Journal of Air Transport Management 124 (2025) 102761

Contents lists available at ScienceDirect

Journal of Air Transport Management

journal homepage: www.elsevier.com/locate/jairtraman

From innovation to adoption: A framework-based evaluation of sustainable adoption strategies for eVTOL vehicles in shared passenger and freight transportation system

Vishal Kashav [a], Chandra Prakash Garg [b,*]

[a] Energy and Transportation Cluster, School of Business, UPES, Dehradun, Uttarakhand, 248007, India
[b] Department of Operations Management & Quantitative Techniques, Indian Institute of Management Rohtak, Haryana, 124010, India

ARTICLE INFO

Keywords:
Shared Passenger and freight transportation
eVTOL
Strategies
Sustainability
Grey DEMATEL

ABSTRACT

Amid ongoing advancements in the transportation sector, the commercial viability of electric Vertical Take-Off and Landing (eVTOL) vehicles is being evaluated for their potential to offer flexible, reliable, rapid, and eco-friendly mobility solutions. While the engineering aspects of eVTOL vehicles have been extensively studied worldwide, the sustainable adoption of this technology has not yet been fully explored. To bridge this gap, the current study first identifies sustainable adoption strategies for eVTOL vehicles in shared passenger and freight transportation arrangements and then evaluates them using the Grey-DEMATEL (Decision-Making Trial and Evaluation Laboratory) method. The methodology uncovers the causal relationships between these strategies and highlights their criticality, allowing for the prioritization of the most essential ones. The key contribution of this study lies in emphasizing top-ranked strategies, particularly the enhancement of customer adoption, which is often overlooked in the existing literature. Most published studies focus primarily on the technical aspects of this innovation, neglecting the crucial importance of prioritizing customer acceptance for sustainable adoption. Additionally, we identified that government support, financial incentives such as subsidies, and a strong understanding of the technology are critical focus areas for accelerating adoption. This study makes a significant contribution by being one of the first attempts to create a Grey-DEMATEL-based framework for evaluating sustainable adoption strategies in the context of eVTOL vehicles' deployment in shared passenger and freight transportation arrangements. Lastly, a sensitivity analysis is conducted to ensure the robustness of the method; consequently, the entire framework is found to be robust.

1. Introduction

The persistent demand for transportation modes that offer greater comfort, safety, speed, environmental friendliness, and cost-effectiveness has been a driving force for revolutionary changes over time. Whether related to passenger or freight transport, customer expectations continue to rise. However, as urbanization accelerates, transportation infrastructure faces challenges such as congestion, accidents, pollution, and delays. To address these issues, alternative transportation options need to be explored (Parker et al., 2021; Ball, 2019). One such technological advancement that has captured the attention of transporters, freight forwarders, logistics professionals, and supply chain stakeholders is eVTOL (electric Vertical Take-Off and Landing). The industry has started developing and testing prototypes, signaling that the commercial usage of eVTOL vehicles will soon become a reality (Bacchini et al., 2021). Currently, more than 450 companies are engaged in prototype development (Pavel, 2022). This technology is gaining prominence for applications such as flying taxis, aerial freight vehicles (AFVs), and emergency evacuation aerial crafts (EEACs) to alleviate surface transportation congestion (Pukhova et al., 2021). Moreover, stakeholders are exploring the possibilities of shared passenger and freight mobility alternatives using eVTOL vehicles, which could represent a groundbreaking initiative in the context of shared transportation.

Despite its promising future, eVTOL technology faces significant operational and technical challenges, as highlighted by prominent researchers. For example, limited battery charging capacity may impact the operational efficiency of eVTOL vehicles, as noted by German et al. (2018). The lack of appropriate charging infrastructure along

* Corresponding author.
E-mail address: cpgarg86@gmail.com (C.P. Garg).

https://doi.org/10.1016/j.jairtraman.2025.102761
Received 17 April 2024; Received in revised form 19 November 2024; Accepted 11 February 2025
Available online 18 February 2025

operational routes poses a critical obstacle to the sustainability of eVTOL technology, according to Ahluwalia et al. (2021). Additionally, Ahmed et al. (2021) and Fu et al. (2019) identified societal acceptance as another crucial challenge, particularly in densely populated areas where safety concerns for commuters arise. Moreover, public reluctance toward eVTOL vehicles could hinder or delay their adoption. Addressing these bottlenecks is essential for policymakers and governments to facilitate the implementation and utilization of such technology-based transportation systems. Furthermore, investors may be hesitant to fund this technology if these concerns are not adequately addressed. Hence, the current study seeks to explore this field by investigating sustainable adoption strategies for the successful integration of eVTOL vehicles.

The study aims to identify strategies through an extensive review of relevant literature and brainstorming sessions with domain experts. These identified strategies are then assessed using the grey-DEMATEL method. The novelty of this manuscript lies in its examination of the sustainability of shared passenger and freight mobility adoption using eVTOL vehicles, a topic that has received limited scholarly attention. As eVTOL vehicle adoption is a relatively new paradigm, it warrants greater interest from stakeholders and investors.

2. Review of literature

The case of electric Vertical Takeoff and Landing (eVTOL) vehicles remains largely uncharted, with limited awareness among stakeholders and society regarding this technological breakthrough. To assess the progress made in this field so far, an extensive examination of existing literature has been conducted. The literature review is structured into three distinct themes, followed by an identification of research gaps.

2.1. Literature on eVTOL vehicles and their sustainability

The existing literature on the sustainable adoption of eVTOL vehicles is limited in both quantity and relevance. Moreover, the focus of published studies predominantly revolves around the technical advancements of eVTOL vehicles. This section effectively and comprehensively evaluates the literature, synthesizing the variables and insights. For instance, Kasliwal et al. (2019), in their analysis, compared the energy use and greenhouse gas (GHG) emissions of VTOLs and ground-based cars, revealing that for a 100 km journey, a single-occupant VTOL emits 35% less GHG than an internal combustion engine vehicle (ICEV) but 28% more than a battery electric vehicle (BEV). However, fully loaded VTOLs demonstrate 52% lower emissions per passenger-kilometer than ICEVs and 6% lower than BEVs. Similarly, Long et al. (2023) identified the demand for Urban Air Mobility (UAM) across various on-demand applications, including passenger and cargo services. They also examined factors influencing UAM market demand, such as time, cost, distance, congestion, safety, privacy, and noise. The study highlighted prevalent methodologies, including stated-preference surveys, discrete choice models, and clustering algorithms. Additionally, it identified several under-researched areas, such as the feasibility of air shuttle services, potential cargo applications, public acceptance, infrastructure placement, integration with existing transportation systems, and innovative demand estimation methods. Likewise, Melo et al. (2022) assessed 24 cities worldwide and developed a Life Cycle Engineering (LCE) framework to analyze key factors such as weight, flight range, payload, and battery technology, all of which are crucial to the success of eVTOLs, particularly regarding the environmental impact of batteries in aircraft applications. Additionally, the study suggests that shorter and faster trips are significantly more feasible with eVTOLs. Liberacki et al. (2023) examined the Environmental Life Cycle Costs (ELCC) of Urban Air Mobility (UAM) and found that these costs are primarily associated with the aircraft's energy consumption during flight, with the remainder attributed to ground infrastructure. Furthermore, energy costs are strongly correlated with both the distance traveled and the size of the aircraft. The longer the flight and the larger the aircraft, the higher the energy costs. Similarly, Pons-Prats et al. (2022) focused on advancements in battery and propulsion technologies and analyzed the requirements of Urban Air Mobility (UAM) from technological, mobility, and societal perspectives. The value added by this paper lies in evaluating the current status and future prospects of the most critical areas of Urban Air Mobility (UAM) through an analysis of both literature and practical applications. The paper also concludes that multidisciplinary constraints may hinder the commercialization of flying vehicles. Kleinbekman et al. (2018), in their study, proposed a novel vertiport terminal area airspace design along with a new rolling-horizon scheduling algorithm featuring route selection capabilities to calculate the optimal required time of arrival for eVTOLs in a tactical manner. The findings of this study indicated that a delay of up to 50 s per eVTOL is expected during peak commuter hours, while a delay of less than 10 s is anticipated during off-peak hours. Furthermore, Yun et al. (2021) introduced a novel distributed Multi-Agent Deep Reinforcement Learning (MADRL) algorithm for managing eVTOL-based drone taxis, enabling multiple vehicles to operate simultaneously without collisions. The algorithm demonstrated effective performance in the autonomous control of these vehicles compared to previously presented models and frameworks. The studies reviewed above primarily focused on the technical feasibility of eVTOL technology, emphasizing the investigation of its practical applications and limitations.

2.2. Literature on shared passenger and freight transportation

This section aims to assess the current state of research on shared passenger and freight transportation by providing a comprehensive overview of relevant literature. A study by Marcucci et al. (2017) evaluated the feasibility and behavioral levers that could facilitate the diffusion of crowdshipping in urban areas. The results indicated that 87% of students would, in principle, be willing to act as crowdshippers (i.e., supply) with adequate compensation, while 93% would be willing to receive their goods through a crowdshipping system (i.e., demand) under certain conditions, particularly regarding delivery timing and punctuality. Similarly, Li et al., 2021 developed and tested an algorithm for shared passenger and freight transportation using real-life data from the Beijing Metro Network. The findings highlighted the benefits and scenarios for integration, emphasizing the need to carefully determine the number of train units required to balance passenger service quality with freight demand volume. Talebian and Zou (2015) concluded that a problem-tailored linearized reformulation provides superior computational performance. Their numerical experiments, using realistic parameter values, showed that passenger delay costs are comparable to in-vehicle travel time costs and rail fares. Typically, the marginal increase in freight costs from scheduling additional passenger trains exceeds the reduction in passenger delay costs. Moving forward, Hörsting and Cleophas (2023) conducted a simulation study addressing scheduling issues in shared passenger and freight transport. The results indicated that a well-planned train schedule significantly enhances service quality and reduces the system's sensitivity to rising freight demand. Additionally, Kiba-Janiak et al. (2021) explored the relationship between city size and administrative structure and their impact on maturity levels. The study revealed that cities achieving optimal results in safety and minimizing environmental degradation have implemented various passenger and freight transport measures while maintaining close, ongoing cooperation with stakeholders and integrating transport strategies for both passenger and freight transport. Likewise, Bruzzone et al. (2021, 2022), and Nocera et al. (2021) made significant efforts to explore how integrated passenger and freight transport could facilitate first- and last-mile arrangements.

2.3. Literature on grey-DEMATEL usage in aerial transportation

This section aims to review studies that have utilized the grey-DEMATEL method in the context of aerial transportation, or specifically for eVTOL vehicles, if such studies are available. The objective of this section is twofold: first, to determine the feasibility of employing this technique for the research problem addressed in this manuscript, and second, to understand whether the grey-DEMATEL method has previously been employed to analyze eVTOL vehicle transportation. In a study conducted by Raj and Sah (2019), the grey-DEMATEL method was used to evaluate critical success factors for the utilization of drones in freight transportation. Similarly, Kamat et al. (2022) employed the grey-DEMATEL technique to assess factors influencing the implementation of aerial vehicles in humanitarian logistics. Furthermore, Poudeh et al. (2019) applied the grey-DEMATEL method to rank factors impacting the subcontracting of Complex Product Systems R&D projects. Please refer to the Table 1 below for the most recent literature published on this topic.

2.4. Research gaps and objectives of this research

This section addresses the research gap that emerged from a comprehensive review of the literature across the three themes outlined above. Additionally, the research gap was further confirmed through extensive discussions with industry experts (as detailed in Section 3.1). This gap highlights that the topic explored in the current research is novel, as it addresses an area that has not been previously investigated. Most importantly, the research gaps identified below are transformed into research objectives, forming the foundation upon which the entire study is structured.

- A substantial part of existing research predominantly focuses on technical aspects. Although these studies offer important insights, but the managerial and commercial dimensions remain insufficiently explored. Notably, there is a distinct gap in the literature regarding sustainable adoption strategies for eVTOL vehicles.
- Most of the studies we reviewed focus on the technical feasibility of eVTOL technology or the optimization of its engineering aspects, such as enhancing battery capacity. However, there is a conspicuous gap in research specifically addressing the integration of shared passenger and freight operations using eVTOL vehicles.
- No study has utilized a grey-DEMATEL-based framework to assess sustainable adoption strategies for eVTOL vehicles within a shared passenger and freight transport model.

The above-mentioned research gaps have prompted the formulation of the following research objectives, which guide the execution of this study.

- To explore and evaluate sustainable adoption strategies for eVTOL vehicles in case of shared passenger and freight arrangement, focusing on the managerial, technical and commercial dimensions.
- To develop a grey-DEMATEL-based framework for assessing sustainable adoption strategies for eVTOL vehicles within a shared passenger and freight transport system.

Table 1
Some recently published studies on eVTOL vehicles and its applications.

Sr. No.	Author (s)	Keywords	Scope	Methodology	Objective (s)
1	Rice et al. (2022)	Vertiports; Air taxis; Safety; Security; Consumer perceptions	United States and India	Mean and Standard Deviation	To discern issues concerning vertiports and UAMs and to assess the significance of those issues.
2	Prakasha et al. (2022)	Conceptual aircraft design; Systems of systems; Urban air mobility; Agent-based simulation; Sensitivity study	Global	Agent-based simulation	To evaluate architecture of the aircraft and fleet using a model for aerial transportation in urban areas.
3	Xie et al. (2021)	Aircraft; Convex optimization; Energy management; Fuzzy logic control; Hybrid electric propulsion system; Non-dominated sorting genetic algorithm; sizing	Global	Fuzzy logic control and Non-dominated sorting genetic algorithm	To review conceptual designs of epowered aircrafts and their energy managing methods.
4	Takacs and Haidegger (2022)	Sustainable urban air mobility; vertical takeoff & landing vehicles; autonomous aerial vehicle safety; self-driving regulations; flying cars	Global	Narrated overview	To understand infrastructural necessities and regulatory threats of sustainable urban air mobility
5	Rajendran and Srinivas (2020)	Air taxi; Network operations; Urban Air Mobility (UAM); Define; Measure; Analyze; Design; And verify (DMADV); Discrete-event system simulation approach; Recommender system	New York City	Discrete-event system simulation approach	To discern the requirement of aerial taxis in the New York city.
6	Rajendran and Srinivas (2020)	Air taxi; Helicopter services; Text analytics; Online customer reviews; Urban air mobility (UAM); Vertical takeoff and landing (VTOL); Industrial engineering; Systems engineering; Environmental assessment; Information science; Psychology	Global	Bigram and trigram analysis	To analyze reviews of the customers and conduct evaluation of the helicopter operations.
7	Rajendran et al. (2021)	Air taxi; Demand prediction; Machine learning algorithms; Ride-and weather-related factors; Urban air mobility (UAM)	New York City	Logistic regression, Artificial neural networks, Random forests, and Gradient boosting	To forecast the demand for air taxi urban air mobility services.
8	Melo et al. (2022)	Life Cycle Engineering; Aviation; VTOLs; Batteries	Global	LCE framework	To study future aircraft system and their life cycle.
9	Marx and Manaugh (2022)	Automobility; Critical future studies; Mobility justice; Technology studies; Future studies; Critical geographies	Global	Critical analysis	To conduct analysis with focus on how experts explain their propounded solutions.
10	Eker et al. (2022)	Flying car; Flying taxi; Urban air mobility; Advanced air mobility; Public perception; Willingness to use; Willingness to pay	United States and rest of the world	Survey data	To study public opinion on aerial taxis.
11	Liu et al. (2022)	Flying car; CO2 emissions; Battery specific energy; Emission factor	China	Modeling flying processes and sizing components	To model the viability of the aerial vehicles.
12	Luo et al. (2021)	Flying car; Power battery; Operating characteristics; Flight mission profile; Backward simulation	Global	Backward simulation	To summarize the important research on performance of battery power in context to VTOLs.

Source: Authors' composition

- To propose the theoretical, policy, and practical implications of this research to the relevant actors and stakeholders within UAM domain.

3. Data collection and flowchart of the study

This section is divided into two sub-sections which are discussed below.

3.1. Identification and finalization of strategies and profile of the experts

In order to identify and finalize sustainable adoption strategies, a comprehensive analysis of published literature was conducted. Subsequently, industry experts were engaged to participate in focused group discussions. A total of approximately 70 mid-level and senior-level professionals were consulted, although only 26 of them responded with relevant feedback (refer Table 2). These professionals were initially contacted via email and were subsequently reminded through phone calls. A questionnaire was circulated among the 26 respondents, and valuable insights were gathered. However, it was advised by these respondents to maintain their confidentiality. The survey primarily targeted six prominent eVTOL vehicle manufacturers and operators, and interviews were conducted with mid-level and senior-level professionals to obtain pertinent feedback. In addition to this, consultation was sought from other experts in the field of electric aerial mobility.

