for autonomous shuttle pilot deployments ranged from three to six months in the USA. This short period presents a challenge to accurately assess the autonomous shuttle's performance, particularly in the domains of operation and safety. Considering this, the survey included a question regarding the optimal duration for the pilot deployments of autonomous shuttles, and the results are presented in Figure 2.

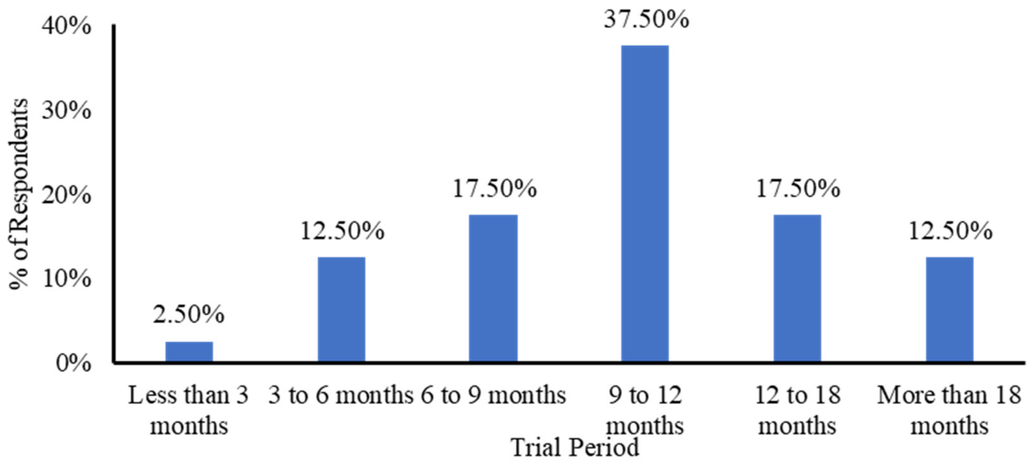

Figure 2. Trial period of pilot deployments.

Figure 2 shows that 37.5% of the respondents suggested a trial period of 9 to 12 months. A significant fraction, about 30% of the respondents, believed that a trial period should extend beyond 12 months. These findings highlight that a more extended pilot phase (trial period) could provide a more comprehensive assessment of the autonomous shuttle's performance.

4.2.3. Safety and Data Security

Regarding the operation and maintenance of autonomous shuttles, 57.5% of the respondents believed that manufacturers and operators play equally critical roles. While 30% of the respondents attributed a more significant role to operators, 12.5% of the respondents suggested that manufacturers hold primary responsibility.

Crash liability, a matter of considerable concern in the deployment of autonomous shuttles, has garnered diverse perspectives due to the involvement of multiple stakeholders. About 47.5% of the respondents suggested that crash liability should be equally distributed among all four stakeholder groups, as visualized in Figure 3. The result highlights the complexity of liability concerns in deploying autonomous shuttles and the need for a balanced responsibility framework.

Autonomous shuttles collect a vast amount of data using sensors, such as light detection and ranging (LiDAR) sensors and a global positioning system (GPS). These technologies contribute to an extensive database of road infrastructure and user data. Moreover, autonomous shuttles are Level 3 and Level 4 AVs; therefore, they plan their motion using artificial intelligence (AI)-based sensing technologies. The large amount of data collected raises concerns about possible data loss or unauthorized access, highlighting the need for strong data-security measures. Given the data security-related vulnerabilities of autonomous shuttles, 92.5% of the respondents concurred that specific policies addressing cyber-security or data breaches should be established for autonomous shuttles, highlighting the critical necessity for robust data-security protocols.

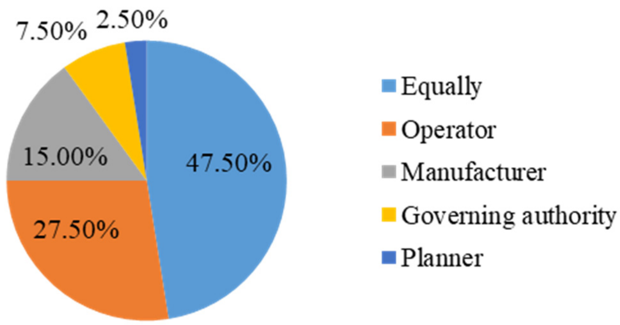

Figure 3. Crash liability.

