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MTI MINETA TRANSPORTATION INSTITUTE

Autonomous Shuttle Implementation and Best Practices

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Report 23-33

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16. Abstract

When, where, and how autonomous shuttles are deployed can have significant safety, economic, and policy impacts on their operation and performance. This research analyzes data related to 120 existing deployments of autonomous shuttles, looking at safety, operational, economic, and policy-related issues. Analysis shows that autonomous shuttles would be an excellent supplement to public transportation. However, improvements to the vehicle and the infrastructure are needed before any permanent deployment. The study also analyzes the perceptions of practitioners, industry experts, and transportation system users toward autonomous shuttles. Principal Component Analysis (PCA) and Multiple Input Multiple Cause Structural Equation Modelling (SEM) approaches were adopted to analyze the perception data. The results from the PCA highlighted critical barriers to autonomous shuttle implementation, including underutilization measures, safety concerns, seating arrangements, reliability, data security, operational aspects, sensor technology, and lane use. The results from the SEM revealed that users'willingness to use autonomous shuttles is influenced by their perceived safety, comfort, trust in autonomous shuttles, familiarity with autonomous shuttles, household income, age, and frequency of transit usage. A set of recommended best practices for deploying autonomous shuttles is proposed based on the insights from multiple case studies and the perceptions of practitioners and industry experts.

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Executive Summary

The emergence of autonomous shuttles represents a significant advancement and addition to public transportation systems and, if efficiently managed, can make transit systems more attractive to transit riders. With a smaller passenger capacity, typically accommodating twelve to fifteen individuals, autonomous shuttles offer a unique and promising solution for short-distance travel needs within urban and rural areas. They are designed to run on pre-defined routes at speeds ranging from eight to twenty miles per hour, providing a reliable and efficient mode of transportation. These shuttles are crucial in addressing the first- and last-mile connectivity gaps for public transportation system users.

Autonomous shuttle technology is an additional component to the existing long-route transit systems, enhancing overall transportation accessibility and efficiency. However, it is imperative to (a) examine existing deployments and (b) capture perceptions of different target audiences towards different aspects of autonomous shuttles to successfully implement autonomous shuttles. Understanding the implications of these driverless vehicles and the acceptance of users is crucial to addressing transportation needs and shaping the future of transit-based mobility. Moreover, it enables the development of data-driven recommendations for effectively and efficiently managing autonomous shuttles and public transportation systems.

This research includes a rigorous and comprehensive global analysis of autonomous shuttle deployments, focusing on comparing the deployments in the United States with those in other countries. It examines over 120 existing autonomous shuttle deployments, in 21 countries, assessing their operational, safety, policy, and economic aspects. The learnings from the existing deployments are presented using the strengths, weaknesses, opportunities, and threats analysis.

The study also offers an in-depth perception survey of transportation system users, practitioners, and industry experts. Based on data from the existing deployments and the perception of practitioners, industry experts, and transportation system users, the study proposes data-driven recommendations or best practices for successfully implementing autonomous shuttles.

In the initial phase of this study, data for autonomous shuttle deployments were collected from multiple sources such as research papers, newspapers, technical reports, and magazines. The results provide valuable insights into the operational, safety, policy-related, and economic factors involved in autonomous shuttle deployment. The deployment-related data were also compared between countries. The comparative analysis between the United States and other countries offers a unique perspective on the existing state of autonomous shuttle deployment.

The user survey solicited the perspectives of transportation system users on their readiness and willingness to use autonomous shuttles. Simultaneously, the experts' survey gathered opinions from industry practitioners and experts, offering a more technical perspective on autonomous shuttle deployment.

The study employed Structural Equation Modeling (SEM) and Principal Component Analysis (PCA) to analyze the collected data. The SEM analysis, conducted on the transportation system users' data, highlights the significance of safety, comfort, and trust along with measured variables such as age, annual household income, frequency of public transportation system use, and familiarity with autonomous shuttles, on the willingness to use autonomous shuttles. In particular, the SEM depicts the importance of trust among all considered variables, emphasizing its influence on users' willingness to use autonomous shuttles. The model also reveals that familiarity with autonomous shuttles significantly influenced users' perceived safety, comfort, and trust.

The PCA was conducted on the practitioners' and industry experts' survey data, revealing eight principal components. These factors highlight critical aspects such as underutilization, safety, seating arrangement, reliability, data security, and operational aspects, significantly contributing to the perception of autonomous shuttles.

Based on these analyses, the study offers a set of recommendations for best practices for autonomous shuttle deployment. These encompass aspects ranging from safety, operational improvements, and policy amendments to modifying the position of Light Detection and Ranging sensors for better blind-spot detection and addressing infrastructure barriers, thereby facilitating a more effective deployment of autonomous shuttles.

The study concludes by emphasizing the need for more focused research, particularly the need to delve deeper into the operational data analysis for each autonomous shuttle deployment type and identify potential challenges. Furthermore, it underscores the importance of gathering perception data from transportation system users who have experience riding autonomous shuttles, as this might significantly differ from general perceptions and provide additional nuances to aid in the effective adoption and deployment of autonomous shuttles in the future.

1. Introduction

Rapid technological advancements in autonomous vehicles (AVs) have revolutionized and are expected to continue to revolutionize transportation systems. AVs are expected to affect the travel and urban form of cities. The associated benefits related to traffic safety and the enhanced efficacy of transportation systems have spurred transportation policy-making authorities to welcome AVs. Although AVs are expected to bring benefits, there are still uncertainties and negative effects that surround AVs; for instance, policymakers are concerned about the negative effect of AVs on transit ridership. One of the practical solutions to tackle the negative effect of AVs on transit ridership is through augmenting the existing public transportation system with AVs. However, applying AVs to the public transportation system needs more attention.

The emergence of autonomous shuttles represents a significant advancement and addition to the public transportation systems and, if efficiently managed, can make transit systems more attractive to transit riders. Autonomous shuttles are driverless micro-transit vehicles that operate more slowly than traditional transit buses. Initial deployments of autonomous shuttles took place in countries such as Australia, Switzerland, France, and the United States, marking the beginning of a transformative journey in urban mobility. With a smaller passenger capacity, typically accommodating twelve to fifteen individuals, autonomous shuttles offer a unique and promising solution for short-distance travel needs within urban and rural areas. They are designed to run on pre-defined routes at speeds ranging from eight to twenty miles per hour, providing a reliable and efficient mode of transportation. These shuttles are crucial in addressing the first- and last-mile (F&LM) connectivity gaps for public transportation system users. Consequently, autonomous shuttle technology is an additional component to the existing long-route transit systems, enhancing overall transportation accessibility and efficiency.

The Society of Automative Engineers (SAE) has established a classification system comprising six levels to categorize AVs (SAE International, 2021). At level 0, no automation is present, and the vehicle relies entirely on human control. Levels 1 to 3 encompass varying degrees of driver involvement, with the driver primarily responsible for vehicle control. In contrast, the autonomous capabilities of the vehicle remain secondary. Conversely, levels 4 and 5 denote full automation with the AV having complete control of the driving task in limited and all environments, respectively. Autonomous shuttles are specifically designed to embody level 4 autonomous technology, characterized by the absence of steering wheels and pedals, signifying a reliance on the autonomous system for all aspects of driving. However, a safety operator on board is still necessary for safety purposes.

1.1 Problem Statement

Autonomous shuttles are a new autonomous addition to the transportation system to supplement the public transportation system by increasing accessibility. Autonomous shuttles can improve mobility and access for regular transportation system users and transportation-disadvantaged users (such as the elderly, people with disabilities, nondriving age groups, etc.), bridging social inequity.

The interest in autonomous shuttles has peaked recently despite having been a part of the transportation industry for a while. The need for the autonomous shuttle has increased as no other transportation mode is better suited to supplement the public transportation system with F&LM connectivity. Considering the benefits autonomous shuttles are expected to bring, researchers have explored various aspects of autonomous shuttle technology, including their operational characteristics, potential benefits, challenges, and perception and acceptance of users towards autonomous shuttles. Understanding the implications of these driverless vehicles and the acceptance of users is crucial for addressing transportation needs and shaping the future of transit-based mobility. Moreover, it enables the development of data-driven recommendations for effectively and efficiently managing autonomous shuttles and public transportation systems.

1.2 Research Objectives

The objectives of the proposed research are:

- to conduct a comprehensive review of autonomous shuttle testbeds and implementations and document their operational, safety, policy-related, and economic factors;
- to survey and capture the perceptions of practitioners, industry experts, and transportation system users toward autonomous shuttles; and,
- to recommend best practices.

1.3 Practical and Scientific Relevance of the Study

In this research, data related to almost 120 autonomous shuttle deployments worldwide have been studied. Almost half of the autonomous shuttle deployments are from the United States. Autonomous shuttle specifications, learning from the deployments and challenges, have been analyzed and reviewed regarding their operational, safety, policy-related, and economic factors. The descriptive statistics of the existing deployments in terms of operational, policy-related, and economic factors are compared to provide an overview and understanding of the autonomous shuttle deployments in the United States and other countries. The perceptions of practitioners, industry experts, and transportation system users towards various aspects of autonomous shuttles and their implementation are collected and analyzed to develop data-driven recommendations for the best practices for implementing them.

1.4 Organization of the Report

The remainder of the report consists of five chapters. Chapter 2 comprehensively discusses the autonomous shuttles' specifications, reviews existing studies, and presents the learning in terms of vehicle performance, safety, policy-related, social justice and equity, weather, traffic management, and user perception-related thematic areas. Research gaps are identified and summarized in Chapter 2. Chapter 3 details the methodological approach used in the study. Chapter 4 discusses the results of the existing deployments and presents the learning and understanding from the existing deployments in the form of a strengths, weaknesses, opportunities, and threats (SWOT) perspective. Chapter 5 details the perception survey results for practitioners, industry experts, and transportation system users separately. Chapter 6 provides data-driven policy-related recommendations or best practices, conclusions, and the scope for future work.

2. Literature Review

A public transportation system provides economical and reliable mobility services to the public, particularly for transportation-disadvantaged people. One of the most significant barriers in most U.S. cities is its accessibility, especially in areas where fixed-route local bus services are inefficient and ridership is unsustainable. For older people, the accessibility of the network system is a significant factor when choosing a mode of travel (Hess, 2003). Similarly, F&LM connectivity is expected to assist people with disabilities by improving the nearness of transit stations. Transit service can be extended by providing micro-transit services to disadvantaged residents (Zuo et al., 2020). Disruptive transportation technologies provide more accessible transportation means that are faster and require less physical energy (Zuo et al., 2020). As a form of disruptive transportation technology and service, autonomous shuttles could support the existing public transportation system by providing F&LM connectivity through improved accessibility (Zuo et al., 2020). Autonomous shuttles could also bridge social inequities by improving accessibility for disabled and disadvantaged populations.

There is a lack of studies focusing on the societal impact of low-speed autonomous shuttles. A few states have begun deployments due to the growing interest in slow-moving vehicles. The use of shuttles is expected to be greater in busier areas. A study has been done to estimate the impact of a fleet of vehicles in Santa Clara County and found that, though autonomous shuttle trips were distributed across the county, the downtown area was subject to the most trips (Hsueh et al., 2021).

2.1 Autonomous Shuttle Specifications

Autonomous shuttles are electric vehicles with a capacity of six to twenty people. They do not require a human to operate, and they operate mainly through sensory mechanisms. Through artificial intelligence (AI), autonomous shuttles can detect the surrounding environment and create a navigable route without violating transportation rules. Autonomous shuttles are increasingly popular as they cater to the need for reliable, efficient, and sustainable transportation alternatives.

Four types of stakeholder organizations—public organizations, partner organizations, shuttle manufacturers, and private operators—are associated with deploying autonomous shuttles (Haque and Brakewood, 2020). Public organizations are mainly the ones who look after the legal process and permissions. For the most part, this group is crompised of the transportation departments of cities, states, and transit agencies. Partner organizations create the whole plan for deploying shuttles with specific plans. This group mainly includes universities, research organizations, and different communities. Shuttle manufacturers are dealers of the hard bodies of shuttles. Private operators are mainly responsible for the software and data collection.

The sensory system of autonomous shuttles can be divided into three parts: navigation and guidance, driving and safety, and vehicle performance (Artificial Intelligence, 2021). There are many companies participating in the global market of autonomous shuttles: Navya, Beep, Local

Motors, EasyMile, Oceaneering, and Coast are the main companies leading the field. Baidu is another dominant company, which is mainly doing business in China.

Shuttle specifications vary with manufacturers, as observed in Table 1. The information related to shuttle specifications is collected from multiple sources (Lin et al., 2018; EasyMile, n.d.; Navya, Irmantas, 2020).

Table 1. Autonomous Shuttle Specifications

Specifications	EasyMile (EZ10)	Navya (Autonom)	Local Motors (Olli)	Coast Autonomous (P1)
Capacity	12	15	10	14
Maximum Speed (mph)	28	45	25	25
Length (m)	4.05	4.78	3.92	3.96
Width (m)	1.892	2.10	2.05	1.83
Height (m)	2.871	2.67	2.5	2.44
Wheelbase (m)	2.8	-	2.528	-
Empty Weight (kg)	2130	2600	2654	-
Gross Weight (kg)	3130	3500	3266	-
Charge Time (hours)	5 to 8	4 (7.2 kW plug)/ 9 (3.6 kW plug)	1.5 (440 V)	-
Average Autonomy (hours)	10 to 12	9	-	~10
Onboard Technology	Cameras, LiDAR, GPS, Radar, Ultrasonic Sensors, Inertial Measurement Unit (IMU), Control and Computing Systems	GNSS, Cameras, LiDAR, Sensors for Odometry, IMU	-	LiDAR, Sensors, Stereo Camera, GPS, V2X Technology
Vehicle Cost ($)	~250,000	~225,000	-	-
Operating Cost ($)/Month or Year	~35,000	~100,000	-	~15,000
Battery Capacity	20.0 kWh	33.0 kWh	18.5 kWh	-

The Boston-based company, Optimus Ride, is another company that has autonomous shuttles. Transdev, Keolis, and Free2move are working as operators with other companies. Toyota also has its minibus shuttle. These buses are aimed at a carbon-neutral future for the automaker's mobility services (Lyon, 2021).

RACQ Smart Shuttles has launched a five-year shuttle plan for trials in different phases to analyze the specific and uncertain issues of shuttles. The first phase carried 1450 passengers in Raby Bay, and the second phase carried 949 passengers at Karragarra Island (RACQ, n.d.).

2.2 Case Studies and Learnings

Autonomous shuttles are different from long-route buses in capacity and route length. The purpose of autonomous shuttles is to supplement long-route transit, mainly from the F&LM connectivity perspective. The main motto of these deployments is to test the technology under real-world scenarios and develop them accordingly (Zank and Rehrl, 2018). As this is a new technology, many challenges remain to be overcome before permanent deployment.

Autonomous shuttles can (i) provide service from predetermined bus stops to public transportation routes for daily commuters (regular or on-demand), (ii) provide service to a particular center for (day) tourists, and (iii) deliver goods and services (Zank and Rehrl, 2018). The deployment offers three main functions: fleet management, system monitoring, and customer experience (UDOT, 2021).

2.2.1 Vehicle Performance

In New South Wales, Australia, an autonomous shuttle was deployed in three phases to check the performance of this new addition in different scenarios. BusBot went through trials starting with a nine-week trial at a high-profile and controlled environment for residents and tourists. The second phase was at the Toormina Marian Grove Retirement Village, a home for 68- to 98-year-olds, in 2019. This trial provided a valuable test case to understand the mobility needs of an older community. In the third phase, at the North Coast Regional Botanic Garden through the beginning of 2020, an autonomous shuttle was deployed in a closed public place (BusBot, n.d.).

One frequently recorded issue was that the shuttle would halt even if no detectable obstacles were on the road. In the case of Austria, the anticipated reason for such incidents could be roadside branches or bushes and unreliable network data transfer, which led to improper signal transmission (Zank and Rehrl, 2018). Another issue was blind spot detection, which can be prevented with the correct positioning of 360° Light Detection and Ranging (LiDAR) sensors (Zank and Rehrl, 2018). The sensors detect objects in the front or the back of the shuttle. Any object moving over 30 km/h cannot be reliably detected. However, this can be improved using higher resolution LiDAR sensors or extra sensor installation (Zank and Rehrl, 2018).

The autonomous shuttles in the recorded pilot programs are mainly SAE level 3 and level 4 AVs. These shuttles can maneuver on pre-defined, simple routes. However, the designed autonomous shuttles still cannot cope with a complicated public route, and the operator needs to act to pass any obstacle or turn left (Zank and Rehrl, 2018).

An additional challenge encountered with autonomous shuttles pertains to their battery life. A specific instance of this issue was observed in the Utah 1950 West deployment, where service had to be curtailed at 5:30 pm instead of the intended 6:00 pm due to a battery power shortage (UDOT, 2021). The operation of autonomous shuttles is impacted by cold weather conditions, resulting in prolonged charging times. Colder temperatures cause a significant drop in the battery core temperature, negatively affecting the shuttle's operations. The charging process also takes longer in cold weather compared to warmer temperatures (BusBot, n.d.). This highlights the importance of battery capacity and management in ensuring uninterrupted service and meeting the operational requirements of autonomous shuttle deployments.

2.2.2 Safety and Security

Drivers of any conventional vehicle must maintain uninterrupted control over the vehicle and adapt the speed as per speed limit requirements. However, in level 4 autonomous shuttles, the operator need not have direct control over the steering wheel. For safety purposes, an operator, who can manually operate the vehicle when in need, is always present in the shuttle. The training of the safety operator includes: technical specifications of the shuttle, manual control of the shuttle, autonomous driving procedure, monitoring and reporting, and the management of emergencies (Zank and Rehrl, 2018).

For autonomous shuttles, one of the biggest challenges is interacting with road users on public roads (Zank and Rehrl, 2018). For increased safety, additional acoustic signals and visual indicators are employed in some of the shuttles (Zank and Rehrl, 2018). In Japan, a visually impaired athlete was injured by an autonomous shuttle while crossing the road (Lyon, 2021). On July 18, 2019, a minor accident occurred in Vienna, Austria. A pedestrian did not see the 12 km/h autonomous shuttle approaching her. The shuttle's reaction time was 1.6 seconds, exactly what it should be (Neuwinger and Karl, 2019). If the shuttle stops by any obstacle, it shows visual information (Zank and Rehrl, 2018). However, pedestrians were not used to the new technology. Furthermore, there is no scientific evidence or rules on what signalization will lead to what behavior of road users (Zank and Rehrl, 2018).

2.2.3 Traffic Management

Autonomous shuttles can improve public transportation through F&LM connectivity (Zank and Rehrl, 2018). However, people prefer private vehicles for long distances (Zank and Rehrl, 2018). Some deployments tried to reduce the number of vehicles on busy roads to reduce congestion. In Sweden, the parking fee near a shuttle station was reduced by half so that people would park their vehicle and take the shuttle (Holo, 2022).

Per most legal frameworks, the maximum speed of autonomous shuttles should not surpass 20 km/h (Zank and Rehrl, 2018). However, to make a left turn without stopping, the shuttle must have a visibility clearance of 150 to 200 feet (Space, n.d.). As a slow-moving vehicle, it performs better with a dedicated lane (City of Calgary, 2019). Traffic signals were modified in some places as the vehicle cannot recognize color (Space, n.d.).

2.2.4 Weather Conditions

Autonomous technology is sensor-based and camera-based. Therefore, autonomous shuttles cannot move in heavy snow or rainfall. The dust can stop autonomous shuttles from the gravel's reaction with the sensors (City of Calgary, 2019). In the case of the deployment at the Calgary Zoo, the vehicle slowed down during snowfall, but once the snow stopped, the autonomous shuttle resumed at normal speed (City of Calgary, 2019). Light rain did not affect the movement of the autonomous shuttle, and the vehicle operated perfectly with snow on the ground. However, the vehicle stopped when it splashed into a puddle (City of Calgary, 2019).

With the existing technology, autonomous shuttles cannot run in extreme weather conditions. In particular, the technology should be tested to check how it operates during heavy snowfall, rain, sleet, and smoky conditions (City of Calgary, 2019). Also, the ventilation system or air-drying system was insufficient to prevent the fogging of the windscreen in cases of damp weather (Zank and Rehrl, 2018). As a result, the onboard operator could not see the road from the inside.

The operational capabilities of the existing EasyMile vehicle are limited to specific weather conditions. It is designed to operate under certain weather parameters, including the absence of heavy or medium snowfall, no water accumulation or flow on the ground, no snowy or frozen road conditions, no heavy rains or storms, humidity levels below 95%, and stabilized wind speeds below 50 km/h (with peak speeds below 65 km/h) (EasyMile, n.d.). Additionally, the vehicle requires a clear track without dust, fog, or vapor. These weather conditions are essential to ensure the safe and reliable operation of the EasyMile vehicle (EasyMile, n.d.).