3.2. Research outline

The sustainable adoption strategies are discerned through a pertinent literature review and feedback from domain specialists (refer Table 3). The discerned strategies are then evaluated using the grey-based DEMATEL technique. The proposed outline of this research work is illustrated in Fig. 1.

4. Methodology

The grey–DEMATEL process is briefed below.

Step 1: Build the primary influenced matrices

Assume ‘c’ is a number that denotes sustainable adoption strategies and ‘n’ is a number for chosen experts (see Table 3). Every expert must allocate effect of x factor over y factor with evaluation criteria as illustrated in Table 4 for all c factors. It will build a primary influenced matrices for all the experts.

Step 2: Establish an appropriate grey matrices

Establish an appropriate grey matrices by changing certain values into respective grey scale as demonstrated in Table 4 (Luthra et al., 2018), i.e.

Table 2
Profile of the respondents.

Sr. No.	Affiliation of interviewed individuals	Number of individuals	Country of respondents
1	Joby Aviation	4	United States
2	Jaunt Air Mobility	4	United States
3	Archer Aviation	3	United States
4	Volocopter	3	Germany
5	Airbus	3	France
6	Urban Aeronautics	2	Israel
7	Other experts in electric aerial mobility domain	7	United States, China, Japan, Germany, U.K., and India
	Total	**26**	

Source: Authors’ composition

$$\otimes A^l_{xy} = \left(\underline{\otimes} A^l_{xy}, \overline{\otimes} A^l_{xy}\right) \tag{4.1}$$

Where $1 \leq l \leq n$; $1 \leq x \leq c$; $1 \leq y \leq c$.

Step 3: Evaluate the average grey matrix

$$\otimes \check{A}_{xy} = \left(\sum_l \frac{\underline{\otimes} A^l_{xy}}{n}, \sum_l \frac{\overline{\otimes} A^l_{xy}}{n}\right) \tag{4.2}$$

Step 4: Convert average grey matrix into crisp relationship matrix

The modified-CFCS approach is applied to convert grey values into crisp values. This conversion process follows these sub-steps (Rajesh and Ravi, 2015):

(i) Lower and upper normalized values.

$$\underline{\otimes} \dot{A}_{xy} = \left(\underline{\otimes} \check{A}_{xy} - \min_y \underline{\otimes} \check{A}_{xy}\right) \Big/ \Delta^{max}_{min} \tag{4.3}$$

Where $\underline{\otimes} \dot{A}_{xy}$ denotes lower normalized limit value of the grey value $\underline{\otimes} \check{A}_{xy}$

$$\overline{\otimes} \dot{A}_{xy} = \left(\overline{\otimes} \check{A}_{xy} - \min_y \overline{\otimes} \check{A}_{xy}\right) \Big/ \Delta^{max}_{min} \tag{4.4}$$

Where $\overline{\otimes} \dot{A}_{xy}$ denotes the upper normalized limit value of the grey value $\overline{\otimes} \check{A}_{xy}$

$$\Delta^{max}_{min} = \max_y \overline{\otimes} \check{A}_{xy} - \min_y \underline{\otimes} \check{A}_{xy} \tag{4.5}$$

(ii) Compute total normalized crisp value

$$B_{xy} = \left(\left(\underline{\otimes} \dot{A}_{xy}\left(1 - \underline{\otimes} \dot{A}_{xy}\right) + \left(\frac{\overline{\otimes} \dot{A}_{xy} \times \overline{\otimes} \dot{A}_{xy})}{\left(1 - \underline{\otimes} \dot{A}_{xy} + \overline{\otimes} \dot{A}_{xy}\right)}\right)\right) \tag{4.6}$$

(iii) Compute final crisp values

$$B^*_{xy} = \left(min\, \underline{\otimes} \dot{A}_{xy} + \left(B_{xy} \times \Delta^{max}_{min}\right)\right) \tag{4.7}$$

$$\text{and } B = \left[B^*_{xy}\right] \tag{4.8}$$

Step 5: Determine normalized direct-relation matrix “N″

N is determined using eqns (4.9) and (4.10). The value of each element in N lies from 0 to 1.

$$L = \frac{1}{\max_{1 \leq x \leq c} \sum_y^c a_{xy}} \tag{4.9}$$

$$N = L^* M \tag{4.10}$$

Step 6: Obtain “T” (total relation matrix) through (4.11)

$$T = N(I - N)^{-1} \tag{4.11}$$

I represent unit matrix.

Step 7: Determine causal factors

Calculate R (rows sum) and D (columns sum) using eqns (4.12) and (4.13):

Table 3
A set of 20 sustainable adoption strategies.

Code	Sustainable adoption strategies	Description	References
SAS1	Acceptance by stakeholders	Every new technology faces the challenge of convincing stakeholders. Similar is the case with eVTOL vehicles as acceptance of stakeholders and society is not sure. For eVTOL vehicle transport to grow, this strategy needs to sustain in a long run.	Nehk et al. (2021)
SAS2	Proficient technical knowledge	The technical knowledge refers flying the eVTOL vehicles and handling them on ground. An eVTOL vehicle transport company with workforce having proficient technical knowledge will increase its sustainability in the business.	Pukhova et al. (2021)
SAS3	Laws and regulations	It is mandatory to obey laws and regulations for the foreign based firms and those who abide laws sustain in the long run.	Nehk et al. (2021)
SAS4	Environmental concerns	The eVTOL vehicle technology is said to be less pollution emitting. Hence, the companies adopting or planning to adopt eVTOL vehicle transport are expected to sustain for long.	Sahu et al. (2023); Rajendran and Srinivas (2020)
SAS5	Develop network to reduce high capital costs	The eVTOL vehicle is a new concept and it needs high capital costs for setting up infrastructure and other requirements. Hence, those who understand this fact and work accordingly will sustain in this business for long.	Marx and Manaugh (2022)
SAS6	Technological innovations to reduce operational costs	As like capital costs, operational costs are also high in case of eVTOL vehicles because it is quite costly to maintain the vehicles and infrastructure.	Eker et al. (2019)
SAS7	Adoption of effective Traffic management	If special emphasis is given on developing traffic management of the eVTOL vehicles, then hassle will be reduced. This will help in sustainability of the entire sector.	Eker et al. (2019)
SAS8	Leadership commitment	Until or unless the leadership is not ambitious, it will be difficult to achieve business sustainability. The commitment of the leadership towards growth of the business plays a major role in sustainability of the business.	Delphi survey
SAS9	Strategic focus on Research and Development	The area of research and development is vital for any company or sector in the initial years throughout the life span. Without research and development, it won't be possible to improve technical and procedural shortfalls. Research and development have direct relationship with sustainability.	Delphi survey
SAS10	Highly skilled workforce	As the eVTOL transportation is a part of aerial mobility and being a new technology, it has so many risks associated. For the smooth operations, highly skilled workforce is required because one incident can change the perception of the stakeholders and society. Therefore, this is an important sustainability strategy.	Delphi survey
SAS11	Develop supportive infrastructure	This refers to necessary operational infrastructure required for smoothing operations. Until the support infrastructure is not provided, the sustainability of this business cannot be ensured.	Rajendran and Zack (2019); Rothfeld et al. (2021)
SAS12	Safety and security	This is probably one of the most important sustainable strategies that refers to the safety and security of passengers and freight. The corporates running eVTOL vehicle transport services needs to ensure stakeholders and society on safety and security aspects. Until safety and security is not established, sustainability will remain a question mark.	Ahmed et al. (2021)
SAS13	Capacity and capability building	This strategy deals with driving range, passenger, and freight capacity of the vehicles. This is certainly going to be an important strategy that will play a crucial role in sustainability of this transport method.	Ahmed et al. (2021)
SAS14	Ease of operation, reliability, and scalability	The strategy of ease of operational performance and reliability of technology is something that the eVTOL vehicle transport companies need to imbibe and work upon. Also, this strategy is something that the companies need to market in order to attract more investors and customers.	Al Haddad et al. (2020)
SAS15	Competitive edge	Although the eVTOL vehicle technology is new but the service providing organizations have already started planning on gaining competitive edge. Once gained, this strategy can help companies sustained in the long run.	Shao et al. (2021)
SAS16	Aids and subsidies provided by the government and other organizations	The eVTOL vehicle transport will require specialized infrastructure and other facilities and for that huge investment and subsides would be required. The companies receiving funds and subsides will gain competitive edge over others and are more likely to sustain in the long run.	Delphi survey
SAS17	Technological adoption for low noise	The noise emission is a prominent issue in the transport sector, and this can be tackled with the use of eVTOL vehicles especially in the urban areas. This is one major reason for the eVTOL vehicles to gain prominence.	Higgins et al. (2021)
SAS18	Global influence	The leading countries doing research on the viability and sustainability of the eVTOL vehicle transportation are becoming motivation for those who are yet to plan this revolutionary mode of transport.	Delphi survey
SAS19	Organizational readiness	This strategy deals with how prepared an organization is to commence eVTOL vehicle operations commercially. The organizational readiness should be checked before initiating each trip. This should be done to ensure hassle free operations.	Mofolasayo (2020)
SAS20	Strategies to counter cybercrime related activities	As we know that modern technologies are vulnerable to hacking so the eVTOL vehicle operators must brace themselves to tackle any such situation, if arises. This is probably the most discussed concern these days especially after few such incidents in the passenger and freight transport sector.	Delphi survey

Source: Authors' composition

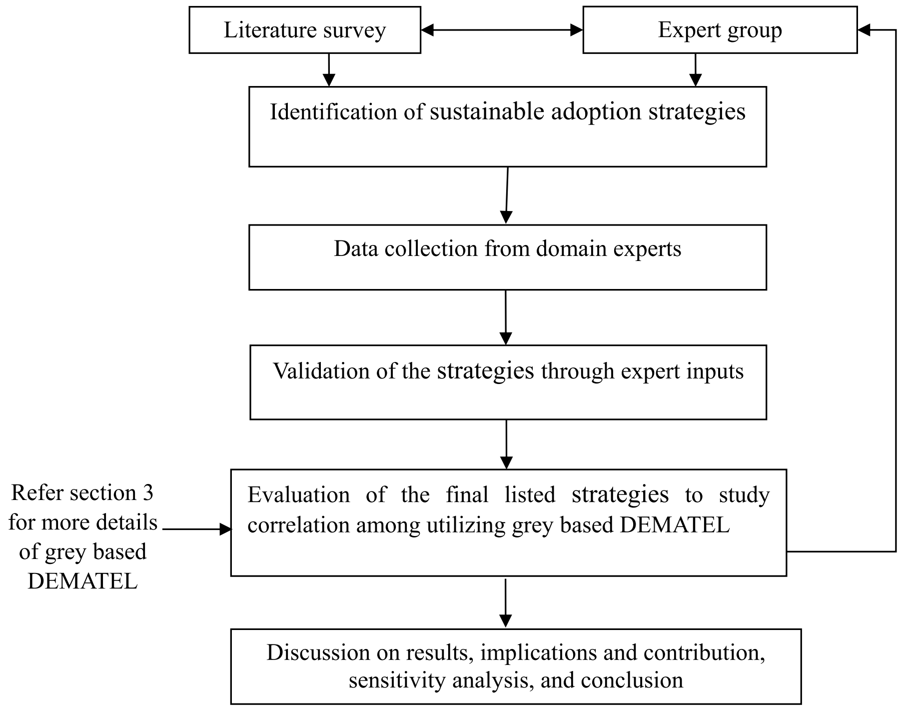

Fig. 1. Stage-wise structure of the study.

Table 4
Evaluation criteria and respective grey numbers.

Criteria of assessment	respective grey scale	specific values
No effect (N)	(0.0, 0.1)	0
Very low effect (VL)	(0.1, 0.3)	1
Low effect (L)	(0.2, 0.5)	2
Medium effect(M)	(0.4, 0.7)	3
High effect (H)	(0.6, 0.9)	3
Very high effect (VH)	(0.9, 1.0)	5

Source: adopted from Garg (2021).

$$R = \left[\sum_{y=1}^{c} a_{xy}\right]_{c\times 1} \tag{4.12}$$

$$D = \left[\sum_{y=1}^{c} a_{xy}\right]_{1\times c} \tag{4.13}$$

Step 8: Draw diagraph

Average values of set (R + D, R-D) denote cause-effect diagram.

This study employs the Grey-DEMATEL (Decision-Making Trial and Evaluation Laboratory) methodology as its primary analytical tool, chosen based on two key considerations: the nature of the research problem and the desired outcomes of the analysis. The study is driven by two main objectives: (1) to identify the influential sustainable adoption strategies for eVTOL vehicles in the Shared Passenger and Freight Transportation System, and (2) to evaluate the strength and direction of influence among these strategies. The Grey-DEMATEL approach is particularly suitable for this analysis, as it enables the conversion of complex interdependencies among sustainable adoption strategies into a structured cause-and-effect model through matrix-based computations. This methodology not only categorizes the strategies into cause and effect groups but also identifies critical strategies within the complex system using an impact-relation diagram. By applying a grey-based enhancement to the traditional DEMATEL, this study offers a nuanced assessment of sustainable adoption strategies, emphasizing both the relational dependencies and the strength of influence among strategies.

The methodology examines the interrelationships and influence forces among the strategies. The resulting cause-and-effect diagram highlights the primary causal factors, allowing decision-makers to identify which strategies have the strongest impact and the highest level of interdependence within the system. These causal strategies, identified as "decisive strategies," are essential for informed decision-making as they exert significant influence on other strategies. Conversely, the effect group consists of strategies that are highly significant but exhibit low levels of influence on other factors; they are primarily influenced by the causal strategies and may not be directly actionable in isolation (Garg, 2020; Rajesh and Ravi, 2015). Compared to other multi-criteria decision-making (MCDM) methods such as TOPSIS, VIKOR, AHP, and BWM, the Grey-DEMATEL approach offers superior insights into the intricate interdependencies within the system, making it an ideal choice for quantifying the mutual impacts among strategies (Raghuvanshi and Garg, 2022). This structured approach allows the decision-making team to prioritize and implement sustainable adoption strategies based on their dominant influence over other strategies within the framework. A key advantage of this integrated grey-based DEMATEL method is its ability to reduce human subjectivity and bias, which is often a limitation in classical DEMATEL applications. The literature review further supports the applicability of the Grey-DEMATEL methodology across various decision-making domains, highlighting the benefits of its integration for analyzing complex interdependencies (Rawat and Garg, 2023; Garg, 2021). Consequently, the Grey-DEMATEL approach proves to be a highly applicable and valuable tool for examining interconnected relationships within a complex system, ranking strategies for long-term strategic decision-making, and identifying areas for improvement (Kashav et al. (2023); Kashav et al. (2022); Garg and Kashav, 2019; Kashav et al. (2023); Kashav et al. (2022); Mahtani and Garg, 2018; Jia and Cui, 2021).

5. An exemplary application of proposed model

The discussion of the above proposed model which is applied to the case company is given below-

Step 1: The expert team consist of 26 domain specialists as discussed above to examine sustainable adoption strategies. These selected domain specialists have more than ten years of working experience. These mid and senior level experts were interviewed to get the feedback. The experts' panel finalized 20 strategies for sustainable adoption of eVTOL vehicles for transporting passengers and freight, simultaneously. Overall, all the specialists agreed with the given list and confirmed to disallow any other addition. They used assessment scale to analyze the effect of one strategy over other.

Step 2: Initially specific grey relationship matrices are constructed as per ratings given in Table 4 considering each expert inputs. Taking inputs of expert group 1, grey relationship matrix is developed as highlighted in Table 5.

Step 3: All experts have assigned equal weightages to bring consistency in decision making. Then mean grey matrix $\left[\otimes \check{A}_{xy}\right]$ is calculated using Eq. (4.2) which represents through Table 6.

Step 4: The crisp relation matrix B was constructed from average grey relation matrix using CFCS method and used Eqs. (4.3)–(4.8) is shown in Table 7.

Step 5: Normalized direct relation matrix (N) was constructed using Eqs. (4.9) and (4.10) which is given in Table 8.

Step 6: Then total relation matrix T is obtained using Eq. (4.11), is shown in Table 9.

Step 7: Let R and D defined to be 20×1 and 1×20 vectors representing sum of row elements and sum of column elements for the total relation matrix T, respectively. Using eqs (4.12) and (4.13). R summarizes both direct and indirect effects given by factor x towards other factors and D summarizes both direct and indirect effects received by factor y from other factors. The cause-and-effect parameters (R + D) and (R-D) were computed from the total relation matrix for values x = y, which is presented in Table 10. To show the net effect and correlation among all the factors and in the sets, a causal and effect diagram is developed (Please see Fig. 2). The relationships among factors are shown through arrows in digraphs (Fig. 2). Threshold value (α) has been fixed to sort out number of relationships which have higher value than α. The threshold value is calculated by adding one standard deviation to the mean. In this case, α is 0.11868 i.e. (0.07885 + 0.03983). All the relationships meeting or exceeding the threshold value are highlighted in the Total relationship matrix (T). Further, the relationships among factors are plotted as shown in Fig. 2 (see Table 2).