4.2.4. Infrastructure

Given the slow-moving nature of autonomous shuttles, their interaction with other vehicles and system users varies across land use types. Consequently, determining whether an autonomous shuttle can operate effectively in all mixed traffic conditions is crucial. Figure 4 summarizes the respondents' views on this subject matter.

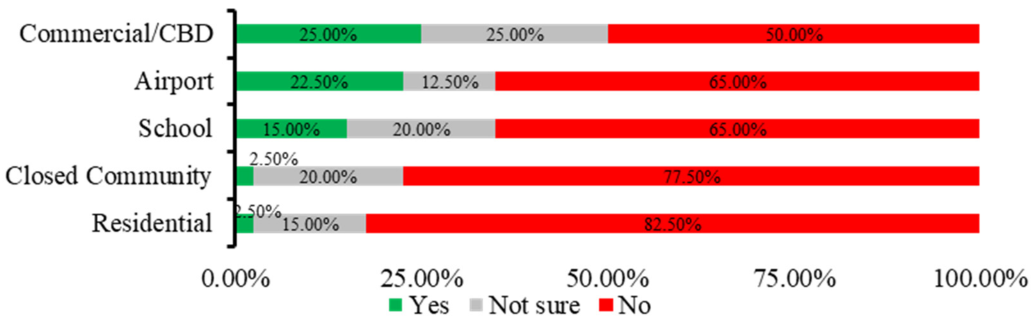

Figure 4. Restriction in autonomous shuttle deployments.

A majority (82.5%) of the respondents believe that no restrictions should be imposed on the operation of autonomous shuttles in residential areas. In comparison, 77.5% of the respondents feel similarly about closed communities. Moreover, 65% of the respondents did not foresee the need for restrictions in schools and airports. However, views on commercial and Central Business District (CBD) areas were more divided. Half of the respondents perceive that autonomous shuttles should not be restricted to these areas. These findings are necessary for deciding land uses where autonomous shuttles can be implemented.

Current road infrastructure and the surrounding environment are designed and built for human driven vehicles [9]. Vehicle-to-infrastructure (V2I) communication may necessitate upgrades or replacements of specific traffic control devices. The survey solicited respondents' opinions on which devices should be upgraded or replaced with radio frequency identification (RFID) or other sensor technologies to facilitate this communication. The most commonly mentioned device for an upgrade was traffic signals, selected by 82.5% of the respondents. Upgrading pavement markings was selected by 65.0% of the respondents, while upgrading stop and school zone signs was selected by 62.5% of the respondents. Upgrading reflectors was selected by 60.0% of the respondents, while upgrading pedestrian control and signs was selected by 55.0% of the respondents. Upgrading temporary traffic control and speed limit signs were selected by 52.5% and 50.0% of the respondents, respectively. The same percentage, 50.0% of the respondents, selected upgrading bus lane signs, road curve ahead signs, and shoulder drop-off/no-shoulder signs. Likewise, upgrading yield signs, directional signs for unconventional intersections (e.g., roundabouts), and parking signs were selected by 45.0%, 40.0%, and 40% of the respondents. Upgrading lane addition/drop signs, one-way/two-way signs, and other regulatory signs as per the MUTCD were selected by 35.0%, 32.5%, and 30.0% of the respondents. Only one respondent (2.5%) selected upgrading other warning signs. These results indicate the importance of infrastructural improvements in facilitating efficient V2I communication.

4.2.5. Budget and Regulatory Body

Introducing autonomous shuttles to supplement public transportation presents new fiscal considerations, as budget allocations have historically not accommodated such innovations. The survey asked respondents whether deploying autonomous shuttles in their jurisdiction would necessitate an additional component in the annual budget allocation. About 70% of the respondents concurred that an additional budgetary provision would be necessary. Conversely, 7.5% of the respondents did not foresee a need for a separate budget allocation. The remaining respondents expressed uncertainty on the matter, underscoring the financial implications and considerations of introducing autonomous shuttles.