Autonomous shuttles operated well, maintaining a safe distance from other vehicles, pedestrians, and obstructions on the track under dry pavement conditions with no precipitation (BusBot, n.d.). According to the City of Calgary report, the sensor needs to be improved to handle all weather conditions before it can be operated without any safety operator (City of Calgary, 2019).

2.2.5 Infrastructure

A solid infrastructure with a good network is essential for the swift running of autonomous shuttles. Autonomous shuttles best fit paved environments with well-maintained roadways (City of Calgary, 2019). Road furniture was installed for LiDAR sensors to correctly map out the Candiac area (Space, n.d.). In the rural area of Koppl, the pilot project was not so prompt due to the limited ability of LiDAR sensors, GPS, poor road infrastructure with irregulated intersections, and high elevation (Zank and Rehrl, 2018). At the Calgary Zoo, a portable ramp was brought in since the roadway gravel impacted the existing ramp (City of Calgary, 2019). Road functional class is also an important factor for route selection. The installation of localization infrastructure was necessary due to the rural nature of one site (Neuwinger, 2019).

Different kinds of modifications were required in almost all the examined deployments. The deployment of Candiac required the installation of a stop sign to allow the shuttle to make a left turn (Candiac Autonomous Shuttle, n.d.). If the route is not circular, the autonomous shuttle needs some extra room for a U-turn. The municipality of Koppl constructed a side road at the end of the route for turning the shuttle (Zank and Rehrl, 2018). For safety reasons, a dry garage is required for the shuttle to store and charge when required. In the hillside area of Koppl, an overlooking place was needed for correct signal passing between the base station and the shuttle (Zank and Rehrl, 2018).

2.2.6 Social Justice and Equity

The micro-transit system improves the quality of the public transportation system, especially in rural areas. Autonomous shuttles encourage people to use the public transportation system with F&LM connectivity as one of the primary objectives (Space, n.d.). In 2018, fleets of autonomous minibusses conducted full-scale demonstrations in low- to medium-demand areas in four European cities (Geneva, Lyon, Copenhagen, and Luxembourg) (Geneva Demonstration Site, n.d.). However, the expense was observed to be too high to run a micro-transit (Zank and Rehrl, 2018), which could be a major reason for the unpopularity of micro-transit systems on public roads.

The municipality of Koppl in Austria believes that autonomous shuttles can fill the gaps of infrequent bus links in the village area (Zank and Rehrl, 2018). The National Federation for the Blind indicated that this technology has much potential for increasing the mobility of disabled passengers (Bowling, 2020). As autonomous shuttles connect the route with public transit, commuters may experience a lack of connectivity after midnight. Hence, it may increase travel time during night hours (Hsueh et al. 2021).

Autonomous shuttles on public roads were intended to become an enduring service for the city (Ames, 2016). Parking is always a problem in the entertainment area or a busy downtown. Some deployments were in busy downtown areas with a vision to address this issue (Holo, 2022).

In the city of Peoria, the elderly community was served by RoboRide and RoboRide Medical (Musto, 2021; Bowling, 2020). Although this new technology comes with the vision of a slow-moving, safe transit motto, it would be more useful if shuttles moved at high speed and on long routes (City of Calgary, 2019).

There is a chance of the loss of driving jobs with autonomous technology in transportation systems (City of Calgary, 2019). However, with level 4 autonomous vehicles, an operator must be in the vehicle. Therefore, the loss of driving jobs may not be severe until autonomous shuttles are fully automated (level 5).

2.2.7 Legal Considerations

Currently, there are no permanent deployments of autonomous shuttles worldwide. Consequently, policies and regular costs associated with autonomous shuttle deployment remain uncertain. For an autonomous shuttle operating at SAE level 3 or higher, a driver or operator's continuous oversight of the road or traffic situation is not required (SAE International, 2021). However, legal requirements are crucial in facilitating shuttle deployments on public roads. One primary requirement is the definition of stakeholder roles.

Additionally, obtaining a test license plate for public road testing is necessary for autonomous shuttle deployments. In Austria, a shuttle deployment included vehicle liability insurance coverage of 20 million Euros (Zank and Rehrl, 2018). These legal considerations and insurance provisions are vital aspects that must be addressed for the successful and regulated operation of autonomous shuttles on public roads.

2.2.8 User Acceptance

User acceptance is crucial for F&LM connectivity. The user experience survey from the pilot program of the Calgary Zoo shows that people are comfortable with the vehicle on a separate right-of-way (City of Calgary, 2019). People prefer to take a car if the distance from home is very far but they may prefer to walk if the distance is too short (Zank and Rehrl, 2018). With the deployments on public roads, people realized that driverless vehicles are no longer a futuristic dream.

Autonomous shuttles perform best when not interacting with other motor vehicles (City of Calgary, 2019). However, passengers realized that regular service would not be available soon with the current technology and present infrastructure. A survey from Austria asked the riders if they could imagine autonomous shuttle service as a replacement for private cars, and only 39.9% responded positively (Zank and Rehrl, 2018). According to the survey report of the Calgary Zoo, 39% of the respondents were comfortable with the autonomous shuttle on normal roadways, and 25% were comfortable on the freeway (City of Calgary, 2019). With the Estonian shuttle, a passenger survey showed that people are ready to accept the technology with its safety and comfort (Hanikewitz, 2021). Similarly, 90% of passengers were satisfied with the shuttle service, and 69% found the shuttle valuable and effective in Sweden (Holo, 2022). About 80% of users in Switzerland were positive about autonomous shuttle safety (Space, n.d.).

According to survey findings from Utah, most respondents (94%) expressed a sense of safety while utilizing the autonomous shuttle service (UDOT, 2021). Furthermore, a notable proportion (14%) utilized the shuttle to connect with existing transit options, demonstrating its effectiveness in facilitating seamless multimodal transportation. The suitability of autonomous shuttles for catering to the transportation needs of the elderly community was exhibited in Florida, specifically in the case of Move Nona, where customers with wheelchairs required assistance during their shuttle commutes (City of Calgary, 2019).

Most of the existing autonomous shuttle deployments are for a short time. Therefore, the passenger surveys reflect the initial excitement scenario (Candiac Autonomous Shuttle, n.d). Long-term experiences may differ from initial perceptions. Giving a unique name to any shuttle seemed to help people get more thrilled and familiar with the autonomous shuttle (City of Calgary, 2019). For example, 72% of the respondents came to Calgary to experience the shuttle ride only (City of Calgary, 2019).

2.3 Research Gaps

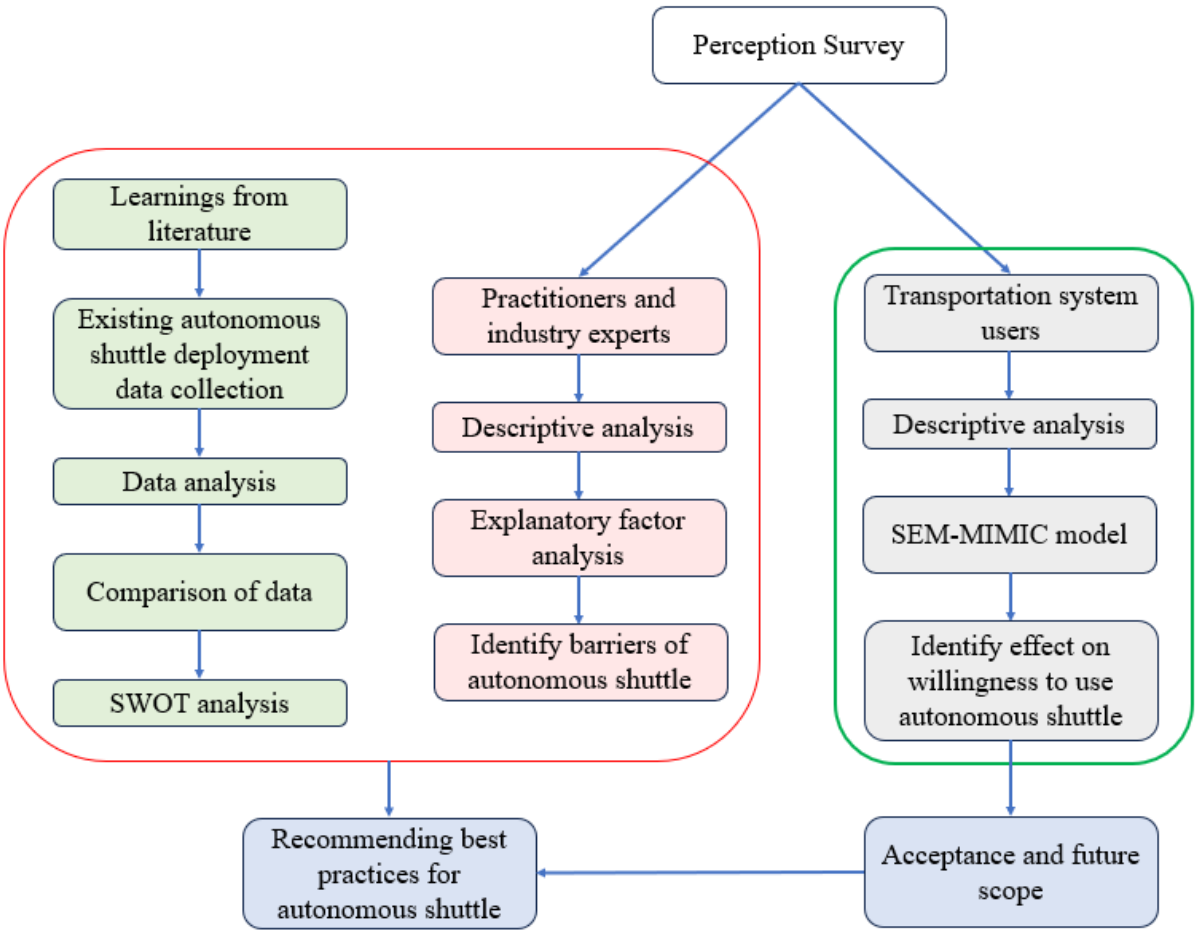
Previous studies primarily concentrated on a limited number of pilot cases, thus failing to conduct comprehensive global and national comparisons. The implementation and acceptance of autonomous shuttles in various locations and by different types of transportation system users with diverse characteristics (such as gender and age) and location characteristics (such as neighborhood, campus, business park, hospital, and recreational park) have not been clearly understood, despite temporary deployments. Moreover, there is limited availability of the knowledge from existing autonomous shuttle deployments, which could offer valuable insights and recommend best practices for implementing autonomous shuttles. While researchers have tried to analyze data from these deployments, the focus has mostly been on individual or regional cases, neglecting a comprehensive comparison of global and national deployments. Such a comparison would provide a wider perspective on operational, safety, economic, and policy considerations.

In most studies, the focus has predominantly been on examining the perceptions of transportation users concerning their acceptance of, and willingness to use, autonomous shuttles. However, there has been a lack of analysis when examining the perceptions of distinct groups, such as practitioners and industry experts. By analyzing the viewpoints of these specific groups separately, barriers and the reasons behind the reluctance to use or deploy autonomous shuttles, as well as potential enablers to improve existing deployments, can be identified. Furthermore, this analysis can help determine the necessary measures before new deployments. Comprehensive information can be gathered by integrating the perspectives of practitioners, industry experts, and transportation users, which can then be used to develop data-driven effective strategies and best practices for successfully implementing autonomous shuttles.

3. Methodology

The chapter details the methodological framework adopted in the present study. The methodology framework has two parts, as illustrated in Figure 1.

Figure 1. Methodological Framework



The first part collects and analyzes the data pertaining to existing autonomous shuttle deployments. These data were collected from multiple sources, such as research papers, deployment reports, magazines, and newspapers. The collected data were analyzed, focusing on the safety, operational, economic, and policy-related aspects of autonomous shuttles. The data were analyzed separately for autonomous shuttle deployments in the United States and for autonomous shuttle deployments in other countries. The learnings from the existing autonomous shuttle deployments are presented using strengths, weaknesses, opportunities, and threats (SWOT) analysis.

In the second part, industry experts, practitioners, and transportation system users' perceptions of various aspects of autonomous shuttles are captured using a well-designed, web-based questionnaire. The professionals specializing in automotives, autonomous shuttle development, and paid mobility constitute the industry experts, whereas practitioners are individuals from government agencies, and planning and development sectors. The transportation system users comprise all individuals utilizing the roadways. Two questionnaires were developed, one for practitioners and industry experts and another for transportation system users. The perceptions of industry experts and practitioners were analyzed using principal component analysis (PCA). The results of the PCA enabled the identification of barriers and the reasons behind the reluctance to use autonomous shuttles, as well as potential enablers to improve existing autonomous shuttle deployments. The user perception data were analyzed using the Multiple Input Multiple Causes (MIMIC) Structural Equation Modelling (SEM) approach. The results derived from the SEM highlight the influences of different variables on the willingness to use autonomous shuttles. Together, the results derived from the existing autonomous shuttle deployments and perception surveys were used to develop data-driven recommendations or best practices for implementing autonomous shuttles.

4. Analysis of Existing Autonomous Shuttle Deployments

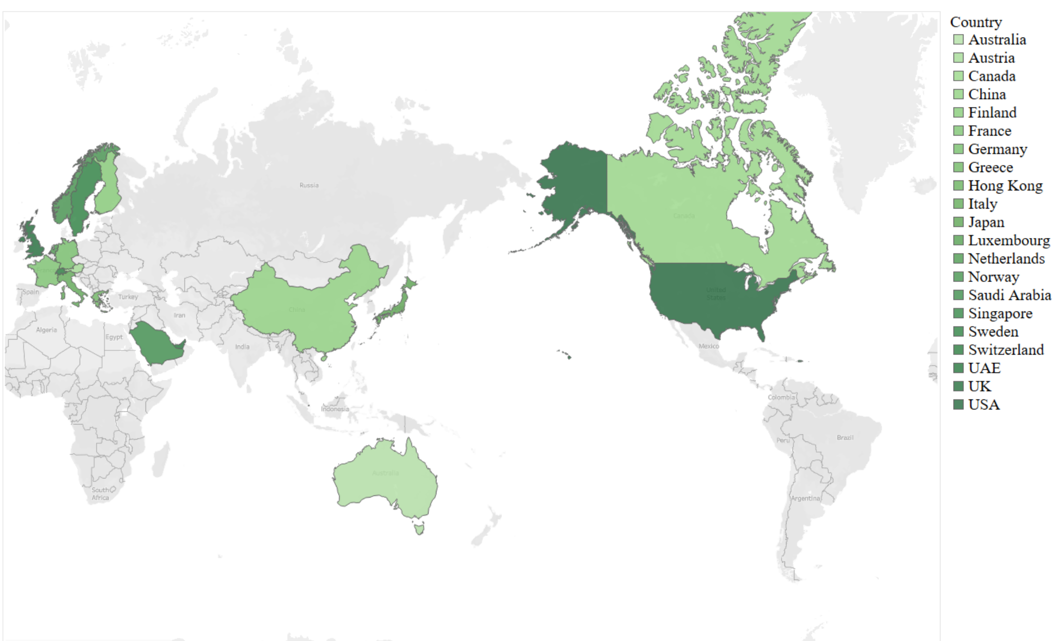
This chapter analyzes the data collected from existing autonomous shuttle deployments and presents the results. These data were collected from multiple sources such as research papers, magazines, technical reports, and newspapers, as summarized in the Appendix.

The descriptive statistics of 120 autonomous shuttle deployments from 21 countries are presented in this chapter. The trial time, deployment environment, length of the route, number of vehicles or stops, cruising speed, and fee for riding the autonomous shuttle are summarized. The comparison of the data was performed in two parts: comparing the deployments of the United States with other countries; and, comparing the cases in terms of environments.

4.1 Deployments in the United States and Other Countries

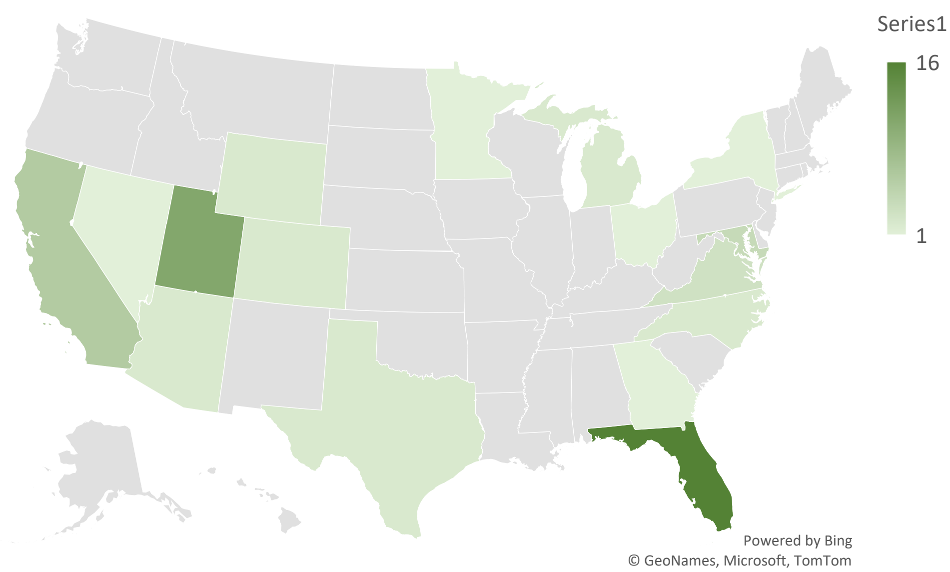
Figure 2 shows the selected deployments all over the world. Of these, 57 deployments were from the United States, 13 from France, eight from China, seven from Australia, five each from Germany and Switzerland, three each from Canada and Norway, two each from Austria, Japan, Luxemburg, Sweden, UAE, and UK and one deployment each from Finland, Greece, Hong Kong, Italy, the Netherlands, Saudi Arabia, and Singapore.

Figure 2. Selected Autonomous Shuttle Deployments



Per the National Highway Traffic Safety Administration, autonomous shuttles can be deployed for a specific time on a fixed route with some regulations. The United States Department of Transportation is trying to increase the successful deployment of relevant projects, ensure the efficient use of public funds, improve awareness and consideration of universal design and accessibility, and inform engagement in this area. The University of Michigan first launched the autonomous shuttle pilot project in February 2016 (Geiser, 2021). Since then, autonomous shuttles have been deployed in various places with different trial periods in the United States. Figure 3 shows the selected deployments in different states of the United States. Many deployments have been done in Florida and Utah. Sixteen autonomous shuttle deployments were observed in Florida while eleven autonomous shuttle deployments were observed in Utah.

Figure 3. Selected Autonomous Shuttle Deployments in the United States



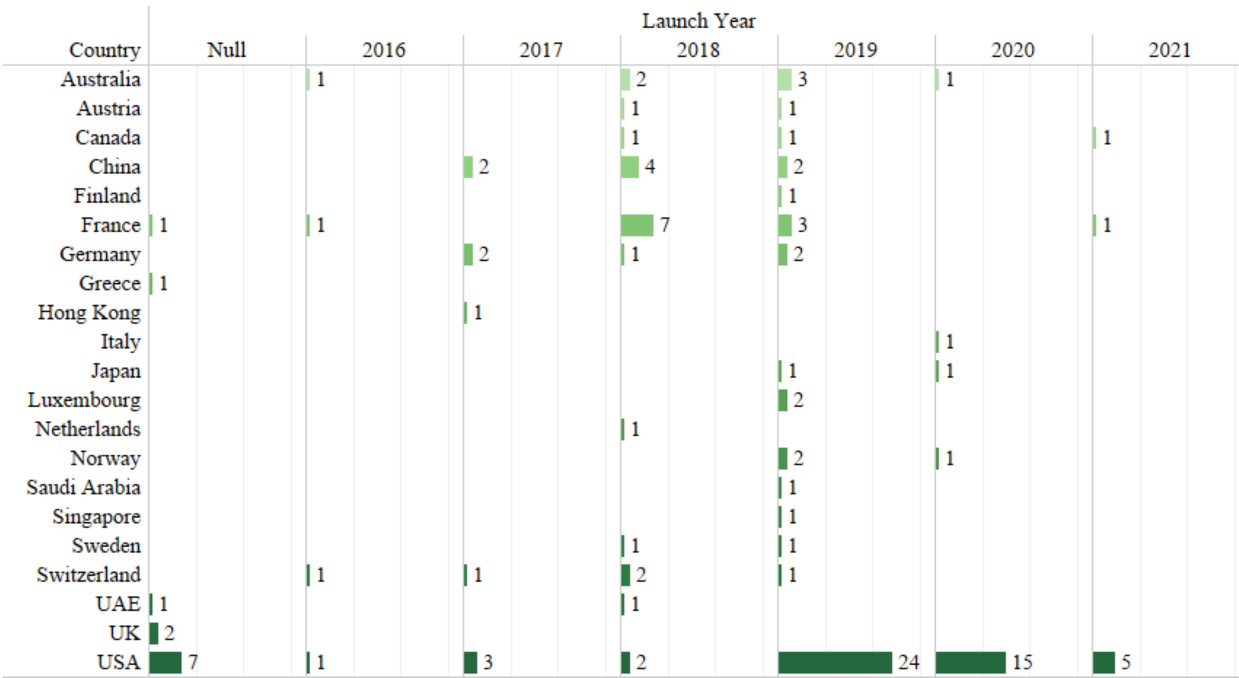
4.2 Autonomous Shuttle Deployments by Year

Figure 4 shows the yearly deployments of autonomous shuttles worldwide. Autonomous shuttle pilot deployments commenced in 2016 across several countries, including Australia, Switzerland, France, and the United States. The year 2019 witnessed the highest number of these deployments. However, the number of deployments experienced a decline in 2020, which can be attributed, at least in part, to the impact of the COVID-19 pandemic on the autonomous shuttle industry.