6. Results and discussions

This study identified a total of 20 sustainable adoption strategies for shared passenger and freight mobility using eVTOL vehicles. By employing the grey-DEMATEL method, the strategies are divided into two groups (as demonstrated in Fig. 2 and Table 10), providing valuable insights to stakeholders. The proposed sustainable adoption strategies are assessed using the grey-DEMATEL method to determine the cause-and-effect relationships. The results obtained are discussed below.

6.1. Cause group

The cause-and-effect diagram demonstrates the causes that need to be examined to identify which prospective strategies are critical and, therefore, must be adopted by industry stakeholders. The strategies that fall into the cause group play a crucial role in the sustainable adoption of eVTOL vehicles. In the analysis, 15 strategies fall into the cause group. These fifteen cause strategies were ranked according to their R-D values (refer to Table 10), based on their prominence and consequences for other strategies. The rank sequence of these fifteen cause group strategies is as follows: SAS1 (Acceptance by stakeholders) > SAS16 (Aids and subsidies provided by the government and other organizations) > SAS2 (Proficient technical knowledge) > SAS17 (Low noise pollution) > SAS7 (Traffic management) > SAS8 (Leadership commitment) > SAS18 (Global influence) > SAS10 (Highly skilled workforce) > SAS20 (International collaborations) > SAS6 (High operational costs) > SAS12 (Safety and security) > SAS9 (Research and Development) > SAS19 (Organizational readiness) > SAS4 (Environmental concerns) > SAS3 (Laws and regulations). Out of the 15 strategies in the cause group, SAS1, i.e., 'Acceptance by stakeholders,' is identified as the most critical strategy (as it holds the top rank) with the highest R-D value of 0.6842. In this context, stakeholders include customers, business partners, and investors. While eVTOL technology for shared passenger and freight transport is compelling, its acceptance depends on stakeholders' potential for monetary profit and customer value. Studies by Shepherd et al. (2012) and Rese and Baier (2020) highlight that customer optimism is vital for the success of any technology. Interestingly, older populations, typically more skeptical about new technologies, show a higher acceptance rate for flying vehicles (Behme and Planing, 2020). However, stakeholders often resist new technologies until they are thoroughly tested. Thus, successful demonstrations of eVTOL for shared transportation could enhance stakeholder acceptance (Astfalk et al., 2021). Further, the prominence of SAS1 was also confirmed by one of the domain experts in the Delphi panel, who stated.

> *"Stakeholder acceptance and usage levels are likely the foremost considerations in any process or technology. While stakeholders prioritize their acceptance and seek to understand the preparedness for the next generation of eVTOL vehicles, public acceptance may take longer."*

Thereafter, SAS16, i.e., 'Aids and subsidies provided by the government and other organizations,' with an R-D score of 0.6004, became the second most crucial sustainable adoption strategy. It is vital for governments to financially support new technological advancements through subsidies and aid to ensure their prominence across sectors. A study by Lin et al. (2020) indicates that reducing aerial vehicle transportation costs per mile is feasible only with government backing. Chen et al. (2020) noted that subsidies are being offered to entities developing eVTOL vehicles in China due to the technology's broad applications. Similarly, Shin (2020) emphasized that subsidies and other forms of temporary monetary support should be provided during the initial stages of business development. Government financial support will not only strengthen existing facilities but also attract foreign direct investments in this domain. The prominence of SAS16 was also confirmed by one of the domain experts in the Delphi panel, who stated.

> *"To promote the acceptance of new technological advancements, governments are examining various proposals for effective subsidy policies. By providing investment subsidies, they can reduce firms' costs and alleviate the financial burden on end users. Consequently, the strategy of subsidies and aid has secured the second rank."*

Moving further, SAS2, i.e., 'Proficient technical knowledge,' earned an R-D score of 0.5052, indicating that SAS2 is the third most critical sustainable adoption strategy. Any new technology strictly requires technical experts to periodically evaluate its performance. This is why Nakamura and Kajikawa (2018) emphasized that sound technical knowledge is a must for the smooth functioning of aerial vehicles. Sound technical knowledge also includes an understanding of weather conditions and skills such as emergency maneuvers and safe landings in case of a GPS system failure. In fact, aerial vehicles are being utilized for socio-economic purposes and are increasingly recognized as technical components of socio-economic development. Unfortunately, no study specifically addresses the requirement for proficient technical knowledge to ensure the sustainability of eVTOL mobility. Furthermore, the prominence of SAS2 was confirmed by one of the domain experts on the Delphi panel, who stated:

Table 5
Grey relationship matrix of SAS by group 1.

	SAS1	SAS2	SAS3	SAS4	SAS5	SAS6	SAS7	SAS8	SAS 9	SAS10	SAS11	SAS12	SAS13	SAS14	SAS15	SAS16	SAS17	SAS18	SAS19	SAS20
SAS1	(0,0.1)	(0.2,0.5)	(0.4,0.7)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)	(0.4,0.7)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)	(0.6,0.9)	(0.2,0.5)	(0.4,0.7)	(0.2,0.5)	(0.2,0.5)	(0,0.1)	(0.2,0.5)	(0.4,0.7)	(0.2,0.5)	(0.2,0.5)
SAS2	(0.2,0.5)	(0,0.1)	(0.4,0.7)	(0.2,0.5)	(0.4,0.7)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)	(0.1,0.3)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)	(0.4,0.7)	(0.2,0.5)	(0.4,0.7)	(0.2,0.5)	(0,0.1)	(0.4,0.7)	(0.2,0.5)	(0.2,0.5)
SAS3	(0.2,0.5)	(0.2,0.5)	(0,0.1)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)	(0.1,0.3)	(0.1,0.3)	(0.4,0.7)	(0.2,0.5)	(0.4,0.7)	(0.2,0.5)	(0.4,0.7)	(0.2,0.5)	(0.2,0.5)	(0,0.1)	(0.2,0.5)	(0.2,0.5)
SAS4	(0.1,0.3)	(0.1,0.3)	(0.2,0.5)	(0,0.1)	(0.2,0.5)	(0.2,0.5)	(0.4,0.7)	(0.1,0.3)	(0.4,0.7)	(0.1,0.3)	(0.4,0.7)	(0.1,0.3)	(0.2,0.5)	(0.4,0.7)	(0.2,0.5)	(0.1,0.3)	(0.1,0.3)	(0.2,0.5)	(0,0.1)	(0.2,0.5)
SAS5	(0.1,0.3)	(0.2,0.5)	(0.2,0.5)	(0.1,0.3)	(0,0.1)	(0.2,0.5)	(0.2,0.5)	(0.1,0.3)	(0.2,0.5)	(0.1,0.3)	(0.4,0.7)	(0.1,0.3)	(0.4,0.7)	(0.2,0.5)	(0.4,0.7)	(0.1,0.3)	(0.2,0.5)	(0.2,0.5)	(0.1,0.3)	(0.2,0.5)
SAS6	(0.2,0.5)	(0.1,0.3)	(0.1,0.3)	(0.2,0.5)	(0.2,0.5)	(0,0.1)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)	(0.6,0.9)	(0.2,0.5)	(0.6,0.9)	(0.4,0.7)	(0.6,0.9)	(0.2,0.5)	(0.1,0.3)	(0.1,0.3)	(0.2,0.5)	(0.2,0.5)
SAS7	(0.2,0.5)	(0.1,0.3)	(0.2,0.5)	(0.2,0.5)	(0.4,0.7)	(0.1,0.3)	(0,0.1)	(0.4,0.7)	(0.2,0.5)	(0.4,0.7)	(0.6,0.9)	(0.4,0.7)	(0.4,0.7)	(0.4,0.7)	(0.4,0.7)	(0.2,0.5)	(0.1,0.3)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)
SAS8	(0.1,0.3)	(0.1,0.3)	(0.1,0.3)	(0.1,0.3)	(0.2,0.5)	(0.4,0.7)	(0.4,0.7)	(0,0.1)	(0.1,0.3)	(0.4,0.7)	(0.6,0.9)	(0.2,0.5)	(0.6,0.9)	(0.4,0.7)	(0.4,0.7)	(0.1,0.3)	(0.1,0.3)	(0.1,0.3)	(0.1,0.3)	(0.2,0.5)
SAS9	(0.1,0.3)	(0.1,0.3)	(0.2,0.5)	(0.1,0.3)	(0.4,0.7)	(0.2,0.5)	(0.1,0.3)	(0.1,0.3)	(0,0.1)	(0.6,0.9)	(0.4,0.7)	(0.1,0.3)	(0.6,0.9)	(0.6,0.9)	(0.4,0.7)	(0.1,0.3)	(0.2,0.5)	(0.2,0.5)	(0.1,0.3)	(0.1,0.3)
SAS10	(0.1,0.3)	(0.1,0.3)	(0.2,0.5)	(0.2,0.5)	(0.4,0.7)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)	(0.6,0.9)	(0,0.1)	(0.4,0.7)	(0.1,0.3)	(0.4,0.7)	(0.2,0.5)	(0.6,0.9)	(0.1,0.3)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)
SAS11	(0,0.1)	(0.1,0.3)	(0.1,0.3)	(0.2,0.5)	(0.4,0.7)	(0.1,0.3)	(0.2,0.5)	(0.2,0.5)	(0.1,0.3)	(0.2,0.5)	(0,0.1)	(0.2,0.5)	(0.6,0.9)	(0.4,0.7)	(0.4,0.7)	(0,0.1)	(0.1,0.3)	(0.1,0.3)	(0.2,0.5)	(0.2,0.5)
SAS12	(0.2,0.5)	(0.2,0.5)	(0.1,0.3)	(0.1,0.3)	(0.2,0.5)	(0.2,0.5)	(0,0.1)	(0.2,0.5)	(0.1,0.3)	(0.2,0.5)	(0.6,0.9)	(0,0.1)	(0.6,0.9)	(0.6,0.9)	(0.4,0.7)	(0.2,0.5)	(0.2,0.5)	(0.1,0.3)	(0.1,0.3)	(0,0.1)
SAS13	(0,0.1)	(0.1,0.3)	(0.1,0.3)	(0.1,0.3)	(0.2,0.5)	(0.1,0.3)	(0.2,0.5)	(0.1,0.3)	(0.2,0.5)	(0.1,0.3)	(0.4,0.7)	(0.1,0.3)	(0,0.1)	(0.4,0.7)	(0.4,0.7)	(0,0.1)	(0.1,0.3)	(0.1,0.3)	(0.1,0.3)	(0.2,0.5)
SAS14	(0.1,0.3)	(0.1,0.3)	(0.1,0.3)	(0.1,0.3)	(0.1,0.3)	(0.1,0.3)	(0.1,0.3)	(0.2,0.5)	(0.1,0.3)	(0.1,0.3)	(0.2,0.5)	(0.1,0.3)	(0.4,0.7)	(0,0.1)	(0.4,0.7)	(0.1,0.3)	(0.2,0.5)	(0.1,0.3)	(0.1,0.3)	(0.1,0.3)
SAS15	(0,0.1)	(0.1,0.3)	(0.1,0.3)	(0.2,0.5)	(0.1,0.3)	(0.1,0.3)	(0.2,0.5)	(0,0.1)	(0.2,0.5)	(0.1,0.3)	(0.2,0.5)	(0.1,0.3)	(0.2,0.5)	(0.4,0.7)	(0,0.1)	(0.1,0.3)	(0.1,0.3)	(0.1,0.3)	(0.2,0.5)	(0.1,0.3)
SAS16	(0,0.1)	(0.2,0.5)	(0.4,0.7)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)	(0.4,0.7)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)	(0.4,0.7)	(0.4,0.7)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)	(0,0.1)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)
SAS17	(0.2,0.5)	(0,0.1)	(0.4,0.7)	(0.2,0.5)	(0.4,0.7)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)	(0.1,0.3)	(0.2,0.5)	(0.2,0.5)	(0.4,0.7)	(0.2,0.5)	(0.2,0.5)	(0.4,0.7)	(0.1,0.3)	(0,0.1)	(0.1,0.3)	(0.2,0.5)	(0.1,0.3)
SAS18	(0.2,0.5)	(0.2,0.5)	(0,0.1)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)	(0.2,0.5)	(0.1,0.3)	(0.1,0.3)	(0.4,0.7)	(0.2,0.5)	(0.4,0.7)	(0.2,0.5)	(0.4,0.7)	(0.2,0.5)	(0.4,0.7)	(0,0.1)	(0.1,0.3)	(0.4,0.7)
SAS19	(0.1,0.3)	(0.1,0.3)	(0.2,0.5)	(0,0.1)	(0.2,0.5)	(0.2,0.5)	(0.4,0.7)	(0.1,0.3)	(0.4,0.7)	(0.1,0.3)	(0.4,0.7)	(0.1,0.3)	(0.2,0.5)	(0.4,0.7)	(0.2,0.5)	(0.2,0.5)	(0.1,0.3)	(0.1,0.3)	(0,0.1)	(0.4,0.7)
SAS20	(0.1,0.3)	(0.2,0.5)	(0.2,0.5)	(0.4,0.7)	(0.4,0.7)	(0.4,0.7)	(0.2,0.5)	(0.1,0.3)	(0.2,0.5)	(0.1,0.3)	(0.4,0.7)	(0.1,0.3)	(0.4,0.7)	(0.2,0.5)	(0.4,0.7)	(0.1,0.3)	(0.2,0.5)	(0.2,0.5)	(0.4,0.7)	(0,0.1)

The level of influence of strategy x the over the strategy y is represented as grey value $\left(\underline{\otimes}A_{xy}^{l}, \overline{\otimes}A_{xy}^{l}\right)$

"eVTOL is an emerging technology with applications in various sectors, including shared passenger and freight transportation. While it is not yet used commercially, eVTOL vehicles are expected to enter commercial use soon. There is a significant need for comprehensive technical knowledge to manage eVTOL traffic effectively. Consequently, there will be a high demand for individuals with the technical expertise to operate eVTOL vehicles, both in the air and on the ground."

Furthermore, SAS17, i.e., "Low noise," is ranked fourth, as the R-D score obtained by SAS17 is 0.4331. Aerial vehicles are gaining significance as this technology promotes low noise and vibration (Garg et al., 2023; Pan et al., 2019). Torija and Clark (2021) examined human responses to understand the impact of these low-noise aerial vehicles on users' lives. Additionally, Torija et al. (2021) noted that efforts are underway to develop quieter aerial vehicles. To address noise issues, Qian et al. (2021) conducted a technical investigation into noise reduction in aerial vehicles. The prominence of SAS17 was also confirmed by one of the domain experts in the Delphi panel, who stated.

"Noise emission is a major concern for the transport sector globally. If eVTOL vehicles can effectively reduce noise pollution, they will significantly contribute to their success, helping make densely populated cities quieter. While air pollution is often discussed, noise pollution and its harmful effects are frequently overlooked."

Going further, SAS7, i.e., "Traffic management," is the fifth-ranked sustainable adoption strategy, with an R-D score of 0.3969. Before eVTOL vehicles can fly commercially, an effective traffic management system must be established. Shvetsov and Shvetsova (2021) noted that current aerial vehicle traffic management programs lack solutions for preventing uncontrolled flight path deviations, raising safety concerns for passengers and freight. Therefore, eVTOL vehicles cannot be deployed until adequate traffic management and safety measures are in place. Currently, no studies examine traffic management solutions for shared passenger and freight transportation in eVTOL systems. The prominence of SAS7 was also confirmed by one of the domain experts in the Delphi panel, who stated:

"Traffic management is crucial for the successful commercialization of this technology. Inefficient traffic management can result in delays, accidents, and significant disruptions. Managing a combined system for transporting passengers and freight will be more challenging than traditional methods. Therefore, special attention must be given to developing a traffic management system tailored for shared eVTOL transportation."