Autonomous shuttle deployments typically involve four key stakeholder groups. To ensure sustainable integration, it is necessary to create a balanced policy [7]. Hence, a dedicated regulatory body is necessary in the existing transportation government system. About 55% of the respondents perceive that an additional statutory body is needed to deploy, operate and maintain autonomous shuttles.

4.2.6. Permanent Deployment

The question of permanently integrating autonomous shuttles into the existing infrastructure following trial deployments is multifaceted, hinging on the specific environmental context and the extent of interaction with other vehicles, infrastructure, and road users. Figure 5 summarizes respondents' perceptions regarding where the autonomous shuttles can be permanently deployed. About 80% of the respondents believe autonomous shuttles could be permanently deployed in closed communities. Similarly, 75% of the respondents view residential areas as suitable for permanent autonomous shuttle integration, and more than half of the respondents expressed the same optimism for airports and schools.

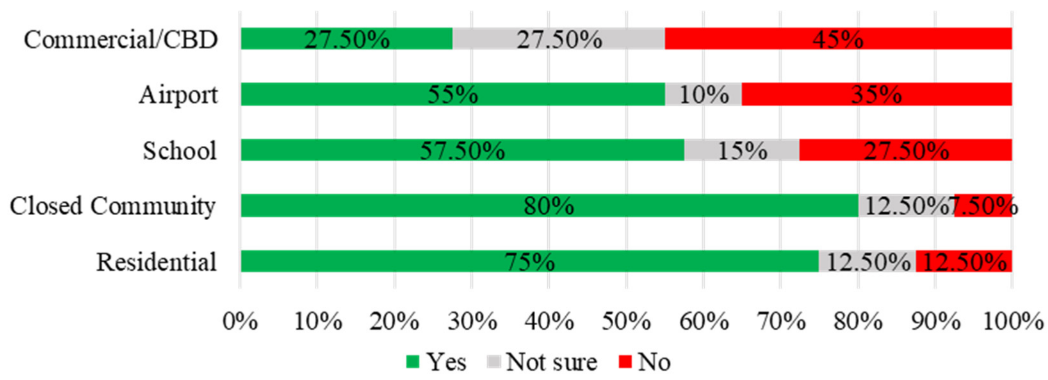

Figure 5. Permanent autonomous shuttle deployments in existing infrastructure.

About 27.5% of the respondents view the CBD area (marked by higher interaction levels with pedestrians and vehicles compared to other environments) as conducive to permanently deploying autonomous shuttles. This disparity underscores the need for environment-specific considerations in planning for the long-term integration of autonomous shuttles into urban infrastructure.

4.2.7. Underutilization of Autonomous Shuttles

Public transportation is not always the preferred mode of transportation in many USA cities, raising potential concerns about the underutilization of autonomous shuttles. Respondents were asked to rank potential reasons for underutilization. The Garrett ranking results are presented separately for respondents involved in deploying autonomous shuttles, as shown in Table 1.

Table 1. Ranking of reasons behind underutilization of autonomous shuttles.

Factors	Average Garret Score	Overall Rank Based on the Perception of the Respondents	Rank Based on the Perception of the Respondents Involved in Autonomous Shuttle Deployment
Passenger safety	63.58	I	II
Data safety	61.48	II	IV
Travel time	60.29	III	VI
Reliability	60.29	III	III
Schedule	60.2	IV	I
Passenger capacity	56.28	V	V
Low speed	56.08	VI	VII
Comfort	53.93	VII	VIII

The results indicate that passenger safety could be the most influential factor, followed by data safety, travel time, and reliability. However, these rankings differ when focusing on respondents involved in autonomous shuttle pilot deployments. From their perspective, the schedule was the most influential factor, followed by passenger safety and reliability. Among these considerations, comfort was deemed the least influential. Paddeu et al. [27] found that comfort and trust positively influence acceptance, but trust is a significant factor for the acceptance of shared AV. These differing viewpoints illustrate the complexity of factors that could potentially contribute to the underutilization of autonomous shuttles and also highlight factors that could be improved to avoid the underutilization of autonomous shuttles.