Between 2016 and 2017, autonomous shuttle deployments were observed in seven countries. Notably, six deployment projects were initiated within the United States from 2016 to 2018. However, 23 deployments were recorded in the United States in the subsequent year, 2019.

Consequently, the advent of the COVID-19 pandemic impacted the progress of autonomous shuttle deployments, leading to an abrupt decline in their numbers. Despite the prevailing pandemic circumstances in the United States, the deployments continued their operations, albeit subject to certain restrictions and guidelines.

Figure 4. Yearly Deployment of Selected Autonomous Shuttle Deployments



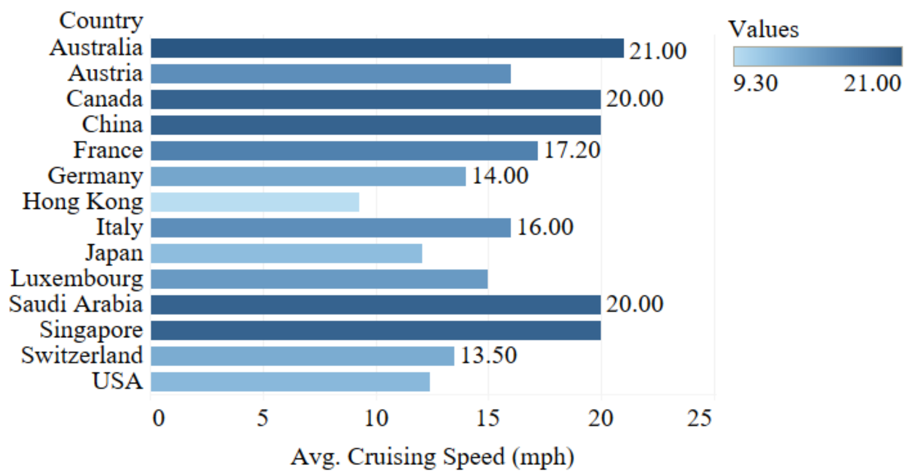
4.3 Comparison of Operational Data

The cruising speed, track length, number of stops per mile, and the density of vehicles per mile are analyzed and summarized in this section. These metrics were used to compare the performance of autonomous shuttle deployments in terms of their operational characteristics.

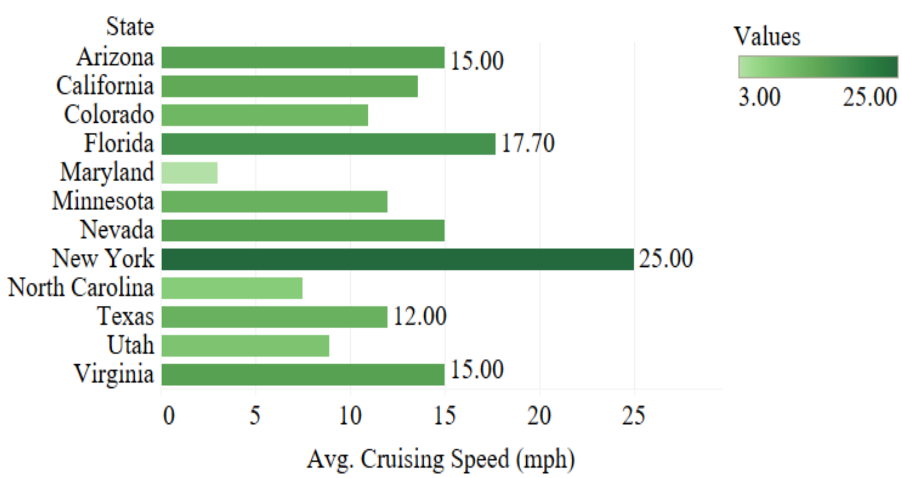
4.3.1 Average Cruising Speed

Autonomous shuttles are categorized as slow-speed, autonomous, micro-transit vehicles, with maximum speeds between 25 to 27 mph. However, the average cruising speed ranged from 3 mph to 25 mph across 63 recorded deployments worldwide. Figure 5(a) provides insights into the average cruising speeds of autonomous shuttle deployments in the United States and other countries, showcasing variations in the operational speeds of autonomous shuttles across the deployments.

Figure 5. Average Cruising Speed of Selected Autonomous Shuttle Deployments



(Other Countries)



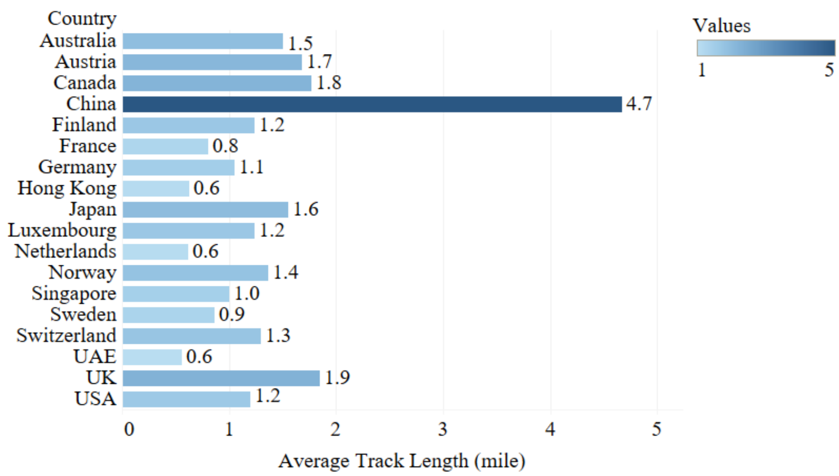
(United States)

Australia has the highest average cruising speed (21 mph), and Hong Kong has the lowest cruising speed (9.3 mph). Variations in cruising speed may be related to track length, road geometry, traffic flow, and other infrastructure-related characteristics. For example, the cruising speed is reduced if autonomous shuttles are deployed on public roads. This could be due to continuous interactions with other vehicles, pedestrians, and the presence of intersections. For the United States, the average cruising speed is 12.4 mph. Figure 5(b) shows the average cruising speed for different states in the United States. The highest average cruising speed is 17.7 mph in Florida, and the lowest average cruising speed is 3.0 mph in Maryland.

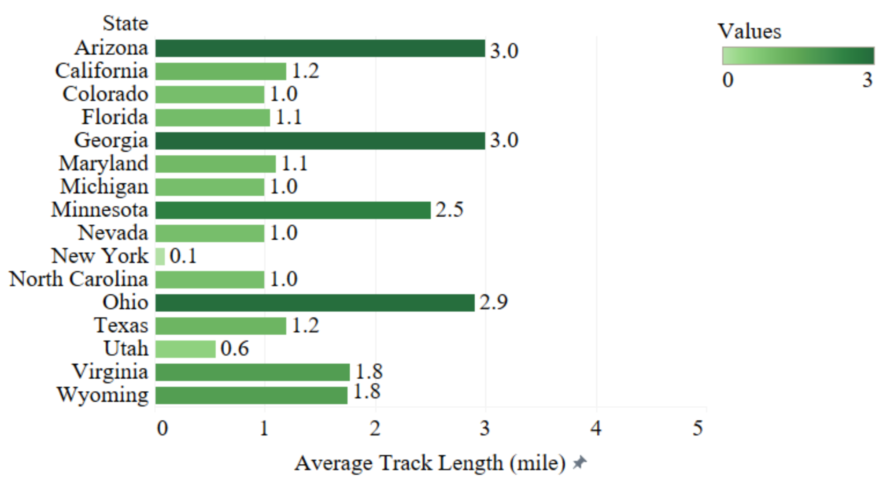
4.3.2 Average Track Length

The design of autonomous shuttles predominantly focuses on facilitating short route travel paths, particularly for F&LM connectivity. These shuttles are optimized for low speeds and serve as connectors between public transportation systems or parking facilities. Figure 6(a) showcases the average track length of selected autonomous shuttle deployments in other countries, highlighting their suitability for short-distance transportation.

Figure 6. Average Track Length of Selected Autonomous Shuttle Deployments



(Other Countries)



(United States)

Note: The pin in the figure indicates that the maximum x-axis value for the United States was set equal to the other countries.

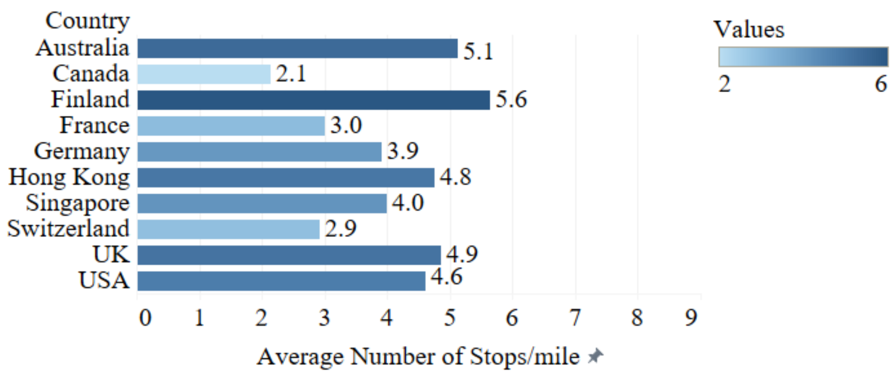
In China, the highest track length for autonomous shuttles is 4.67 miles. In comparison, the overall average track length for 82 deployments stands at 1.35 miles. If the deployments in the United States are excluded, the average track length for autonomous shuttle deployments is 1.54 miles. Within the United States, the average track length is slightly shorter, measuring 1.1 miles. Figure 6(b) shows the average track length in different states of the United States.

Within the United States, track lengths have been measured for 35 deployments. Among these, the autonomous shuttle deployment in Virginia has the highest recorded track length (3.5 miles). On the other hand, the lowest track length recorded is a mere 0.07 miles in Minnesota, indicating a comparatively short route for autonomous shuttle operations in that particular case (MnDOT, 2018).

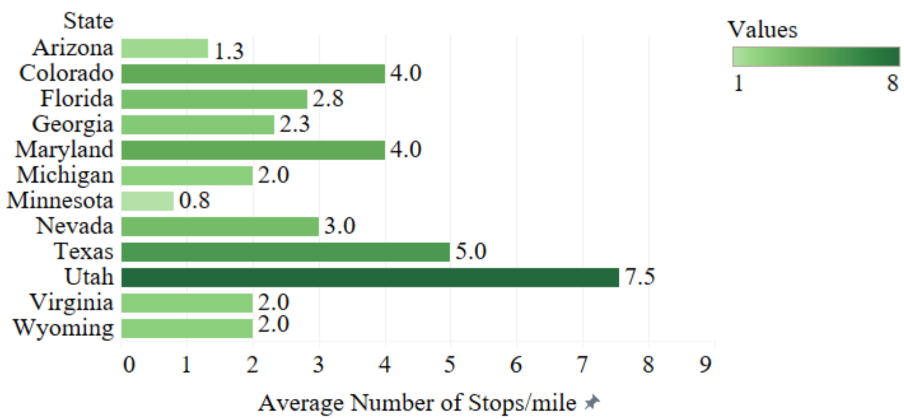
4.3.3 Average Number of Stops per Mile

Figure 7(a) provides an overview of the average number of stops per mile for selected autonomous shuttle deployments in other countries, shedding further light on the distribution of stops in these deployments.

Figure 7. Average Number of Stops per Mile for Selected Autonomous Shuttle Deployments



(Other Countries)



(United States)

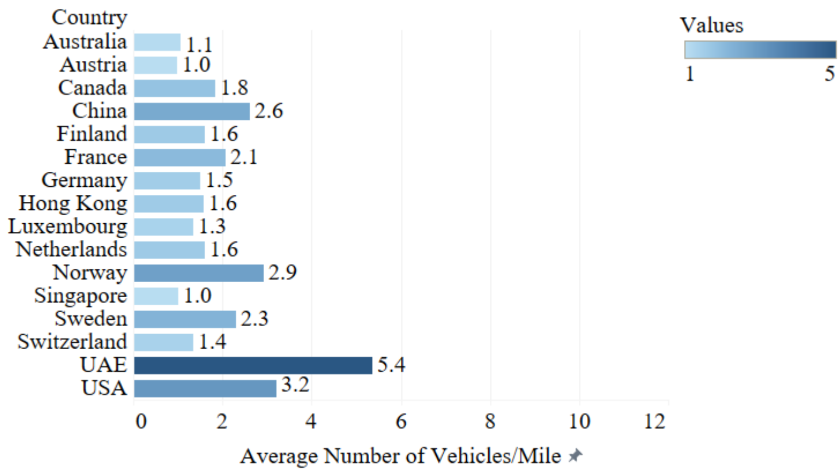
Note: The pin in the figure indicates that the maximum x-axis value for the United States was set equal to the other countries.

Approximately 60% of the selected autonomous shuttle deployments have two or three stops. However, there are exceptions to this trend. One autonomous shuttle deployment in Australia had 36 stops (5.12 stops per mile) while another one in the UK had nine stops (4.865 stops per mile) (Drive, 2016; Greater Cambridge Partnership, 2021). Figure 7(b) illustrates the average number of stops across different states of the United States. Of the 33 autonomous shuttle deployments with recorded stop numbers, 13 deployments had only two stops. Notably, Florida exhibits the highest number of stops among the considered states in the United States.

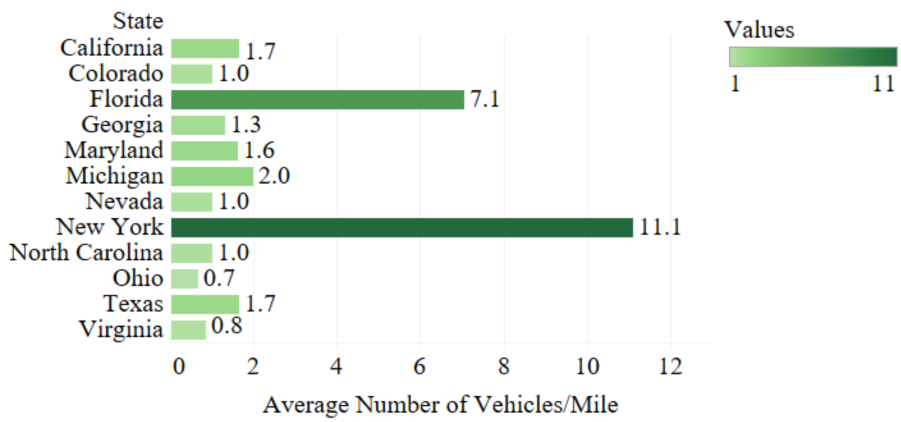
4.3.4 Average Number of Vehicles per Mile

Data were avaiable for 88 out of the selected 120 autonomous shuttle deployments. Figure 8(a) presents the average number of vehicles per mile for autonomous shuttle deployment in other countries, providing valuable insights into the general trends observed in the industry.

Figure 8. Average Number of Vehicles/Mile for Selected Autonomous Shuttle Deployments



(Other Countries)



(United States)

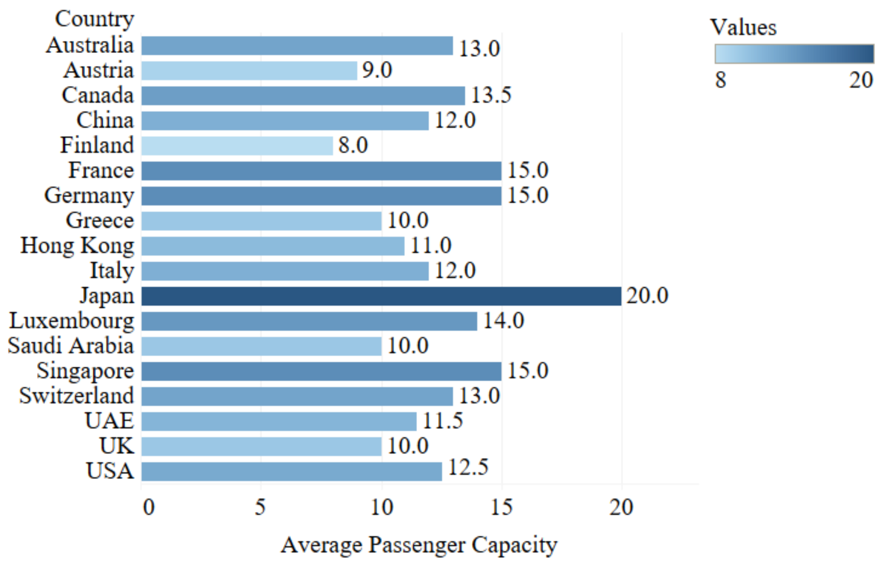
Note: The pin in the figure indicates that the maximum x-axis value for the other countries was set equal to United States.

Only one vehicle was used in 47% of the deployments while two vehicles were used in 33% of the deployments. The average number of vehicles/mile is highest for UAE followed by the United States. Figure 8(b) shows the average number of vehicles per mile used in each deployment in the United States. The highest number of vehicles used in a deployment was eight in Florida. The average number of vehicles used in deployments in the United States is three.

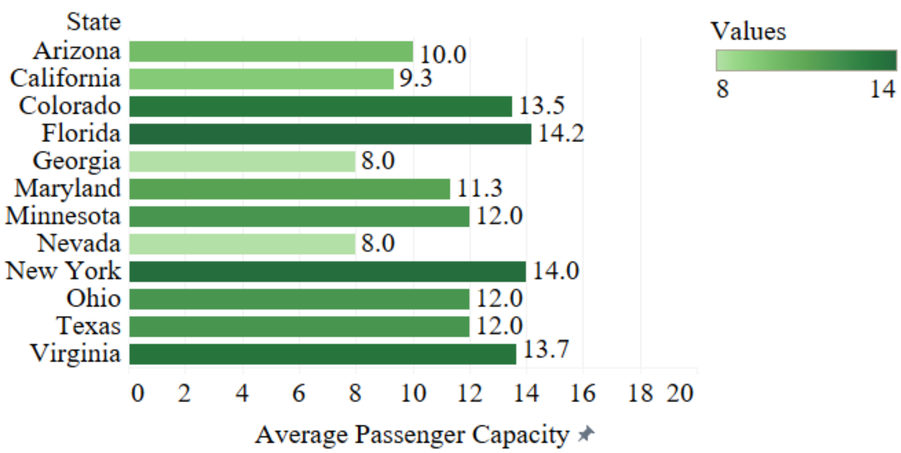
4.3.5 Average Passenger Capacity

According to the design specifications, the passenger capacity of an autonomous shuttle can range from six to twenty people per vehicle. However, the average passenger capacity is approximately 13 people per vehicle based on data from 65 recorded deployments worldwide. Notably, many deployments reduced the number of passengers riding the shuttle during the COVID-19 pandemic by half for safety reasons. Figure 9(a) provides an overview of the average passenger capacity for other countries, highlighting the variations in passenger capacity across different regions.

Figure 9. Average Passenger Capacity of Selected Autonomous Shuttle Deployments



(Other Countries)



(United States)

Note: The pin in the figure indicates that the maximum x-axis value for United States was set equal to the other countries.

The passenger capacity was 20 people per vehicle in an autonomous shuttle deployment in Japan. The lowest average passenger capacity (eight people/vehicle) was in Finland. Figure 9(b) shows the average passenger capacity of autonomous shuttles for different states of the United States. The highest average passenger capacity is in Florida.

