Exploring opportunities and challenges for aerial drones at the interface of warehouse and last-mile delivery operations

International Journal of Physical Distribution & Logistics Management

1041

Mujtaba Hussain, Rico Merkert and Michiel C.J. Bliemer
School of International Business, Logistics and Supply Chains, The University of Sydney Business School, Sydney, Australia

Received 13 May 2025
Revised 20 October 2025
25 May 2026
8 July 2026
11 July 2026
Accepted 11 July 2026

Abstract

Purpose – This paper investigates the technological, organizational and environmental factors that shape the adoption of aerial drone operations at the warehouse–last-mile delivery interface, addressing benefits and barriers of drone adoption, most suitable functional areas, stakeholder collaboration and support of a low-altitude airspace management (LAAM) system for successful integration.

Design/methodology/approach – Drawing on the technology–organization–environment (TOE) theoretical framework, we employ a qualitative research design, analyzing data collected during semi-structured interviews with 38 managers representing warehousing companies and drone operators around the world.

Findings – Successful drone integration in retail logistics depends not only on one firm's technology, organization and external context, but also on a collaborative effort across the supply chain. While drones offer clear benefits in logistics, full-scale adoption requires inter-organizational ecosystem coordination (and, depending on the governance structure, also collaboration) to overcome challenges such as infrastructural readiness and regulatory coordination.

Practical implications – Examining operations at the interface of warehouse operations and last-mile delivery yields management insights that can drive effective strategies for implementing drones. Building on the TOE framework, we conceptualize inter-organizational ecosystem coordination as a critical enabler of drone integration and innovation adoption in logistics. Based on our findings, we suggest that drone operators should integrate more deeply into logistics services rather than focusing solely on delivery, and warehouses should explore current uses for drone technology rather than simply considering future applications. We identify three governance models for integrating drones into logistics ecosystems: vertical integration, inter-organizational collaboration and partial adoption with intra-organizational collaboration.

Originality/value – We contribute to the evolving understanding of technology adoption and drone integration at the warehouse–last-mile delivery interface by examining managers' perspectives for the first time. Extending the application of TOE from the firm level to inter-organizational coordination better captures infrastructural enablers of innovation adoption and active collaboration between organizations in logistics operations.

Keywords Aerial drones, Last-mile delivery, Warehouse operations, Technology–Organization–Environment (TOE) theory, Vertical integration, Inter-organizational coordination, Innovation adoption

Paper type Research article

1. Introduction

The retail landscape is undergoing a significant transformation driven by technological advancements, which are reshaping fulfillment models and customer expectations (Ta *et al.*, 2025). Demand for warehousing and last-mile delivery has grown substantially in recent years, driven by e-commerce, globalization and the increasing complexity of retail supply chain networks. With consumers expecting quick delivery, often within one or two hours (Snoeck *et al.*, 2023; Zhang *et al.*, 2019), warehouse managers need innovative technologies that can

International Journal of Physical Distribution & Logistics Management
Vol. 56 No. 8, 2026
pp. 1041-1072
Emerald Publishing Limited
e-ISSN: 1758-664X
p-ISSN: 0960-0035
DOI 10.1108/IJPDLM-05-2025-0232

reduce excess inventory and ensure precision (Arkabaev *et al.*, 2024). For retail warehousing, margins are low (Principal Logistics Technologies, 2015; Sides and Skelly, 2021); thus, maintaining a competitive edge requires minimizing operational costs and delivery time (Companik *et al.*, 2018). As retail supply chains grow increasingly complex, third- and fourth-party logistics (3PL/4PL) providers have emerged as important enablers of retail fulfillment, managing warehousing and last-mile delivery. To ensure sustained competitive advantage, 3PL/4PL providers aim to remove bottlenecks from their supply chains. This puts operational efficiency at the core of their warehousing strategies, especially for providers seeking to eliminate inefficiencies and streamline internal logistics.

Aerial drones have great potential to increase operational efficiency and could fundamentally change warehouse operations and last-mile delivery (Filiopoulou *et al.*, 2025). In practice, however, early efforts to use drones in retail logistics have been highly fragmented. This has resulted in an industry characterized by siloed trials rather than a cohesive network. Large firms such as IKEA have begun deploying autonomous drones for inventory counting in their warehouses (Maghazei *et al.*, 2022). Likewise, DHL has pioneered drone deliveries with its Parcelcopter trials, collaborating with Microdrones to deliver pharmaceuticals in Germany (Yigit *et al.*, 2024). While these examples demonstrate the ability of drones to enhance logistics performance on a larger scale, such implementations remain sparse. Moreover, initiatives such as Amazon's drone delivery arm Prime Air have faced significant challenges, including regulatory hurdles, technical limitations and high operational costs, leading to multiple site closures (Palmer, 2023). Therefore, a lack of clarity persists around the economic feasibility and real-world applicability of aerial drones across integrated supply chain processes (Merkert and Bushell, 2020).

Existing research on drones in logistics has tended to emphasize consumer perception (Merkert *et al.*, 2022), technical performance and algorithmic optimization (e.g. Mourtzis *et al.*, 2024), with comparatively limited attention to drones as viable business tools embedded in warehouse and delivery operations. As a result, scholarly understanding remains fragmented regarding how drones are perceived, evaluated and adopted by warehouse operators and drone service providers, particularly at the organizational interface between these actors. This represents a consequential gap, given the interdependence of warehousing and last-mile delivery services in shaping the operational and organizational feasibility of drone adoption across retail supply chains.

While empirical studies have examined drone applications in retail warehousing and last-mile delivery as largely discrete domains (Kembro and Norrman, 2022; Maghazei *et al.*, 2022; Merkert *et al.*, 2022; Perotti *et al.*, 2022), integrative analyses spanning these contexts remain scarce. In particular, the B2B operational interface governing coordination between warehouse operators and drone service providers, encompassing both intra-warehouse activities and outbound last-mile delivery processes, has received limited scholarly attention. This omission is nontrivial, as successful drone integration requires coordinated decision-making across multiple organizational boundaries and operational domains.

To address this gap, our study examines aerial drone technology adoption and feasibility of collaborative processes at the B2B warehouse–delivery operations interface of the retail supply chain from a dual-stakeholder perspective, encompassing both warehouse operators and aerial drone-based last-mile delivery providers. Drawing on the technology–organization–environment (TOE) theoretical framework, we investigate how TOE factors shape functional adoption within warehouses, coordination across delivery operations and the organizational arrangements required for effective drone implementation at this interface, with implications for the performance of retail last-mile delivery systems.

Our research is grounded in the TOE framework, which provides a structured approach for examining technological innovation at the organizational level (Baker, 2011). While alternative theories, such as diffusion of innovation or the unified theory of acceptance and use of technology (UTAUT), primarily emphasize individual user adoption, the TOE framework focuses on organizational decision-making. This enables systematic identification and analysis of the technological, organizational and environmental factors that influence adoption outcomes at a broader, inter-organizational scale (Awa *et al.*, 2017; Benchis *et al.*, 2025; Tornatzky and Fleischer, 1990).

The TOE framework has been applied across various industries to explore technology adoption. Prior studies have employed TOE to examine warehouse automation (Ali *et al.*, 2021), supply chain blockchain adoption (Benchis *et al.*, 2025; Chittipaka *et al.*, 2023), enterprise resource planning systems (Awa *et al.*, 2017) and cross-country organizational studies (Malik *et al.*, 2022). However, traditional applications of the TOE framework have predominantly adopted a firm-centric perspective, focusing on technological innovation and adoption within individual organizations (Baker, 2011). For instance, studies applying TOE to drone technologies and warehouse automation have primarily examined adoption decisions at the level of single firms (Ali *et al.*, 2024; Maghazei *et al.*, 2022). These studies emphasize how organizations assess technological readiness, organizational capacity and environmental pressures when deploying autonomous systems within their own operations. In contrast, this single-firm focus overlooks the critical B2B interactions between warehouse operators and drone service providers, as well as the collaborative arrangements through which technologies are implemented and operational integration is coordinated. The TOE framework is well suited to address this limitation, as it offers both theoretical grounding and empirical support across technology adoption contexts (Benchis *et al.*, 2025; Tornatzky and Fleischer, 1990). Importantly, adopting a dual stakeholder perspective enables a structured evaluation of adoption factors across organizational boundaries, extending the application of TOE beyond individual firms to examine collaborative B2B adoption dynamics in the retail supply chain and their implications for last-mile delivery.