4.2.8. Improvement Before Permanent Deployment

Autonomous shuttles are an innovative addition to the dynamics of transportation. However, the real-world readiness for such systems necessitates prioritizing improvements. The survey inquired about respondents' priority for improvements across various areas (data safety, passenger safety, road signage, operator training, LiDAR positioning, shuttle interior, seating arrangements, transit parking, road geometry, speed, and passenger capacity) before permanently deploying autonomous shuttles.

The aforementioned priorities were ranked using the Garrett ranking method. The results, as displayed in Table 2, indicate that data safety should be the foremost area of improvement, followed by passenger safety and road signage. However, a different picture emerges when focusing on respondents involved in autonomous shuttle pilot deployments. From their perspective, the training of operators is the top priority, followed by passenger safety and road signage. Speed and passenger capacity ranked the lowest in their list of priorities. These diverging views underscore the various perspectives in the field concerning what improvements are needed to ensure the successful deployment of autonomous shuttles.

Table 2. Ranking of factors improved before permanent deployments.

Factor	Average	Overall Rank Based on the Perception of the Respondents	Rank Based on the Perception of the Respondents Involved with Autonomous Shuttle Deployment
Data safety	74.06	I	V
Passenger safety	73.74	II	II
Road sign	71.48	III	III
Training of Operator	70.80	IV	I
LiDAR position	69.64	V	VII
Interior of the shuttle	68.21	VI	IX
Sitting position	67.95	VII	VIII
Transit parking	65.56	VIII	IV
Road geometry	65.25	IX	VI
Speed	65.14	X	X
Passenger capacity	64.98	XI	XI

4.2.9. Barriers to Autonomous Shuttle Adoption and Implementation: Results from EFA

Twenty-two variables from the questionnaire were considered for the EFA. After conducting the necessary iterations in the fitting process, an optimal model was produced by the EFA, which grouped all the variables into eight factors based on their corresponding Eigenvalues. Bartlett's test of sphericity (Chi-Square = 371.735; $p < 0.001$) and the Kaiser–Meyer–Olkin test (KMO ≥ 0.5) confirmed the appropriateness of employing EFA with the principal components in the dataset.

Table 3 lists the 22 observed variables considered for the model, each associated with a specific factor name. A cumulative variance of 75.63% was explained through these eight primary components. Table 4 summarizes the individual contributions of these factors to the explained variance and their cumulative variance percentages. The variance was impacted to varying extents by each factor, with 'underutilization' being the most influential, contributing 17.37%, and 'safety' following at 12.22%. This factor-based delineation offers a numerical and distinct understanding of the influence exerted by each component within the dataset.

Table 3. Results of PCA: factors and observed variables of EFA.

Factor	Labels	Observed Variables
F1	V16–V22	Reasons for the underutilization of autonomous shuttles [passenger safety, low speed, comfort, travel time, schedule, reliability, passenger capacity]
F2	V1–V3	How safe is the autonomous shuttle for different age groups?
F3	V4	Do you think that the seating arrangements of the autonomous shuttle would be more comfortable than the general shuttle?
	V5	With any barrier detection, the autonomous shuttle is designed to stop immediately. Do you think that the passenger sitting position is safe for sudden stops?
F4	V7	Do you think an autonomous shuttle is a safe and reliable addition in regions with heavy rains?
	V8	Do you think an autonomous shuttle is a safe and reliable addition to routes with steep vertical curves and sharp horizontal curves?

Table 3. *Cont.*

Factor	Labels	Observed Variables
F5	V14	As existing infrastructure is not fully autonomous-friendly, is it a barrier to autonomous shuttle deployment?
	V15	Are autonomous shuttle data a threat/cyber-security loss?
F6	V11	As the autonomous shuttle is a slow-moving vehicle (10 mph–20 mph usually), do you think people will not prefer to use it because of lower speeds?
	V12	Is low passenger capacity (8 to 15) a barrier to using an autonomous shuttle as a public transportation mode?
F7	V6	Do you think that the position of the LiDAR of the autonomous shuttle should be revised to improve the blind spot?
	V13	If autonomous technology is not camera based, should the road infrastructure elements be upgraded or replaced with other sensors for communication?
F8	V9	The autonomous shuttle cannot change lanes or overtake any stopping vehicle. Will it be a barrier for the passengers?
	V10	Do you think that autonomous shuttles would require dedicated lanes?