Thereafter, SAS8, i.e., "Leadership commitment," secured the sixth rank in the analysis with an R-D score of 0.3624. Without strong leadership commitment, no initiative can gain momentum or achieve significant milestones. Strong leadership is not only essential for establishing a business but also plays a pivotal role in scaling it to the next level. The eVTOL technology can only gain momentum if senior leadership remains dedicated throughout the adoption process. Further, SAS18, i.e., "Global influence," attained the seventh rank in the analysis with an R-D score of 0.3327. Global influence is always impactful, and examples of such frameworks provide perspective on the responsibilities that global influence entails. The global influence scenario acts as a motivation for developing and underdeveloped countries to adopt new technologies or processes. Similarly, SAS10, i.e., "Highly skilled workforce," is ranked eighth with an R-D score of 0.3167. Actors involved in shared passenger and freight transportation using eVTOL mobility will require highly skilled professionals capable of operating and maintaining these aerial vehicles. Additionally, there will be a high demand for individuals who can integrate machine learning and artificial intelligence with eVTOL technology. The unavailability of a highly skilled workforce will delay the adoption and implementation of this concept, which is why SAS10 demands immediate attention. Moving on, SAS20, i.e., "Strategies to counter cybercrime-related activities," obtained the ninth rank with an R-D score of 0.2655. Cybercrimes have increased in

Table 6
Average grey relationship matrix of SAS.

	SAS1	SAS2	SAS3	SAS4	SAS5	SAS6	SAS7	SAS8	SAS 9	SAS10	SAS11	SAS12	SAS13	SAS14	SAS15	SAS16	SAS17	SAS18	SAS19	SAS20
SAS1	(0, 0.1)	(0.18, 0.45)	(0.4, 0.7	(0.2, 0.5)	(0.2, 0.5)	(0.2, 0.5)	(0.4, 0.7)	(0.2, 0.5)	(0.2, 0.5)	(0.2, 0.5)	(0.35, 0.65)	(0.3, 0.6)	(0.25, 0.55)	(0.25, 0.55)	(0.2, 0.5)	(0.05, 0.2)	(0.13, 0.35)	(0.3, 0.6)	(0.18, 0.45)	(0.25, 0.55)
SAS2	(0.18, 0.45)	(0, 0.1)	(0.35, 0.65)	(0.18, 0.45)	(0.4, 0.7)	(0.2, 0.5)	(0.18, 0.45)	(0.18, 0.45)	(0.13, 0.35)	(0.18, 0.45)	(0.25, 0.55)	(0.3, 0.6)	(0.4, 0.7)	(0.2, 0.5)	(0.4, 0.7)	(0.18, 0.45)	(0.03, 0.15)	(0.25, 0.5)	(0.2, 0.5)	(0.3, 0.6)
SAS3	(0.18, 0.45)	(0.2, 0.5)	(0, 0.1)	(0.2, 0.5)	(0.18, 0.45)	(0.18, 0.45)	(0.2, 0.5)	(0.2, 0.5)	(0.1, 0.3)	(0.1, 0.3)	(0.4, 0.7)	(0.2, 0.5)	(0.4, 0.7)	(0.2, 0.5)	(0.4, 0.7)	(0.15, 0.4)	(0.18, 0.45)	(0.05, 0.2)	(0.15, 0.4)	(0.2, 0.5)
SAS4	(0.13, 0.35)	(0.13, 0.35)	(0.2, 0.5)	(0, 0.1)	(0.2, 0.5)	(0.2, 0.5)	(0.4, 0.7)	(0.1, 0.3)	(0.4, 0.7)	(0.1, 0.3)	(0.4, 0.7)	(0.1, 0.3)	(0.2, 0.5)	(0.4, 0.7)	(0.2, 0.5)	(0.13, 0.35)	(0.13, 0.35)	(0.2, 0.5)	(0, 0.1)	(0.15, 0.4)
SAS5	(0.1, 0.3)	(0.2, 0.5)	(0.2, 0.5)	(0.1, 0.3)	(0, 0.1)	(0.2, 0.5)	(0.18, 0.45)	(0.13, 0.35)	(0.2, 0.5)	(0.13, 0.35)	(0.4, 0.7)	(0.13, 0.35)	(0.4, 0.7)	(0.2, 0.5)	(0.4, 0.7)	(0.1, 0.3)	(0.18, 0.45)	(0.2, 0.5)	(0.13, 0.35)	(0.25, 0.55)
SAS6	(0.18, 0.45)	(0.1, 0.3)	(0.1, 0.3)	(0.18, 0.45)	(0.2, 0.5)	(0, 0.1)	(0.2, 0.5)	(0.2, 0.5)	(0.18, 0.45)	(0.2, 0.5)	(0.6, 0.9)	(0.2, 0.5)	(0.6, 0.9)	(0.4, 0.7)	(0.6, 0.9)	(0.2, 0.5)	(0.1, 0.3)	(0.1, 0.3)	(0.2, 0.5)	(0.18, 0.45)
SAS7	(0.2, 0.5)	(0.13, 0.35)	(0.20, 0.5)	(0.2, 0.5)	(0.4, 0.7)	(0.4, 0.7)	(0, 0.1)	(0.4, 0.7)	(0.2, 0.5)	(0.4, 0.7)	(0.6, 0.9)	(0.4, 0.7)	(0.4, 0.7)	(0.4, 0.7)	(0.4, 0.7)	(0.2, 0.5)	(0.13, 0.35)	(0.2, 0.5)	(0.18, 0.45)	(0.2, 0.5)
SAS8	(0.13, 0.35)	(0.1, 0.3)	(0.1, 0.3)	(0.1, 0.3)	(0.2, 0.5)	(0.2, 0.5)	(0.4, 0.7)	(0, 0.1)	(0.15, 0.35)	(0.4, 0.7)	(0.6, 0.9)	(0.2, 0.5)	(0.6, 0.9)	(0.4, 0.7)	(0.4, 0.7)	(0.1, 0.3)	(0.13, 0.35)	(0.13, 0.35)	(0.1, 0.3)	(0.2, 0.5)
SAS9	(0.1, 0.3)	(0.1, 0.3)	(0.20, 0.5)	(0.13, 0.35)	(0.4, 0.7)	(0.2, 0.5)	(0.1, 0.3)	(0.15, 0.4)	(0, 0.1)	(0.55, 0.85)	(0.4, 0.7)	(0.1, 0.3)	(0.6, 0.9)	(0.6, 0.9)	(0.4, 0.7)	(0.13, 0.35)	(0.13, 0.35)	(0.15, 0.35)	(0.13, 0.35)	(0.08, 0.25)
SAS10	(0.13, 0.35)	(0.13, 0.35)	(0.2, 0.5)	(0.2, 0.5)	(0.4, 0.7)	(0.1, 0.3)	(0.2, 0.5)	(0.2, 0.5)	(0.5, 0.8)	(0, 0.1)	(0.4, 0.7)	(0.1, 0.3)	(0.4, 0.7)	(0.2, 0.5)	(0.6, 0.9)	(0.1, 0.3)	(0.15, 0.35)	(0.2, 0.5)	(0.18, 0.45)	(0.2, 0.5)
SAS11	(0, 0.1)	(0.13, 0.35)	(0.1, 0.3)	(0.18, 0.45)	(0.4, 0.7)	(0.13, 0.35)	(0.18, 0.45)	(0.18, 0.45)	(0.13, 0.35)	(0.2, 0.5)	(0, 0.1)	(0.2, 0.5)	(0.6, 0.9)	(0.4, 0.7)	(0.4, 0.7)	(0.03, 0.15)	(0.1, 0.3)	(0.1, 0.3)	(0.18, 0.45)	(0.18, 0.45)
SAS12	(0.18, 0.45)	(0.2, o.5)	(0.13, 0.35)	(0.1, 0.3)	(0.2, 0.5)	(0.2, 0.5)	(0, 0.1)	(0.2, 0.5)	(0.1, 0.3)	(0.2, 0.5)	(0.6, 0.9)	(0, 0.1)	(0.6, 0.9)	(0.6, 0.9)	(0.5, 0.8)	(0.2, 0.5)	(0.2, 0.5)	(0.13, 0.35)	(0.1, 0.3)	(0, 0.1)
SAS13	(0, 0.1)	(0.1, 0.3)	(0.1, 0.3)	(0.1, 0.3)	(0.2, 0.5)	(0.1, 0.3)	(0.2, 0.5)	(0.1, 0.3)	(0.2, 0.5)	(0.1, 0.3)	(0.3, 0.6)	(0.1, 0.3)	(0, 0.1)	(0.35, 0.65)	(0.35, 0.65)	(0.05, 0.2)	(0.13, 0.35)	(0.13, 0.35)	(0.1, 0.3)	(0.18, 0.45)
SAS14	(0.13, 0.35)	(0.15, 0.35)	(0.13, 0.35)	(0.13, 0.35)	(0.13, 0.35)	(0.13, 0.35)	(0.1, 0.3)	(0.2, 0.5)	(0.1, 0.3)	(0.13, 0.35)	(0.2, 0.5)	(0.1, 0.3)	(0.35, 0.65)	(0, 0.1)	(0.35, 0.65)	(0.13, 0.35)	(0.25, 0.55)	(0.1, 0.3)	(0.18, 0.45)	(0.1, 0.3)
SAS15	(0.1, 0.25)	(0.1, 0.3)	(0.1, 0.3)	(0.2, 0.5)	(0.1, 0.3)	(0.1, 0.3)	(0.2, 0.5)	(0, 0.1)	(0.2, 0.5)	(0.1, 0.3)	(0.25, 0.55)	(0.1, 0.3)	(0.3, 0.6)	(0.4, 0.7)	(0, 0.1)	(0.13, 0.35)	(0.13, 0.35)	(0.1, 0.3)	(0.2, 0.5)	(0.1, 0.3)
SAS16	(0.03, 0.15)	(0.18, 0.45)	(0.3, 0.6)	(0.18, 0.45)	(0.2, 0.5)	(0.2, 0.5)	(0.4, 0.7)	(0.2, 0.5)	(0.2, 0.5)	(0.2, 0.5)	(0.3, 0.6)	(0.4, 0.7)	(0.25, 0.55)	(0.3, 0.6)	(0.25, 0.55)	(0, 0.1)	(0.2, 0.5)	(0.25, 0.55)	(0.18, 0.45)	(0.18, 0.45)
SAS17	(0.18, 0.45)	(0, 0.1)	(0.3, 0.6)	(0.2, 0.5)	(0.4, 0.7)	(0.2, 0.5)	(0.2, 0.5)	(0.2, 0.5)	(0.1, 0.3)	(0.2, 0.5)	(0.3, 0.6)	(0.4, 0.7)	0.35, 0.65)	(0.2, 0.5)	(0.4, 0.7)	(0.15, 0.35)	(0, 0.1)	(0.18, 0.45)	(0.25, 0.55)	(0.18, 0.45)
SAS18	(0.18, 0.45)	(0.18, 0.45)	(0.03, 0.15)	(0.2, 0.5)	(0.2, 0.5)	(0.2, 0.5)	(0.2, 0.5)	(0.2, 0.5)	(0.1, 0.3)	(0.1, 0.3)	(0.4, 0.7)	(0.2, 0.5)	(0.4, 0.7)	(0.2, 0.5)	(0.4, 0.7)	(0.2, 0.5)	(0.3, 0.6)	(0, 0.1)	(0.15, 0.4)	(0.25, 0.55)
SAS19	(0.1, 0.3)	(0.1, 0.3)	(0.2, 0.5)	(0.03, 0.15)	(0.2, 0.5)	(0.2, 0.5)	(0.4, 0.7)	(0.1, 0.3)	(0.4, 0.7)	(0.1, 0.3)	(0.4, 0.7)	(0.1, 0.3)	(0.2, 0.5)	(0.4, 0.7)	(0.2, 0.5)	(0.13, 0.35)	(0.13, 0.35)	(0.15, 0.35)	(0, 0.1)	(0.35, 0.65)
SAS20	(0.1, 0.3)	(0.2, 0.5)	(0.2, 0.5)	(0.4, 0.7)	(0.4, 0.7)	(0.4, 0.7)	(0.2, 0.5)	(0.1, 0.3)	(0.2, 0.5)	(0.1, 0.3)	(0.4, 0.7)	(0.1, 0.3)	(0.4, 0.7)	(0.2, 0.5)	(0.4, 0.7)	(0.1, 0.3)	(0.15, 0.35)	(0.18, 0.45)	(0.35, 0.6)	(0, 0.1)

The level of influence of strategy x the over the strategy y is represented as grey value $\left(\underline{\otimes}A^{l}_{xy}, \overline{\otimes}A^{l}_{xy}\right)$

Table 7
Crisp relationship matrix of SAS.

	SAS1	SAS2	SAS3	SAS4	SAS5	SAS6	SAS7	SAS8	SAS9	SAS10	SAS11	SAS12	SAS13	SAS14	SAS15	SAS16	SAS17	SAS18	SAS19	SAS20
SAS1	0.0000	0.2815	0.5500	0.3000	0.3000	0.3000	0.5500	0.3000	0.2889	0.2842	0.4600	0.4250	0.3400	0.3400	0.2800	0.0611	0.1750	0.4429	0.2657	0.3700
SAS2	0.2815	0.0000	0.4875	0.2540	0.5500	0.3000	0.2540	0.2540	0.1629	0.2412	0.3400	0.4250	0.5200	0.2800	0.5200	0.2815	0.0274	0.3423	0.3143	0.4333
SAS3	0.2815	0.3333	0.0000	0.3000	0.2540	0.2540	0.3000	0.3000	0.1250	0.1235	0.5200	0.3000	0.5200	0.2800	0.5200	0.2318	0.2657	0.0591	0.2192	0.3067
SAS4	0.1845	0.1845	0.3000	0.0000	0.3000	0.3000	0.5500	0.1286	0.5333	0.1235	0.5200	0.1286	0.2800	0.5200	0.2800	0.1845	0.1750	0.3143	0.0000	0.2143
SAS5	0.1400	0.3333	0.3000	0.1286	0.0000	0.3000	0.2540	0.1472	0.2889	0.1607	0.5200	0.1681	0.5200	0.2800	0.5200	0.1400	0.2657	0.3143	0.1750	0.3700
SAS6	0.2815	0.1400	0.1286	0.2540	0.3000	0.0000	0.3000	0.3000	0.2450	0.2842	0.7600	0.3000	0.7600	0.5200	0.7600	0.3333	0.1333	0.1333	0.3143	0.2595
SAS7	0.3333	0.1845	0.3000	0.3000	0.5500	0.5500	0.0000	0.5500	0.2889	0.5263	0.7600	0.5500	0.5200	0.5200	0.5200	0.3333	0.1750	0.3143	0.2657	0.3067
SAS8	0.1845	0.1400	0.1286	0.1286	0.3000	0.3000	0.5500	0.0000	0.2029	0.5263	0.7600	0.3000	0.7600	0.5200	0.5200	0.1400	0.1750	0.1750	0.1333	0.3067
SAS9	0.1400	0.1400	0.3000	0.1681	0.5500	0.3000	0.1286	0.2100	0.0000	0.7079	0.5200	0.1286	0.7600	0.7600	0.5200	0.1845	0.1750	0.2192	0.1750	0.0930
SAS10	0.1845	0.1845	0.3000	0.3000	0.5500	0.1286	0.3000	0.3000	0.6556	0.0000	0.5200	0.1286	0.5200	0.2800	0.7600	0.1400	0.2192	0.3143	0.2657	0.3067
SAS11	0.0000	0.1845	0.1286	0.2540	0.5500	0.1681	0.2540	0.2540	0.1629	0.2842	0.0000	0.3000	0.7600	0.5200	0.5200	0.0279	0.1333	0.1333	0.2657	0.2595
SAS12	0.2815	0.3333	0.1681	0.1286	0.3000	0.3000	0.0000	0.3000	0.1250	0.2842	0.7600	0.0000	0.7600	0.7600	0.6400	0.3333	0.3143	0.1750	0.1333	0.0000
SAS13	0.0000	0.1400	0.1286	0.1286	0.3000	0.1286	0.3000	0.1286	0.2889	0.1235	0.4000	0.1286	0.0000	0.4600	0.4600	0.0611	0.1750	0.1750	0.1333	0.2595
SAS14	0.1845	0.2000	0.1681	0.1681	0.1681	0.1681	0.1286	0.3000	0.1250	0.1607	0.2800	0.1286	0.4600	0.0000	0.4600	0.1845	0.3786	0.1333	0.2350	0.1308
SAS15	0.1167	0.1400	0.1286	0.3000	0.1286	0.1286	0.3000	0.0000	0.2889	0.1235	0.3400	0.1286	0.4000	0.5200	0.0000	0.1845	0.1750	0.1333	0.3143	0.1308
SAS16	0.0279	0.2815	0.4250	0.2540	0.3000	0.3000	0.5500	0.3000	0.2889	0.2842	0.4000	0.5500	0.3400	0.4000	0.3400	0.0000	0.3143	0.3786	0.2657	0.2595
SAS17	0.2815	0.0000	0.4250	0.3000	0.5500	0.3000	0.3000	0.3000	0.1250	0.2842	0.4000	0.5500	0.4600	0.2800	0.5200	0.2318	0.0000	0.2350	0.3786	0.2306
SAS18	0.2815	0.2815	0.0270	0.3000	0.3000	0.3000	0.3000	0.3000	0.1250	0.1235	0.5200	0.3000	0.5200	0.2800	0.5200	0.3333	0.4429	0.0000	0.2192	0.3836
SAS19	0.1400	0.1400	0.3000	0.0270	0.3000	0.3000	0.5500	0.1286	0.5333	0.1235	0.5200	0.1286	0.2800	0.5200	0.2800	0.1845	0.1750	0.2192	0.0000	0.4967
SAS20	0.1400	0.3333	0.3000	0.5500	0.5500	0.5500	0.3000	0.1286	0.2889	0.1235	0.5200	0.1286	0.5200	0.2800	0.5200	0.1400	0.2192	0.2657	0.4546	0.0000

Table 8
Normalized direct relationship matrix of SAS.