Specifically, we identify promising use cases by examining how warehouse operators and drone service providers perceive adoption decisions and collaborative arrangements at the technological, organizational and environmental dimensions. Our focus is on the B2B segment of retail supply chains, where decisions by 3PL/4PL providers, together with drone operators, determine whether drone logistics can transition from isolated pilot projects to integrated and scalable operations. These decisions have a direct impact on warehouse processes such as dispatch readiness, inventory management and handoff coordination, as well as on the operational feasibility of drone-enabled last-mile delivery.

Our empirical analysis draws on semi-structured interviews with senior managers from large-scale warehouse operations and drone service providers primarily engaged in last-mile delivery.

We contribute to the literature in several important ways. First, to our knowledge, our study is the first to provide firsthand managerial insights from both warehouse managers and drone service providers regarding demand for and feasibility of aerial drone use at the warehouse–last-mile delivery interface in retail supply chains. Second, drawing on the TOE framework, we analyze how organizational readiness, technological constraints and external regulatory conditions jointly influence drone adoption in this inter-organizational context. Third, we offer practical implications for managers and policymakers by identifying governance and coordination structures that either facilitate or impede drone adoption at the warehouse–last-mile delivery interface.

2. Literature review

Our study focuses on drone operations management in retail warehouses and last-mile delivery, with emphasis on the operational and governance interface between operators and drone service providers, where drones support both intra-warehouse activities and downstream delivery operations.

2.1 Warehouse functions and drone operations

As retail fulfillment and distribution warehouses grow in size and complexity, traditional manual methods are becoming increasingly labor-intensive and error-prone. Drones are increasingly viewed as part of broader smart warehouse solutions, particularly when combined with technologies such as radio frequency identification (RFID) and advanced sensor systems. Drones offer significant advantages in automating various functions. For instance, Afandi *et al.* (2024) demonstrated how using drones reduces the time required for inventory tracking from 15 to 2 min. Equipped with cameras and sensors, drones can achieve high detection accuracy. With collision avoidance systems and RFID technology, drones can safely navigate across aisles. Drones now also have the ability to use advanced positioning systems to safely navigate confined warehouse environments (Geetha *et al.*, 2023).

Researchers have examined the adoption of drone technology in warehouses, but most findings are based on single case study observations (e.g. Maghazei *et al.*, 2022). There is a need for a more comprehensive framework that can help decision-makers assess the practical implementation challenges and timing of this technology adoption. Although scholars have developed theoretical models and algorithms for drone operations (e.g. Moshref-Javadi *et al.*, 2020; Mourtzis *et al.*, 2024), there is limited research on the practical challenges of implementing these systems. Current studies focus on ideal conditions rather than dynamic and complex real-world warehouse environments (Stanko *et al.*, 2022). Issues such as demand, operational requirements, operational models, payload capacity, battery life and integration with low-altitude airspace operations remain underexplored. Moreover, researchers have not fully addressed the practical integration of drones into daily operations or explored organizational, regulatory and economic constraints. Appendix A summarizes key studies on drone operations in warehousing, defined here as those that are highly cited.

2.2 Aerial drones in last-mile delivery and the B2B retail supply chain interface

Interest in drone applications has also increased in the last-mile delivery segment, largely driven by the expansion of e-commerce. Consumers are increasingly time-sensitive (Zhang *et al.*, 2021), and warehouse managers need innovative technologies to reduce delivery times and ensure precision (Kembro and Norrman, 2022). Practical examples of companies such as Walmart, Zipline, DoorDash, Manna Drones and Wing have shown that drones are not only technically viable but are starting to shape last-mile delivery practices (Merkert *et al.*, 2022).

Studies (e.g. Merkert and Bushell, 2020; Rejeb *et al.*, 2023) have emphasized the operational advantages of drones in urban and rural contexts, including faster delivery times, reduced road congestion and lower emissions. Recent research has advanced the technical foundations of drone-enabled delivery, focusing on route optimization and infrastructure planning. For example, Nguyen and Dang (2024) proposed a system that manages individual drones and swarms using advanced air traffic management and flight control systems. Building on route optimization, Chour *et al.* (2023) addressed the multi-route weighted packaged delivery problem, and Murray and Chu (2015) developed a mathematical model for drone scheduling and the optimal distribution of parcels. Complementary studies have examined infrastructure considerations. For example, Aurambout *et al.* (2019) modeled the optimal location of drone beehives, and Yurek and Ozmutlu (2018) focused on minimizing the combined delivery completion time.

Although these contributions enhance the technical feasibility of drones in last-mile delivery, most remain focused on isolated operational aspects. Very few scholars (Maghazei *et al.*, 2022; Purtell *et al.*, 2025) have explored how organizational, infrastructural and ecosystem-related factors affect the deployability of aerial drones in real-world settings. Existing research instead prioritizes business-to-consumer (B2C) applications and operational optimization. Most of the research streams focus on algorithmic optimization, routing efficiency, vehicle–drone collaborative systems, consumer acceptance and environmental sustainability (Agatz *et al.*, 2018; Boysen *et al.*, 2018; Dorling *et al.*, 2017). Consequently, the literature overlooks an important aspect: the organizational decision-making and inter-organizational coordination mechanisms that determine how such partnerships are formed and governed within the B2B segment of retail supply chains prior to last-mile distribution. This gap underscores the need for integrated frameworks that can account for multi-actor coordination, especially at warehouse–last-mile delivery interface.

The practical significance of this research gap is immediate. Drone adoption in the B2B segment of retail supply chains requires alignment between warehouse operators who manage inventory and order fulfillment operations and drone service providers who manage autonomous delivery operations (Merkert *et al.*, 2021; Purtell *et al.*, 2025). These are separate organizations with different operational needs, technical capabilities, resource limitations and business priorities (Ali *et al.*, 2024; Maghazei *et al.*, 2022). Within warehouses, initial implementation projects including stocktaking and order picking for retail/e-commerce items require close collaboration between warehouse operators and drone service providers (Maghazei *et al.*, 2022; Perotti *et al.*, 2022). The warehouse-to-delivery interface introduces additional complexity, such as determining whether the same drone fleets serve both warehouse delivery functions, as all require governance structures between warehouse operators and last-mile service providers (Hofmann *et al.*, 2019; Kellermann *et al.*, 2020). Without understanding these collaborative processes, scaling drone operations from fragmented pilots to viable commercial systems, a transition that depends on effective B2B collaboration between warehouse operators and drone service providers, remains underexplored.

2.3 Summary of research gaps

Although drones have been studied in both warehouse and last-mile delivery contexts, the literature is largely technical or algorithmic in nature, with limited exploration of real-world business feasibility. Researchers rarely examine how operational decision-makers perceive drone adoption in terms of demand, risks and implementation strategies, especially at the critical warehouse–last-mile delivery interface. Most scholars treat drone adoption as a firm-level decision that is independent from the surrounding ecosystem and inter-firm adoption dynamics. In response to calls to explore practical and innovative solutions in logistics and supply chain management (Purtell *et al.*, 2025; Rejeb *et al.*, 2023; Ta *et al.*, 2025), we evaluate the deployability of, and potential demand for, drone technology in (integrated) warehouse and last-mile delivery operations and identify potential use cases at that crucial interface. We adopt the TOE framework to examine organizational adoption of drone technology in the B2B segment of retail supply chains, focusing on the coordination interface between warehouse operators and drone operators. The TOE framework provides a structured approach to understand how technological characteristics, organizational capabilities of each party and environmental conditions interact to enable or constrain adoption and coordination. Appendix A presents an overview of key studies on drone applications in the last-mile delivery context.