Table 4. Results of PCA: factors contribution in explained variance (%).

Factor	Interpretation of the Factor	% of Variance	% Cumulative Variance
1	Underutilization	17.37	17.37
2	Safety	12.22	29.59
3	Seating arrangement	9.31	38.90
4	Reliability	8.15	47.05
5	Data security and environment	8.04	55.09
6	Operational aspect	7.64	62.74
7	LiDAR and other sensors	6.55	69.28
8	Lane	6.35	75.63

Figure 6 supplements the results of the EFA by visually representing the model, illustrating the factor loadings (Cf), and visually demonstrating the correlations between the observed and latent variables, also referred to as factors.

In PCA, factor loadings represent the correlations between the original variables and the latent factors or principal components. A positive factor loading signifies a direct correlation between the original variable and the principal component. The key findings of the EFA are summarized next.

Factor 1, referred to as underutilization, identifies the possible reasons for the underutilization of autonomous shuttles. All the variables have positive factor loadings (Cf+), shown in Figure 6. Hence, all seven variables are possible reasons for the underutilization of autonomous shuttles. Positive factor loading reveals that comfort, travel time, and reliability exhibit the highest factor loading (Cf > 0.73), signifying that they are the most critical factors resulting in the underutilization of autonomous shuttles. The previous literature found that comfort and trust are crucial factors in the public acceptance of shared AVs [27]. Passenger capacity is the least influencing factor affecting the underutilization of autonomous shuttles. Hence, passenger capacity is not a potential reason for the underutilization of autonomous shuttles. It could be because autonomous shuttles are typically designed for shorter routes/trips, and comfort may not be an issue in such cases for transportation system users [1].