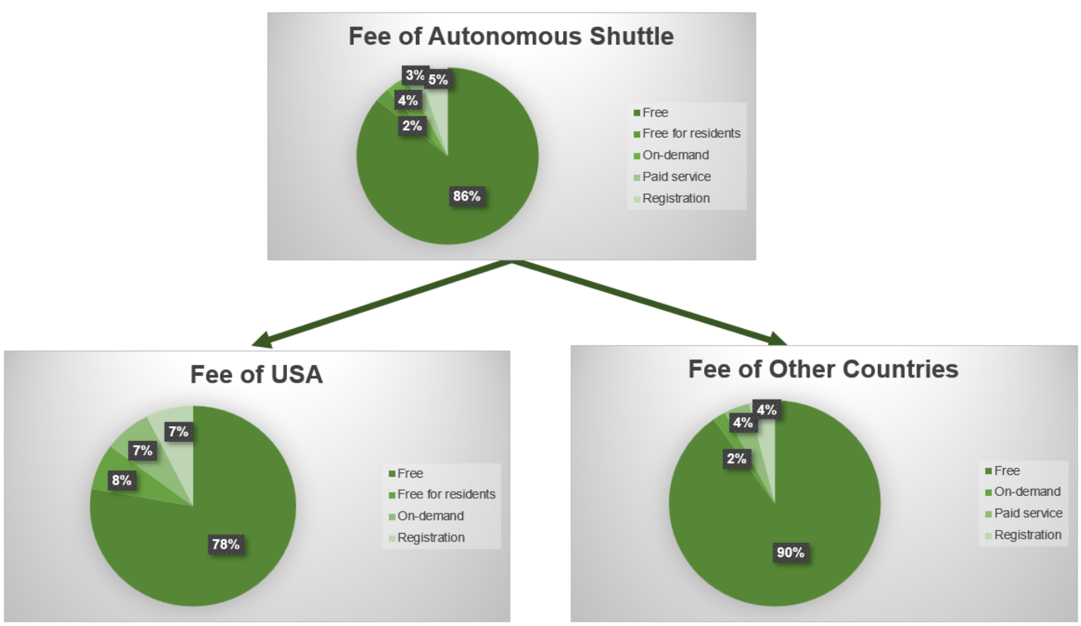
4.4 Comparison of Policy-Related Data

This section discusses policy-related data, mainly the riding fees and environment/land-uses of deployments. Additionally, the operational data are compared based on the different environments in the later part of this section.

4.4.1 Riding Fee

Figure 10 shows the shuttle riding fee for the selected deployments. In most cases, for pilot autonomous shuttle deployments, riding is free for riders. However, some deployments charged a small amount to experiment with the behavior of passengers (BusBot, n.d.). Some pilot deployments need registration before riding the shuttle, while some are on-demand. Considering all the cases, 86% of rides are free and 2% are free for residents. In the United States, all the shuttles are free for passengers to ride. However, some shuttle rides need registration. In other countries, 4% of rides are paid services.

Figure 10. Riding Fee of Autonomous Shuttle Deployments

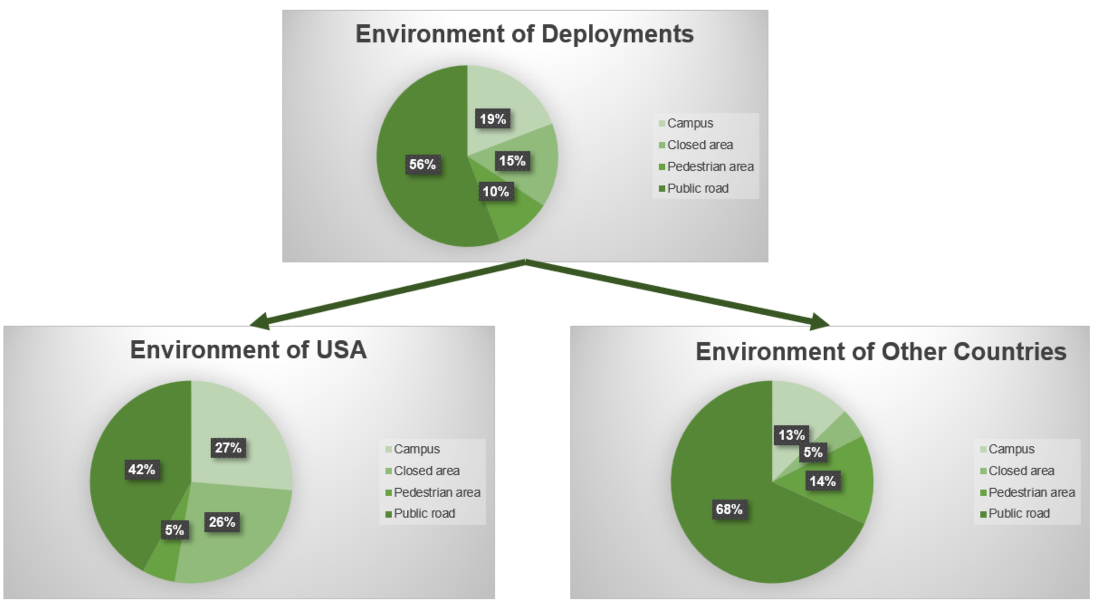


4.4.2 Environments of Routes

The environments for selected deployments are classified into four groups: campus, closed area, pedestrian area, and public road. Campus is defined as routes with limited interactions with other modes of transportation, not a public road, i.e., a college campus, office park, or stadium. Closed area is mainly routes inside a closed community, where the autonomous shuttle hardly interacts with other vehicles. Pedestrian area is defined as low-speed routes where frequent autonomous shuttle-pedestrian interaction is possible. Public road is mainly open, where the autonomous shuttle interacts frequently with other vehicles.

Figure 11 shows the environments of the selected autonomous shuttle deployments in other countries and in the United States. Within the United States, 27% of autonomous shuttle deployments have been on campus. In other countries, only 13% of autonomous shuttle deployments have been on campus. Likewise, 26% and 5% of the autonomous shuttle deployments in the United States and other countries were in a closed area. The United States has a higher deployment percentage in pedestrian areas than other countries. However, deployments are higher on public roads in other countries.

Figure 11. Environments of Routes

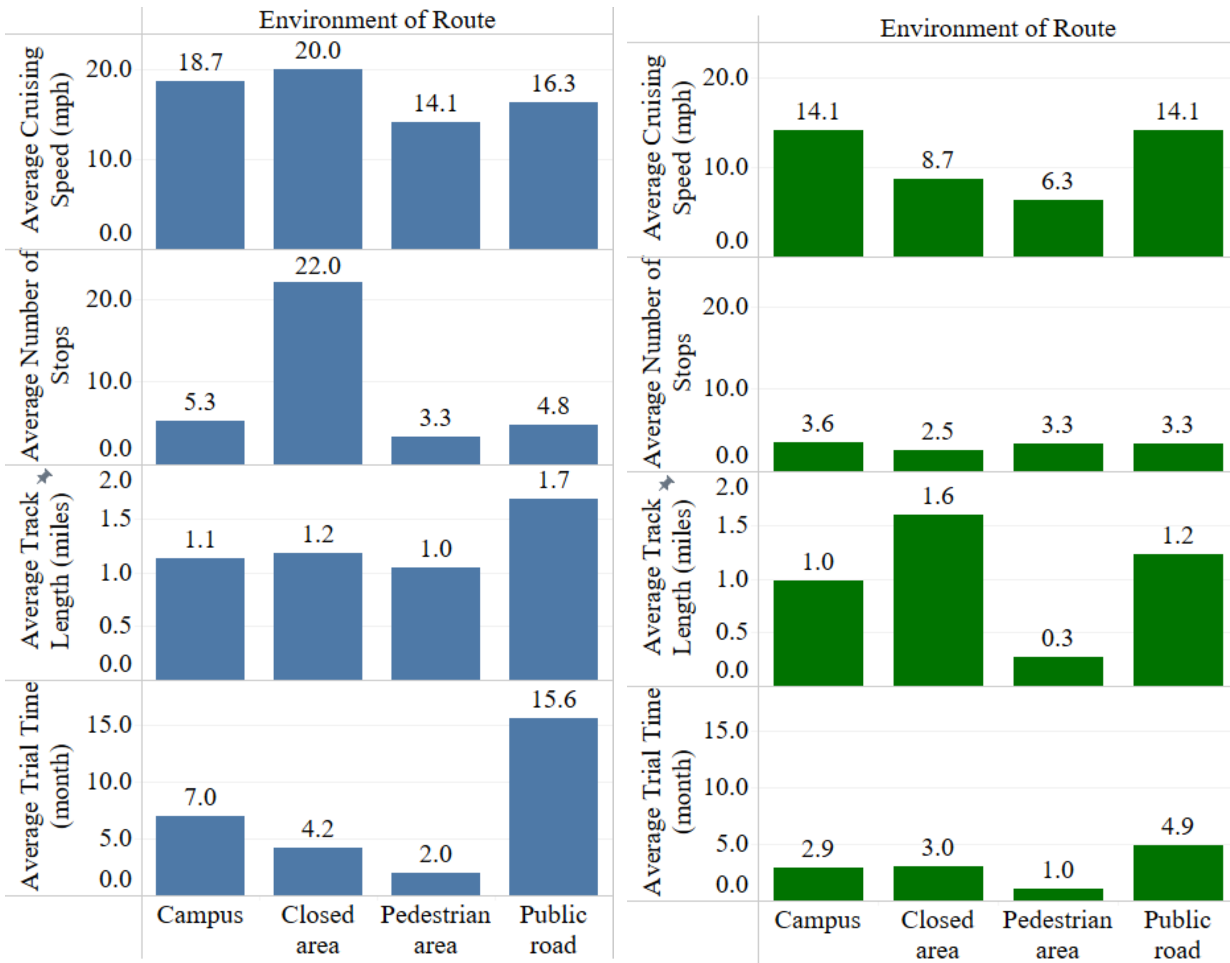


The geographical location of an autonomous shuttle deployment significantly influences the operational environment. Autonomous shuttle deployments are more feasible and practical in Europe, where slower speeds and narrower dimensions characterize many public roads. The design and capabilities of autonomous shuttles are well-suited to navigate and operate effectively on these types of roads, making them a practical choice for transportation solutions in such environments.

4.4.3 Comparison in Terms of Environment of Autonomous Shuttle Deployments

The operational characteristics of an autonomous shuttle deployment vary with the type of environment in which the deployment takes place. Figure 12 shows the average cruising speed, the number of stops, track length, and trial time for road environments in other countries and the United States.

Figure 12. Characteristics in Terms of Route Environment of Selected Autonomous Shuttle Deployments



(a) (b)

Several comparisons can be drawn from Figure 12 regarding different aspects of autonomous shuttle deployments. In other countries, the average cruising speed is highest in closed areas. At the same time, the highest average cruising speed on campuses is in the United States. For pedestrian areas, the cruising speed is lower than the other areas for both the United States and other countries. As expected, the cruising speed is lower in those areas due to higher interaction between autonomous shuttles and pedestrians. Moreover, the United States has the lowest average cruising speed in pedestrian areas. However, the speed in other countries is more than double that of the United States. The average number of stops is highest in closed areas in other countries, driven by an Australian deployment with 36 stops. However, the average number of stops in the United States does not significantly vary based on the route environment. Other countries exhibit the highest average track length on public roads. At the same time, the United States shows the highest average track length in closed areas, with public roads being the second highest. Additionally, public roads have a longer average trial time in both cases. However, for other countries, the trial time on public roads is more than three times higher compared to the United States.

4.5 SWOT Analysis

A SWOT analysis is presented in this section. It is based on the literature review and existing autonomous shuttle deployments.

4.5.1 Strengths

- The autonomous shuttle is mainly designed to supplement the existing transit system by closing gaps in transportation services (F&LM connectivity) (Navya, n.d.).

- As the shuttle will contribute to F&LM connectivity, there is a chance of an increase in the number of passengers in public transportation.

- As there are accessibility ramps on autonomous shuttles, they allow elderly and disabled people to commute independently. Hence, an increase in the mobility of disabled passengers can be expected (Smart Cities World, 2021).

- Autonomous shuttles could reduce the travel time and delay of public transportation system users as they ride the shuttle for ingress and egress.

- Mayo Clinic used autonomous shuttles to collect COVID samples for tests. Hence, autonomous shuttles can be useful for emergencies (Beep, n.d.).

- Autonomous shuttles can efficiently deliver goods and services within short routes.

- The average autonomy of an autonomous shuttle ranges from ten to twelve hours. Consequently, as the use of autonomous shuttles increases, gas trips could be reduced due to increased reliance on public transportation. With fewer gas trips, emissions are expected to be reduced as well.

4.5.2 Weaknesses

- Autonomous shuttles are slow-moving level 3 and level 4 AVs (Navya, n.d.). Hence, low speed can be a concern for other road users.

- In mixed traffic, without an exclusive lane, the operation of autonomous shuttles may affect other vehicles' travel time and delay.

- The main purpose of an autonomous shuttle is to supplement public transportation. Hence, its target consumers are only those who commute using public transportation systems.

- In the United States, public transportation systems are often not fully utilized, raising the possibility of underutilizing autonomous shuttles.

- After midnight, users of autonomous shuttles may experience a lack of next/previous vehicles (Drive, 2016).

- Autonomous shuttles are still in the testing period. Hence, the license and data security policies are not clear yet.

- Autonomous shuttles cannot change lanes automatically, which can be a barrier for travelers.

- Users are less willing to commute in autonomous shuttles with fees (Keolis Canada, 2019).

- The passenger capacity of an autonomous shuttle is eight to fifteen, limiting its applicability to lower travel demand scenarios.

4.5.4 Opportunities

- In the long run, autonomous shuttle service can increase the use of public transportation and decrease the number of personal vehicle trips.

- It could be a solution for improving the viability of low-ridership corridors and areas that cannot support the high cost of fixed-route service.

- It could be a perfect addition to the autonomous future.

- After successfully implementing the autonomous shuttle, long-route autonomous buses may complete the transportation chain.

4.5.5 Threats

- Demand-supply analysis from real-time data is not possible yet due to the pandemic.
- In the long run, this technology can reduce the physical activity of adults.
- One of the most challenging aspects is the uncertainty with respect to the reasons for stops and incidents.
- Uncertainty concerning public acceptance and adoption of autonomous shuttles could be a barrier.
- The autonomous shuttle cannot operate in bad weather.

From the SWOT analysis, it can be said that autonomous shuttles would be an excellent supplement for public transportation. However, improvements are needed in the vehicle and the infrastructure before the permanent deployment of autonomous shuttles for varying purposes. Additionally, more deployments and research are required to come to a solid conclusion. In order to make informed decisions related to infrastructure improvements, it is necessary to capture the perception of different target audiences, such as practitioners, industry experts, and transportation system users, towards various aspects of the autonomous shuttle. The next chapter covers the results related to the perceptions of practitioners, industry experts, and transportation system users toward autonomous shuttles.

5. Perception Survey Analysis

Autonomous shuttles are an innovative supplement to current public transportation infrastructure. They are in their trial phase within the United States, and their permanent introduction necessitates a comprehensive evaluation of societal attitudes.

Perception toward autonomous shuttles is not uniform across all segments of the population. A notable discrepancy in perspectives is anticipated between two pivotal groups: general public transportation system users and those embedded within the transportation industry, such as practitioners and industry experts. Capturing the viewpoints of these groups could significantly impact the overall acceptance and successful integration of autonomous shuttles into transportation networks.

In this study, two distinct surveys were undertaken. The initial questionnaire was reviewed and refined based on Institutional Review Board input for comprehensive data collection on autonomous shuttle adoption. A Google survey form was then disseminated via email and social media platforms to reach a wide range of respondents. The first survey targeted practitioners and industry experts. It captures their perceptions of autonomous shuttles' safety, operation, planning, and policy-related aspects. The second survey was tailored toward transportation system users. It captures users' perceptions of the safety, comfort, trust, willingness to use, and willingness to pay aspects of autonomous shuttles.

This chapter presents a thorough analysis of the responses from these two surveys. The intention is to extract valuable insights that may influence the future trajectory of autonomous shuttles within the more extensive transportation networks.

5.1 Perception of Practitioners and Industry Experts

The research instrument developed for practitioners and industry experts was composed of a series of queries that broadly address general information, familiarity with autonomous shuttles, perceptions of safety, comfort, security, operational barriers, infrastructure, and areas of potential improvement. A web-based questionnaire was developed based on the potential factors identified from the literature. It was designed to capture what these knowledgeable individuals perceive and suggest about autonomous shuttles, particularly regarding the improvements that are necessary for a permanent deployment. It is important to mention that employees of the state and regional departments of transportation, private consultants, and consulting firms are considered practitioners. In contrast, people involved in manufacturing autonomous shuttles are considered industry experts. The survey was initiated in April 2023 and was kept open for three months, garnering a total of 40 responses within this duration. Table 2 provides in-depth demographics and professional profiles of the participants, thereby facilitating a comprehensive understanding of the diversity and expertise present within the sample group.

Table 2. General Information of the Respondents

Age			
Work Experience (Years)	Female	Male	Grand Total
18-24	5.00%	2.50%	7.50%
1-5	5.00%	2.50%	7.50%
25-54	20.00%	42.50%	62.50%
1-5	5.00%	12.50%	17.50%
5-10	12.50%	12.50%	25.00%
10-20	0.00%	10.00%	10.00%
20+	2.50%	7.50%	10.00%
55-64	10.00%	20.00%	30.00%
1-5	2.50%	0.00%	2.50%
5-10	2.50%	5.00%	7.50%
10-20	2.50%	7.50%	10.00%
20+	2.50%	7.50%	10.00%
Grand Total	35.00%	65.00%	100.00%

Table 3 provides a detailed summary of the respondents' affiliations, roles within their respective organizations, and familiarity with autonomous shuttles.

The respondents of this survey represent a broad spectrum of organizations, including state, city, and regional transportation departments, as well as consultants and industry experts. Furthermore, their professional roles within these organizations vary, encompassing fields such as transportation planning, road design, traffic signals, or intelligent transportation systems. About 95% of the respondents are familiar with autonomous shuttles. In terms of their level of familiarity, 25% of the respondents are experts while 70% of the respondents know a little about autonomous shuttles.

From the collected data, 25% of the respondents are involved in deploying autonomous shuttles in their region. This indicates that many survey participants have direct experience and in-depth knowledge about these vehicles. This level of direct engagement contributes substantial first-hand insights into the operational aspects of autonomous shuttles, providing a richer context to the collected research data.

Table 3. Organization and Familiarity of the Respondents

Organization	% of Respondents
State department of transportation	42.5%
Regional transportation agency	7.5%
City/town transportation agency	5.0%
Industry experts	5.0%
Other	40%
Departmental affiliation	
Transportation planning	17.5%
Road design	10.0%
Traffic signals / intelligent transportation systems	22.5%
Traffic safety	22.5%
Other	27.5%
Familiarity with autonomous shuttles	
Experts	25.0%
Just a little	70.0%
Not at all	5.0%

5.1.1 Familiarity and Perception Towards Autonomous Shuttles

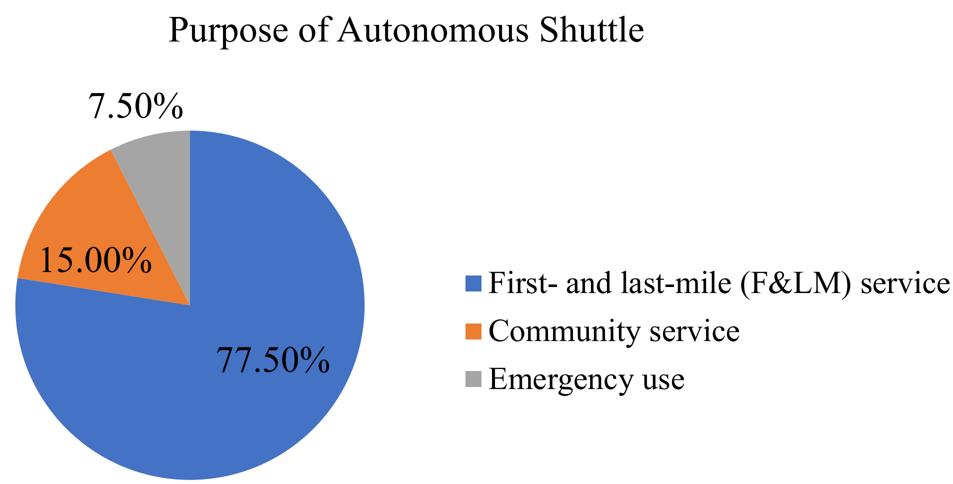
Diverse viewpoints have emerged when examining the potential of autonomous shuttles within the public transportation system. Based on the survey data, 75% of the respondents believe that autonomous shuttles are a feasible addition that could potentially increase the accessibility of public transportation. Conversely, a smaller fraction, 15% of the respondents, deem it an unfeasible addition. These findings reveal a wide range of opinions on the role and impact of autonomous shuttles in shaping the future of public transportation systems.

Autonomous shuttles are slow-moving vehicles intended for shorter routes. However, prioritizing longer over shorter routes arises with the potential reality of long-route automated transit on the horizon. Approximately 37.5% of the respondents believe focusing on long-route automated public transportation services is more important. In comparison, 47.5% of the respondents hold the contrary view. Additionally, 15% of the respondents remain uncertain about the issue.

Autonomous shuttles have been found to serve various purposes. Predominantly, they have been deployed in the context of F&LM connectivity. Additionally, their utility has extended to community services in certain instances. Mayo Clinic is a notable example--it utilized autonomous shuttles for COVID-19 sample collection during the height of the pandemic.