3. Theoretical framework

The TOE framework (Tornatzky and Fleischer, 1990) offers a useful lens to examine factors influencing the adoption of technological innovations (Baker, 2011). It includes three dimensions that shape an organization’s ability and willingness to implement new technologies: technology, referring to the characteristics of existing and new technologies; organization, capturing firm-level structural and managerial attributes; and environment, representing external regulatory, competitive and industry conditions (Baker, 2011). By integrating these three dimensions, the TOE framework enables researchers and practitioners to systematically assess technological opportunities, evaluate firms’ internal readiness and understand external constraints. Oliveira and Martins (2011) reviewed firm-level technology adoption models and found the TOE framework most suitable for studying technology adoption, as it includes the environmental context.

From a theoretical perspective, we aim to build on the TOE framework to examine the interplay between technological, organizational and environmental factors that are important to the successful integration of drones in warehousing and last-mile delivery. Importantly, traditional applications of TOE have largely been firm-centric and focused on a single firm or organization (Baker, 2011). Despite literature on inter-firm innovation in the supply chain integration context (Wang and Zhang, 2024), evidence on the degree of coordination and collaboration at operational interfaces (e.g. warehouse management and last-mile delivery) is sparse. Moreover, the research designs of nearly half of the published studies (for an overview, see Appendix A) lack a theoretical foundation, thereby limiting the advancement of knowledge within the rapidly evolving field of drone-based systems in logistics (Garg *et al.*, 2023).

Using the TOE framework as a sensitizing lens, we structured our interview guide across three broad dimensions. To address the *technology* dimension, we explored how actors evaluate characteristics of drone technology and its existing capabilities in warehouses and delivery contexts, including perceived benefits, technical constraints and integration challenges. For the *organization* dimension, we examined firms' internal capacity to adopt drone technology, including resource availability, governance structures and organizational readiness. To address the *environment* dimension, we investigated external factors that influence drone adoption, including regulatory frameworks, industry standards, infrastructure availability and ecosystem alignment.

4. Methodology

Given the exploratory nature of drone adoption at the warehouse–last-mile delivery interface, we adopted a theory-informed inductive approach (Varpio *et al.*, 2020), using the TOE framework to structure our research design and guide data collection and analysis, while allowing themes to emerge inductively from participant responses.

4.1 Data collection

We collected data primarily via semi-structured expert interviews, using an interview guide based on the three domains of the TOE framework (Tornatzky and Fleischer, 1990). We interviewed 38 managers representing 12 logistics service providers, mainly 3PL and 4PL firms operating warehouses serving e-commerce and retail activities (see Appendix D for the interview guide) and 26 drone operators (see Appendix E for the interview guide). Participants were based across Australia, Brazil, various European and Asian countries and the USA. Our sampling strategy focused on countries and organizations leading in drone logistics innovation, targeting regions where commercial drone use is actively piloted or operational and where operators were willing to talk to us. This approach facilitated insights across diverse regulatory and operational contexts. The sample sizes of logistics service providers and drone operators differed due to purposive sampling and data saturation. Interviews with warehouse managers achieved thematic saturation early, as logistics service providers in large 3PL and 4PL environments consistently expressed similar views on the demand for drone-supported warehouse functions and last-mile integration. Consequently, additional warehouse interviews yielded limited new insights. In contrast, the drone ecosystem has significant functional and institutional diversity, including drone logistics providers, technology developers and airspace management organizations. Expanding the drone operator sample enabled us to capture varied operational roles, technological maturity and regulatory environments across different regions in the implementation phase of drones.

Our informants held strategic or operational roles with direct knowledge of drone technology, warehousing systems or last-mile logistics. Logistics participants were senior practitioners from 3PL and 4PL warehouses, with prior exposure to, or informed knowledge of, drone applications. Drone participants were managers involved in the application of drones within logistics operations, including professionals from drone start-ups, drone manufacturing firms and organizations developing commercial drone use cases. This dual-perspective enabled analysis of drone adoption across intra-warehouse operations and last-mile delivery interfaces. Through purposive sampling, we were able to recruit managers with a diverse range of perspectives. Informants were purposively selected and recruitment continued until thematic saturation was reached (Fusch and Ness, 2015). Table 1 provides details about the managers interviewed.

Following ethics approval, interviews were conducted between August 2024 and March 2025, either in person or via video conferencing, recorded with consent and transcribed verbatim. Secondary data, including industry reports and regulatory documents, were collected to support contextualization and triangulation.

4.2 Data analysis and coding

We deployed a theory-informed inductive approach (Varpio *et al.*, 2020), where the TOE framework served as a sensitizing lens for thematic analysis. The coding process commenced with TOE-aligned categories but allowed for additional codes to be created when participants' narratives extended beyond the existing framework. This approach ensured that factors not encompassed by the original TOE framework could be incorporated into the analysis.

The TOE framework provided a general structure without predetermining specific findings, enabling representatives of both warehousing companies and drone operators to share their experiences within these theoretical dimensions. The TOE framework was "let in" during interpretation to help organize the inductively derived themes around technological, organizational and environmental dimensions, while ensuring informants' voices and unexpected findings could emerge organically (Nguyen *et al.*, 2022). Open-ended questions within the TOE structure allowed for unexpected insights to surface about technology adoption benefits, organizational challenges and environmental factors. This theory-informed inductive approach aligns with recent methodological guidance advocating for flexible application of theoretical frameworks in qualitative research (McGowan *et al.*, 2020; Proudfoot, 2023), allowing theoretical insights to guide analysis while remaining open to emergent themes that may extend beyond existing frameworks (Sarraf-Yazdi *et al.*, 2024).

To identify and categorize recurring themes and patterns, we analyzed the collected data using NVivo software and Python (Maher *et al.*, 2018; Saldaña, 2021). Interview transcripts were anonymized and imported into NVivo. Python was used as a complementary tool to organize coded outputs, support comparison across categories and assist in grouping governance models based on economic, operational and infrastructure-related factors. Intercoder reliability was established through a collaborative coding process involving the researcher and two high-level supervisors. Emerging codes and thematic interpretations were regularly reviewed and discussed, with discrepancies addressed through iterative dialogue and refinement of the coding framework until consensus was achieved.

We thematically analyzed our data by following the coding process proposed by Braun and Clarke (2006). We first familiarized ourselves with the transcripts, generated initial codes and iteratively grouped these into higher-order themes aligned with the TOE dimensions. Themes were then reviewed and refined to ensure internal coherence and conceptual clarity. To improve transparency in how participant insights were organized and presented, the resulting coding hierarchy was structured in a manner consistent with the data organization logic of Gioia *et al.* (2013). This iterative process resulted in the thematic structure presented in Appendix B, mapping themes to TOE dimensions and emergent sub-themes. Figure 1 illustrates the coding progression using selected sample quotes, from initial codes to refined themes.

We also applied the following strategies to ensure rigor:

(1) *Triangulation:* We collected data from multiple sources (logistics service providers and drone operators; primary and secondary data) to enhance the credibility and validity of our study (Meydan and Akkaş, 2024).