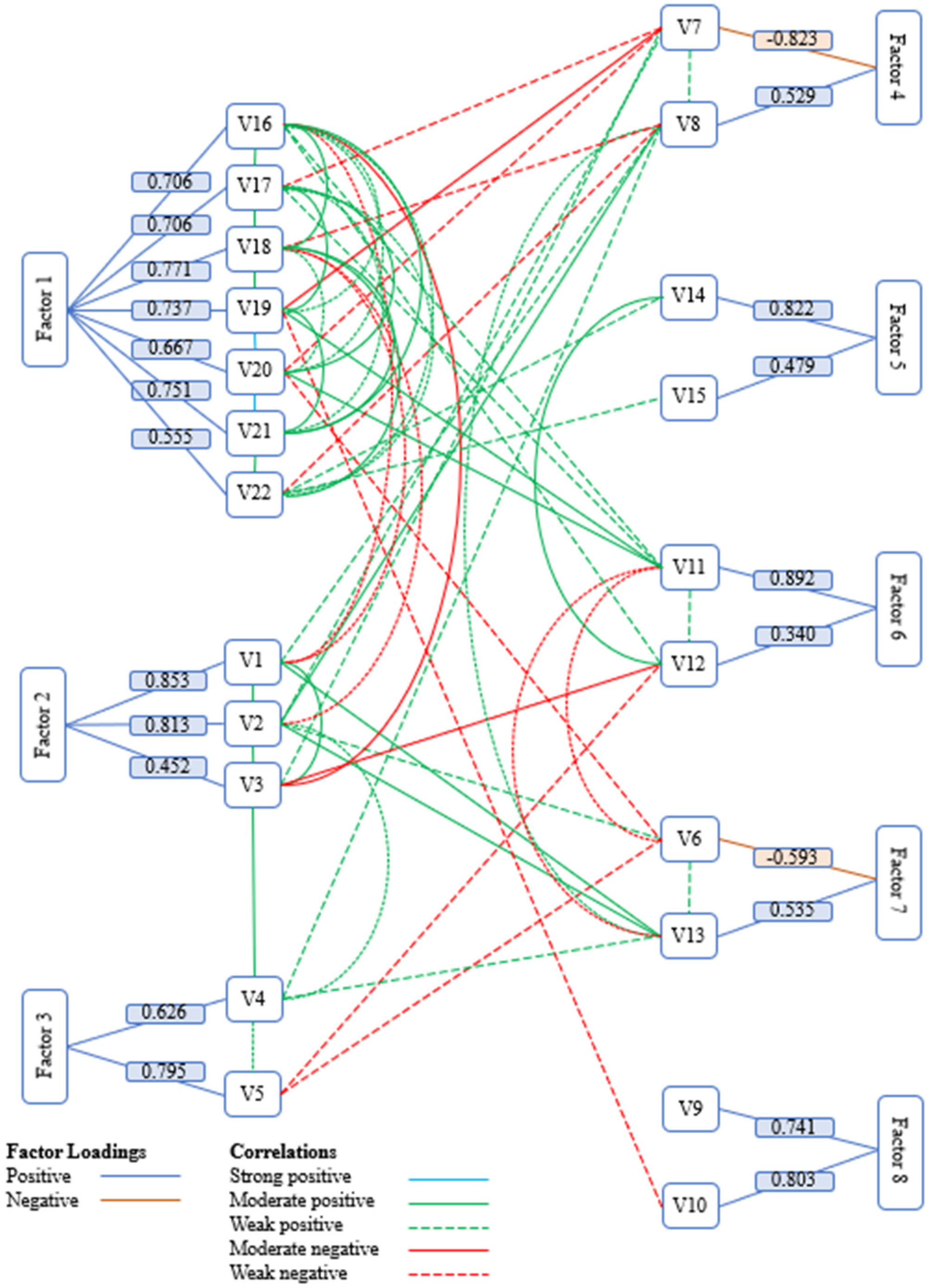

Figure 6. Results of PCA—factor loadings and correlations.

Factor 2 represents the safety of passengers in terms of age group. All the variables have positive factor loadings (Cf+) with the latent variables shown in Figure 6. Therefore, autonomous shuttles generally provide a safe commuting environment for all users. However, the weightage of this factor decreases for elderly individuals (Cf < 0.50), indicating that the safety of autonomous shuttles for older adults is relatively less compared to the middle-aged adults. The literature review reveals a need for more knowledge concerning the AV usage preferences of older adults, despite their potential to enhance mobility in urban and peripheral areas [28]. A demonstration study showed that older adults showed decreased suspicion and increased trust after riding the shuttle [29].

Factor 3 is associated with the seating arrangement of the autonomous shuttle, which is different from regular public transportation. Two variables are associated with the latent variable, and both have positive factor loadings, as shown in Figure 6. Hence, autonomous shuttles' seating arrangement is more comfortable for riders than regular vehicles (Cf > 0.6). A previous study found that trust showed significant relationships with the independent variables, 'direction of face' (forward/backward) and 'maximum vehicle speed'. At the same time, perceived comfort did not exhibit statistically significant relationships with the independent variables [27]. From this analysis, seating is also safe for these sudden stops. However, autonomous shuttle rides can be uncomfortable at the time of sudden braking due to false object detection by sensors [13].

The safety and reliability of autonomous shuttles are represented by Factor 4; one variable is positively associated (Cf+), while the other is negatively associated (Cf−). Autonomous shuttles may pose safety concerns in areas experiencing extreme weather conditions, such as heavy rainfall or snowfall. During heavy rain or snow, the LiDAR system may be unable to detect the road, and as a result, the autonomous shuttle comes to a complete stop [30]. However, autonomous shuttles are expected to navigate safely on roads characterized by steep horizontal and vertical curves. The observation necessitates the enhancement of autonomous shuttles' weather compatibility to ensure safe operation in all climatic conditions.

Factor 5 refers to the potential data-security threats and infrastructural hindrances for implementing autonomous shuttles. The existing infrastructure is not fully ready for V2I communication, which offers various benefits, including safety, mobility, and environmental advantages by collecting and sharing data [31]. The positive factor loading of V14 shows that the existing infrastructure is a barrier to autonomous shuttles deployment (Cf > 0.8). Additionally, the positive loadings of V15 indicate that autonomous shuttle data can be a possible cyber-security loss (Cf+). Automated city shuttles rely on real-time data exchange with internal components and the external environment, leading to privacy and data protection concerns [32]. The results highlight the need for specific data-security policies and autonomous shuttle-friendly infrastructure to implement autonomous shuttles successfully.