Figure 13 summarizes respondents' perceptions of the most effective purpose for autonomous shuttles. About 77.5% of the respondents indicate that autonomous shuttles are best suited for F&LM connectivity. On the other hand, 15% of the respondents view community services as the best application, while 7.5% of the respondents perceive that autonomous shuttles are best used for emergency services. This distribution of opinions reflects diverse viewpoints on the primary function that autonomous shuttles should fulfill.

Figure 13. Best Purpose of Autonomous Shuttles

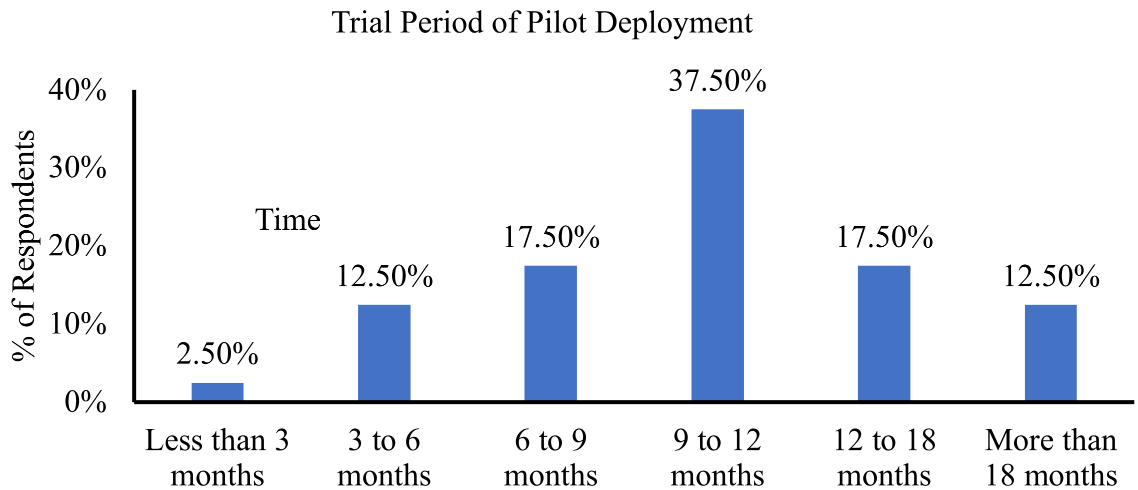


About 77.5% of the respondents are optimistic that introducing autonomous shuttles, particularly as a F&LM connectivity, will increase the demand for public transportation. However, regarding the potential preference of autonomous shuttles over traditional public transportation, 35% of the respondents believe that autonomous shuttles will not surpass traditional public transportation in popularity. About 30% of the respondents believe the contrary while 35% of the respondents remain uncertain.

5.1.2 Policy and Regulations – Trial Period

As discussed in Chapter 4, the trial periods for autonomous shuttles typically range from three to six months in the United States. This short period presents a challenge for the accurate assessment of the autonomous shuttle's performance, particularly in the domains of operation and safety. In light of this, the survey included a question regarding the optimal duration for pilot deployments of autonomous shuttles, and the results are presented in Figure 14.

Figure 14. Trial Period of Pilot Deployment



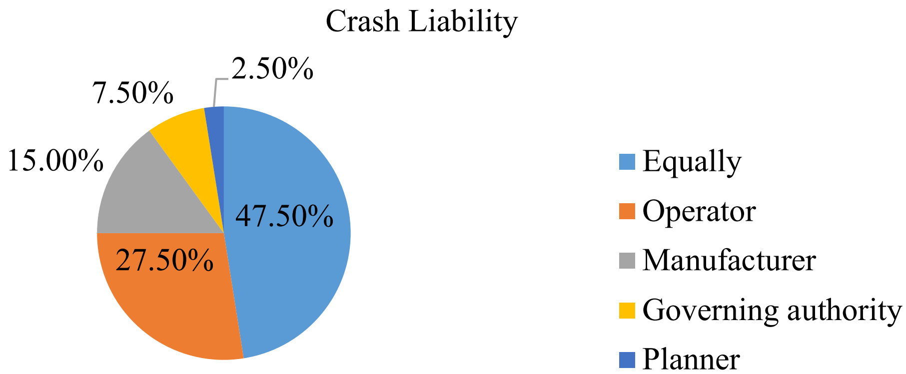
As depicted in Figure 14, the responses reveal that approximately 37.5% of the respondents suggest a trial period of 9 to 12 months. A significant fraction, about 30% of the respondents, believed that a trial period should extend beyond 12 months. These findings highlight that a more extended pilot phase could provide a more comprehensive assessment of the autonomous shuttle's performance.

5.1.3 Policy and Regulations – Safety and Security

Regarding the operation and maintenance of autonomous shuttles, 57.5% of the respondents believe that manufacturers and operators play equally critical roles. While 30% of the respondents attribute a more significant role to operators, 12.5% of the respondents suggest 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 suggest that crash liability should be equally distributed among all four stakeholder groups, as visualized in Figure 15. This highlights the complexity of liability concerns in the context of the deployment of autonomous shuttles and the need for a balanced responsibility framework.

Figure 15. Crash Liability

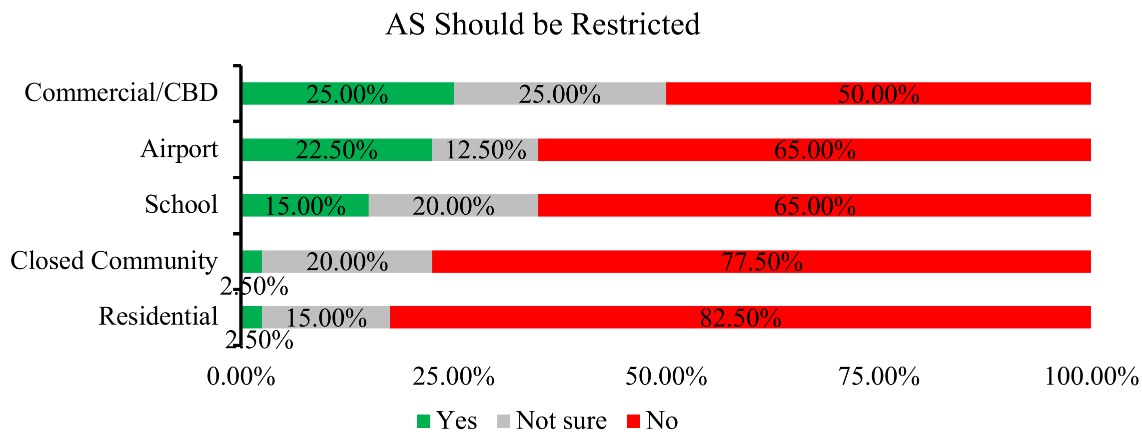


The advanced technological design of the autonomous shuttle incorporates various sensors, such as LiDAR sensors and global positioning systems, yielding an extensive collection of road infrastructure and user data. Moreover, autonomous shuttles are level 3 and level 4 AVs; therefore, they plan their motion using AI-based sensing technologies. This abundance of data raises concerns over potential data loss or unauthorized access, underscoring the need for rigorous data security measures. Given the unique data-related vulnerabilities of autonomous shuttles, 92.5% of the respondents concur that specific policies addressing cyber-security or data breaches should be established for autonomous shuttles, highlighting the critical necessity of robust data security protocols.

5.1.4 Policy and Regulations – Infrastructure

Given the slow-moving nature of autonomous shuttles, their interaction with other vehicles and system users varies across land-use types like commercial/central business district (CBD), airport, achool, closed community, and residential areas. Consequently, determining whether an autonomous shuttle can operate effectively in all mixed traffic conditions is crucial. Figure 16 summarizes the respondents' views on this subject matter.

Figure 16. Restriction in Autonomous Shuttle Deployments



A significant 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 do not foresee the need for restrictions in schools and airports. However, views on commercial areas and CBDs are more divided. Half of the respondents believe that autonomous shuttles should not be restricted in these areas. These findings are necessary for deciding land uses where autonomous shuttles can be implemented.

Vehicle-to-infrastructure communication may necessitate upgrades or replacements of certain traffic control devices. The survey solicited respondent opinions on which devices should be upgraded or replaced with radio frequency identification or other sensor technologies to facilitate this communication. The results are summarized in Table 4.

82.5% of the respondents identify traffic signals as a critical component needing an upgrade. More than half of the respondents also note the necessity of advancing several other devices. These include pavement markings, stop signs, school zone signs (encompassing both pedestrian and traffic controls), reflectors, pedestrian controls and signs (such as walk zones, flashing beacons, push-button signs, etc.), as well as temporary traffic control signs (used for work zones, severe weather conditions, detouring, etc.). The results summarized in Table 4 indicate the importance of infrastructure improvements in facilitating efficient vehicle-to-infrastructure communication.

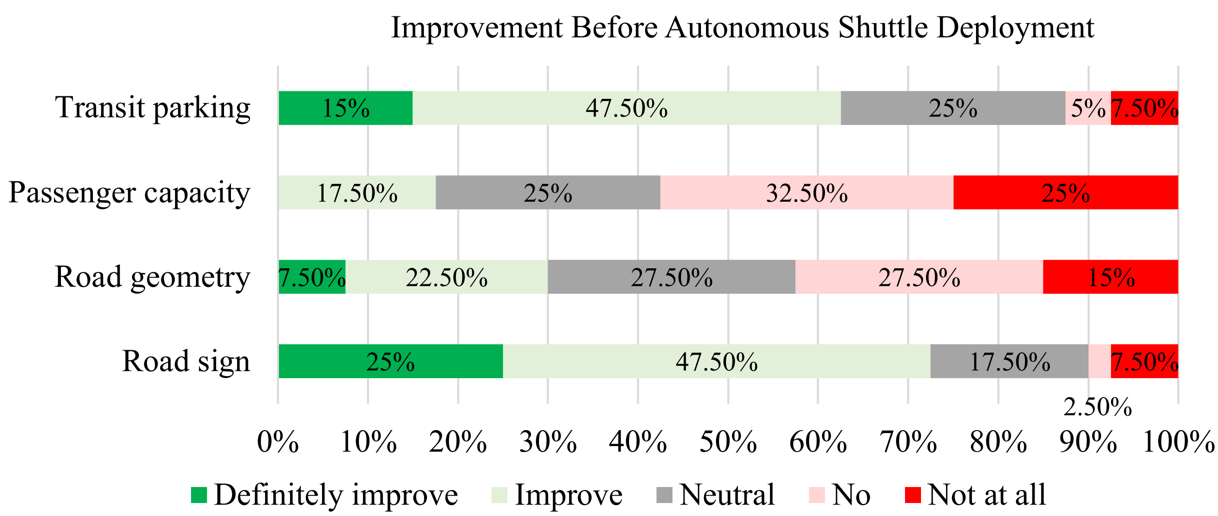
Table 4. Upgrading or Replacement Need of Traffic Control Devices

Traffic control devices	% of the Respondents
Traffic signals	82.5%
Pavement markings	65.0%
Stop signs	62.5%
School zone signs (pedestrian and traffic control)	62.5%
Reflectors	60.0%
Pedestrian controls and signs (walk zones, flashing beacons, push-button signs, etc.)	55.0%
Temporary traffic control signs (for work zone, severe weather, detouring, etc.)	52.5%
Speed limit signs	50.0%
Bus lane signs	50.0%
Road curve ahead signs	50.0%
Shoulder drop-off/no shoulder signs	47.5%
Yield signs	45.0%
Directional signs (for unconventional intersections such as roundabouts)	40.0%
Parking signs	40.0%
Lane addition/drop signs	35.0%
One-way/two-way signs	32.5%
Other regulatory signs (as per the MUTCD)	30.0%
Other warning signs (as per the MUTCD)	2.5%

5.1.5 Policy and Regulations – Improvement Before Pilots

For widespread adoption of autonomous shuttles, improvements to pilot deployments must be made before permanent deployments. Respondents were queried regarding their views on what elements should be improved before autonomous shuttle deployments. The results are presented in Figure 17.

Figure 17. Improvement Before Autonomous Shuttle Deployment



From the responses summarized in Figure 17, 72.5% of the respondents indicate a need for improvements in road signage, while 62.5% of the respondents suggest an improvement in transit parking. In the case of improvements to road geometry, divided opinions were noted: 30% of the respondents believe that it requires improvement while a higher proportion, 52.5% of the respondents, deem it unnecessary. Regarding passenger capacity, 57.5% of the respondents do not view improvements as necessary, and 25% of the respondents remain neutral. These insights underscore the varied perceptions of the infrastructure modifications needed to accommodate autonomous shuttles.

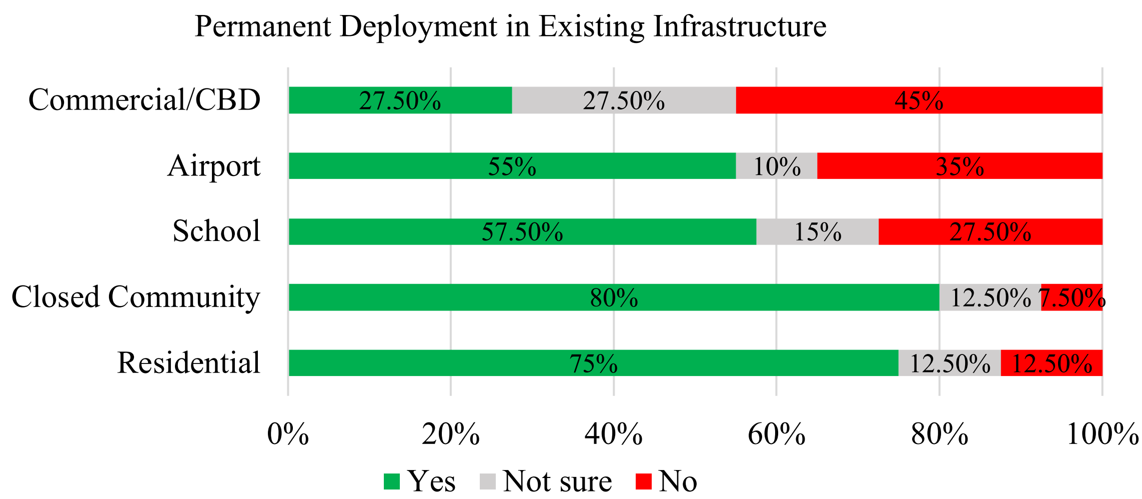
5.1.6 Policy and Regulations – Improvement Before Permanent Deployment

Introducing autonomous shuttles to supplement public transportation presents new fiscal considerations, as budget allocations have not historically accommodated such innovations. Thus, 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 concur that an additional budgetary provision would indeed be necessary. Conversely, 7.5% of the respondents do not foresee a need for a separate budget allocation. The remaining respondents express uncertainty on the matter, underscoring the financial implications and considerations of introducing autonomous shuttles.

Autonomous shuttle deployments typically involve four key stakeholder groups. About 55% of the respondents perceive that an additional statutory body is needed to deploy, operate, and maintain autonomous shuttles.

The question of whether to permanently integrate 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 18 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 express the same optimism for airports and schools.

Figure 18. Permanent Autonomous Shuttle Deployment in Existing Infrastructure



About 27.5% of the respondents view CBDs (areas 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.

5.1.7 Operational Aspect – Underutilization

Public transportation is not always the preferred mode of transportation in many U.S. cities, raising potential concerns about the underutilization of autonomous shuttles. Respondents were asked to rank potential reasons for underutilization. The Garrett ranking method was used to rank reasons for the potential underutilization of autonomous shuttles. The formula for Garrett ranking is shown in Equation (1).

$$Percent\ position = \frac{100*(R-0.05)}{N} \quad (1)$$

where N = Number of factors; and, R = Ranking

The Garrett ranking results are presented separately for respondents involved in deploying autonomous shuttles, as shown in Table 5.

Table 5. Ranking of Reasons for Underutilization of Autonomous Shuttles

Factors	Average Garrett 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	V	I
Passenger capacity	56.28	VI	V
Low speed	56.08	VII	VII
Comfort	53.93	VIII	VIII

The results suggest that passenger safety is 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. These differing viewpoints illustrate the complexity of factors that could potentially contribute to the underutilization of autonomous shuttles and also highlights factors that could be improved to avoid underutilization of autonomous shuttles.

5.1.8 Operational Aspect – Improvement Before Permanent Deployment

Autonomous shuttles are an innovative addition to the dynamics of transportation. However, the real-world readiness of such systems necessitates prioritizing improvements. The survey inquired about respondents' priority rankings 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 the permanent deployment of autonomous shuttles.

Using the Garrett ranking method, these priorities were ranked. The results, as displayed in Table 6, suggest 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 rank 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 6. Ranking of Factors Improved Before Permanent Deployments

Factors	Average Garrett Score	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

5.1.9 Explanatory Factor Analysis (EFA)

Explanatory Factor Analysis (EFA) is a multivariate statistical approach to the interpretation of the underlying structure of relationships among various variables. In this study, EFA was applied to assess questionnaire data, utilizing the Principal Component Analysis (PCA) methodology. This procedure involves constructing latent variables from specific question sets as per Equation (2).

$$y_q = \sum a_q x_q \qquad (2)$$

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

PCA extracts factors represented by the model's original variables to illustrate the behavior of the evaluated data. The primary focus was to investigate the influence of observed variables on latent variables and to discern potential barriers to integrating autonomous shuttles into the transportation system. Thus, implementing EFA through PCA provides a robust framework for analyzing the complex relationship of variables in this context.

Two statistical tests, Bartlett's Test of Sphericity and the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy, were used to ascertain the model's appropriateness. The results of these tests are presented in Table 7. The KMO value exceeds the threshold of 0.4, signifying a satisfactory level of sampling adequacy for the factor analysis.

Table 7. KMO and Bartlett's Test Results

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.540
Bartlett's Test of Sphericity	Approx. Chi-Square	371.735
	df	231
	Sig.	<0.001

Twenty-two variables were considered. These variables were aggregated into eight principal components based on the corresponding Eigenvalues. A total of 75.6% of the variance is explained through the eight principal components. It is essential to mention that only data related to practitioners were considered for PCA. The individual contributions of these factors to the explained variance and the cumulative variance percentages are summarized in Table 8. Each factor contributes to the variance at different magnitudes, with 'Underutilization' accounting for 17.4%, followed by 'Safety' at 12.2%. This factor-based breakdown provides a clear and quantified understanding of each component's influences within the dataset.

Table 8. Results of PCA: Factors Contribution to Explained Variance (%)

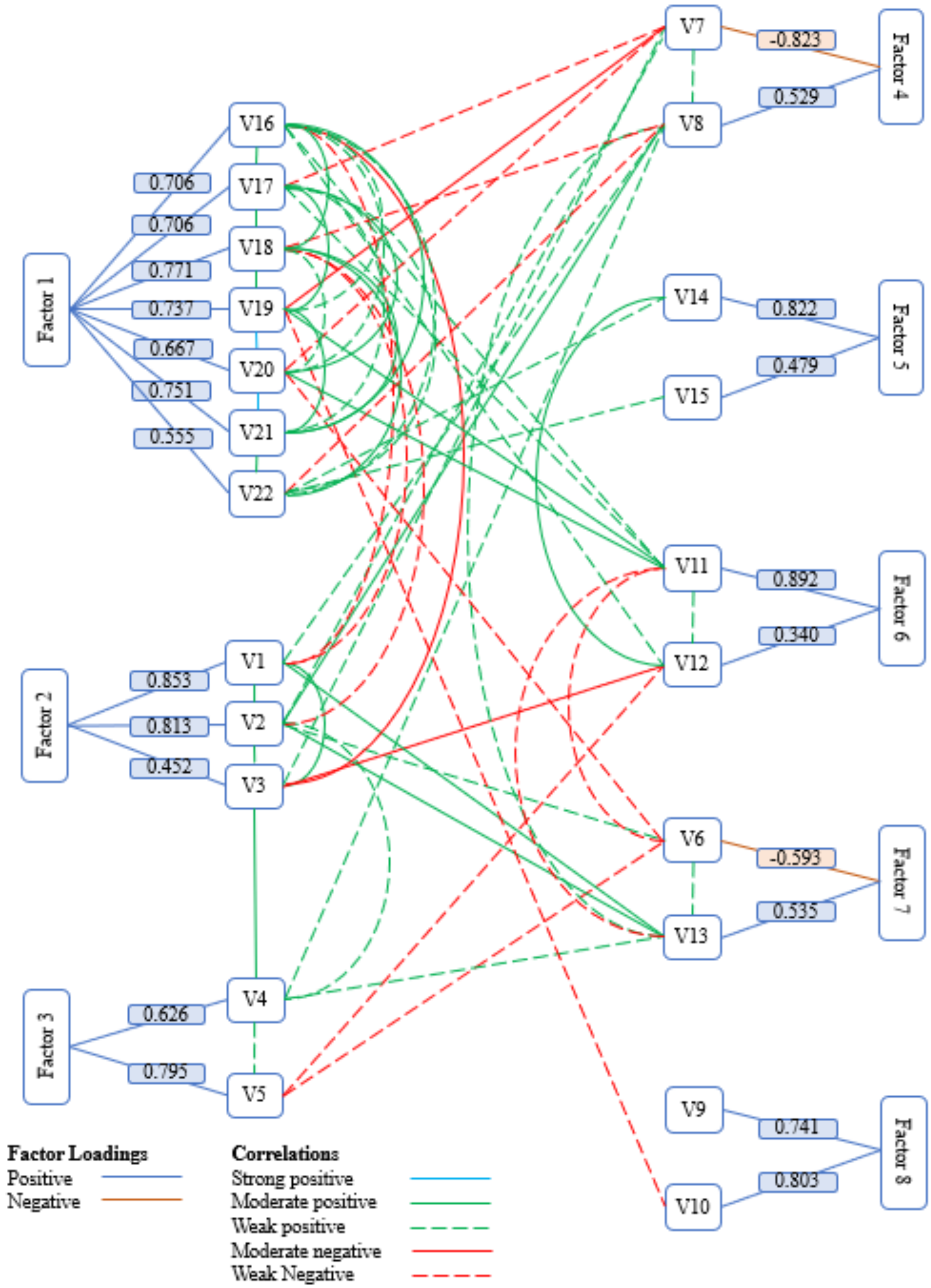
Factor	Interpretation of the factor	% of Variance	Cumulative %
1	Underutilization	17.37	17.37
2	Safety	12.22	29.59
3	Seating arrangement	9.31	38.90
4	Reliability	8.15	47.05
5	Data security and environment	8.04	55.09
6	Operational aspect	7.64	62.74
7	LiDAR and other sensors	6.55	69.28
8	Lane	6.35	75.63

Table 9 outlines the 22 observed variables considered for modeling, each associated with a specific factor name. Figure 19 complements this by graphically representing the model, detailing the factor loadings (Cf), and visually depicting the correlations between the observed and latent variables, also known as factors.