Table 1. Description of 38 informants

ID[a]	Role	Organization type	Duration of interview	Country
Logistics service providers				
W-1-A	Supply chain lead	Retail supply chain (3PL)	33 min	UAE
W-2-B	Logistics manager	Retail supply chain (3PL/4PL)	53 min	Australia
W-3-C	Program manager	Retail supply chain (3PL/4PL)	35 min	Australia
W-4-D	Solutions design manager	Retail supply chain (3PL/4PL)	48 min	Australia
W-5-E	Founder	Retail supply chain (3PL/4PL)	51 min	Australia
W-6-F	Solutions design manager	Retail supply chain (3PL/4PL)	53 min	Australia
W-7-G	Sales director	Retail supply chain (3PL)	44 min	Romania
W-8-H	Supply chain manager	Retail supply chain (3PL/4PL)	40 min	Singapore
W-9-I	Procurement manager	Retail supply chain (3PL)	49 min	Sri Lanka
W-10-J	Procurement analyst	Retail supply chain (3PL)	42 min	Australia
W-11-K	Logistics lead	Retail supply chain (3PL)	46 min	Australia
W-12-L	Logistics manager	Retail supply chain (3PL/4PL)	58 min	USA
Drone operators				
D-1-A	CEO and founder	Logistics and delivery	52 min	Australia
D-2-B	Acquisitions manager	Logistics and delivery	40 min	Australia
D-3-C	CEO and founder	Logistics and delivery	35 min	Australia
D-4-D	Partner	Logistics and delivery	50 min	Finland
D-5-E	Executive leader	Logistics and delivery	56 min	Australia
D-6-F	Founder	Logistics and delivery	49 min	Australia
D-7-G	Airspace mobility solutions	Airspace management and drone traffic systems	46 min	Australia
D-8-H	Founder	Logistics and delivery	51 min	USA
D-9-I	Partnerships manager	Airspace management and drone traffic systems	51 min	USA
D-10-I	Commercial growth manager	Airspace management and drone traffic systems	49 min	Singapore
D-11-G	Director market development	Airspace management and drone traffic systems	48 min	Australia
D-12-J	Corporate sales manager	Logistics and delivery	44 min	New Zealand
D-13-K	Innovation manager	Logistics and delivery	59 min	Australia
D-14-G	Innovation manager	Airspace management and drone traffic systems	40 min	Singapore
D-15-L	CEO and founder	Logistics and delivery	48 min	Australia
D-16-M	Technical director, avionics	Airspace management and drone traffic systems	57 min	Australia
D-17-N	CEO	Logistics and delivery	57 min	USA
D-18-O	Supply chain manager	Logistics and delivery	50 min	Australia
D-19-P	Founder and CTO	Airspace management and drone traffic systems	59 min	Israel
D-20-Q	Senior manager	Airspace management and drone traffic systems	43 min	Belgium
D-21-R	Team lead and logistics	Logistics and delivery	42 min	Switzerland
D-22-S	CEO and founder	Logistics and delivery	49 min	Australia
D-23-T	Chair	Logistics and delivery	53 min	Australia
D-24-U	President and founder	Logistics and delivery	44 min	Brazil
D-25-V	CEO and founder	Logistics and delivery	55 min	Australia
D-26-W	Founder	Logistics and delivery	49 min	Australia

Note(s): [a]W-1-A = warehousing company A; D-1-A = drone operator A
Source(s): Authors' own work

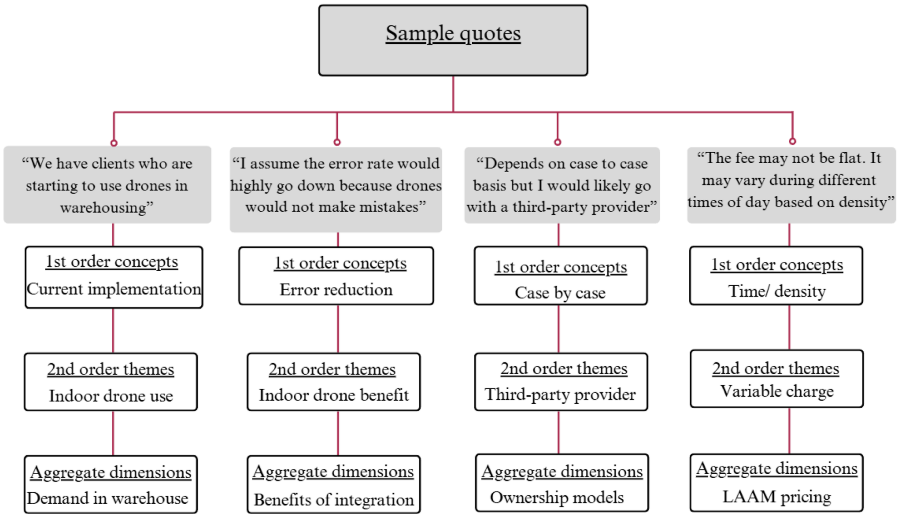

Figure 1. Coding process from sample quotes to selective codes. Source: Authors' own work

(2) *Saturation:* We interviewed representatives of relevant firms in the industry, and our sample size was determined by conceptual saturation.

(3) *Audit trail:* We maintained detailed memos in NVivo during coding and theme development.

(4) *Transparency:* We documented our coding framework and interpretation steps.

(5) *Reflexivity:* We minimized interviewer bias by employing bracketing and consistent protocols.

5. Findings

Table 2 presents a synthesis of the thematic findings derived from the 38 interviews, organized around the TOE framework. Each dimension captures the key themes, subthemes and illustrative quotes that emerged from the data, alongside summarized findings. The following sections discuss each identified theme in turn, beginning with demand assessment within warehouse environments.

5.1 Technological dimension

5.1.1 Perceived demand inside warehouses. Most informants confirmed the potential to adopt drones for warehouse functions, agreeing that drones have emerged as a transformative technology. By automating repetitive tasks and reducing human error, drones offer a cost-effective solution for 3PL and 4PL warehouses. Several companies already have advanced projects in development, with demonstrations taking place as early as four years ago (in 2025) (informant D-20-Q). Drone pilot programs for warehouse automation and systems integration were implemented as early as 2016 (W-8-H). Acknowledging potential applications, one CEO said their company had invested in drone testing with cameras and engineering support and was conducting proof-of-concept studies with 2–3 customers: "*The concept was proven; it was more about how we make it compelling to actually roll this out*" (W-5-E). Operators said drones were found to be very useful for verifying inventory (W-8-H). They were open to drone

Table 2. Mapping of TOE framework dimensions to identified factors and examples

Themes	Subthemes	Findings from interviews	Illustrative quotes/sources
Technological (T)			
Perceived demand inside warehouses	Perceived usefulness, automation potential, high labor cost	Optimism about drones for inventory scanning and intra-organizational logistics, especially in large warehouses	*"We have clients who are increasingly adopting aerial drones in warehousing. As large companies like Amazon establish themselves, they will definitely be implementing drones for stocktaking operations."*
Perceived benefits/ key functional areas inside warehouses	*Perceived benefits* Automating repetitive tasks, reducing human error, cost-effective, Warehouse Management System integration	Benefits include higher accuracy, speed and cost reduction Primary applications: stocktaking, cycle counting, item retrieval, and shelf audits	*"Your biggest cost is manpower. One of the biggest downsides to that is inventory accuracy, and I think that is where the drones are currently playing a big role in being able to quickly and efficiently scan high rise pallets or stock."*
	Functional operations Stocktake, cycle counting, item picking, shelf audits		*"Drones are proven to be useful, not just for stocktaking but also for quickly locating items and improving inventory flow."*
Perceived barriers inside warehouses	Multi-layer pallet difficulty, battery life, payload limits, operator proximity safety	Conventional multi-layer pallet layouts are difficult to scan; safety risks persist in mixed human–drone environments	*"Irrespective of how automated a warehouse is, you would still have operators on the floor, and drones operating within the warehouse is a risk."*
Perceived demand for last-mile delivery	Defined delivery radius, flights per hour, hub proximity to retail, standardized parcel boxes	Strong support in rural/ suburban areas; drone providers extend value chain beyond transport into logistics	*"We build bridges between points, so we have point A, point B and there is an air corridor that connects these points. So, it's like a hub-to-hub approach.*"
Perceived benefits and barriers for last-mile delivery	*Perceived benefits* Speed, cost reduction, reduced congestion	Usefulness tied to reduced congestion and faster delivery Limited urban viability due to airspace and regulatory challenges	*"As we use the technology more and we apply it to the logistics sector, it will build up to arrive as close as possible to people's homes. Without noise and privacy concerns and very fast.*"
	Perceived barriers Privacy, infrastructure, connectivity, regulation, low battery capacity		*"The problem with doorstep delivery is of course infrastructure. It's not every house you can go to, and you cannot deliver at anybody's door.*"