	SAS1	SAS2	SAS3	SAS4	SAS5	SAS6	SAS7	SAS8	SAS9	SAS10	SAS11	SAS12	SAS13	SAS14	SAS15	SAS16	SAS17	SAS18	SAS19	SAS20
SAS1	0.0000	0.0282	0.0550	0.0300	0.0300	0.0300	0.0550	0.0300	0.0289	0.0284	0.0460	0.0425	0.0340	0.0340	0.0280	0.0061	0.0175	0.0443	0.0266	0.0370
SAS2	0.0282	0.0000	0.0488	0.0254	0.0550	0.0300	0.0254	0.0254	0.0163	0.0241	0.0340	0.0425	0.0520	0.0280	0.0520	0.0282	0.0027	0.0342	0.0314	0.0433
SAS3	0.0282	0.0333	0.0000	0.0300	0.0254	0.0254	0.0300	0.0300	0.0125	0.0124	0.0520	0.0300	0.0520	0.0280	0.0520	0.0232	0.0266	0.0059	0.0219	0.0307
SAS4	0.0185	0.0185	0.0300	0.0000	0.0300	0.0300	0.0550	0.0129	0.0533	0.0124	0.0520	0.0129	0.0280	0.0520	0.0280	0.0185	0.0175	0.0314	0.0000	0.0214
SAS5	0.0140	0.0333	0.0300	0.0129	0.0000	0.0300	0.0254	0.0147	0.0289	0.0161	0.0520	0.0168	0.0520	0.0280	0.0520	0.0140	0.0266	0.0314	0.0175	0.0370
SAS6	0.0282	0.0140	0.0129	0.0254	0.0300	0.0000	0.0300	0.0300	0.0245	0.0284	0.0760	0.0300	0.0760	0.0520	0.0760	0.0333	0.0133	0.0133	0.0314	0.0259
SAS7	0.0333	0.0185	0.0300	0.0300	0.0550	0.0550	0.0000	0.0550	0.0289	0.0526	0.0760	0.0550	0.0520	0.0520	0.0520	0.0333	0.0175	0.0314	0.0266	0.0307
SAS8	0.0185	0.0140	0.0129	0.0129	0.0300	0.0300	0.0550	0.0000	0.0203	0.0526	0.0760	0.0300	0.0760	0.0520	0.0520	0.0140	0.0175	0.0175	0.0133	0.0307
SAS9	0.0140	0.0140	0.0300	0.0168	0.0550	0.0300	0.0129	0.0210	0.0000	0.0708	0.0520	0.0129	0.0760	0.0760	0.0520	0.0185	0.0175	0.0219	0.0175	0.0093
SAS10	0.0185	0.0185	0.0300	0.0300	0.0550	0.0129	0.0300	0.0300	0.0656	0.0000	0.0520	0.0129	0.0520	0.0280	0.0760	0.0140	0.0219	0.0314	0.0266	0.0307
SAS11	0.0000	0.0185	0.0129	0.0254	0.0550	0.0168	0.0254	0.0254	0.0163	0.0284	0.0000	0.0300	0.0760	0.0520	0.0520	0.0028	0.0133	0.0133	0.0266	0.0259
SAS12	0.0282	0.0333	0.0168	0.0129	0.0300	0.0300	0.0000	0.0300	0.0125	0.0284	0.0760	0.0000	0.0760	0.0760	0.0640	0.0333	0.0314	0.0175	0.0133	0.0000
SAS13	0.0000	0.0140	0.0129	0.0129	0.0300	0.0129	0.0300	0.0129	0.0289	0.0124	0.0400	0.0129	0.0000	0.0460	0.0460	0.0061	0.0175	0.0175	0.0133	0.0259
SAS14	0.0185	0.0200	0.0168	0.0168	0.0168	0.0168	0.0129	0.0300	0.0125	0.0161	0.0280	0.0129	0.0460	0.0000	0.0460	0.0185	0.0379	0.0133	0.0235	0.0131
SAS15	0.0117	0.0140	0.0129	0.0300	0.0129	0.0129	0.0300	0.0000	0.0289	0.0124	0.0340	0.0129	0.0400	0.0520	0.0000	0.0185	0.0175	0.0133	0.0314	0.0131
SAS16	0.0028	0.0282	0.0425	0.0254	0.0300	0.0300	0.0550	0.0300	0.0289	0.0284	0.0400	0.0550	0.0340	0.0400	0.0340	0.0000	0.0314	0.0379	0.0266	0.0259
SAS17	0.0282	0.0000	0.0425	0.0300	0.0550	0.0300	0.0300	0.0300	0.0125	0.0284	0.0400	0.0550	0.0460	0.0280	0.0520	0.0232	0.0000	0.0235	0.0379	0.0231
SAS18	0.0282	0.0282	0.0027	0.0300	0.0300	0.0300	0.0300	0.0300	0.0125	0.0124	0.0520	0.0300	0.0520	0.0280	0.0520	0.0333	0.0443	0.0000	0.0219	0.0384
SAS19	0.0140	0.0140	0.0300	0.0027	0.0300	0.0300	0.0550	0.0129	0.0533	0.0124	0.0520	0.0129	0.0280	0.0520	0.0280	0.0185	0.0175	0.0219	0.0000	0.0497
SAS20	0.0140	0.0333	0.0300	0.0550	0.0550	0.0550	0.0300	0.0129	0.0289	0.0124	0.0520	0.0129	0.0520	0.0280	0.0520	0.0140	0.0219	0.0266	0.0455	0.0000

Table 9
Total relationship matrix of SAS.

	SAS1	SAS2	SAS3	SAS4	SAS5	SAS6	SAS7	SAS8	SAS9	SAS10	SAS11	SAS12	SAS13	SAS14	SAS15	SAS16	SAS17	SAS18	SAS19	SAS20
SAS1	0.0250	0.0569	0.0864	0.0626	0.0804	0.0677	0.0952	0.0630	0.0647	0.0628	0.1148	0.0772	0.1067	0.0944	0.0966	0.0333	0.0478	0.0736	0.0590	0.0725
SAS2	0.0505	0.0293	0.0796	0.0570	0.1009	0.0659	0.0668	0.0559	0.0523	0.0559	0.1006	0.0750	0.1202	0.0867	0.1164	0.0529	0.0331	0.0634	0.0627	0.0776
SAS3	0.0473	0.0567	0.0292	0.0574	0.0680	0.0567	0.0663	0.0567	0.0440	0.0417	0.1085	0.0601	0.1117	0.0801	0.1078	0.0446	0.0510	0.0327	0.0500	0.0607
SAS4	0.0381	0.0419	0.0568	0.0276	0.0718	0.0606	0.0870	0.0411	0.0809	0.0429	0.1069	0.0429	0.0886	0.1012	0.0844	0.0401	0.0425	0.0561	0.0280	0.0503
SAS5	0.0332	0.0559	0.0566	0.0407	0.0424	0.0599	0.0596	0.0411	0.0580	0.0441	0.1061	0.0460	0.1103	0.0778	0.1068	0.0354	0.0506	0.0557	0.0455	0.0659
SAS6	0.0491	0.0418	0.0452	0.0568	0.0784	0.0356	0.0718	0.0605	0.0612	0.0616	0.1393	0.0633	0.1440	0.1120	0.1394	0.0569	0.0430	0.0435	0.0633	0.0604
SAS7	0.0607	0.0534	0.0691	0.0686	0.1138	0.0974	0.0520	0.0927	0.0735	0.0933	0.1572	0.0956	0.1401	0.1254	0.1344	0.0637	0.0544	0.0680	0.0659	0.0734
SAS8	0.0401	0.0411	0.0441	0.0447	0.0789	0.0644	0.0931	0.0320	0.0563	0.0846	0.1388	0.0629	0.1435	0.1098	0.1173	0.0382	0.0463	0.0468	0.0456	0.0642
SAS9	0.0348	0.0403	0.0595	0.0466	0.0992	0.0614	0.0520	0.0505	0.0359	0.0992	0.1124	0.0438	0.1400	0.1289	0.1150	0.0413	0.0462	0.0498	0.0480	0.0431
SAS10	0.0404	0.0459	0.0617	0.0612	0.1025	0.0490	0.0708	0.0597	0.0998	0.0348	0.1165	0.0461	0.1211	0.0882	0.1389	0.0387	0.0509	0.0607	0.0581	0.0649
SAS11	0.0183	0.0404	0.0380	0.0495	0.0914	0.0450	0.0574	0.0490	0.0459	0.0536	0.0536	0.0547	0.1288	0.0982	0.1037	0.0231	0.0372	0.0370	0.0513	0.0533
SAS12	0.0476	0.0579	0.0466	0.0420	0.0740	0.0605	0.0394	0.0583	0.0453	0.0582	0.1327	0.0323	0.1389	0.1286	0.1237	0.0550	0.0584	0.0448	0.0437	0.0331
SAS13	0.0146	0.0311	0.0326	0.0330	0.0601	0.0356	0.0541	0.0324	0.0502	0.0337	0.0799	0.0337	0.0449	0.0820	0.0861	0.0221	0.0359	0.0356	0.0339	0.0467
SAS14	0.0331	0.0374	0.0386	0.0376	0.0490	0.0402	0.0415	0.0497	0.0365	0.0381	0.0712	0.0362	0.0906	0.0397	0.0880	0.0347	0.0560	0.0332	0.0447	0.0366
SAS15	0.0259	0.0312	0.0338	0.0490	0.0442	0.0358	0.0555	0.0209	0.0515	0.0338	0.0746	0.0344	0.0826	0.0886	0.0417	0.0342	0.0362	0.0324	0.0508	0.0352
SAS16	0.0278	0.0561	0.0739	0.0572	0.0796	0.0669	0.0942	0.0628	0.0640	0.0628	0.1082	0.0892	0.1060	0.1001	0.1018	0.0272	0.0611	0.0670	0.0586	0.0607
SAS17	0.0501	0.0285	0.0728	0.0600	0.0998	0.0647	0.0703	0.0601	0.0483	0.0600	0.1056	0.0866	0.1135	0.0866	0.1153	0.0476	0.0296	0.0523	0.0678	0.0569
SAS18	0.0487	0.0532	0.0343	0.0597	0.0757	0.0637	0.0691	0.0587	0.0461	0.0438	0.1126	0.0628	0.1159	0.0835	0.1120	0.0561	0.0702	0.0289	0.0524	0.0702
SAS19	0.0340	0.0384	0.0576	0.0317	0.0733	0.0621	0.0879	0.0414	0.0820	0.0433	0.1084	0.0431	0.0901	0.1023	0.0858	0.0404	0.0431	0.0474	0.0291	0.0783
SAS20	0.0368	0.0601	0.0619	0.0847	0.1018	0.0894	0.0717	0.0436	0.0652	0.0451	0.1170	0.0467	0.1201	0.0875	0.1162	0.0395	0.0502	0.0560	0.0760	0.0362

Table 10
Cause/effect relationship of SAS.

Code	Sustainable adoption strategies	R	D	R + D	R-D
SAS1	Acceptance by stakeholders	1.4403	0.7561	2.1964	0.6842
SAS2	Proficient technical knowledge	1.4029	0.8977	2.3006	0.5052
SAS3	Laws and regulations	1.2313	1.0782	2.3095	0.1532
SAS4	Environmental concerns	1.1894	1.0277	2.2171	0.1617
SAS5	Develop network to reduce high capital costs	1.1916	1.5854	2.7770	−0.3938
SAS6	Technological innovations to reduce operational costs	1.4269	1.1825	2.6094	0.2444
SAS7	Adoption of effective Traffic management	1.7527	1.3557	3.1084	0.3969
SAS8	Leadership commitment	1.3925	1.0302	2.4227	0.3624
SAS9	Strategic focus on Research and Development	1.3481	1.1616	2.5097	0.1865
SAS10	Highly skilled workforce	1.4099	1.0931	2.5030	0.3167
SAS11	Develop supportive infrastructure	1.1295	2.1648	3.2943	−1.0354
SAS12	Safety and security	1.3209	1.1327	2.4536	0.1882
SAS13	Capacity and capability building	0.8783	2.2577	3.1360	−1.3794
SAS14	Ease of operation, reliability, and scalability	0.9325	1.9014	2.8338	−0.9689
SAS15	Competitive edge	0.8924	2.1315	3.0239	−1.2391
SAS16	Aids and subsidies provided by the government and other organizations	1.4251	0.8247	2.2499	0.6004
SAS17	Technological adoption for low noise	1.3767	0.9436	2.3203	0.4331
SAS18	Global influence	1.3177	0.9850	2.3027	0.3327
SAS19	Organizational readiness	1.2197	1.0343	2.2540	0.1854
SAS20	Strategies to counter cybercrime related activities	1.4059	1.1404	2.5463	0.2655

recent times, with technologies being hacked and confidential information leaked. The technology used to operate eVTOL vehicles will also be vulnerable to cyberattacks, potentially resulting in accidents or operational breakdowns. Therefore, it is crucial to devise strategies to counter cybercrime-related activities. Finally, SAS6, i.e., "High operational costs," secured the tenth rank with an R-D score of 0.2444. During the initial phase of implementing this technology, costs are expected to rise significantly. The reasons for these higher costs include ongoing technical improvements, expensive spare parts, service station expansions, electric charging station setups, and more. Furthermore, the number of suppliers and vendors available to meet various requirements will be limited.

Following SAS6, SAS12, i.e., "Safety and Security," acquired the eleventh rank with an R-D score of 0.1882. Safety and security are worrisome issues due to the number of casualties in aerial accidents in the past (Shvetsov and Shvetsova, 2021). Numerous instances of aircraft crashes have resulted in significant loss of lives. For this reason, this strategy is included in the study and ranks eleventh. Additionally, there is a risk of terrorist attacks, which must also be considered. The installation of sustainable safety and security features in eVTOL vehicles is vital for the success of this technology. Thereafter, SAS9, i.e., "Research and Development," obtained the twelfth rank with an R-D score of 0.1865. Research and development are indispensable for the growth of any corporation or sector. The role of research and development is to suggest periodic amendments to satisfy stakeholders and keep pace with technological advancements. A skilled research and development team is essential for any corporation to sustain itself in the long run, making it crucial for eVTOL mobility at this juncture. Further, "Organizational Readiness," with code SAS19, is ranked as the thirteenth sustainable adoption strategy with an R-D score of 0.1854. SAS19 pertains to whether an organization venturing into eVTOL mobility is adequately prepared to operate the business smoothly. Organizational readiness is primarily assessed by examining two areas: operational and managerial.

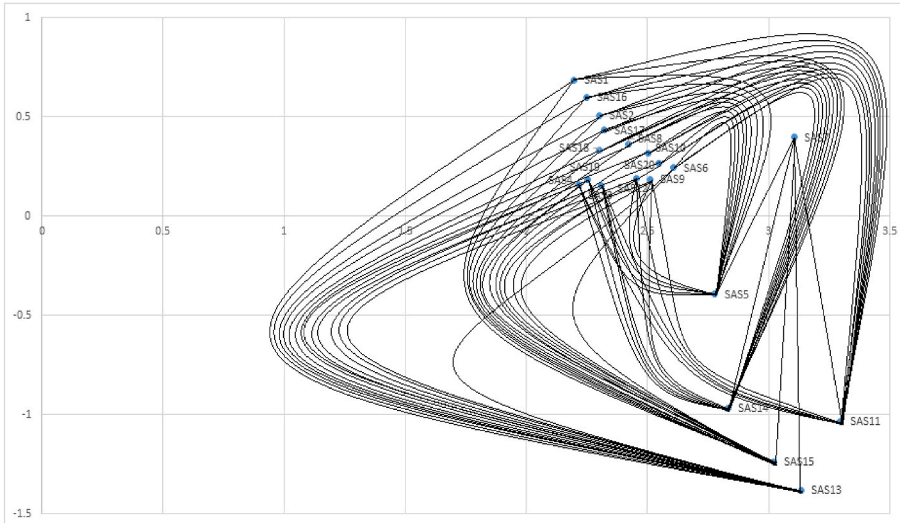

Fig. 2. Diagraph represents causal relationship among SASs.