Table 9. Results of PCA: Factors and Observed Variables

Factor	Labels	Observed Variables
F1	V16-V22	Reasons for 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? (1= not safe at all, 5= most safe) [kids, adults, elderly people]
F 3	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?
F5	V14	As existing infrastructure is not fully autonomous-friendly, is it a barrier to autonomous shuttle deployment?
	V15	Is autonomous shuttle data a threat / cyber-security loss?
F6	V11	As the autonomous shuttle is a slow-moving vehicle (10–20 mph, usually), do you think people will not prefer to use it because of lower speeds?
	V12	Is low passenger capacity (eight to fifteen) a barrier to using an autonomous shuttle as a public transportation mode?
F7	V6	Do you think that the position of LiDAR on 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 this be a barrier for the passengers?
	V10	Do you think that autonomous shuttles require dedicated lanes?

Figure 19. Results of PCA: Factor Loadings and Correlations



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, i.e., as the value of the original variable increases, the value of the factor increases, and vice versa. The key findings of the PCA are summarized next.

- Factor 1, denoting underutilization, shows that travel time and schedule possess the highest factor loadings, implying that they are the most influential factors causing the underutilization of autonomous shuttles.

- Factor 2 corresponds to safety, and indicates that autonomous shuttles are generally safe for all users. However, the factor's weight decreases slightly for elderly individuals. Therefore, autonomous shuttles are unsafe for older adults compared to middle-aged people.

- Factor 3 relates to seating comfort, and suggests that autonomous shuttles are more comfortable than regular shuttles. However, during sudden stops, the seating arrangement may present a challenge.

- Factor 4 reveals that autonomous shuttles may be unsafe in areas with severe weather conditions like heavy rain or snow. At the same time, they remain safe on roads with steep horizontal and vertical curves.

- Factor 5 pertains to data security threats and the potential barrier posed by existing unfriendly infrastructure for autonomous shuttles. It highlights the need for specific data-security policies and autonomous shuttle-friendly infrastructure to implement autonomous shuttles successfully.

- Factor 6 suggests that people may resist autonomous shuttles due to their low speed and passenger capacity.

- Factor 7 concludes that changing the LiDAR position for better blind spot detection is unnecessary, and that road infrastructure elements do not need upgrading or replacing with other sensors for communication.

- Factor 8 suggests that the inability of autonomous shuttles to change lanes on the road and the absence of dedicated lanes for autonomous shuttles can be barriers to their widespread adoption.

In summary, each factor represents unique attributes of autonomous shuttles. Understanding their influence is pivotal for overcoming barriers and optimizing the utilization of autonomous shuttles.

5.2 Perception of Transportation System Users

Autonomous shuttles are deployed to augment public transportation by strengthening accessibility for transportation system users. Therefore, understanding how users perceive and adapt to this novel technology is crucial. Specifically, it is essential to ascertain whether individuals are inclined toward using autonomous shuttles. This study conducted a comprehensive survey targeting transportation system users to gather empirical insights regarding the willingness of users to adopt autonomous shuttles. A detailed analysis of the findings from this perception study is presented next.

5.2.1 Socio-Demographic Characteristics

Table 10 represents demographic data of transportation system users from a sample size of 126 survey responses, and provides an in-depth evaluation segmented by age, gender, marital status, and geographical location, specifically rural, suburban, and urban areas. The age group spanning 25–54 years represents the most populous segment, accounting for 68.6% of the responses. Within this age group, the most represented subgroup comprises suburban males, accounting for 32.23% of the responses, closely followed by suburban females at 15.7%. In contrast, the 18–24 age demographic constitutes a smaller portion of the total at 11.57%, with the majority residing in rural and suburban areas across both genders.

Table 10. Socio-Demographic Characteristics of the Respondents

Age & Marital Status	Rural		Suburban		Urban		Total
	Female	Male	Female	Male	Female	Male	
18–24	-	-	4.13%	3.31%	1.65%	2.48%	11.57%
Single	-	-	3.31%	1.65%	1.65%	2.48%	9.09%
Married	-	-	0.83%	1.65%	-	-	2.48%
25–54	1.65%	0.83%	15.70%	32.23%	8.26%	9.92%	68.60%
Single	-	-	7.44%	22.31%	1.65%	2.48%	33.88%
Married	1.65%	0.83%	8.26%	9.92%	6.61%	6.61%	0.83%
Prefer not to say	-	-	-	-	-	0.83%	33.88%
55–64	1.65%	0.83%	4.96%	5.79%	0.83%	3.31%	17.36%
Single	-	-	0.83%	0.83%	-	-	1.65%
Married	0.83%	0.83%	4.13%	4.96%	0.83%	3.31%	14.88%
Prefer not to say	0.83%	-	-	-	-	-	0.83%
65–74	0.83%	-	-	0.83%	-	0.83%	2.48%
Married	0.83%	-	-	0.83%	-	0.83%	2.48%
Total	4.13%	1.65%	24.79%	42.15%	10.74%	16.53%	100.00%

Table 11 shows the relationship between education levels and household size based on the responses. The largest demographic segment is individuals holding a Master's degree, representing 46.03% of the responses. Within this educational group, the majority reside as one-person households, which accounts for 21.43% of the responses, followed by those residing as two-person households at 13.49% of the respondents. In addition, respondents with a Bachelor's degree form the second largest group at 21.43% of the responses. Most of these respondents reside as one-person households, contributing 13.49% of the responses. The data also shows that households with more than five members are solely represented by respondents with an educational level below 9th grade.

Table 11. Education and Household Size of the Respondents

Education	Household size						
	One	Two	Three	Four	Five	>Five	Total
9th to 12th grade, no diploma	1.59%	1.59%	2.38%	0.79%	-	-	6.35%
Associate degree	-	0.79%	-	0.79%	-	-	1.59%
Bachelor's degree	13.49%	4.76%	-	2.38%	0.79%	-	21.43%
Doctorate degree	0.79%	3.97%	4.76%	1.59%	-	-	11.11%
High school graduate (includes equivalency)	2.38%	-	1.59%	-	-	-	3.97%
Less than 9th grade	-	1.59%	2.38%	0.79%	-	1.59%	6.35%
Master's degree	21.43%	13.49%	7.14%	3.17%	0.79%	-	46.03%
Professional degree	-	-	-	0.79%	-	-	0.79%
Some college, no degree	-	-	1.59%	-	0.79%	-	2.38%
Grand total	39.68%	26.19%	19.84%	10.32%	2.38%	1.59%	100.00%

5.2.2 Trip Characteristics and Employment

Table 12 provides a detailed assessment of the regular modes of travel used by the respondents, segmented by employment status and the primary purpose of their trips. About 52.38% of the respondents are engaged in part-time or casual employment. Those in full-time employment or self-employment represent 31.75% of the respondents, while 15.87% of the respondents are retired, homemakers, or currently not employed. The dominant mode of travel, as indicated by 69.84% of the respondents, is the personal vehicle. Within this group, full-time or self-employed individuals account for 25.4% of the respondents.

Respondents who use personal vehicles as regular transportation modes commute to work, accounting for 34.13% of total trips, followed by school-related commuting at 20.63% of total trips. Transit options such as buses are used by 13.49% of the respondents, with a significant percentage of these users being part-time or casual workers. School and work trips constitute the most frequent trip purposes for utilizing bus or transit services, representing 11.11% and 2.38% of the total trips, respectively. Walking and biking are less commonly used modes of travel, represented by 12.7% and 3.97% of the respondents, respectively. School and work-related trips emerge as the primary reasons for these transport choices.

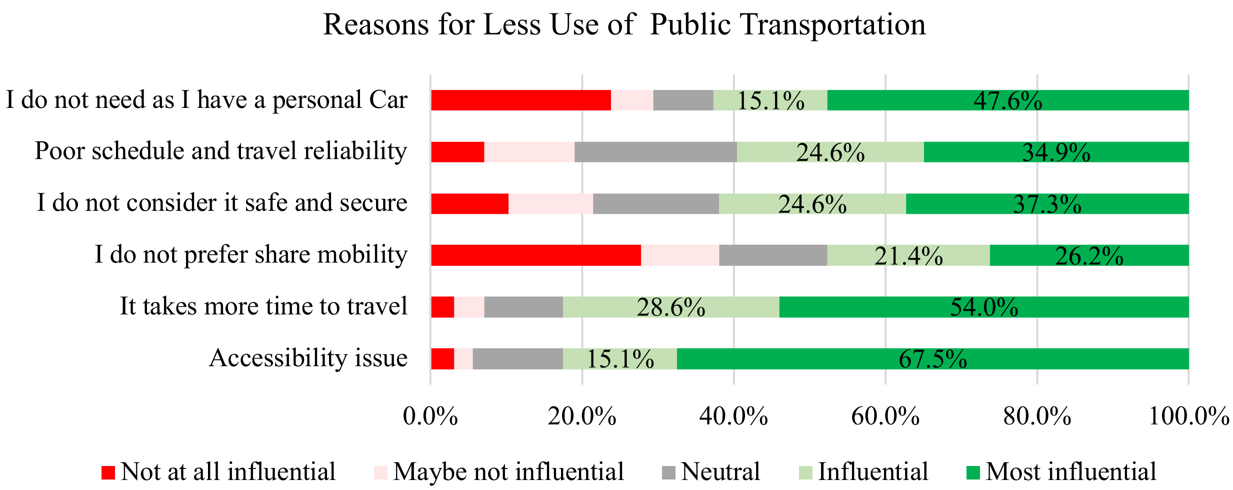
Table 12. Employment and Trip Characteristics of the Respondents

Mode Trip purpose	Full-time or Self Employment	Part-time or Casual Employment	Retired, Homemaker, or Not Employed	Total
Bike	1.59%	2.38%	-	3.97%
School	0.79%	0.79%	-	1.59%
Social and recreational	-	1.59%	-	1.59%
Work	0.79%	-	-	0.79%
Bus or other transit	1.59%	11.11%	0.79%	13.49%
School	1.59%	8.73%	0.79%	11.11%
Work	-	2.38%	-	2.38%
Personal vehicle	25.40%	30.95%	13.49%	69.84%
School	2.38%	16.67%	1.59%	20.63%
Shopping	1.59%	1.59%	7.14%	10.32%
Social and recreational	-	0.79%	3.97%	4.76%
Work	21.43%	11.90%	0.79%	34.13%
Walk	3.17%	7.94%	1.59%	12.70%
School	0.79%	3.97%	-	4.76%
Shopping	-	-	0.79%	0.79%
Social and recreational	-	-	0.79%	0.79%
Work	2.38%	3.97%	-	6.35%
Total	31.75%	52.38%	15.87%	100.00%

5.2.3 Less Use of Public Transportation

There exists a multitude of potential factors influencing an individual's choice with respect to the utilization of public transportation. Figure 20 provides insight into participants' perceptions of this subject matter. A considerable majority of the respondents (67.5%) indicated that issues related to accessibility (i.e., their ability to access the transit due to a lack of proximity rather than due to a disability) exert the most significant influence on their transportation choices. The time required for travel was identified as the second most influential determinant for 54% of the respondents. Concurrently, possessing a private vehicle was deemed the primary influential factor for 47.6% of the respondents. Additionally, nearly 60% of the respondents noted that inadequate public transportation scheduling was a significant element in their decision-making.

Figure 20. Reasons for Less Use of Public Transportation



5.2.4 Important Features of Autonomous Shuttles

It is essential to discern which autonomous shuttle features users deem most crucial. This understanding was pursued through a survey question, wherein participants were asked to rank seven distinct features of autonomous shuttles according to their importance. The results from the Garrett ranking method are summarized in Table 13.

Table 13. Garrett Ranking of Important Features of Autonomous Shuttle

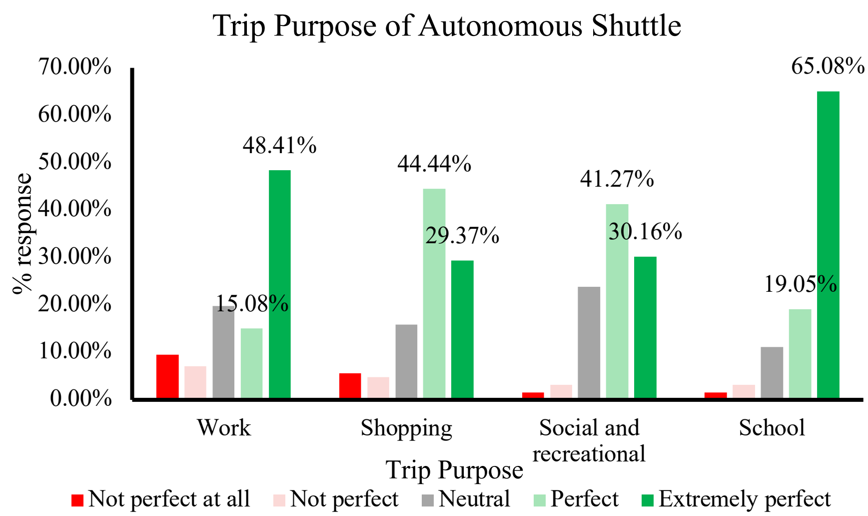
Features	Average score	Ranking
Reliability	55.59	I
Faster and save travel time	54.28	II
Easy to use	53.66	III
Daily schedule of the autonomous shuttle	53.21	IV
Comfort and ease of use	51.39	V
Using this service is fun	35.82	VI
Exterior design looks cool	33.64	VII

'Reliability', with an average score of 55.59, was highly rated, followed by 'faster and save travel time' with an average score of 54.28, and 'easy to use' with an average score of 53.66. 'Daily schedule of the autonomous shuttle' ranked fourth with an average score of 53.21 while 'comfort and ease of use' came fifth with an average score of 51.39. The features 'using this service is fun' and 'exterior design looks cool' were less influential, achieving average scores of 35.82 and 33.64, respectively. The findings present invaluable insights into user preferences and can guide the improvement and evolution of autonomous shuttles.

5.2.5 Trip Purpose of Autonomous Shuttles

Active modes of transport, such as autonomous shuttles, can serve various trip purposes, including, but not limited to, work, shopping, social activities, recreational endeavors, and school-related travel. As illustrated in Figure 21, over 65% of the respondents believe that autonomous shuttles are exceptionally well-suited for school transportation. Furthermore, 48% of the respondents regard these shuttles as highly appropriate for work-related commuting.

Figure 21. Trip Purpose of Autonomous Shuttle



5.2.6 Factors Influencing Adoption or Willingness to Use Autonomous Shuttles

The proclivity of users to adopt autonomous shuttles is influenced by several factors, including perceptions of safety, comfort, trust, familiarity with autonomous shuttles, and various socioeconomic indicators. SEM was used to decode this complex problem and discern the relationships among these variables. SEM comprises observed and latent variables. The latent variables encompass users' perceptions of safety, comfort, and trust. The SEM allows for the simultaneous examination of multiple dependent relationships and the inclusion of latent variables, which are not directly observed but are inferred from observed variables. The MIMIC model, a particular form of SEM, further elucidates the relationship between latent variables and their indicators while considering the direct influence of observed variables on latent ones. Thus, the MIMIC model of SEM is better equipped to disentangle the complexity of the factors influencing the adoption of autonomous shuttles. Table 14 illustrates all the variables considered in the development of the model.

Table 14. Variables Considered for SEM

Latent Variables	Observed Variables
Safety	S1: Do you think an autonomous shuttle will help you reach your destination more safely?
	S2: Do you think autonomous shuttles will be safe on public roads?
	S3: As there is neither a steering wheel nor any pedals in the autonomous shuttle, will you feel safe to use the autonomous shuttle?
Comfort	C1: Are you comfortable if the shuttle runs at full capacity (with six seats and standing passengers)?
	C2: As the autonomous shuttle may stop in light rain or snow, are you comfortable using it just before or after the rain or snow?
	C3: As an autonomous shuttle will stop if any vehicle stops in front of it, are you comfortable riding it on a busy road where overtaking is sometimes necessary?
Trust	T1: Do you entirely trust the autonomous shuttle ride with an attendant/operator?
	T2: How likely are you willing to use an autonomous shuttle with your child/other non-driving population in your family?
Willingness to Use	W1: How likely are you willing to use the autonomous shuttle option to commute to a campus?
	W1: How likely are you willing to use the autonomous shuttle option to commute to a closed community?
	W3: How likely are you willing to use the autonomous shuttle option to commute to a parking area?
	W4: How likely are you willing to use the autonomous shuttle option to commute to public roads?
	W5: How likely are you willing to use the autonomous shuttle option to commute to a pedestrian area?

It is hypothesized that users' perceived safety, comfort, and trust level influence their willingness to use autonomous shuttles. In addition to these factors, familiarity with autonomous shuttles, frequency of public transportation system use, household income, and age also influence the willingness to use autonomous shuttles. Moreover, it is also assumed that users' familiarity with autonomous shuttles significantly influences their perceived safety, comfort, and trust. The MIMIC model was developed in IBM SPSS AMOS.

Evaluating the model fit and reliability is critical in applying SEM. The measures used for this assessment include the PC_{min}, the Comparative Fit Index (CFI), the Root Mean Square Error of Approximation (RMSEA), and the F_{min}. In the given MIMIC model, these measures present promising results.

The PC_{min} value of the model, a scaled version of the chi-square test statistic, is 2.4. This value is less than the threshold of 3.0, suggesting that the model fits well with the data. The CFI, which compares the existing model with a null model, reports a value of 0.64. Although values close to 1 typically indicate a good fit, this value may still be acceptable depending on the complexity of the model and the specifics of the data set. Additionally, the RMSEA value is 0.10. While values less than 0.08 generally indicate a good fit, a value of 0.10 may suggest a moderate fit, dependent on the model's complexity and the data's characteristics. Finally, the F_{min} value, which represents the minimum discrepancy function, is 2.35. This is an improvement compared to other model iterations, indicating that the model demonstrates a satisfactory fit with the data. These model fit indices collectively suggest a good fit of the model with the observed data, thereby underlining the reliability of the MIMIC model for this data set.