(*continued*)

Table 2. Continued

Themes	Subthemes	Findings from interviews	Illustrative quotes/sources
Organizational (O)			
Operator's expertise	Operator skillsets, technology readiness, regulatory alignment, qualified trainers	Skills gap identified; logistics firms often lack technical frameworks; profitable operations depend on vertical integration or collaboration	*"We have achieved 30,000 flights this year with no accidents; the cost is a fraction of alternatives."*
Governance models	*Governance and ownership models* In-house vs outsourced operations, collaboration at the interface, economic factors, operational factors *Management priorities* Internal organization and management priorities, ROI	Large 3PLs prefer internal integration; smaller firms explore partnerships. Hybrid docking-station models are emerging	*"Offering drone operations as a service would be beneficial – the provider acts just like any other carrier."* *"Top-management support and ROI are critical in shaping adoption strategy. Our throughputs are significant. For us, the investment is not so much the bottleneck, it's more where's the benefit to the customer rather than just throughput."*
Environmental (E)			
Low-altitude operations and emerging case for LAAM systems	*Low-altitude management system* Airspace traffic management, fee structure, economic feasibility, geofencing *Infrastructure availability* BVLOS, vertiports, air corridors, geolocation	Commercial drone traffic requires national-level air traffic control or tolling systems; standardized BVLOS approvals and air corridors urgently needed	*"In Brazil we have 172,000 drones registered – the only way to manage that is an intelligent system."* *"Multiple UTM systems that compete between themselves because you want to have economy competition like pricing service. Quick in response and having a very smart algorithm that can change the route"*
	Regulatory frameworks Regulatory constraints, government policies, airspace rules, drone corridor approvals		*"There definitely needs to be clear regulations for people to fly aircraft, unmanned aircraft and drones. And at the moment that is not clear."*
Need for ecosystem level standards and coordination across warehousing and delivery	Collaborative governance, complexity of drone approvals and certification requirements, ongoing support for technology advancement, shared airspace systems	National drone operating standards needed inside and outside warehouses; siloed innovation must evolve toward shared infrastructure and collaboration	*"We've got great technology and capable teams. However, most warehouses don't really know how drones fit into their operations yet, so we end up running our own trials. We hope collaboration comes as the industry matures."*

Source(s): Authors' own work

adoption for warehouse operations and cited labor shortages as a major challenge that drones could address (W-7-G).

Drone adoption is also influenced by the scale and complexity of warehouse operations. Larger facilities with higher throughput have greater incentives to integrate automation for cost savings: "*It depends on the scale of your manufacturing. If the scale is large, then definitely you need to have innovative technologies. You need to keep your inventory in an order where drones can go and scan the inventory*" (W-1-A). Moreover, most small- and medium-size enterprises are likely to become subcontractors of a 3PL provider. Companies like Google Wing, OK and Amazon are particularly well placed to be 4PL providers, as they have their own warehouses and fulfillment centers (D-7-G) where drones are most suited for stocktaking. Furthermore, regulatory changes in the USA and Australia in 2025 and 2026 are making indoor drone operations more feasible:

> We have clients who are starting to use drones in warehousing more. As more and more larger companies come to Perth, like Amazon, they will definitely be using drones to do the stocktake part. It's only in the last 12 months I have seen CASA [Australia's Civil Aviation Safety Authority] come along and saying, "Yes, there is a different set of rules for aircraft which are flying inside in an enclosed space" (D-3-C).

5.1.2 Perceived benefits and key functional areas inside warehouses. Discussions about the implementation of drones in warehouses were guided by the technological dimension of the TOE framework. Operators indicated that the primary functional applications for drones in warehouses are stocktaking, inventory cycle counting, item retrieval and shelf audits. These functions are labor-intensive and are important in inventory management. A logistics team lead explained: "*In our operations, one of the biggest challenges is aligning physical inventory with system records, especially in our case like fast-moving environments. There have been instances where a SKU couldn't be found, despite being shown in the system*" (W-12-L). Drones could also assist in small item order picking or transferring small parts between warehouse zones (Thomaidis and Zeimpekis, 2024). This would reduce reliance on manual labor for time-consuming tasks (W-11-K). Operators emphasized that in regions like Australia, where labor costs are high, automation can help reduce high operational costs for warehouses (W-2-B).

> A key challenge in warehouse management is the efficient utilization of storage space. Idle stock impacts profitability because warehouse space is a major cost. Traditional warehouses are aware of this, but many are still reluctant to adopt automation. (. . .) Drones are proven to be useful, not just for stocktaking but also for quickly locating items and improving inventory flow (W-12-L).

A supply chain manager described their experience integrating drones into warehouse operations systems. Warehouses at clients' sites require regular verification of stock accuracy in terms of total stock, pallet locations and SKU details. Tasks include weekly stocktakes (subsets of stock), full stocktakes (2x/year) and identifying obsolete stock and shrinkage. These activities are typically done by hand and are very labor-intensive. Now, autonomous drones are used to map pallet positions by scanning and taking images of each aisle. Pallet IDs are obtained from barcodes in these images and compared against warehouse management system (WMS) data. A drone can check 3,000–4,000 pallets per day and operate outside normal operating hours. This amounts to substantial cost savings, as the annual cost of a stock counting employee can be up to USD 80,000 (in any jurisdiction). Drones can also record images as proof of product condition, collect additional data on pallet or racking conditions, ensure additional surveillance to minimize product theft and scan inventory at high speed (W-8-H).

Warehouse operators emphasized that the successful integration of drones depends on technological compatibility with existing warehouse management systems (D-6-F). A CEO and founder introduced the concept of a 4PL warehouse ecosystem, where aerial drones work in coordination with ground-based robots:

> Eight years ago, you were looking at 20 minutes maximum for a drone, now you have got 50 minutes of flight time. The drones can pick up all the data and the robot on the ground is moving along with it as a charging station. You are getting live data 24/7 (D-3-C).

Some drone operators further highlighted the potential application of drones for order picking, although they acknowledged that this would require more complex integration into warehouse operations compared to inventory management (D-4-D). They also mentioned that drones could be used for small item picking or internal warehouse transfers (D-16-M).

5.1.3 Perceived barriers inside warehouses. Despite the potential of drones in 3PL/4PL warehouse operations, managers revealed several challenges. Technical limitations in barcode reading and quantity verification present challenges for accurate stock counting (W-4-D). Unless drones can achieve the required accuracy in quantity verification, warehouse operators are reluctant to invest in the technology (W-4-D). They explained that while drones can read front-facing barcodes, they might struggle to count items in multi-layer pallets (D-5-E). Warehouse operators also emphasized the importance of integrating drones with existing WMS to ensure the technology is effective (W-2-B). For instance, DHL closed its Parcelcopter division due to such technical constraints:

> Flying the drone is one aspect, but you have a camera capturing the images. How it captures the images and how does it compare with the WMS data is always a bit more challenging. The technology has been tested. There are a lot of discussions going on about implementing it. We might implement it on a full scale at some point of time, but we are not there yet (D-13-K).

Informants also highlighted infrastructural challenges, including current warehouse layouts and storage methods. In conventional layouts, items are stacked in multiple layers on pallets, which are difficult to lift with drones (W-9-I). Facilities must be redesigned to maximize the benefits of drone technology. A partnerships manager also pointed out environmental issues in traditional warehouses:

> What if you have a powerful HVAC system because it is a chilled warehousing environment, and all of a sudden you have got air blasting from the top affecting the drone? There are just so many environmental conditions that make it complex (D-9-I).

Challenges of battery life and payload limitations have also stalled full commercial deployment: "*We had a few challenges from a safety perspective. We also faced issues with battery life and payload. Flying a drone is not as simple as people might think*" (W-5-E). Safety considerations and operator proximity within confined spaces were also mentioned as significant barriers:

> Within the four walls of a warehouse, it would be a difficult case. Irrespective of how automated a warehouse is, you would still have [human] operators on the floor, and drones operating within the warehouse in proximity to workers might have some health and safety concerns (W-3-C).