Operational aspects are represented by Factor 6. Both the variables have positive factor loadings, as shown in Figure 6. The latent variable indicates that low speed and limited passenger capacity are possible barriers to adopting autonomous shuttles. However, low speed is more important than passenger capacity as a barrier for autonomous shuttle deployments (Cf > 0.9). Cyclists found it challenging to overtake the autonomous shuttle due to its speed (up to ~9.3 mph), leading to frustration among faster cyclists in Europe [10].

LiDAR and other sensors are represented by Factor 7, meaning adjusting the position of LiDAR for better blind spot detection is not required (Cf−). However, upgrading or replacing road infrastructure elements with additional sensors for communication (Cf+) is necessary. The literature suggests that blind spot detection can be enhanced through proper positioning and higher resolution LiDAR sensors or additional sensor installation to reliably detect objects, even those moving over ~18.6 mph [13].

Factor 8 is associated with autonomous shuttles' lane change behavior and dedicated lanes. Two variables are associated with this factor and have high positive loadings (Cf > 0.7). The inability of autonomous shuttles to switch lanes on the road and the lack of designated lanes for these shuttles can impede their widespread adoption. As a slow-moving vehicle, it performs better with a dedicated lane by decreasing delay [33]. This result highlights the need for infrastructural modifications, such as dedicated lanes, to ensure the seamless integration of autonomous shuttles into the current transportation system.

5. Recommendations for Best Practices

The recommendations for the best practices for deploying autonomous shuttles are proposed based on Garret ranking results and EFA. They are divided into operational, safety, policy, and economic aspects, supporting pilot and permanent deployments. The objective is to ensure safe, reliable, and trusted autonomous shuttle systems that cater to stakeholders' needs. The comprehensive approach provides a framework to address potential challenges in adopting autonomous transit solutions and effectively guide the deployments of autonomous shuttles.

5.1. Operational Aspect

From the operational perspective, adjusting the pilot deployment trial period from 6 to 12 months is essential. This duration provides sufficient time to monitor and address unforeseen challenges and operational issues. In the service context, autonomous shuttles seem particularly effective for F&LM connectivity. This specific utilization can help bridge gaps in public transportation accessibility and potentially increase its overall usage.

Infrastructure improvements constitute a crucial part of autonomous shuttle deployment. Before initiating pilot projects, efforts should focus on enhancing transit parking facilities and road signage. Such advancements not only streamline the operation of autonomous shuttles but also promote safety and ease of use for all road users. Moreover, providing a dedicated lane for autonomous shuttles is worth considering. This approach reduces interactions with other vehicles, fostering a more controlled environment for autonomous shuttles and smoother deployment.

Improving the level of autonomy is necessary from a technical viewpoint. The operational aspects that call for particular attention are lane changing and the navigation of steep curves. Enhancements in these areas can augment the efficiency and safety of autonomous shuttles. Refining the positioning of LiDAR sensors and the simultaneous improvement in road signage using other sensors can improve the safety performance of autonomous shuttles, even under adverse weather conditions.

5.2. Safety and Security Aspect

Safety and security are most important for any transportation system. Data safety, passenger safety, road signage, transit parking, and operator training require meticulous evaluation and improvement before the permanent deployment of autonomous shuttles. Among these elements, data safety, passenger safety, road signage, and operator training should be given precedence due to their direct impact on user experience and trust in the system.

Data safety is vital for the functional operation of autonomous shuttles and for maintaining the users' trust. Improving measures to protect and secure data can substantially alleviate concerns regarding potential cyber threats. Establishing robust data-security measures and adapting the existing infrastructure to cater to the needs of autonomous shuttles can go a long way in ensuring the successful integration of these vehicles into the mainstream transportation system. Similarly, passenger safety is a non-negotiable aspect, and it is essential to guarantee the utmost protection for all passengers during transit.

Operator training is another crucial area that needs attention for the successful deployment of autonomous shuttles. Even though the ultimate goal is complete autonomy, well-trained operators can play a pivotal role in managing and troubleshooting the systems if required in the transition phase. Hence, investing in the comprehensive and systematic training of operators is a prerequisite for a smooth transition to autonomous shuttles.

5.3. Policy Aspect

There are several essential considerations before moving toward long-route autonomous bus services. One primary point of focus should be the efficient operation of autonomous shuttles. The success and wide-scale acceptance of autonomous shuttles could pave the way for extended autonomous transit routes.