The internal consistency of the study was assessed using Cronbach's Alpha (CB) and Construct Reliability (CR). CB and CR were computed using Equations 3 and 4.

$$CB = \frac{N*c}{v+(N-1)*c} \quad (3)$$

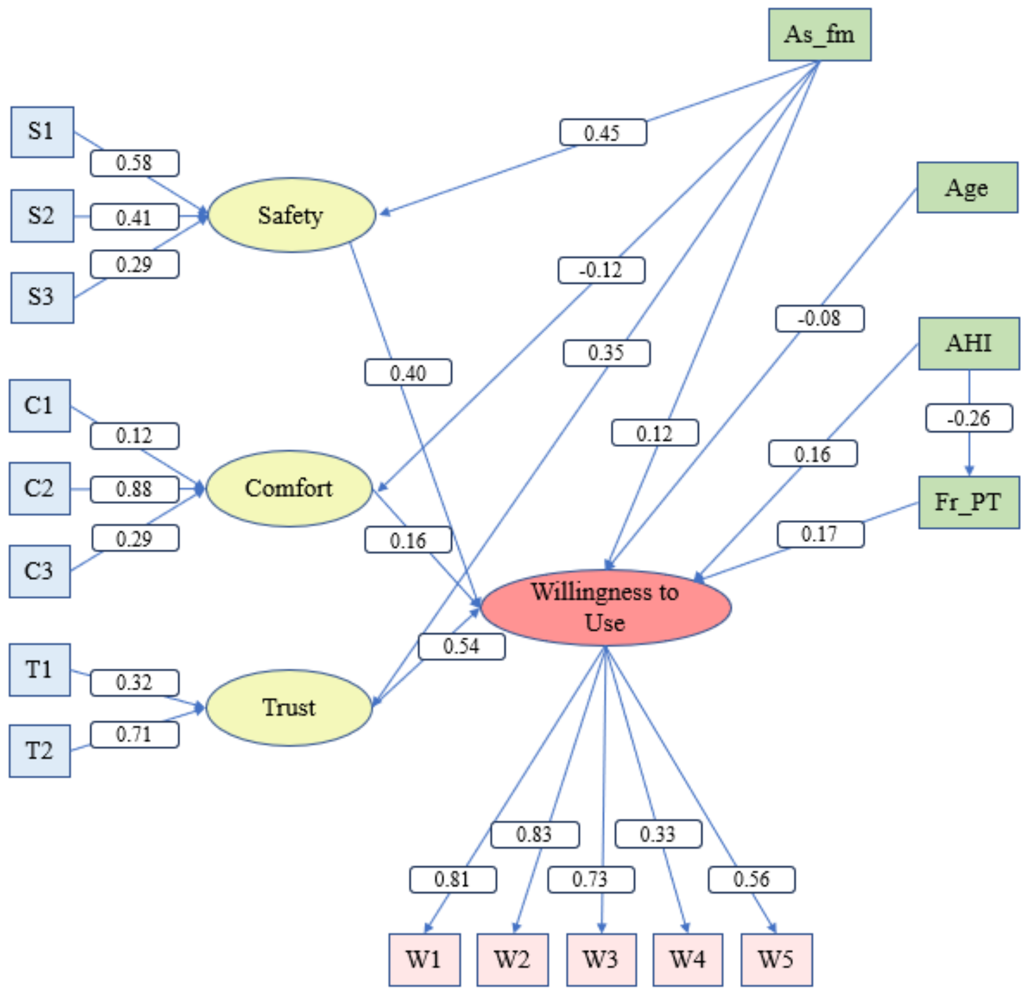
$$CR = \frac{(\sum L)^2}{(\sum L)^2+(\sum e)} \quad (4)$$

where N = number of items, v = average variance, c = average inter-item covariance, L = standard factor loading, and e = error term.

CB demonstrated good reliability for the measured items, with a value above 0.7. For the construct's 'safety' and 'trust', CR values were greater than 0.6, indicating acceptable reliability. Meanwhile, 'willingness to use' had a CR exceeding 0.7, denoting good reliability and internal consistency. Therefore, these results confirm the consistent representation of each latent construct by their respective measures.

Figure 22 visually depicts the developed MIMIC model. As postulated in the study design, the primary dependent variable is 'willingness to use.' This variable is primarily influenced by three latent variables: safety, comfort, and trust. Measured variables, such as age, annual household income, frequency of public transportation use, and familiarity with autonomous shuttles, also determine the willingness to use autonomous shuttles. The model captures the effect of annual household income on the frequency of public transportation use. In a similar vein, familiarity with autonomous shuttles displays effects on all four latent variables. This graphically depicted model, therefore, provides a visual understanding of the complex relationships between these variables in the context of autonomous shuttles.

Figure 22. Graphical Representation of the MIMIC Model



Note: Refer to Table 14 for the definitions of the variables shown in Figure 22.

As depicted in Figure 22, the factor loadings are statistically significant at a 95% confidence level for all variables except for 'age.' Key insights derived from the MIMIC model are summarized as follows:

- Each variable positively impacts the propensity of transportation system users to utilize the autonomous shuttle service. Among the considered factors, 'trust' emerges as the most potent, its significant weight substantiating the argument that trust is highly influential in fostering a willingness among users to engage with autonomous shuttles.
- The demographic factor 'age' does not seem to influence the 'willingness to use' the autonomous shuttles directly. This absence of significant influence may indicate a broad appeal of autonomous shuttles across different age groups.

- The factor 'familiarity with autonomous shuttles' positively impacts the perception of 'safety' and 'trust' regarding the autonomous shuttle. As users' familiarity with the autonomous shuttle increases, their assessment of its safety and trustworthiness increases.
- The loading of -0.26 between the frequency of public transportation use and annual household income reveals an inverse relationship. An increase in annual household income is associated with a decrease in public transportation use.

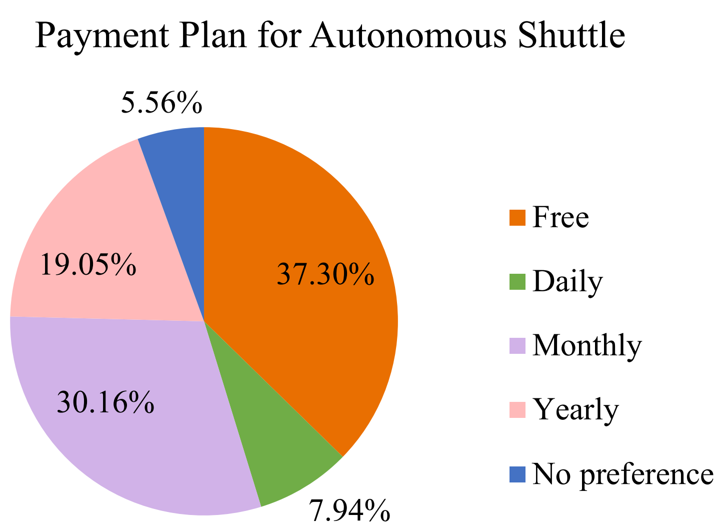
The findings from the study indicate a notable willingness among transportation system users to engage with the autonomous shuttle. Further reinforcing this trend, 58.7% of the survey respondents, when considering the context of F&LM connectivity, expressed a willingness to adopt public transportation as their primary mode of transit in the event of autonomous shuttles becoming widely accessible within the transportation ecosystem. This suggests a positive anticipation for integrating autonomous shuttles into mainstream transport infrastructure and its potential to strengthen the utilization of public transportation.

5.2.7 Willingness to Pay

The subject of consumer willingness to pay for micro-transit services, including autonomous shuttles, is a recurring theme in transport economics. To explore this further, the inclination of users to pay for autonomous shuttles was investigated. The results indicate a near balance, with 44.4% of the respondents expressing a willingness to pay for autonomous shuttle rides, contrasted against 48.4% of the respondents who are opposed to paying for the ride. The question of preferred payment structures for autonomous shuttle usage was also examined, offering a range of insightful perspectives.

Figure 23 illustrates the payment structure preferences: 31.3% of participants suggest that the autonomous shuttles should be complementary; 30.2% endorse a monthly payment plan; a yearly scheme is preferred by 19.1%; and a smaller group, 7.9%, lean towards a daily payment system.

Figure 23. Payment Plan for Autonomous Shuttles



A deeper dive into specific monetary amounts that respondents would be willing to allocate for autonomous shuttles is presented in Table 15. The results indicate that 70.4% would consider paying up to $0.4 per trip. In contrast, a minimal proportion, only 3.2%, state a willingness to pay more than $1 per trip. These results highlight consumer attitudes towards payment for autonomous shuttles, providing valuable guidance for future strategic pricing decisions.

Table 15. Willingness to Pay Per Trip

Range	Ready to Pay per Trip for an Autonomous Shuttle Ride
$0.10-$0.20	50.40%
$0.20-$0.40	20.00%
$0.40-$0.60	10.40%
$0.60-$0.80	7.20%
$0.80-$1.00	7.20%
More than $1.00	3.20%
Prefer not to say	1.60%

6. Conclusions

6.1 Recommendations for Best Practices

A set of recommended best practices for deploying autonomous shuttles is proposed based on the insights from multiple case studies and the perceptions of practitioners and industry experts. These recommendations, encapsulating operational, safety, policy, and economic aspects, facilitate pilot deployments of autonomous shuttles and their full-scale, permanent implementation. The aim is to ensure that autonomous shuttle deployments are safe, reliable, and trusted among all stakeholders and system users. This comprehensive approach helps to guide the development of autonomous shuttles in a manner that meets the needs of users, policymakers, and operators alike while also providing a robust framework for addressing potential challenges in adopting autonomous transit solutions.

6.1.1 Operational Aspect

From the operational perspective, adjusting the pilot deployment trial period to an extended six to twelve 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 solutions. This specific utilization can significantly bridge gaps in public transportation and potentially increase its overall usage.

Infrastructure improvements constitute a crucial part of autonomous shuttle deployments. 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.

From a technical viewpoint, improving the level of autonomy of autonomous shuttles is necessary. 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.

Safety and security are of paramount importance in any transport system. Before the permanent deployment of autonomous shuttles, areas requiring meticulous evaluation and improvement included data safety, passenger safety, road signage, transit parking, and operator training. 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.

Concerning sensor configuration, refining the positioning of LiDAR sensors can result in better blind spot detection, thereby increasing the overall safety performance of autonomous shuttles. However, it is noteworthy that potential challenges such as data security threats and unfriendly infrastructure represent considerable barriers to the successful deployment of autonomous shuttles. These challenges necessitate practical and strategic solutions to ensure a secure and seamless operationalization of autonomous shuttles.

6.1.2 Safety Aspect

Several vital areas demand attention and improvement before the permanent deployment of autonomous shuttles. These include data safety, passenger safety, road signage, transit parking, and operator training.

Data safety is paramount for the functional operation of autonomous shuttles and for maintaining users' trust. Improving measures to protect and secure data can substantially alleviate concerns regarding potential cyber threats. Similarly, passenger safety is a non-negotiable aspect, and it is essential to guarantee the utmost protection for all passengers during transit.

Road signage is significant in ensuring smooth navigation and operation of autonomous shuttles. Hence, comprehensible and efficiently placed road signs can help optimize these vehicles' efficiency and safety. Additionally, transit parking facilities must be improved to offer autonomous shuttles a convenient and easy-to-navigate environment.

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

LiDAR sensors, the crucial components of autonomous shuttles for object detection and navigation, must be strategically placed to ensure optimal blind spot detection. Effective positioning of these sensors can significantly enhance the safety profile of autonomous shuttles.

Lastly, 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.

6.1.3 Policy Aspect

There are several essential considerations that must be addressed before moving towards 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 not as prominent as expected, with only about 30% of the population showing a preference for such a change. This observation suggests that more efforts should be expended to encourage the public to adapt to autonomous public transportation.

Cybersecurity is a significant concern in the context of autonomous shuttles, and it is imperative to develop specific policies addressing data breaches. Such policies would go a long way in building trust among the users, assuring them of their safety and privacy.

Stakeholders should equally shoulder the responsibilities related to the operation and maintenance of autonomous shuttles and liability in the event 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 help provide an extra layer of regulation and control. This body could be instrumental in monitoring and ensuring adherence to safety protocols and guidelines.

Lastly, the factors that could potentially contribute to the underutilization of autonomous shuttles include safety, followed by travel time, schedule adherence, and reliability. 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.

6.1.4 Economic Aspect

Autonomous shuttles are a viable enhancement to the existing public transportation system. 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.

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

6.2 Summary and Conclusions

The study provides a comprehensive understanding of the public's perception towards integrating autonomous shuttles into existing transportation networks, highlighting the key factors influencing the willingness to adopt this emerging technology. The findings confirm that safety, comfort, trust, and familiarity with autonomous shuttles are critical determinants shaping users' willingness to use these services. Additionally, the study identifies and ranks crucial features of autonomous shuttles that users consider essential, such as reliability, speed, and ease of use. Users' preferences towards the adoption or willingness to use autonomous shuttles is also revealed. However, this willingness is largely dependent on perceived safety, trust, and comfort. The SEM employed here provides valuable insights into these relationships, offering significant guidance for future service planning and design.

Moreover, the PCA reveals eight principal components. These factors highlight critical barriers for autonomous shuttle implementation, including underutilization measures, safety concerns, seating arrangements, reliability, data security, operational aspects, sensor technology, and lane use.

The best practices for the smooth deployment of autonomous shuttles, considering operational, safety, policy, and economic aspects, are also proposed based on the comprehensive analysis of survey data and expert opinions. Important recommendations include longer trial periods, improved data and passenger safety measures, operator training, better road signage, and considering dedicated lanes for autonomous shuttles.

These findings must guide policymakers, transit authorities, and stakeholders as they make decisions regarding the future of autonomous shuttles. Future research should build upon these findings, perhaps investigating more particular areas of concern identified and keeping up with the rapidly evolving autonomous vehicle technology landscape.

To conclude, this study marks a crucial step towards understanding and addressing users' concerns and expectations regarding autonomous shuttles. It provides a data-driven framework for decision-making, aiming to ensure a smooth transition toward the widespread acceptance and use of autonomous shuttles in public transportation systems.

6.3 Limitations and Future Scope

The study leverages existing deployment data gathered from publicly accessible sources, providing a valuable foundation for the analysis. However, each deployment type presents unique characteristics and challenges, which have not been explored in-depth in this study. 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.

Moreover, a noted limitation in the adopted approach concerns the nature of user perception data. This study does not distinguish the perceptions of general transportation system users and actual autonomous shuttle riders. This distinction could lead to significantly divergent viewpoints. Future research should strive to gather and analyze these two distinct data sets separately. This would provide a more thorough understanding of the attitudes influencing the willingness to use autonomous shuttles, offering deeper insights into how to overcome barriers for autonomous shuttle adoption. This refined understanding will create more user-centric and effective strategies for the successful integration of autonomous shuttles into existing transport systems.

Appendix

Country	Launch date	Road Type	States	Source
Australia	2016-Jul	Public road	-	(Drive, 2016)
Australia	2018-Jun	Public road	-	(Government of South Australia, 2019)
Australia	2019-Aug	Public road	-	(Smart Cities World, 2021)
Australia	2018-Dec	Pedestrian area	-	(BusBot, n.d.)
Australia	2019-Apr	Closed area	-	(BusBot, n.d.)
Australia	2019-Jun	Pedestrian area	-	(The Driven, 2021)
Australia	2020-Nov	Closed area	-	(Redland City Council, 2021)
Austria	2018-Apr	Public road	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
Austria	2019-Jun	Public road	-	(Neuwinger, Karl, 2019)
Canada	2019-May	Public road	-	(Keolis Canada, 2019)
Canada	2018-Sep	Public road	-	(City of Calgary, 2019)
Canada	2021-Nov	Public road	-	(Intelligent Transportation, 2021)
China	2018-Feb	Public road	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
China	2018-Apr	Public road	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
China	2018-Mar	Pedestrian area	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
China	2019-May	Pedestrian area	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)

Country	Launch date	Road Type	States	Source
China	2017-Dec	Public road	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
China	2017-Dec	Public road	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
China	2019-Jan	Public road	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
China	2018-Oct	Pedestrian area	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
Finland	2019-Jun	Public road	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
France	2016-Sep	Pedestrian area	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
France	2019-Feb	Public road	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
France	2019-Mar	Public road	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
France	2018-May	Pedestrian area	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
France	2018-Dec	Public road	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
France	2018-Jan	Public road	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
France	2018-Nov	Campus	-	(Lin, Kourtellis, Menon, Chen, &

Country	Launch date	Road Type	States	Source
				Rangaswamy, 2020)
France	2019-Nov	Closed area	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
France	2021-Mar	Public road	-	(Smart Cities World, 2021)
France	2018-Jun	Public road	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
France	2018-Nov	Public road	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
France	2018-Dec	Public road	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
France	-	Public road	-	(Sustainable Bus, 2021)
Germany	2019-May	Public road	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
Germany	2017-Oct	Public road	-	(Bad Birnbach, n.d.)
Germany	2017-Dec	Public road	-	(Mobility in Cities, 2018)
Germany	2019-Aug	Public road	-	(IOKI, 2019)
Germany	2018-Jun	Public road	-	(EasyMile, 2020)
Greece	-	Public road	-	(Kassimi, 2016)
Hong Kong	2017-Jul	Pedestrian area	-	(West Kowloon, 2017)
Italy	2020-Jan	Campus	-	(Sustainable Bus, 2020)
Japan	2020-Nov	Public road	-	(Kyodo News, 2020)
Japan	2019-Oct	Public road	-	(Shivdas, 2021)
Luxembourg	2019-Sep	Public road	-	(Avenue, n.d.)
Luxembourg	2019-Sep	Public road	-	(Avenue, n.d.)
Netherlands	2018-Aug	Public road	-	(North, 2018)
Norway	2019-May	Public road	-	(Navya, n.d.)

Country	Launch date	Road Type	States	Source
Norway	2019-Dec	Public road	-	(Navya, n.d.)
Norway	2020-May	Public road	-	(Navya, n.d.)
Saudi Arabia	2019-Dec	Campus	-	(Arab News, n.d.)
Singapore	2019-Jul	Campus	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
Sweden	2018-May	Campus	-	(Holo, 2022)
Sweden	2019-Apr	Public road	-	(Holo, 2022)
Switzerland	2018-Sep	Public road	-	(Avenue, n.d.)
Switzerland	2016-Jun	Public road	-	(Brouet, 2016)
Switzerland	2018-Mar	Public road	-	(Navya, n.d.)
Switzerland	2017-Aug	Public road	-	(Navya, n.d.)
Switzerland	2019-Jun	Public road	-	(Lin, Kourtellis, Menon, Chen, & Rangaswamy, 2020)
UAE		Campus	-	(Khalifa University, 2021)
UAE	2018-Sep	Pedestrian area	-	(Masdar, 2018)
UK	-	Campus	-	(Greater Cambridge Partnership, 2021)
UK	-	Campus	-	(UK Space Agency, 2021)
USA	2020-Feb	Public road	Arizona	(Musto, 2021)
USA	2020-Jan	Public road	Arizona	(Beep, n.d.)
USA	2019-Oct	Public road	California	(Berman, 2019)
USA	2019-Feb	Campus	California	(Reid, 2019)
USA	2019-Aug	Campus	California	(Auvsi News, 2019)
USA	2019-Aug	Public road	California	(Transdev, 2020)
USA	2017-Mar	Campus	California	(Haque & Brakewood, 2020)
USA	2021-Aug	Campus	Colorado	(Fleet Forward, 2021)
USA	2019-Jan	Public road	Colorado	(Haque & Brakewood, 2020)
USA	2019-Sep	Public road	Florida	(Beep, n.d.)
USA	2019-Sep	Public road	Florida	(Beep, n.d.)
USA	2019-Sep	Public road	Florida	(Beep, n.d.)
USA	2019-Sep	Campus	Florida	(Beep, n.d.)

Country	Launch date	Road Type	States	Source
USA	2019-Sep	Closed area	Florida	(Beep, n.d.)
USA	2020-Mar	Closed area	Florida	(Beep, n.d.)
USA	2020-Nov	Public road	Florida	(Beep, n.d.)
USA	2021-Dec	Public road	Florida	(Beep, 2021)
USA	2020-Dec	Closed area	Florida	(Gourarie, 2020)
USA	2020-Dec	Closed area	Florida	(Gourarie, 2020)
USA	2020-Oct	Public road	Florida	(Beep, n.d.)
USA	-	Public road	Florida	(Tampa Bay Times, 2020)
USA	-	Public road	Florida	(Tampa Bay Times, 2020)
USA	2020-Feb	Campus	Florida	(University of Florida, 2020)
USA	2019-Feb	Campus	Florida	(Plautz, 2019)
USA	-	Campus	Florida	(Tampa Bay Business Journal, 2020)
USA	-	Public road	Georgia	(Government Technology, 2021)
USA	-	Closed area	Maryland	(Bhuiya, 2016)
USA	2019-Jun	Public road	Maryland	(Aaron, 2019)
USA	2019-Oct	Public road	Maryland	(Graham, 2019)
USA	-	Public road	Maryland	(Lindsay, 2019)
USA	2016-Feb	Campus	Michigan	(Navya, n.d.)
USA	-	Campus	Michigan	(Geiser, 2021)
USA	2018-Jan	Closed area	Minnesota	(MnDOT, 2018)
USA	2017-Nov	Public road	Nevada	(O'Kane, 2019)
USA	2018-Jul	Public road	New York	(Ortiz, 2023)
USA	2019-Sep	Campus	New York	(Insurance Journal, 2018)
USA	2020-Feb	Campus	North Carolina	(Peeler, 2020)
USA	2021-Apr	Closed area	North Carolina	(NCDOT, 2022)
USA	2020-Feb	Closed area	Ohio	(Easy Mile, 2020)
USA	2019-Feb	Closed area	Texas	(Zheng, 2020)
USA	2017-Aug	Campus	Texas	(Haque & Brakewood, 2020)
USA	2019-Apr	Closed area	Utah	(UDOT, 2021)
USA	2020-Feb	Closed area	Utah	(UDOT, 2021)
USA	2019-May	Public road	Utah	(UDOT, 2021)
USA	2019-Jun	Public road	Utah	(UDOT, 2021)

Country	Launch date	Road Type	States	Source
USA	2019-Jul	Public road	Utah	(UDOT, 2021)
USA	2019-Aug	Campus	Utah	(UDOT, 2021)
USA	2019-Aug	Pedestrian area	Utah	(UDOT, 2021)
USA	2020-Mar	Pedestrian area	Utah	(UDOT, 2021)
USA	2019-Oct	Pedestrian area	Utah	(UDOT, 2021)
USA	2020-Feb	Closed area	Utah	(UDOT, 2021)
USA	2020-Jul	Campus	Utah	(UDOT, 2021)
USA	2019-May	Closed area	Virginia	(VolkovaMaria, 2019)
USA	2019-May	Public road	Virginia	(EasyMile, n.d.)
USA	2020-Jul	Public road	Virginia	(Woolsey, 2019)
USA	2021-Jun	Closed area	Wyoming	(National Park Service, n.d.)
USA	2021-Jun	Closed area	Wyoming	(National Park Service, n.d.)