Although six managers remained skeptical of drone deployment within warehouses, all managers acknowledged growing demand for last-mile delivery via drones, especially for e-commerce goods and food items. They expressed confidence that drone delivery systems are already being implemented and are expected to scale rapidly in the near future. Where drones are unconstrained by high-density urban environments and traffic congestion, they can provide rapid, on-demand delivery. This capability is becoming increasingly important since customers now prioritize speed and reliability for last-mile fulfillment. Although scholars have examined drone delivery from a customer perspective in detail, demand from the supply side remains underexplored (Maghazei *et al.*, 2022). We address this gap in the next section, with findings from organizations that are actively contributing to the growth of the last-mile delivery sector.

5.1.4 Perceived demand for last-mile delivery and desire for vertical integration. A few of our informants represent organizations that are actively and publicly contributing to the growth of the last-mile delivery sector. Manna, Wing, Zipline, Matternet and Speedbird Aero have all created logistics concepts that structure the current model for successful drone delivery. In the B2C market, Manna has a defined delivery radius that contributes to profitability. As the delivery fee is fixed, the number of flights per hour is decisive. Wing flies drones faster and farther (8–15 km) than most competitors. Although their drones make fewer flights, the catchment area per hangar is larger. Both Manna and Wing place their hubs close to retail locations. Wing carries a sample stock and can pick up parcels from partners and deliver them. Matternet provides standardized parcel boxes for drones to pick up and an integrated workflow for medical deliveries. Speedbird Aero has collaborated with Skyports as its global drone delivery partner. During interviews, operators mentioned that B2B deliveries have been slow to scale, but they do expect deliveries between warehouses and consumption points to grow. Nevertheless, at this point:

> No-one is interested in the flying; everyone wants the logistics capacity. As aviation is quite specialized, it is important for a drone logistics provider to extend their value chain into the realm of not just transport, but logistics, and understand how their operation can be fitted into their customers' workflows (D-4-D).

5.1.5 Perceived benefits and barriers for last-mile delivery. Most operators reported growing demand for drone-enabled last-mile delivery, particularly for e-commerce goods, food items and other time-sensitive deliveries like medical supplies. This demand is primarily driven by faster speed, traffic avoidance and the ability to serve locations where traditional road-based delivery is less efficient. As one operator explained, moving parcels "*from the warehouse to the end user*" or "*from hub to node*" with a drone provides an operational advantage because drones "*can move faster*" and are "*not subject to traffic*" (D-1-A). This advantage is particularly significant in congested urban environments, where one manager noted that customers are willing to "*pay a premium for a three-hour delivery over a three-day delivery*" (D-12-J). Operators also identified specific use cases where drone delivery could provide greater value than conventional delivery modes. These include food delivery, urgent medical supplies and premium products (W-3-C). Demonstrating the capability for urgent deliveries could help prove the technology and business case for broader adoption:

> If you can prove the technology and you can prove the business case by initially focusing on urgent deliveries, it becomes easier to convince people (D-5-E).

In addition to direct consumer delivery, operators identified hub-based and corridor-based models as more practical options for implementation. One operator suggested that last-mile drone delivery could be effectively managed through "*two or three key distribution points*" in cities, especially as operators can now manage multiple drones with fewer regulatory constraints (D-3-C). Another operator described a fixed-route model, explaining that "*we build bridges between points, so we have point A and point B, and there is an air corridor that connects these points*", while also reporting more than "*30,000 successful flights*" (D-24-U).

Operators also suggested that several concerns commonly associated with drone delivery, particularly noise and privacy, are becoming more manageable as the sector matures. Although customers, industry stakeholders and authorities often perceive noise and privacy as barriers, operators argued that these concerns can be reduced through appropriate measures:

> If you fly at 50 m or lower, noise can be an issue, but if you got to 65–80 m above ground, noise stops being an issue. Cameras are typically only used for safety reasons and are not switched on all the time because of data privacy principles (D-4-D).

Despite the perceived benefits, operators identified several barriers that may limit the near-term scalability of drone-enabled last-mile delivery. The most frequently mentioned barriers were related to technical readiness, regulatory approvals and supporting infrastructure. Technical concerns focused on aircraft conspicuity and detect-and-avoid capabilities, with one participant noting that drones will need to "*share the airspace with many other vehicles that we don't know where they are*" and that current systems are not yet "*super reliable*" (D-20-Q). Regulatory capacity and the processes for obtaining BVLOS approvals were also seen as significant constraints. Participants expressed concern that regulations are "*2–3, maybe four steps behind*", as technology is evolving faster than the approval processes can keep up (D-22-S). Additionally, regulatory understaffing was noted as a major obstacle, with some approvals taking longer than nine months (D-15-L).

Operators also highlighted the need for appropriate ground and operational infrastructure. One operator argued that drone delivery depends on "*safe landing zones or ditch zones or crash zones on route*", comparing these to rest areas for heavy trucks and emphasizing that the service "*will rely on the provision of ground infrastructure*" (D-7-G). Others pointed to geolocation infrastructure, anti-collision systems, battery charging, downtime and the need to monitor drones during operations (D-11-G; W-2-B). Operators also emphasized that the economics must match the use case. As one participant noted, high-value or critical deliveries may justify drone costs, but "*most likely an e-commerce customer would not be willing to pay*" very high delivery charges (D-13-K).

5.2 Organizational dimension

5.2.1 Expertise of drone operators. An important yet underexplored theme is the role of drone operators' expertise in advancing drone operations (Companik *et al.*, 2018; Kumbhani and Kant, 2024; Rejeb *et al.*, 2023). Drone operators expressed strong support for integrating drones into logistics networks. Interestingly, the chair of a drone company described an innovation that supports vertical integration: "*We have a fully autonomous drone that integrates into the pick and fill. After locating the product, it picks the product and then autonomously departs towards the destination*" (D-23-T). Discussions revealed three interrelated themes: technology readiness, regulatory alignment and infrastructure maturity. Technologically, drones are now capable of handling complex warehouse operations and last-mile deliveries. However, logistics firms often lack the technical frameworks to integrate them into existing supply chains.

Drone operators are emerging as pioneers in advancing the technological adoption of drones in logistics and supply chain processes. A CEO of a drone operating company indicated that their company is enabling adoption of long-range aerial data solutions at scale by being the first in Australia to manufacture all-carbon-composite airframes for unmanned aerial vehicles and the first to commercialize hybrid drones in the >7 kg category (D-5-E). A market development director indicated that progress in drone technology is no longer confined to controlled trials; drone delivery systems are now deployed in complex, real-world scenarios, such as medical supply delivery in remote areas and time-sensitive e-commerce fulfillment (D-11-G). It is noteworthy that many drone operators reported that their businesses are profitable, despite the common conception to the contrary. One operator disclosed: "*Typical delivery in less than 3 min, and profitable—truly inspiring and at a level of professionalism that will help the industry move forward*" (D-4-D).

A potential barrier voiced by drone operators was that logistics operators, often lacking technical knowledge, are concerned about the risks of integrating drones into their operations and the capabilities of a drone ecosystem. In response, drone operators are focusing on implementing practical solutions and ensuring their trainers are qualified and have backgrounds in the industry (D-3-C). All operators mentioned the importance of regulatory alignment and maintaining compliance with fast-changing airspace regulations. Regulatory frameworks have been lagging behind, as confirmed by a CEO in the USA who said their firm had the capability long ago to launch regular flights in a controlled airspace between cities up to 100 km, but the time-consuming and costly process of obtaining certifications ended their ambitions (D-15-L). To overcome such challenges, drone operators have been collaborating with regulatory authorities on the development of unmanned traffic management and wireless connectivity (D-4-D). A CEO explained: *"We are registered with the Civil Aviation Safety Authority [CASA, Australia] and the Australian Skills Quality Authority [ASQA] training organization"* (D-3-C). An operator was optimistic about recent developments:

> We expect 2025 to be a year of transition; a year of preparations for a new era of flights beyond the visual range of the operator, when aircraft piloted by remote operators will have the possibility of crossing international boundaries (D-21-R).