Before going commercial, it is necessary to effectively audit the organization's readiness for business sustainability. Moving on, SAS4, i.e., "Environmental Concerns," attained the fourteenth rank with an R-D score of 0.1617. A study by Kellermann et al. (2020) highlights multiple times that modern aerial vehicles are an environmentally friendly transportation alternative. Unfortunately, no study specifically addresses the environmental benefits of eVTOL vehicles for shared passenger and freight mobility. Lastly, SAS3, i.e., "Laws and Regulations," acquired the fifteenth rank with an R-D score of 0.1532. SAS3 pertains to laws and regulations enforced by state/provincial and central/federal governments. For sustainability, corporations investing in and operating eVTOL mobility must comply with these laws and regulations.

6.2. *Effect set*

The effect set exhibits sustainable adoption strategies with high importance but illustrates weak implications. The strategies in the effect group may not be accepted and implemented directly but may be adopted along with causal set strategies. In the effect group (as shown in Table 10 and Fig. 2), five sustainable adoption strategies are ranked based on R-D values, which are SAS5 (High capital costs) > SAS14 (Ease of operation, reliability, and scalability) > SAS11 (Support infrastructure) > SAS15 (Competitive edge) > SAS13 (Capacity and capability). Among the above-mentioned strategies, SAS5 holds the sixteenth rank with an R-D value of −0.3938. A study by Ahluwalia et al. (2021) discusses how capital costs and other related expenses impact the urban air mobility business. According to experts from Joby Aviation and Archer Aviation, the capital cost is high when setting up infrastructure for the smooth operation of eVTOL vehicles. However, these costs will gradually be passed on to the customers. Furthermore, SAS14 is ranked seventeenth with an R-D score of −0.9689. The likely operators are focused on safety certification and clearance for flying the eVTOLs. Hence, it is too early to comment on reliability and scalability. However, it is certain that for sustainability, operators need to emphasize ease of operation, reliability, and scalability. Following this, SAS11 ranks eighteenth with an R-D value of −1.0354. A strong infrastructure will be required to enable eVTOL vehicles to integrate with existing air traffic control systems. Finally, SAS15 and SAS13 rank nineteenth and twentieth with R-D values of −1.2391 and −1.3794, respectively.

6.3. *Sensitivity analysis*

To validate the strength of the suggested model and evaluate the causal relationship and ranking patterns, sensitivity analysis was conducted to check consistency in decision-making process (Garg and Kashav (2022) Garg and Kashav (2020); Garg et al., 2022; Mahtani and Garg, 2018). The experts have been divided into four distinct random groups. The experts' group weights are varied to assess the consistency. In analysis 1; group 1 has assigned the weightage value 0.4 and rest group have allocated the weightage value of 0.2, then causal relationship has been established among sustainable adoption strategies. The results of analysis 1 indicates that SAS1, SAS16, SAS4, SAS19 and SAS18 are the five crucial SASs and top three causal and effect SASs are SAS1, SAS16 and SAS2; SAS5, SAS14 and SAS11 respectively (See Table 11 and Fig. 3). Similarly, in analysis 2, group 2 has assigned the weightage value 0.4 and rest group have allocated the weightage value of 0.2, then causal relationship has been established among sustainable adoption strategies. It shows that SAS1, SAS4, SAS19, SAS3 and SAS2 are topmost severe SASs and top three cause, and effect SASs are SAS1, SAS16 and SAS2; SAS5, SAS14 and SAS11 respectively (See Table 11 & Fig. 4). Analysis 3 where group 3 has assigned the weightage value 0.4 and rest groups have allocated the weightage value of 0.2, then causal relationship has been established among sustainable adoption strategies. The results of analysis 3 indicates that SAS1, SAS4, SAS16, SAS19 and SAS17 are the five crucial SASs and top three causal and effect SASs are SAS1, SAS16 and SAS2; SAS5, SAS14 and SAS11 respectively (See Table 11 & Fig. 5). Finally, in analysis run 4, group 4 has assigned the weightage value 0.4 and rest groups have allocated the weightage value of 0.2, then causal relationship has been established among sustainable adoption strategies. The results of analysis 4 indicates that SAS1, SAS4, SAS16, SAS19 and SAS18 are the five crucial SASs and top three causal and effect SASs are SAS1, SAS16 and SAS2; SAS5, SAS14 and SAS11 respectively (See Table 11 & Fig. 6). The performed analysis indicates that SAS categories have minor variation despite significant weightage value variation. This proves the robustness of the proposed framework which is highlighted in Figs. 3–5. Hence, the obtained result from the suggested model is consistent throughout the analysis.

7. Implications and practical contribution

7.1. *Theoretical implications and contribution*

This study explores the theoretical implications of sustainable adoption strategies for stakeholders in shared passenger and freight transportation using eVTOL vehicles. While discussions on the commercialization of eVTOLs for public transport and freight have persisted for years, this research emphasizes the necessity of sustainable adoption. For instance, a study by Kasliwal et al. (2019) specifically focused on the analysis of carbon emissions reduction using VTOLs. In contrast, this study works on a broader horizon of sustainable adoption strategies for this widely discussed technology. One novel contribution of this study lies in its aim to identify adoption strategies for shared passenger and freight transportation through eVTOLs, which have not been explored earlier. Similarly, Long et al. (2023) examined factors influencing UAM market demand, such as time, cost, distance, congestion, safety, privacy, and noise. While the current study certainly examines the aforementioned factors, it additionally focuses on the viability of eVTOL technology through government support and financial incentives, such as subsidies, which rank among the top strategies. A study by Melo et al. (2022) and Pons-Prats et al. (2022) motivated this research by focusing on the technical feasibility of eVTOL technology. However, the current study examines both the technical and commercial aspects of this technology. New technologies are often scrutinized for the costs involved in their implementation. Liberacki et al. (2023), for instance, discussed the costs associated with an aircraft's energy consumption during flight. That study, however, restricted itself to costs and did not consider other factors necessary for the successful implementation of eVTOL technology-factors that the current study has comprehensively addressed.

This study offers novel theoretical contributions by advancing the discourse on sustainable adoption strategies for eVTOL vehicles in shared passenger and freight transportation systems. Unlike existing literature, which primarily focuses on the technical feasibility or market demand for eVTOL technology, this research integrates multiple dimensions-technical, social, economic, and environmental-into a unified framework. Notably, it highlights stakeholder acceptance as a critical factor, addressing a gap in the literature where stakeholder perspectives are often underexplored. Furthermore, this study highlights the importance of government aid and subsidies, linking financial incentives to the broader viability of eVTOL adoption - a connection that has been insufficiently examined in prior research. By emphasizing proficient technical knowledge as a strategic enabler, the study bridges the gap between technology readiness and practical implementation. Additionally, it dives into the implications of low noise pollution and traffic management, areas typically analyzed in isolation but here considered as interconnected components of urban air mobility systems. These contributions provide a more holistic understanding of the sustainable adoption of eVTOL vehicles, offering actionable insights for policymakers, technology developers, and urban planners while expanding theoretical frameworks in transportation and sustainability studies.

7.2. Contribution to the industry and policy implications

7.2.1. Policy implications; a macro perspective

The introduction of eVTOL (electric Vertical Take-Off and Landing) vehicles is expected to significantly influence government policies on freight and passenger transportation worldwide. The adoption of this technology will require new policies to ensure safe operations, addressing aspects such as airspace management, infrastructure needs, licensing, privacy, security, and environmental impacts. Governments must establish frameworks to govern eVTOL operations, including routes and integration with existing networks, while promoting investment and research partnerships. By proactively tackling these policy challenges, governments can unlock the full potential of eVTOL technology, fostering a more efficient and sustainable transportation ecosystem. Potential policy implications from this study include:

- **Regulatory Framework Development:** Regulatory Framework Development is critical for sustainably adopting eVTOL vehicles in shared passenger and freight systems. It involves creating adaptive airspace protocols, integrating urban air mobility with existing transport systems, and setting standards for safety, emissions, and infrastructure. Collaborative efforts between governments and industry can ensure seamless global operability, fostering innovation while prioritizing sustainability and public acceptance.
- **Incentives and Funding Programs:** Incentives and Funding Programs play a pivotal role in the sustainable adoption of eVTOL vehicles by addressing high costs, infrastructure gaps, and early-stage uncertainties. Targeted financial incentives and funding for R&D, infrastructure, and public-private partnerships can accelerate innovation, operational readiness, and social acceptance. This strategy ensures economic viability while fostering long-term environmental and societal benefits globally.
- **Infrastructure Planning:** Infrastructure planning is pivotal for the sustainable adoption of eVTOL vehicles, requiring the development of vertiports, charging stations, and maintenance hubs tailored to eVTOL operations. Policymakers must prioritize public-private partnerships, renewable energy integration, and noise reduction strategies to ensure environmentally friendly and economically feasible infrastructure. This approach enables seamless integration with urban mobility systems, fostering an equitable and sustainable transportation ecosystem.
- **Collaboration and Partnerships:** Collaboration and Partnerships is pivotal for the sustainable adoption of eVTOL vehicles, enabling

Table 11
Sensitivity experiments.

SASs	Analysis 1				Analysis 2				Analysis 3				Analysis 4			
	R + D	Rank	R-D	Rank	R + D	Rank	R-D	Rank	R + D	Rank	R-D	Rank	R + D	Rank	R-D	Rank
SAS1	2.1611	1	0.6543	1	2.1977	1	0.6800	1	2.2180	1	0.7105	1	2.2181	1	0.6935	1
SAS2	2.2558	6	0.4608	3	2.2969	5	0.4979	3	2.3092	6	0.5208	3	2.3481	6	0.5439	3
SAS3	2.2635	7	0.1265	15	2.2956	4	0.1649	13	2.3358	8	0.1595	14	2.3515	7	0.1649	13
SAS4	2.2065	3	0.1842	12	2.2118	2	0.1553	15	2.2216	2	0.1522	15	2.2347	2	0.1556	14
SAS5	2.7620	15	−0.3854	16	2.7766	15	−0.3876	16	2.7793	15	−0.4026	16	2.7963	15	−0.3995	16
SAS6	2.5847	14	0.2223	10	2.6012	14	0.2473	10	2.6209	14	0.2532	10	2.6374	14	0.2563	9
SAS7	3.0726	18	0.4255	5	3.1080	18	0.3862	5	3.1207	18	0.3860	5	3.1396	19	0.3908	5
SAS8	2.3922	9	0.3782	6	2.4401	9	0.3667	6	2.4185	9	0.3509	7	2.4456	9	0.3548	6
SAS9	2.5002	11	0.1925	11	2.4868	12	0.1624	14	2.5136	12	0.1961	11	2.5454	12	0.1955	12
SAS10	2.5103	13	0.3286	7	2.4772	11	0.2946	9	2.5126	11	0.3243	8	2.5180	11	0.3207	7
SAS11	3.2778	20	−1.0246	18	3.2852	20	−1.0440	18	3.3172	20	−1.0508	18	3.3046	20	−1.0219	18
SAS12	2.4418	10	0.1693	14	2.4717	10	0.1907	12	2.4419	10	0.1906	13	2.4642	10	0.2035	11
SAS13	3.1228	19	−1.3647	20	3.1546	19	−1.3698	20	3.1419	19	−1.3765	20	3.1316	18	−1.4064	20
SAS14	2.8369	16	−0.9478	17	2.8538	16	−0.9556	17	2.8190	16	−0.9918	17	2.8312	16	−0.9811	17
SAS15	3.0097	17	−1.2204	19	3.0475	17	−1.2178	19	3.0147	17	−1.2638	19	3.0303	17	−1.2552	19
SAS16	2.1771	2	0.6065	2	2.3061	6	0.5620	2	2.2494	3	0.6148	2	2.2765	3	0.6174	2
SAS17	2.2744	8	0.4589	4	2.3315	8	0.3911	4	2.3062	5	0.4105	4	2.3778	8	0.4718	4
SAS18	2.2522	5	0.3185	8	2.3098	7	0.3442	7	2.3123	7	0.3540	6	2.3458	5	0.3125	8
SAS19	2.2388	4	0.1754	13	2.2476	3	0.2140	11	2.2562	4	0.1923	12	2.2863	4	0.1539	15
SAS20	2.5038	12	0.2413	9	2.5316	13	0.3177	8	2.5689	13	0.2698	9	2.5913	13	0.2292	10

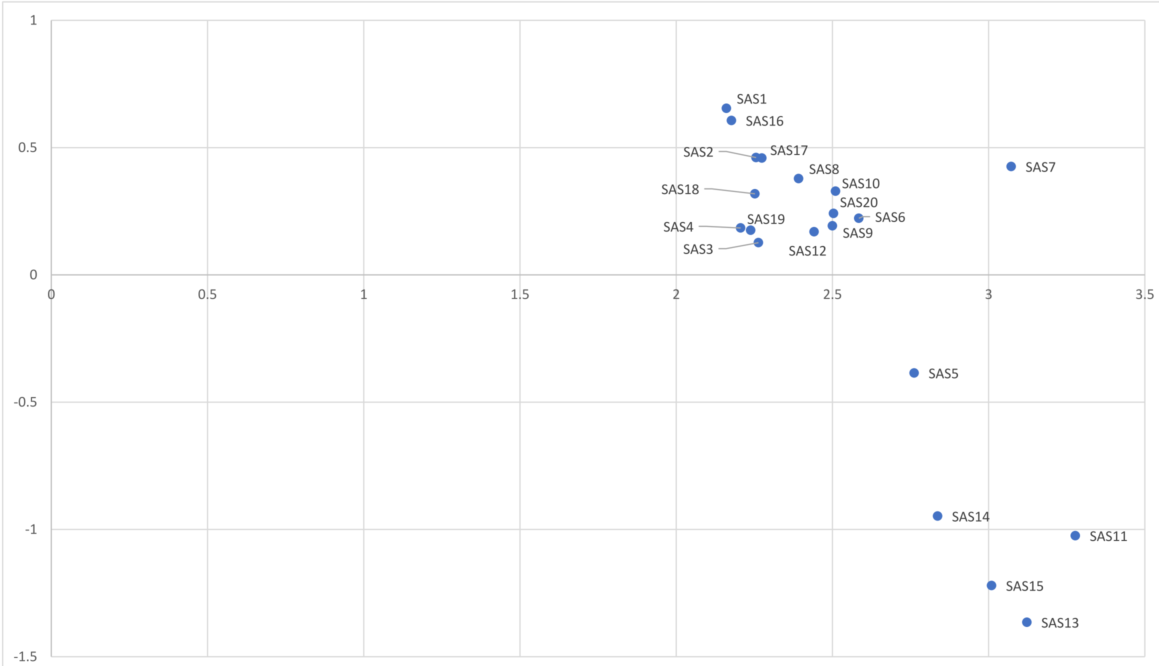

Fig. 3. Causal relationship among SASs in analysis run 1.

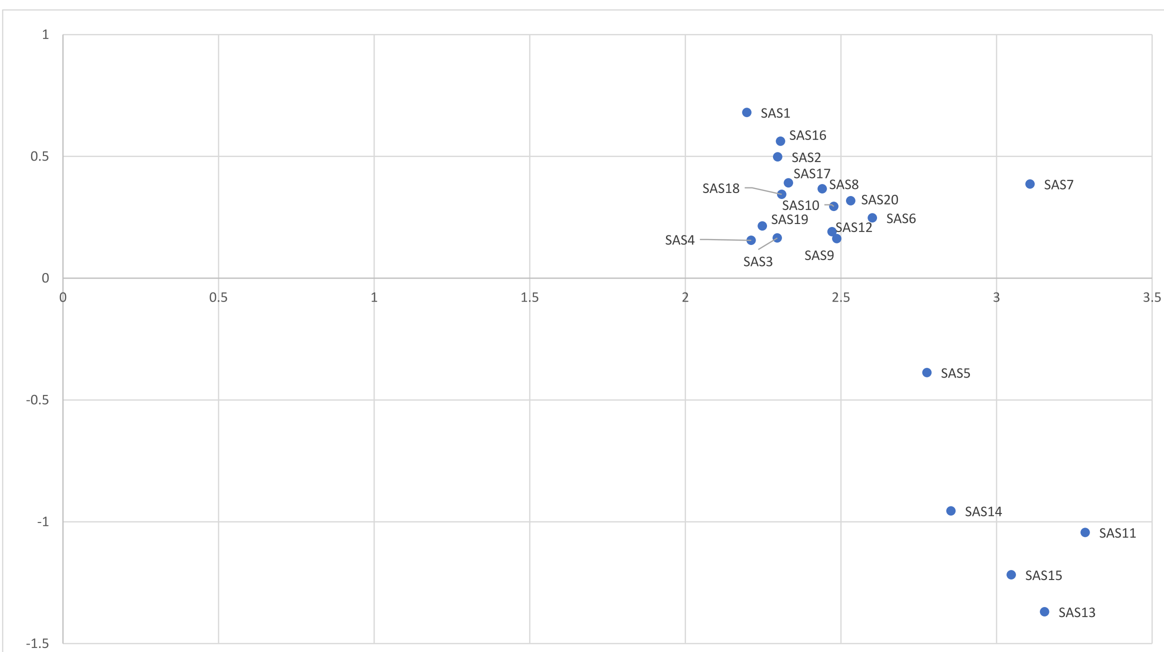

Fig. 4. Causal relationship among SASs in analysis run 2.

seamless integration into shared passenger and freight systems through multi-stakeholder synergy. Governments and aviation bodies can drive innovation by fostering partnerships with urban planners, energy providers, and international regulators to standardize infrastructure, safety, and operational guidelines. This collaborative approach ensures scalability, eco-friendly operations, and inclusive policies, aligning global sustainability goals with next-generation transportation needs.