Bibliography

Aaron, J. (2019, June 5). Watch: self-driving shuttle bus coming to National Harbor, Arlington. Last retrieved August 16, 2023, from Wtop news: https://wtop.com/dc-transit/2019/06/watch-self-driving-shuttle-bus-coming-to-national-harbor-arlington/

Ames, Chris. (2016, September 5). Two French companies have launched what they say is the world's first driverless public transport bus service in a suburb of Lyon. Last retrieved August 16, 2023, from Transport Network: https://www.transport-network.co.uk/100-French-driverless-bus-service-launches/13248

Arab News. (n.d.). Saudi university launches kingdom's first self-driving buses. Last retrieved August 16, 2023, from https://www.arabnews.com/node/1597686/saudi-arabia

ARL Now. (2019, April 8). Autonomous vehicles shuttles rolling out soon at Fort Myer. Last retrieved August 16, 2023, from https://www.arlnow.com/2019/04/08/autonomous-vehicles-shuttles-rolling-out-soon-at-fort-myer/

Artificial Intelligence. (2021, August 21). Five challenges in designing a fully autonomous system for driverless cars. Last retrieved August 16, 2023, from IIOT World: https://www.iiot-world.com/artificial-intelligence-ml/artificial-intelligence/five-challenges-in-designing-a-fully-autonomous-system-for-driverless-cars/

Auvsi News. (2019, August 9). Local motors' Olli autonomous shuttle now operating in Rancho Cordova, California. Last retrieved August 16, 2023, from https://www.auvsi.org/industry-news/local-motors-olli-autonomous-shuttle-now-operating-rancho-cordova-california

Avenue. (n.d.). Geneva demonstrator sites. Last retrieved August 16, 2023, from https://h2020-avenue.eu/?portfolio=geneva

Avenue. (n.d.). Luxembourg demonstration sites. Last retrieved August 16, 2023, from https://h2020-avenue.eu/portfolio-item/luxembourg/

Bad Birnbach. (n.d.). Autonomous minibus. Last retrieved August 16, 2023, from https://www.badbirnbach.de/en/stories/autonomous-minibus

Beep. (2021, December 15). Beep at the beach: PSTA brings autonomous vehicles to clearwater. Last retrieved August 16, 2023, from https://ridebeep.com/2021/12/15/beep-autonomous-vehicles-clearwater/

Beep. (n.d.). City of Peoria. Last retrieved August 16, 2023, from https://ridebeep.com/location/robo-ride/

Beep. (n.d.). Lake Nona. Last retrieved August 16, 2023, from: https://ridebeep.com/location/move-nona/

Beep. (n.d.). Mayo clinic - Jacksonville, FL. Last retrieved August 16, 2023, from https://ridebeep.com/wp-content/uploads/2021/05/Case-Study-FINAL-Mayo-Clinic.pdf

Beep. (n.d.). PSTA. Last retrieved August 16, 2023, from: https://ridebeep.com/location/psta/

Berman, B. (2019, November 13). GoMentum begins testing autonomous shuttles. Last retrieved August 16, 2023, from https://www.sae.org/news/2019/11/gomentum-begins-testing-autonomous-shuttles

Bhuiya, J. (2016, June 16). Meet Olli, the self-driving shuttle you can talk to — thanks to IBM's Watson. Last retrieved August 16, 2023, from https://www.vox.com/2016/6/16/11948448/watson-ibm-self-driving-shuttle-olli

Bowling, J. (2020, February 5). Spring training fans in Peoria can get around on a driverless shuttle (azcentral). Last retrieved August 16, 2023, from https://www.azcentral.com/story/news/local/peoria/2020/02/05/metro-phoenix-city-offer-driverless-shuttle-rides-end-month/4666486002/

Brouet, A.-M. (2016, June 23). Autonomous shuttles start giving rides in Sion. Last retrieved August 16, 2023, from https://phys.org/news/2016-06-autonomous-shuttles-sion.html

BusBot. (n.d.). Phase 3: North Coast regional botanic garden. Last retrieved August 16, 2023, from https://www.busbot.com.au/three-phase-trial/

City of Calgary. (2019, May 31). Calgary autonomous shuttle ACATS final report. Last retrieved July 7, 2022, from https://tcdocs.ingeniumcanada.org/sites/default/files/2020-03/Autonomous%20Shuttle%20Pilot%20Report%20-%20City%20of%20Calgary.pdf

Drive. (2016, September 2). Australia's first autonomous bus hits the road in Perth. Last retrieved August 16, 2023 from https://www.drive.com.au/news/australias-first-autonomous-bus-hits-the-road-in-perth/

EasyMile. (2020, February 6). EZ10 autonomous shuttles deployed in Columbus neighbourhood. Last retrieved August 16, 2023, from https://easymile.com/news/ez10-autonomous-shuttles-deployed-columbus-neighbourhood

EasyMile. (2020, October 28). GreenTEC and EasyMile bring level 4 autonomous driving to Germany. Last retrieved August 16, 2023, from https://easymile.com/news/greentec-and-easymile-bring-level-4-autonomous-driving-germany

EasyMile. (n.d.). A snapshot of our global success. Last retrieved August 16, 2023, from https://easymile.com/success-stories

EasyMile. (n.d.). EZ10 passenger shuttle. Last retrieved August 16, 2023, from https://easymile.com/vehicle-solutions/ez10-passenger-shuttle

Fleet Forward. (2021, August 11). EasyMile autonomous shuttle launches in Colorado. Last retrieved August 16, 2023, from https://www.fleetforward.com/10149237/easymile-shuttle-launches-in-colorado

Geiser, T. (2021, September 3). GameAbove College of Engineering and Technology kicks off school year by unveiling autonomous shuttles and signing lease agreement with American Center for Mobility. Last retrieved August 16, 2023, from https://today.emich.edu/story/story/11845

Gourarie, C. (2020, November 27). Mattamy homes launches autonomous shuttle network in Florida. Last retrieved August 16, 2023, from https://commercialobserver.com/2020/11/mattamy-autonomous-shuttle-network-in-tradition/

Government of South Australia. (2019, September 3). Flinders autonomous shuttle trial. Last retrieved August 16, 2023, from https://www.dit.sa.gov.au/news?a=371235

Government Technology. (2021, October 8). Peachtree Corners, Ga., launches autonomous shuttle route. Last retrieved August 16, 2023, from https://www.govtech.com/fs/peachtree-corners-ga-launches-autonomous-shuttle-route

Graham, M. (2019, October 24). Autonomous shuttle Olli is expanding its testing in National Harbor. Last retrieved August 16, 2023, from https://technical.ly/startups/atonomous-shuttle-olli-is-expanding-its-testing-in-national-harbor/

Greater Cambridge Partnership. (2021, May 27). GCP - SMART Autonomous Shuttle Trials Spring/Summer 2021. Last retrieved August 16, 2023, from https://www.youtube.com/watch?v=dwL2VVXshaw

Hanikewitz, S. (2021, January 16). An Estonian consortium tests an autonomous bus in Greece. Last retrieved August 16, 2023, from Estonian World: https://estonianworld.com/technology/an-estonian-consortium-tests-an-autonomous-bus-in-greece/

Haque, A. M., & Brakewood, C. (2020, September). A synthesis and comparison of American automated shuttle pilot projects. Case Studies on Transport Policy, 8(3). https://doi.org/10.1016/j.cstp.2020.05.005

HART. (n.d.). Last retrieved August 16, 2023, from Beep: https://ridebeep.com/location/hart-hillsborough-area-regional-transit/

Hess, D. B. (2003). Access to Public Transit and Its Influence on Ridership for Older Adults in Two U.S. Cities. Journal of Transportation and Land Use, 2(1). https://doi.org/10.5198/jtlu.v2i1.11

Holo. (2022, January 14). Gothenburg. Last retrieved August 16, 2023, from https://www.letsholo.com/gothenburg

Hsueh, G., Czerwinski, D., Poliziani, C., Becker, T., & Hughes, A. (2021). Using BEAM Software to Simulate the Introduction of On-Demand, Automated, and Electric Shuttles for Last Mile Connectivity in Santa Clara County. SJSU Scholar Works. Mineta Transportation Institute Publications, 2021. https://doi.org/10.31979/mti.2021.1822

Insurance Journal. (2018, August 20). First driverless shuttle demonstration held in NYC by coast autonomous. Last retrieved August 16, 2023, from https://www.insurancejournal.com/magazines/mag-features/2018/08/20/498102.htm#

Intelligent Transportation. (2021, November 10). Metrolinx introduces new autonomous electric shuttle in Whitby, Canada. Last retrieved August 16, 2023, from https://www.intelligenttransport.com/transport-news/130419/metrolinx-autonomous-electric-shuttle-canada/

IOKI. (2019, August 16). Autonomous bus in the streets of Berlin. Last retrieved August 16, 2023, from https://ioki.com/en/autonomous-bus-in-the-streets-of-berlin/

Irmantas, B. (2020, November 11). Meet 3D printed self-driving Olli bus. Last retrieved August 16, 2023, from Global Motor Media: https://www.globalmotormedia.com/self-driving-olli-minibus/

Kassimi, A. (2016, March 21). World's most successful driverless bus pilot in Trikala. Last retrieved August 16, 2023, from https://www.greece-is.com/news/worlds-successful-driverless-bus-pilot-trikala/

Keolis Canada. (2019, May 14). Electric self-driving shuttle back in Candiac for summer 2019. Last retrieved August 16, 2023 from Cision Canada: https://www.newswire.ca/news-releases/electric-self-driving-shuttle-back-in-candiac-for-summer-2019-810155449.html

Khalifa University. (2021, December 7). Meet Khalifa University's autonomous shuttle. Last retrieved August 16, 2023, from https://www.youtube.com/watch?v=k4qmW9vgAio

Kyodo News. (2020, November 25). SoftBank unit to begin Japan's 1st public road autonomous bus service. Last retrieved August 16, 2023, from https://english.kyodonews.net/news/2020/11/90a5ee06e959-softbank-unit-to-begin-japans-1st-public-road-autonomous-bus-service.html

Lin, P.-S., Kourtellis, A., Menon, N., Chen, C., & Rangaswamy, R. (2020). Campus Automated Shuttle Service Deployment Initiative. USF Center for Urban Transportation Research, Florida Department of Transportation. University of South Florida. Last retrieved August 16, 2023, from https://digitalcommons.usf.edu/cgi/viewcontent.cgi?article=1045&context=cutr_nctr

Lindsay, J. (2019, November 21). Self-driving shuttle coming to Montgomery county. Last retrieved August 16, 2023, from https://www.mymcmedia.org/self-driven-shuttle-coming-to-montgomery-county/

Lyon, P. (2021, August 28). Collision with paralympic athlete forces Toyota to halt self-driving bus service in Olympic village. (Forbes) Last retrieved August 16, 2023, from https://www.forbes.com/sites/peterlyon/2021/08/28/collision-with-paralympic-athlete-forces-toyota-to-halt-self-driving-bus-service-in-olympic-village/?sh=3418d197f873

Masdar. (2018, October 28). NAVYA autonom shuttle launch at Masdar City [Motion Picture]. Last retrieved August 16, 2023, from https://www.youtube.com/watch?v=144uiurUAHg

MnDOT. (June, 2018). MnDOT autonomous bus pilot project. Last retrieved May 8, 2022, from http://www.dot.state.mn.us/research/reports/2019/201904.pdf

Mobility in Cities. (2018, July 12). Robot buses- a revolution in public transportation. Last retrieved August 16, 2023, from https://www.tuev-nord.de/explore/en/reveals/robot-buses-a-revolution-in-public-transport/

Musto, J. (2021). Yellowstone introduces autonomous shuttles. Last retrieved August 16, 2023, from https://www.foxnews.com/us/yellowstone-introduces-autonomous-shuttles

National Park Service. (2022, May 2). Automated shuttle pilot. Last retrieved August 16, 2023, from https://www.nps.gov/yell/learn/management/automated-shuttle-pilot.htm

Navya. (n.d.). Autonom®. Last retrieved August 16, 2023, from https://navya.tech/wp-content/uploads/documents/Brochure-Autonom-Shuttle-Evo-EN.pdf

Navya. (n.d.). Self-driving shuttle for passenger transportation. Last retrieved August 16, 2023, from https://navya.tech/en/solutions/moving-people/self-driving-shuttle-for-passenger-transportation/#storeLocator__bottomHalf

Neuwinger, Karl. (2019, June 23). Driverless buses in Vienna's Seestadt on the road again. Last retrieved August 16, 2023, from https://metropole.at/driverless-buses-in-viennas-seestadt/

North. (2018, August 2). Autonomous shuttle bus at the Ommelander Ziekenhuis. Last retrieved August 16, 2023, from https://www.at-north.nl/en/nieuws/on-the-road/autonomous-shuttle-bus-at-the-ommelander-ziekenhuis/

O'Kane, S. (2019, July 11). Self-driving shuttle crashed in Las Vegas because manual controls were locked away. Last retrieved August 16, 2023, from https://www.theverge.com/2019/7/11/20690793/self-driving-shuttle-crash-las-vegas-manual-controls-locked-away

Ortiz, P. (2023, February 9). What was Local Motors and the 3-D Printed Olli Shuttle? Last retrieved August 16, 2023, from https://housegrail.com/what-was-local-motors-and-the-3d-printed-olli-shuttle/

Peeler, T. (2020, February 5). Driverless shuttle a smart move for centennial campus. Last retrieved August 16, 2023 from https://news.ncsu.edu/2020/02/driverless-shuttle-a-smart-move-for-centennial-campus/

Plautz, J. (2019, February 14). University of South Florida launches autonomous shuttle trial. Last retrieved August 16, 2023, from Dive Brief: https://www.smartcitiesdive.com/news/university-of-south-florida-launches-autonomous-shuttle-trial/548408/

RACQ. (n.d.). RACQ Smart Shuttle. Last retrieved August 16, 2023, from https://www.racq.com.au/about-us/advocacy/future-mobility/racq-smart-shuttle

Redland City Council. (2021, June 28). Redlands coast smart mobility trial. Last retrieved August 16, 2023, from https://yoursay.redland.qld.gov.au/SmartMobilityTrial

Reid, D. (2019, August 1). Despite some wrinkles, Olli experiment judged a success. Last retrieved August 16, 2023, from Sacramento State News: https://www.csus.edu/news/articles/2019/8/1/Despite-some-wrinkles-Olli-experiment-judged-a-success.shtml

SAE International. (2021, May 3). SAE Levels of Driving Automation™ Refined for Clarity and International Audience. Last retrieved August 16, 2023, from https://www.sae.org/blog/sae-j3016-update

Shivdas, S. (2021, August 28). Toyota halts all self-driving e-Palette vehicles after Olympic village accident. Last retrieved August 16, 2023, from Reuters: https://www.reuters.com/business/autos-transportation/toyota-halts-all-self-driving-e-pallete-vehicles-after-olympic-village-accident-2021-08-27/

Smart Cities World. (2021, April 1). Driverless passenger shuttle launched in Paris Ile-de-France. Last retrieved August 16, 2023, from https://www.smartcitiesworld.net/news/news/driverless-passenger-shuttle-launched-in-paris-ile-de-france-6262

Smart Cities World. (2021, March 3). Renmark tests autonomous electric shuttle. Last retrieved August 16, 2023 from https://www.smartcitiesworld.net/news/news/renmark-tests-autonomous-electric-shuttle-6147

Space. (n.d.). Candiac autonomous shuttle. Last retrieved August 16, 2023, from https://space.uitp.org/initiatives/candiac-av-canada

Space. (n.d.). Marly autonomous TPF shuttles. Last retrieved August 16, 2023, from https://space.uitp.org/initiatives/marly-autonomous-tpf-shuttles-av-switzerland

Sustainable Bus. (2020, January 17). Olli debuts in Italy: Turin deploys the 3D-printed driverless shuttle. Last retrieved August 16, 2023, from Sustainable Bus: https://www.sustainable-bus.com/its/olli-debuts-in-italy-turin-deploys-the-3d-printed-driverless-shuttle/

Sustainable Bus. (2021, May 27). NAVETTY R&D project launched: autonomous shuttle in Paris industrial site. Last retrieved August 16, 2023, from https://www.sustainable-bus.com/its/navetty-autonomous-shuttle-paris-ariane/

Tampa Bay Business Journal. (2020, February 9). Saint Leo readies to launch autonomous campus shuttle. Last retrieved August 16, 2023, from https://www.bizjournals.com/tampabay/news/2020/02/19/saint-leo-readies-to-launch-autonomous-campus.html

Tampa Bay Times. (2020, October 9). Driverless shuttle launches in downtown Tampa. Last retrieved August 16, 2023, from https://www.tampabay.com/news/transportation/2020/10/09/driverless-shuttle-launches-in-downtown-tampa/

The Driven. (2021, April 7). Automated BusBot begins driverless trials in Coffs Harbour. Last retrieved August 16, 2023, from https://thedriven.io/2021/04/07/automated-busbot-begins-driverless-trials-in-coffs-harbour/

Transdev. (2020, July 14). Transdev partners with LAVTA to begin testing of its Shared Autonomous Vehicle. Last retrieved August 16, 2023, from https://transdevna.com/news/2020/07/14/transdev-partners-with-lavta-to-begin-testing-of-its-shared-autonomous-vehicle/

UDOT. (2021, April). Utah autonomous shuttle pilot. Last retrieved August 16, 2023, from AV Shuttle Utah: http://www.avshuttleutah.com/pdfs/UtahAutomatedShuttle_FinalReport_1-3-2022.pdf

UK Space Agency. (2021, November 29). New autonomous passenger shuttle service trialled in Oxfordshire. Last retrieved August 16, 2023, from https://www.gov.uk/government/news/all-aboard-new-autonomous-passenger-shuttle-service-trialled-in-oxfordshire

University of Florida. (2020, February 4). Autonomous shuttle ready for passengers. Last retrieved August 16, 2023, from University of Florida Herbert Wertheim College of Engineering: https://www.eng.ufl.edu/newengineer/news/autonomous-shuttle-ready-for-passengers//

West Kowloon. (2017, June 6). West Kowloon cultural district to introduce autonomous vehicle in the district. Last retrieved August 16, 2023, from https://www.westkowloon.hk/en/press-release/west-kowloon-cultural-district-to-introduce-autonomous-vehicle-in-the-district

Woosley, A. (2019, November 19). Dominion taps EasyMile for driverless shuttle pilot. Last retrieved August 16, 2023, from https://www.fairfaxtimes.com/articles/dominion-taps-easymile-for-driverless-shuttle-pilot/article_144c792e-07eb-11ea-99f7-93061e96a140.html

Zank, C., & Rehrl, K. (2018). Digibus 2017: Experiences with the first self-driving shuttlebus on open roads in Austria. European Transport Research Review, 10(2), 1-11. https://doi.org/10.1186/s12544-018-0326-4

Zheng, L. (2020, February 19). DFW Airport Testing Driverless Shuttle to Transport Passengers. Last retrieved August 16, 2023, from https://www.nbcdfw.com/news/local/dfw-airport-testing-driverless-shuttle-to-transport-passengers/2314053/

Zuo, T., Weia, H., & Chen, N. (2020). Promote transit via hardening first-and-last-mile accessibility: Learned from modeling commuters' transit use. Transportation Research Part D: Transport and Environment, 86(2020), 102446. https://doi.org/10.1016/j.trd.2020.102446

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