5.2.2 Governance models. Two interconnected themes emerged from the interviews concerning ownership and, more specifically, governance models for drone operations at the warehouse–last-mile delivery interface. First, uncertainty remains as to whether warehouses should develop in-house drone capabilities or rely on third-party service providers to manage drone logistics. Second, it is unclear whether the same drones should be used for both internal warehouse operations and last-mile delivery or whether specialized drones should be deployed for each task, requiring coordination between drones and/or human operators at the interface. Drawing on the organizational dimension of the TOE framework, we examine how successful drone implementation depends on governance structures and alignment with business objectives.

Warehouse operators indicated that economic considerations play a central role in decisions regarding whether to adopt in-house drone systems or rely on third-party service providers. In particular, return on investment is a key criterion in assessing the economic viability of automation initiatives. One logistics lead emphasized that partnering with a third-party provider offers the flexibility required to scale operations: "*Investing in a drone fleet involves substantial upfront capital, alongside ongoing maintenance costs that can significantly affect budgeting. By contracting third-party providers, we can achieve greater cost control and flexibility to scale*" (W-11-K). Similarly, a founder suggested that offering drone operations as a service may be advantageous, as specialized providers are better positioned to manage technical and regulatory complexities (D-6-F). In such a model, third-party providers would manage delivery operations in a manner comparable to traditional carrier services.

Operational considerations are also key in determining whether warehouses should maintain in-house drone fleets or outsource drone operations. In-house ownership requires internal capabilities in drone management, including ongoing maintenance, personnel training and compliance with aviation regulations. A logistics manager noted that many companies face operational challenges due to a lack of specialized expertise. This capability gap may be mitigated by engaging consultants or specialized firms capable of managing procurement and implementation processes. At the same time, one operator highlighted the potential for in-house management, citing Amazon as an example. However, large firms may encounter difficulties when organizational leadership is grounded in traditional logistics expertise but lacks specific operational capabilities in drone systems (D-25-V). Operators also emphasized that maintenance requirements are likely to remain a critical challenge.

Regarding the second theme, one approach discussed was an integrated drone system, in which the same drone performs both internal warehouse operations and last-mile deliveries. However, interviewees noted that this approach faces several challenges. Warehouse tasks typically involve short-range movements within confined spaces, such as between aisles, and require high levels of precision in navigation, with minimal payload requirements. In contrast, last-mile delivery tasks generally require drones with extended flight ranges and greater payload capacity (D-21-R). These differences suggest a potential trade-off between integration and specialization, with implications for governance design and operational coordination at the interface. Acknowledging the higher initial capital cost, a warehouse operator suggested using different drones:

> From a warehouse point of view, it's easy to dispatch. It's not a big issue. You can have a dispatch schedule and dispatch zones within the warehouse. Just like currently, what happens in the warehouse, they have doors for every carrier to come and collect their goods (W-4-D).

Warehouses could also leverage a hybrid model by implementing a docking station handover system. Retrieved packages can be transported to designated docking stations at the warehouse exit via drones. At these docking stations, last-mile drones can pick up parcels and proceed with deliveries. Relationships between warehouse operators and drone delivery providers can be established based on service-level agreements or performance-based contracts that define operational expectations, insurance coverage and payment terms. Compliance with aviation safety standards, airspace permissions and privacy requirements is an important element in agreements. One informant whose company has trialed such a system explained: *"Our contracts outline responsibilities [for] who maintains docking stations, what happens in case of drone collision or exact timeframes for drone handovers"* (D-15-L).

5.3 Environmental dimension

5.3.1 Low-altitude operations and emerging case for LAAM systems. Interestingly, discussions with the drone operators centered largely on regulatory constraints, particularly restrictions on flights beyond visual line of sight (BVLOS). Overcoming these barriers would require the introduction of a low-altitude airspace management (LAAM) system to govern commercial drone operations (Merkert *et al.*, 2021). Such a system could enable safe and scalable operations in increasingly congested airspaces, for example, by coordinating drone traffic through designated air corridors. One operator noted that their firm is currently the only provider authorized to conduct BVLOS flights over urban areas in Switzerland:

> We have something developing in the same way as LAAM here in Switzerland, or in Europe for that matter. You plan your flight; you ask for the approval to fly that particular route. We are now about to go into a test phase in early next year, 2025 (D-21-R).

The collected evidence suggests that drone operators are currently focused on establishing BVLOS capabilities, which consume substantial managerial attention and resources. While warehouse applications are recognized as promising, they are not an immediate priority.

Another major challenge highlighted by operators concerns collaboration with existing aviation stakeholders who are often reluctant to invest in drone-related infrastructure (D-20-Q). Understaffing in regulatory bodies was also identified as a major bottleneck for drone implementation. An operator explained: *"There are too few assessors in CASA's [Civil Aviation Safety Authority, Australia] drone team, and it takes forever to get the approval. We have got to wait 9 months, and we'll pay $30,000 or $40,000 to get that"* (D-18-O). These constraints point to the need for regulatory frameworks to evolve alongside technological capabilities in order to support safe and efficient operations. "*There is a need for regulation on this. For example, who gets the priority when two drones want to cross each other? If you address the safety properly, there is a lot of scope in the market*" (D-6-F).

5.3.2 Need for ecosystem-level standards and coordination across warehousing and delivery. Prior research suggests that successful technology adoption in complex retail logistics ecosystems often depends on collaborative governance arrangements, such as aligning commercial proximity between stakeholders to enable coordinated investment and operational integration (Bushell *et al.*, 2025). Consistent with this, themes centered on inter-organizational and ecosystem coordination and collaboration emerged from our interviews, as managers frequently discussed the practical arrangements required to integrate drones into existing logistics systems.

Our interview findings indicate that drone integration is unlikely to progress through isolated organizational efforts. Instead, it requires coordinated ecosystem development across logistics operators, drone service providers, regulatory authorities and supporting industries. Multiple participants emphasized cost efficiency as a driver of collaborative arrangements over independent drone deployment. Recognizing the technical complexity of drone operations as a barrier to in-house deployment, one operator noted:

> Just as you would not necessarily have your own transport fleet, the general logic is to outsource it to a logistics provider. You should stick to your strengths (W-3-C).

Moreover, the complexity of drone approval and certification processes further reinforces the need for collaborative approaches, with participants noting that *"drone approvals are difficult to get and difficult to understand and therefore it would cost a lot to achieve that"* (D-4-D). This dynamic creates a natural division of labor, with warehouse operators focusing on inventory management while relying on specialized drone operators for flight operations.

Our interview findings also highlight the intermediate role of consultants in bridging capability gaps between logistics providers and drone operators. As one operator explained:

> A lot of companies need to partner with consultants who can run a procurement program. They have really good data, and they can do the gap analysis (D-17-N).

This approach may also facilitate initial infrastructure setup, with ongoing support provided for maintenance and technological development. Such a phased model would involve warehouse operators initially partnering with drone service providers, before potentially transitioning to greater ownership as volumes and internal capabilities develop (W-2-B).

Drone operators also emphasized the mismatch between logistics expertise and aviation knowledge. One operator, for example, noted Amazon's challenges with *"leaders that are in the logistics area, but they have limited knowledge about drones"* (D-16-M). This capability gap encourages some drone operators to pursue vertical integration, developing *"a vertically integrated service that starts with transportation capability and has software that plan, track and follow up shipments, taking care of the flight operations"* (D-11-G). The interdependence between flight operations and service design was frequently emphasized, with one participant arguing that *"you need to co-develop them"* rather than attempting to separate these functions (W-6-F).