- **Public Acceptance and Integration:** Public Acceptance and Integration is pivotal for the sustainable adoption of eVTOL vehicles, requiring transparent communication on safety, environmental benefits, and affordability to build public trust. Governments must address concerns like noise, privacy, and access while fostering intermodal connectivity and regulatory frameworks. These efforts can drive widespread acceptance, enabling sustainable and inclusive urban and regional mobility systems.
- **Airspace Management:** Effective airspace management is crucial for the sustainable adoption of eVTOL vehicles in shared passenger and freight systems, requiring innovative frameworks to integrate eVTOLs with traditional air traffic. This includes creating designated flight paths, tailored air traffic control, and real-time data-sharing to ensure safety and efficiency. Sustainable airspace management also addresses environmental concerns, optimizing routes to reduce

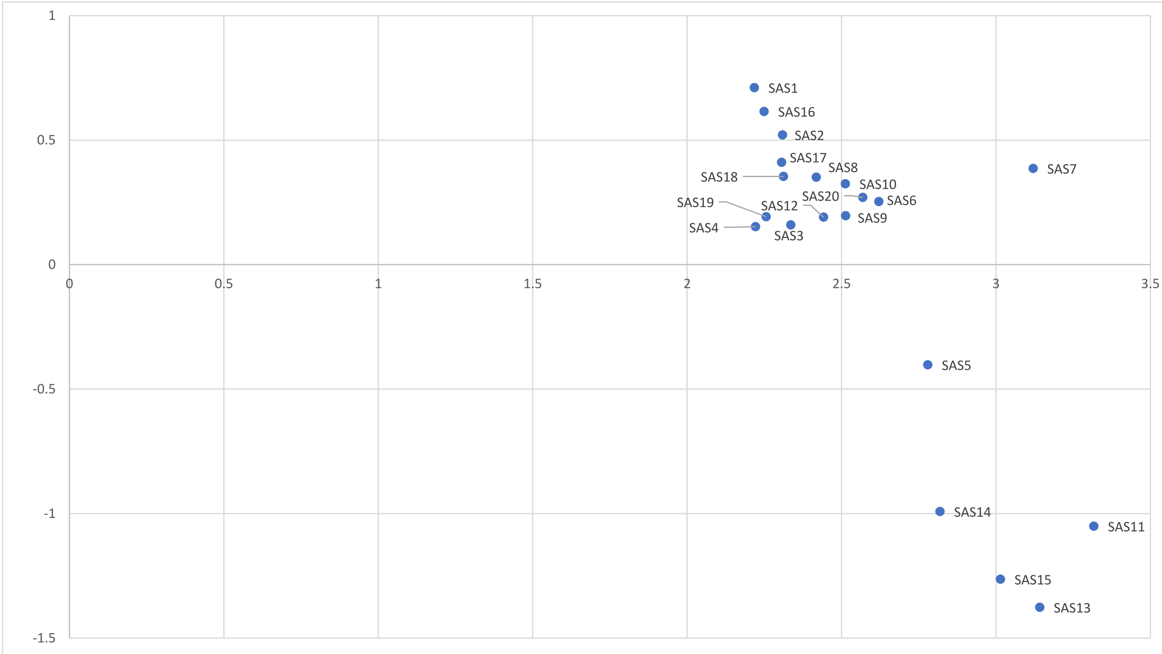

Fig. 5. Causal relationship among SASs in analysis run 3.

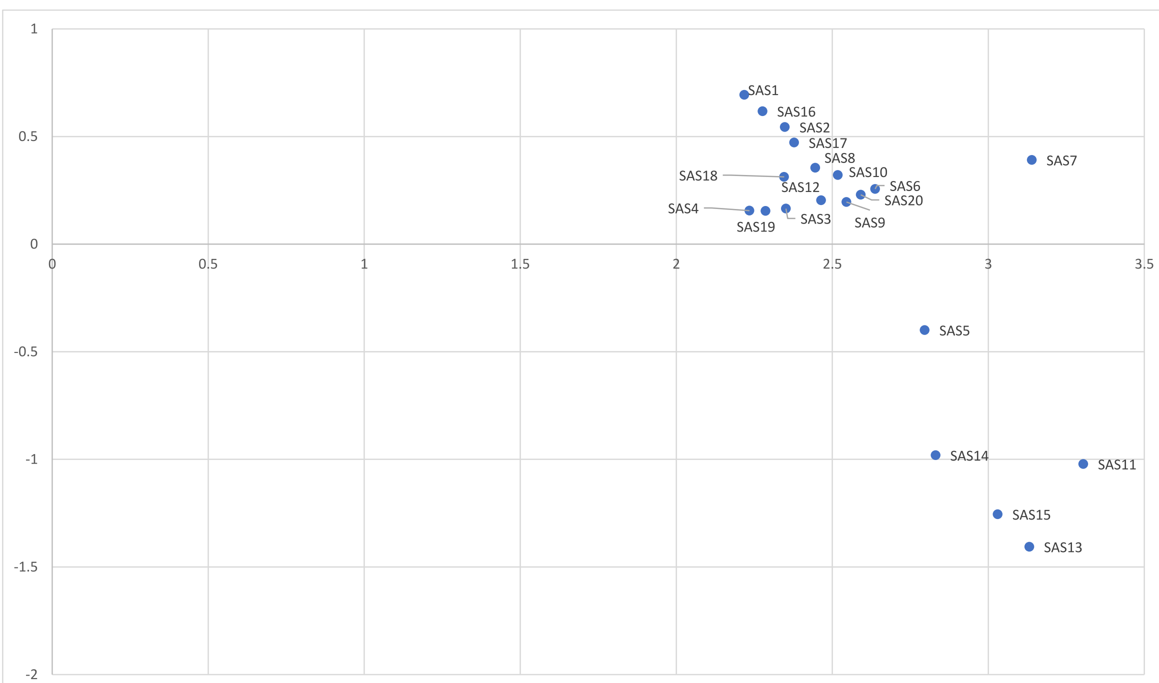

Fig. 6. Causal relationship among SASs in analysis run 4.

emissions and noise pollution, contributing to a greener transportation ecosystem.

- **Environmental Considerations:** This strategy for eVTOL vehicles emphasizes the need for policies that reduce carbon emissions, noise pollution, and energy consumption. Governments must incentivize renewable energy use, enforce stringent environmental standards, and promote sustainable eVTOL infrastructure. Collaboration between stakeholders will be crucial to ensure eVTOL adoption contributes to global sustainability goals while fostering innovation.

7.2.2. Policy implications: a micro perspective

The study holds significant value for those engaged in last-mile delivery services, urban logistics, and passenger transportation. Notably, there are companies currently transporting both passengers and freight, primarily within cities using road-based systems. In fact, rail systems are also carrying passengers and freight in a combined setup. This study suggests that this can be achieved using eVTOL vehicles, but it requires meticulous preparedness, planning, and execution to ensure efficiency. Furthermore, there is substantial demand for technically skilled professionals in this field. Without a skilled workforce and adequate technological arrangements, attracting stakeholders for business and investments becomes challenging. This is why the SAS1 strategy ranks first in this study. To ensure the successful introduction and adoption of this new technology, governments and related agencies must provide support. Typically, government assistance and subsidies are provided, which is why SAS16 ranks second in this study. As previously mentioned, skilled professionals-including pilots, as well as technical and managerial staff-play a vital role in promoting a positive outlook on this technology. Hence, SAS2 attains the third rank in this research. Similarly, all the strategies identified and evaluated in this study are sustainable in nature and have significant implications for policymakers.

Through this work, academic researchers and industry practitioners involved in shared passenger and freight transportation via aerial mobility can identify areas of weakness and gaps in their operations. A key advantage of eVTOL (electric Vertical Take-Off and Landing) vehicles is their ability to fly, which is highly beneficial in densely populated cities where road traffic congestion is frequent during peak hours. As a result, eVTOL vehicles can offer an efficient solution by providing emergency passenger and freight services during such congested periods, reducing the strain on traditional road-based transportation systems. Moreover, considering the role of public transport in the spread of COVID-19, the integration of eVTOLs into urban transport systems could play a crucial role in mitigating the impact of such disruptive events in the future. These aerial vehicles could serve as an alternative to crowded public transit, thus reducing close contact between passengers and enhancing public health safety. Furthermore, this study also outlines policy implications for the post-pandemic era, particularly as uncertainties often arise in the absence of prior indications. As the world adjusts to new norms, policymakers need to address the need for innovative transportation solutions that can withstand future disruptions. To explore these policy implications in greater depth, the authors have employed the grey-DEMATEL approach, which helps in analyzing complex systems and identifying causal relationships between various factors. This methodology is crucial for understanding how eVTOLs can be integrated into existing transport infrastructure and how various barriers and opportunities may influence their adoption. Overall, this study primarily focuses on sustainability perspectives, emphasizing the potential of eVTOL technology to reduce environmental impacts and contribute to more resilient transportation systems. Future research should further explore how the proposed strategies for eVTOL adoption can be effectively implemented, especially in terms of regulatory frameworks, public acceptance, and technological advancements. Additionally, investigating the long-term environmental and economic impacts of eVTOLs, as well as their role in supporting sustainable urban mobility, will be critical for ensuring the successful integration of these vehicles into future transportation networks.

8. Conclusion and future scope of the research

8.1. Conclusion of this study

This study analyzes and assesses the criticality of each sustainable adoption strategy identified in this manuscript. Through thorough discussion and argumentation, the research provides valuable recommendations for industry managers, researchers, and policymakers to enhance their competitive advantage in the field of eVTOL mobility. This study holds immense significance as it is the first of its kind to examine the shared transportation of passengers and freight using eVTOL vehicles. The literature review in this research focuses on two main themes, aiming to encompass various aspects such as technology, integration, regulation, research, and infrastructure within the domain of eVTOL vehicle transportation. The results obtained through the grey-DEMATEL method reveal that the strategy "Acceptance of stakeholders" (SAS1) attains the highest rank and the highest R-D score, indicating its utmost importance. Following closely, the strategy "Aids and subsidies provided by the government and other organizations" (SAS16) secures the second rank based on the R-D score. Similarly, the strategy "Proficient technical knowledge" (SAS2) claims the third rank. All identified sustainable adoption strategies are ranked according to their criticality, establishing their relative importance. The robustness of the grey-DEMATEL model is validated through sensitivity analysis, ensuring the reliability of the findings. The manuscript thoroughly discusses the results in consultation with industry experts, providing a comprehensive examination of the outcomes. Finally, the research suggests implications for policymakers, industry managers, and researchers, offering valuable insights for their consideration.

8.2. Limitations and suggestions for future research

The advent of eVTOL vehicle technology has the potential to revolutionize traditional approaches to urban logistics and passenger transportation. Moreover, the concept of shared passenger and freight transport utilizing eVTOL vehicles represents an unprecedented development. The study's findings were rigorously validated through expert feedback from relevant fields. Moving forward, there are opportunities to identify and evaluate additional strategies, as well as explore potential implementation barriers. The model employed in this study was constructed based on insights provided by domain experts. Therefore, experts' input can be subjective and may vary. To further enhance its validity, future research could incorporate empirical analysis. Given that this study is pioneering in nature, the authors encountered numerous challenges during the data collection process. Due to limited data sources, the authors anticipate minimal impact on the overall results. Nonetheless, it is recommended that future investigations get into a more granular level of analysis to acquire deeper insights. Understanding the perspectives of stakeholders and society is crucial to gaining accurate intelligence regarding acceptance behavior and the sustainability of eVTOL vehicle transportation.

CRediT authorship contribution statement

Vishal Kashav: Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Conceptualization. **Chandra Prakash Garg:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Conceptualization.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jairtraman.2025.102761.

Data availability

No data was used for the research described in the article.

References

Ahluwalia, R.K., Peng, J.K., Wang, X., Papadias, D., Kopasz, J., 2021. Performance and cost of fuel cells for urban air mobility. Int. J. Hydrogen Energy 46 (74), 36917–36929. https://doi.org/10.1016/j.ijhydene.2021.08.211.

Ahmed, S.S., Fountas, G., Eker, U., Still, S.E., Anastasopoulos, P.C., 2021. An exploratory empirical analysis of willingness to hire and pay for flying taxis and shared flying car services. J. Air Transport. Manag. 90, 101963. https://doi.org/10.1016/j.jairtraman.2020.101963.

Al Haddad, C., Chaniotakis, E., Straubinger, A., Plötner, K., Antoniou, C., 2020. Factors affecting the adoption and use of urban air mobility. Transport. Res. Pol. Pract. 132, 696–712. https://doi.org/10.1016/j.tra.2019.12.020.

Astfalk, S., Silberer, J., Planing, P., Müller, P., 2021. The effect of a functional prototype on user acceptance in transportation: assessing the level of acceptance before and after the first demonstration flight of an air taxi. Transp. Res. Interdiscip. Perspect. 11, 100444. https://doi.org/10.1016/j.trip.2021.100444.

Bacchini, A., Cestino, E., Van Magill, B., Verstraete, D., 2021. Impact of lift propeller drag on the performance of eVTOL lift+cruise aircraft. Aero. Sci. Technol. 109, 106429. https://doi.org/10.1016/j.ast.2020.106429.

Ball, A.M., 2019. The autonomous vehicle parking problem. Transp. Policy 75, 99–108. https://doi.org/10.1016/j.tranpol.2019.01.003.

Behme, J., Planing, P., 2020. Air taxis as a mobility solution for cities—empirical research on customer acceptance of urban air mobility. Innovations for Metropolitan Areas 93–103. https://doi.org/10.1007/978-3-662-60806-7_8.

Bruzzone, F., Cavallaro, F., Nocera, S., 2021. The integration of passenger and freight transport for first-last mile operations. Transp. Policy 100, 31–48. https://doi.org/10.1016/j.tranpol.2020.10.009.

Bruzzone, F., Cavallaro, F., Nocera, S., 2022. Appropriate key performance indicators for evaluating integrated passenger-freight transport. In: Conference on Sustainable Urban Mobility, CSUM 2022: Smart Energy for Smart Transport, pp. 1278–1290. https://doi.org/10.1007/978-3-031-23721-8_103.

Chen, Q., Wachenheim, C., Zheng, S., 2020. Land scale, cooperative membership and benefits information: unmanned aerial vehicle adoption in China. Sustainable Futures 2, 100025. https://doi.org/10.1016/j.sftr.2020.100025.

Eker, U., Ahmed, S.S., Fountas, G., Anastasopoulos, P.C., 2019. An exploratory investigation of public perceptions towards safety and security from the future use of flying cars in the United States. Analytic Methods in Accident Research 23, 100103. https://doi.org/10.1016/j.amar.2019.100103.

Eker, U., Fountas, G., Ahmed, S.S., Anastasopoulos, P.C., 2022. Survey data on public perceptions towards flying cars and flying taxi services. Data Brief 41, 107981. https://doi.org/10.1016/j.dib.2022.107981.

Fu, M., Rothfeld, R., Antoniou, C., 2019. 'Exploring preferences for transportation modes in an urban air mobility environment: Munich case study. Transp. Res. Rec.: J. Transport. Res. Board 2673 (10), 427–442. https://doi.org/10.1177/0361198119843858.

Garg, C.P., 2020. A robust hybrid decision model to evaluate critical factors of reverse logistics implementation using Grey-DEMATEL framework. Opsearch 57 (3), 837–873.

Garg, C.P., 2021. Modeling the e-waste mitigation strategies using Grey-theory and DEMATEL framework. J. Clean. Prod. 281, 124035.

Garg, C.P., Kashav, V., 2019. Evaluating value creating factors in greening the transportation of Global Maritime Supply Chains (GMSCs) of containerized freight. Transport. Res. Transport Environ. 73, 162–186. https://doi.org/10.1016/j.trd.2019.06.011.