Although the advent of autonomous shuttles has gained significant popularity, the shift from private vehicles to public transportation, such as autonomous buses, is lower than expected, with only about 30% of the population showing a preference for such a change [34]. This observation suggests that more efforts should be expended to encourage the public to adapt to autonomous public transportation.

Stakeholders should equally share the responsibilities related to the operation and maintenance of autonomous shuttles, as well as handling liability in the case of crashes. Shared responsibility could lead to better management and oversight of autonomous shuttle operations.

Introducing an additional statutory body, distinct from the existing stakeholders, could provide an extra layer of regulation and control. This body could be instrumental in monitoring and ensuring adherence to safety protocols and guidelines.

Autonomous shuttles are a viable enhancement to the existing public transportation system. Autonomous shuttles are promising for medium-distance travel, especially when they reduce access route lengths [35]. In particular, F&LM connectivity is anticipated to increase public transportation uptake significantly. The deployment of autonomous shuttles, especially as a supplement to traditional transit services, merits careful consideration in strategic transportation planning.

Lastly, safety, travel time, schedule adherence, and reliability could contribute to the utilization of autonomous shuttles. These aspects require careful attention and planning to enhance the efficiency of autonomous shuttles and ensure a smoother transition toward a fully autonomous transit system.

5.4. Economic Aspect

An additional budgetary component may be needed to cater to the successful implementation of autonomous shuttles within existing transportation systems. Such financial foresight is crucial to ensure autonomous shuttles' sustainable operation and maintenance, contributing to their long-term success and widespread acceptance.

The recommendations for deploying autonomous shuttles are categorized into operational, safety, policy, and economic aspects to aid in clarity and practical use. Although these areas are interconnected, this separation helps practitioners focus on specific challenges relevant to their needs. As autonomous shuttles move toward permanent deployment, it is crucial to understand that improvements in one area can enhance others, supporting the overall advancement of autonomous transit solutions.

6. Conclusions and a Way Forward

This study provides a comprehensive understanding of stakeholders' perceptions toward integrating autonomous shuttles into transportation systems and reveals the key factors influencing their adoption. Based on the findings from the EFA and the Garrett ranking, the best practices for deployment, encompassing operational, safety, policy, and economic factors were proposed. The following are some of the important conclusions drawn from the study.

- Comfort, travel time, and reliability are the most critical factors resulting in the underutilization of autonomous shuttles.

- Autonomous shuttles generally provide a safe commuting environment for all users. However, older adults find autonomous shuttles relatively unsafe compared to middle-aged individuals.
- Autonomous shuttles may pose safety concerns in areas experiencing extreme weather conditions, such as heavy rainfall or snowfall.
- The existing infrastructure and data security are barriers to autonomous shuttle deployment, highlighting the need for specific data-security policies and autonomous shuttle-friendly infrastructure for their successful implementation.
- Low speed and limited passenger capacity are also possible barriers to adopting autonomous shuttles.
- The inability to switch lanes on the road and the lack of designated lanes for autonomous shuttles can impede their widespread adoption.

Overall, this study contributes to a better understanding of stakeholders' expectations and provides a perception-based framework for decision-making. The findings help to promote the widespread acceptance of autonomous shuttles and their integration into public transportation systems.

This study has a few limitations. First, future research should focus on gathering and analyzing the perception of users who used autonomous shuttles to understand the attitudes influencing the willingness to use autonomous shuttles, offering more profound insights into overcoming barriers to autonomous shuttle adoption. A refined understanding will create more user-centric and effective strategies for successfully integrating autonomous shuttles into existing transportation systems. Second, each deployment type presents unique characteristics and challenges, which this study has not explored. Future studies should aim to collect operational data specific to each deployment type, scrutinize their nuances, and determine the implications for autonomous shuttle adoption and utilization.

The number of responses collected from the industry experts is relatively lower than that from the practitioners. Exploring novel approaches to engage and collect more responses from industry experts will help compare how their perceptions and expectations differ from the practitioners. It will help identify solutions to bridge the gap between these stakeholders and proactively build the transportation infrastructure. This merits further investigation.

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