Garg, C.P., Kashav, V., 2020. Assessment of sustainable initiatives in the containerized freight Railways of India using fuzzy AHP framework. Transp. Res. Procedia 48, 522–539. https://doi.org/10.1016/j.trpro.2020.08.057.

Garg, C.P., Kashav, V., 2022. Modeling the supply chain finance (SCF) barriers of Indian SMEs using BWM framework. J. Bus. Ind. Market. 37 (1), 128–145. https://doi.org/10.1108/JBIM-05-2020-0248.

Garg, C.P., Kashav, V., Wang, X., 2022. Evaluating sustainability factors of green ports in China under fuzzy environment. Environ. Dev. Sustain. https://doi.org/10.1007/s10668-022-02375-7.

Garg, C.P., Görçün, Ö.F., Küçükönder, H., 2023. A novel model based on the fuzzy Grey Relational Analysis (F-GRA) approach for selecting the appropriate high-speed train set. Soft Comput. 1–18.

German, B., Daskilewicz, M., Hamilton, T.K., Warren, M.M., 2018. Cargo delivery in by passenger eVTOL aircraft: a case study in the San Francisco bay area. Advanced/Transformational Aircraft Requirements, Concepts of Operations, and Markets. https://doi.org/10.2514/6.2018-2006.

Higgins, R.J., Barakos, G.N., Shahpar, S., Tristanto, I., 2021. A computational fluid dynamic acoustic investigation of a tiltwing eVTOL concept aircraft. Aero. Sci. Technol. 111, 106571. https://doi.org/10.1016/j.ast.2021.106571.

Hörsting, L., Cleophas, C., 2023. Scheduling shared passenger and freight transport on a fixed infrastructure. Eur. J. Oper. Res. 306 (3), 1158–1169. https://doi.org/10.1016/j.ejor.2022.07.043.

Jia, X., Cui, Y., 2021. Examining interrelationships of barriers in the evolution of maritime port smartification from a systematic perspective. Transp. Policy 114, 49–58. https://doi.org/10.1016/j.tranpol.2021.09.004.

Kamat, A., Shanker, S., Barve, A., 2022. Assessing the factors affecting implementation of unmanned aerial vehicles in Indian humanitarian logistics: a g-DANP approach. J. Model. Manag. https://doi.org/10.1108/JM2-02-2021-0037 ahead-of-print No. ahead-of-print.

Kashav, V., Garg, C.P., Kumar, R., Sharma, A., 2022. Management and analysis of barriers in the maritime supply chains (MSCs) of containerized freight under fuzzy environment. Research in Transportation Business & Management 43, 100793. https://doi.org/10.1016/j.rtbm.2022.100793.

Kashav, V., Garg, C.P., Kumar, R., 2023. Ranking the strategies to overcome the barriers of the maritime supply chain (MSC) of containerized freight under fuzzy environment. Ann. Oper. Res. 324, 1223–1268. https://doi.org/10.1007/s10479-021-04371-y.

Kasliwal, A., Furbush, N.J., Gawron, J.H., McBride, J.R., Wallington, T.J., De Kleine, R. D., Kim, H.C., Keoleian, G.A., 2019. Role of flying cars in sustainable mobility. Nat. Commun. 10, 1555. https://doi.org/10.1038/s41467-019-09426-0.

Kellermann, R., Biehle, T., Fischer, L., 2020. Drones for parcel and passenger transportation: a literature review. Transp. Res. Interdiscip. Perspect. 4, 100088. https://doi.org/10.1016/j.trip.2019.100088.

Kiba-Janiak, M., Thompson, R., Cheba, K., 2021. An assessment tool of the formulation and implementation a sustainable integrated passenger and freight transport strategies. An example of selected European and Australian cities. Sustain. Cities Soc. 71, 102966. https://doi.org/10.1016/j.scs.2021.102966.

Kleinbekman, I.C., Mitici, M.A., Wei, P., 2018. eVTOL arrival sequencing and scheduling for on-demand urban air mobility. In: 2018 IEEE/AIAA 37th Digital Avionics Systems Conference (DASC), pp. 1–7. https://doi.org/10.1109/DASC.2018.8569645.

Li, Z., Shalaby, A., Roorda, M.J., Mao, B., 2021. Urban rail service design for collaborative passenger and freight transport. Transport. Res. E Logist. Transport. Rev. 147, 102205. https://doi.org/10.1016/j.tre.2020.102205.

Liberacki, A., Trincone, B., Duca, G., Aldieri, L., Vinci, C.P., Carlucci, F., 2023. The environmental life Cycle costs (ELCC) of urban air mobility (UAM) as an input for sustainable urban mobility. J. Clean. Prod. 389, 136009. https://doi.org/10.1016/j.jclepro.2023.136009.

Lin, Z., Xie, F., Ou, S., 2020. Modeling the external effects of air taxis in reducing the energy consumption of road traffic. Transp. Res. Rec.: J. Transport. Res. Board 2674 (12), 176–187. https://doi.org/10.1177/0361198120952791.

Liu, M., Qian, Y., Hao, H., Liu, Z., Zhao, F., Sun, X., Xun, D., Gao, S., Geng, J., 2022. CO2 emissions from electric flying cars: impacts from battery specific energy and grid emission factor. eTransportation 13, 100189. https://doi.org/10.1016/j.etran.2022.100189.

Long, Q., Ma, J., Jiang, F., Webster, C.J., 2023. Demand analysis in urban air mobility: a literature review. J. Air Transport. Manag. 112, 102436. https://doi.org/10.1016/j.jairtraman.2023.102436.

Luo, Y., Qian, Y., Zeng, Z., Zhang, Y., 2021. Simulation and analysis of operating characteristics of power battery for flying car utilization. eTransportation 8, 100111. https://doi.org/10.1016/j.etran.2021.100111.

Luthra, S., Mangla, S.K., Chan, F.T.S., Venkatesh, V.G., 2018. Evaluating the drivers to information and communication technology for effective sustainability initiatives in supply chains. Int. J. Inf. Technol. Decis. Making 17 (1), 311–338. https://doi.org/10.1142/S0219622017500419.

Mahtani, U.S., Garg, C.P., 2018. An analysis of key factors of financial distress in airline companies in India using fuzzy AHP framework. Transport. Res. Pol. Pract. 117, 87–102. https://doi.org/10.1016/j.tra.2018.08.016.

Marcucci, E., Le Pira, M., Carrocci, C.S., Gatta, V., Pieralice, E., 2017. Connected shared mobility for passengers and freight: investigating the potential of crowdshipping in urban areas. In: 2017 5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS), 17097872. https://ieeexplore.ieee.org/abstract/document/8005629/references#references.

Marx, P., Manaugh, K., 2022. Flying cars and boring companies: interrogating the feasibility of the transport futures of tech executives. Futures 136, 102880. https://doi.org/10.1016/j.futures.2021.102880.

Melo, S.P., Cersas, F., Barke, A., Thies, C., Spengler, T.S., Herrmann, C., 2022. Life Cycle Engineering Modelling Framework for batteries powering electric aircrafts – the contribution of eVTOLs towards a more sustainable urban mobility. Procedia CIRP 105, 368–373. https://doi.org/10.1016/j.procir.2022.02.061.

Mofolasayo, A., 2020. Potential policy issues with flying car technology. Transp. Res. Procedia 48, 8–22. https://doi.org/10.1016/j.trpro.2020.08.002.

Nakamura, H., Kajikawa, Y., 2018. Regulation and innovation: how should small unmanned aerial vehicles be regulated? Technol. Forecast. Soc. Change 128, 262–274. https://doi.org/10.1016/j.techfore.2017.06.015.

Nehk, N., Tiberius, V., Kraus, S., 2021. Urban air mobility: projections for air taxis. Int. J. Innovat. Technol. Manag. 18 (7), 2150033. https://doi.org/10.1142/S0219877021500334.

Nocera, S., Pungillo, G., Bruzzone, F., 2021. How to evaluate and plan the freight-passengers first-last mile. Transp. Policy 113, 56–66. https://doi.org/10.1016/j.tranpol.2020.01.007.

Pan, Z.F., An, L., Wen, C.Y., 2019. Recent advances in fuel cells based propulsion systems for unmanned aerial vehicles. Appl. Energy 240, 473–485. https://doi.org/10.1016/j.apenergy.2019.02.079.

Parker, M.E.G., Li, M., Bouzaghrane, M.A., Obeid, H., Hayes, D., Frick, K.T., Rodriguez, D.A., Sengupta, R., Walker, J., Chatman, D.G., 2021. Public transit use in the United States in the era of COVID-19: transit riders' travel behavior in the COVID-19 impact and recovery period. Transp. Policy 111, 53–62. https://doi.org/10.1016/j.tranpol.2021.07.005.

Pavel, M.D., 2022. Understanding the control characteristics of electric vertical take-off and landing (eVTOL) aircraft for urban air mobility. Aero. Sci. Technol. 125, 107143. https://doi.org/10.1016/j.ast.2021.107143.

Pons-Prats, J., Živojinović, T., Kuljanin, J., 2022. On the understanding of the current status of urban air mobility development and its future prospects: commuting in a flying vehicle as a new paradigm. Transport. Res. E Logist. Transport. Rev. 166, 102868. https://doi.org/10.1016/j.tre.2022.102868.

Poudeh, H.D., Cheshmberah, M., Torabi, H., Gavareshki, M.H.K., Hosnavi, R., 2019. Determining and prioritizing the factors influencing the outsourcing of Complex Product Systems R&D projects employing ANP and grey-DEMATEL method (case study: aviation Industries Organization, Iran). Technol. Soc. 56, 57–68. https://doi.org/10.1016/j.techsoc.2018.09.005.

Prakasha, P.S., Naeem, N., Ratei, P., Nagel, B., 2022. Aircraft architecture and fleet assessment framework for urban air mobility using a system of systems approach. Aerospace Sci. Technol. 125, 107072. https://doi.org/10.1016/j.ast.2021.107072.

Pukhova, A., Llorca, C., Moreno, A., Staves, C., Zhang, Q., Moeckel, R., 2021. Flying taxis revived: can Urban air mobility reduce road congestion? Journal of Urban Mobility 1, 100002. https://doi.org/10.1016/j.urbmob.2021.100002.

Qian, Y., Wei, Y., Kong, D., Xu, H., 2021. Experimental investigation on motor noise reduction of Unmanned Aerial Vehicles. Appl. Acoust. 176, 107873. https://doi.org/10.1016/j.apacoust.2020.107873.

Raghuvanshi, J., Garg, C.P., 2022. Shaping the handicraft cluster through innovation capability. International Journal of Innovation Studies 6 (2), 102–117.

Raj, A., Sah, B., 2019. Analyzing critical success factors for implementation of drones in the logistics sector using grey-DEMATEL based approach. Comput. Ind. Eng. 138, 106118. https://doi.org/10.1016/j.cie.2019.106118.

Rajendran, S., Srinivas, S., 2020. Air taxi service for urban mobility: a critical review of recent developments, future challenges, and opportunities. Transport. Res. E Logist. Transport. Rev. 143, 102090. https://doi.org/10.1016/j.tre.2020.102090.
Rajendran, S., Srinivas, S., Grimshaw, T., 2021. Predicting demand for air taxi urban aviation services using machine learning algorithms. Journal of Air Transport Management,Vol 92, 102043. https://doi.org/10.1016/j.jairtraman.2021.102043.
Rajendran, S., Zack, J., 2019. Insights on strategic air taxi network infrastructure locations using an iterative constrained clustering approach. Transport. Res. E Logist. Transport. Rev. 128, 470–505. https://doi.org/10.1016/j.tre.2019.06.003.
Rajesh, R., Ravi, V., 2015. Modeling enablers of supply chain risk mitigation in electronic supply chains: a Grey–DEMATEL approach. Comput. Ind. Eng. 87, 126–139. https://doi.org/10.1016/j.cie.2015.04.028.
Rawat, A., Garg, C.P., 2023. Modeling the strategies to accelerate the natural gas business market growth in a developing country. J. Bus. Ind. Market. 38 (5), 1116–1134.
Rese, A., Baier, L.G.D., 2020. Chatbots in retailers' customer communication: how to measure their acceptance? J. Retailing Consum. Serv. 56, 1–14. https://doi.org/10.1016/j.jretconser.2020.102176.
Rice, S., Winter, S.R., Crouse, S., Ruskin, K.J., 2022. Vertiport and air taxi features valued by consumers in the United States and India. Case Stud. Transport Pol. 10 (1), 500–506. https://doi.org/10.1016/j.cstp.2022.01.010.
Rothfeld, R., Fu, M., Balać, M., Antoniou, C., 2021. Potential urban air mobility travel time savings: an exploratory analysis of Munich, Paris, and san francisco. Sustainability 13 (4), 2217. https://doi.org/10.3390/su13042217.
Sahu, A., Agrawal, S., Garg, C.P., 2023. Measuring circularity of a manufacturing organization by using sustainable balanced scorecard. Environ. Sci. Pollut. Control Ser. 1–15.
Shao, Q., Shao, M., Lu, Y., 2021. Terminal area control rules and eVTOL adaptive scheduling model for multi-vertiport system in urban air Mobility. Transport. Res. C Emerg. Technol. 132, 103385. https://doi.org/10.1016/j.trc.2021.103385.
Shepherd, S., Bonsall, P., Harrison, G., 2012. Factors affecting future demand for electric vehicles: a model based study. Transp. Policy 20, 62–74. https://doi.org/10.1016/j.tranpol.2011.12.006.
Shin, E.J., 2020. Commuter benefits programs: impacts on mode choice, VMT, and spillover effects. Transp. Policy 94, 11–22. https://doi.org/10.1016/j.tranpol.2020.05.001.
Shvetsov, A.V., Shvetsova, S.V., 2021. A method for managing the route of an unmanned aerial vehicle. Russ. Aeronaut. 64, 142–145. https://doi.org/10.3103/S1068799821010190.
Takacs, A., Haidegger, T., 2022. Infrastructural requirements and regulatory challenges of a sustainable urban air mobility ecosystem. Buildings 12 (6), 747. https://doi.org/10.3390/buildings12060747.
Talebian, A., Zou, B., 2015. Integrated modeling of high performance passenger and freight train planning on shared-use corridors in the US. Transp. Res. Part B Methodol. 82, 114–140. https://doi.org/10.1016/j.trb.2015.10.005.
Torija, A.J., Clark, C., 2021. A psychoacoustic approach to building knowledge about human response to noise of unmanned aerial vehicles. Int. J. Environ. Res. Publ. Health 18 (2), 682. https://doi.org/10.3390/ijerph18020682, 2021.
Torija, A.J., Chaitanya, P., Li, Z., 2021. Psychoacoustic analysis of contra-rotating propeller noise for unmanned aerial vehicles. J. Acoust. Soc. Am. 149, 835. https://doi.org/10.1121/10.0003432.
Xie, Y., Savvarisal, A., Tsourdos, A., Zhang, D., Gu, J., 2021. Review of hybrid electric powered aircraft, its conceptual design and energy management methodologies. Chin. J. Aeronaut. 34 (4), 432–450. https://doi.org/10.1016/j.cja.2020.07.017.
Yun, W.J., Jung, S., Kim, J., Kim, J.H., 2021. Distributed deep reinforcement learning for autonomous aerial eVTOL mobility in drone taxi applications. ICT Express 7 (1), 1–4. https://doi.org/10.1016/j.icte.2021.01.005.

Dr. Vishal Kashav currently holds the position of Assistant Professor at Energy and Transportation Cluster, School of Business, UPES, Dehradun Uttarakhand, India – 248,007. His expertise lies in the fields of Supply Chain Management, Maritime Logistics, Sustainability, and Decision Sciences, as evidenced by his publication of 10 research papers in renowned international journals. Prior to join academia, Dr. Vishal served as a consultant and researcher in the corporate sector for approx. 8 years. He obtained his doctorate in supply chain management from the University of Petroleum and Energy Studies, India, and holds an MBA in Ports and Shipping from the same institution. He earned a Bachelors degree in Shipping with a sub-specialization in Multi-modal Transportation from AMET University, India. Additionally, Dr. Vishal has successfully completed two diploma courses in Transport Economics, and in Multi-modal Transportation, offered by the Ministry of Railways, Government of India.

Chandra Prakash Garg** is working as an Assistant Professor at Indian Institute of Management, Rohtak - India. His current areas of research are Transportation research, Aviation Management Sustainability, Maritime Supply Chains, E-Waste Management, Reverse Logistics, Green Supply Chain Management, and Inventory Control. He has completed Masters in Mathematics and an MBA degree as well. He obtained Doctor of Philosophy from Indian Institute of Technology Roorkee, India. He has published more than 45 research papers in reputed journals and conferences.