Our interview findings also indicate that competitive advantage in drone logistics depends on ecosystem development rather than sole ownership:

> Initially, as a warehouse operator or warehouse investor, we will consider joining with drone service providers. Then when we see more potential in terms of our volumes and our customers, we can look at acquiring and setting up the 4PL drone full ownership concept (W-4-D).

These inter-organizational dynamics suggest that drone logistics is likely to evolve through collaborative ecosystem development rather than isolated firm-level deployment. However, such ecosystem development does not follow a single configuration. Across our interviews, participants described three approaches to organizing drone integration at the warehouse–delivery interface, each reflecting a different distribution of capabilities and responsibilities between warehouse operators and drone service providers. The first configuration centers on a single actor maintaining full control over fleet operations. The second combines in-house operations with selective outsourcing of specific functions. The third involves collaborative partnerships, in which warehouse operators work with specialized drone providers to coordinate activities, particularly in last-mile delivery. Table 3 presents illustrative quotes for each configuration. We return to these configurations in Section 6.3, where we develop their implications at the organization–environment intersection.

Table 3. Configurations for organizing drone integration across warehousing and delivery

Configuration	Illustrative quotes and sources
Single-actor full-stack arrangement	"This configuration aligns most closely with what we've previously identified as a monolithic-autonomous stack, where a single actor maintains full control of fleet operations, inventory visibility, route optimization, and customer experience" (D-8-H) "Relying on separate operators to adopt OEM equipment poses significant commercial risk" (D-7-G) "Large organizations, like Amazon, and then only if commercial issues (e.g. confidentiality) outweigh those of operational efficiency" (D-4-D) "Given the strict regulatory requirements, a single or tightly integrated operating model is also necessary" (D-7-G) "In scenarios where predictability, regulatory compliance, and rapid iteration are critical such as drone deployments in constrained urban airspaces or sensitive biopharma delivery corridors this model provides the clearest line of accountability" (D-8-H) "The vertical model also enables better real-time AI learning loops since data stays within the same feedback architecture, reducing latency in optimization" (W-2-B) "As a general premise, we have found that vertical integration is essential in the current drone ecosystem given its immaturity" (D-7-G) "Aviation authorities want to deal with an overall responsible entity and see consistency in procedures, risk assessments" (D-7-G)
Partial adoption	"In mixed-delivery mesh environments combining human riders and drone hubs, this model suits geographies with fragmented topographies, though human–drone transitions must be tightly choreographed" (D-8-H) "I think this model better captures how the industry will ramp-up. It also offers a solution for deliveries in dense areas with many apartment and office buildings as opposed to suburban areas" (D-7-G) "Regarding partial adoption, this is really driven by economics" (W-4-D) "An integrated approach may use a combination of flying drones, ground robots, autonomous road vehicles etc. to make sure each leg is optimized" (W-4-D)
Partnerships and pooling capabilities	"This is perhaps the most intellectually rich model, but also the most prone to what we've previously termed interface entropy" (D-22-S) "Handoff points become friction sites without harmonized protocols, shared telemetry, and real-time coordination between actors" (D-22-S) "Early interoperability trials, notably in Shenzhen's industrial zones and Rotterdam's port, have tested this model, where port authorities coordinate inbound drone freight with last-kilometer operators" (D-22-S) "Large players may well contract out last-mile delivery, particularly for low-cost commodities where knowledge of their customer base is not commercially sensitive" (W-6-F) "It is unlikely that a service provider will enter into exclusive arrangements with the warehouse operator" (W-6-F) "Rather than transforming existing warehouses for drone operations, which would be costly and slow to roll out, a carrier service model using dedicated sortation centers would allow drone operators to dispatch goods more efficiently from the outset" (D-6-F) "The fragility here lies in resilience across organizational cultures: misaligned incentives, latency in updates, and fragmented liability can erode efficiency" (D-14-G) "This is more efficient for the warehouse operator as it both optimizes delivery networks and introduces competition for the last-mile delivery. If we look at Amazon again, the actual road delivery is done by a variety of delivery service partners" (D-1-A) "UPS has been experimenting with 'motherships' in the form of hybrid-electric delivery trucks with drone nests built into their roofs" (D-7-G)

Source(s): Authors' own work

6. Discussion

Our interviews with warehouse and drone operators revealed several technological, organizational and environmental factors that shape the adoption of aerial drone operations at the warehouse–last-mile delivery interface in retail supply chains. It is evident that it is technologically possible to adopt and deploy aerial drones not just in last-mile delivery services, but also in warehouse operations, and more importantly, in a system that integrates both logistics components. Deploying such integrated systems at scale requires addressing technological, organizational and environmental concerns.

6.1 Discussion of our findings through the lens of the TOE framework

Our findings indicate that drones are viewed as a transformative technology with the potential to automate labor-intensive functions in a retail warehouse, including stocktaking, cycle counting, item retrieval and shelf audits. Operators have reported significant cost savings, especially in larger, high-throughput facilities. This aligns with evidence showing that automation technologies can deliver efficiency gains in retail logistics environments where scale facilitates growth and maturity (Boysen *et al.*, 2018; Fragapane *et al.*, 2021). The readiness for adoption was found to be contingent on the technological compatibility of drones with existing WMS. This underscores the idea that successful integration with current systems, rather than just the technology's capabilities, determines the outcomes of adoption (Oliveira and Martins, 2011; Tornatzky and Fleischer, 1990). However, operators also identified some barriers to full deployment in retail warehouses. A primary concern is technical limitations regarding barcode reading accuracy and quantity verification. Operators expressed hesitation to invest until these accuracy issues are resolved. Additionally, infrastructure challenges have been identified as factors that slow down the commercial rollout. These challenges include the need to redesign warehouse layouts, battery life constraints, payload limitations and safety concerns in confined spaces. These findings are consistent with the broader literature on technology adoption, which shows that technical immaturity and integration complexity can hinder adoption, even when perceived benefits are recognized (Rogers, 2003; Rejeb *et al.*, 2023).

In the context of last-mile delivery within retail supply chains, informants expressed strong confidence in the growth of drone delivery systems, especially for e-commerce and food retail distribution. Unlike traditional road-based delivery, drones can operate without the hindrances of traffic congestion and geographic limitations, allowing for faster order fulfillment. Most of the operators we interviewed represented organizations that are actively participating in the last-mile delivery sector. This reflects a growing body of evidence indicating that last-mile drone delivery is transitioning from pilot programs to operational deployment (Aurambout *et al.*, 2019; Goodchild and Toy, 2018; Stolaroff *et al.*, 2018). Interestingly, some managers who were skeptical about the use of drones in warehouses recognized the increasing demand and momentum behind last-mile delivery. This distinction highlights a critical technological interface in the retail supply chain: the handoff points between warehouse operators and drone delivery operators. At this B2B interface, the technical requirements extend beyond the capabilities of individual systems. They also encompass the need for interoperability between WMS and drone fleet management systems, which would involve real-time coordination of dispatch and retrieval operations. Operators noted that this integration would enhance the overall value that drones can provide across the supply chain. This represents a key finding of our study: the adoption of drones in logistics cannot be evaluated in isolation, whether from the warehouse or the delivery perspective. It must also consider the technical infrastructure that connects the two.

From an organizational perspective, drone operators have emerged as key drivers of adoption in retail supply chain operations. Their roles have evolved beyond early trials, with operators confirming that drone systems are now being deployed in complex, real-world scenarios for retail fulfillment. Operators have also indicated that drone delivery businesses are already profitable, contrary to the common perception that commercial viability has yet to be achieved (Kumbhani and Kant, 2024; Rejeb *et al.*, 2023). However, a significant organizational challenge identified was the knowledge gap in logistics. Warehouse operators, often lacking technical expertise, expressed concern about the risks of integrating drones into their operations. In response, drone operators have focused on building qualified training teams with industry backgrounds to bridge this gap. This aligns with research demonstrating that inter-organizational knowledge transfer plays an important role in adopting emerging technologies (Autry *et al.*, 2010; Oliveira and Martins, 2011). Regulatory alignment has also emerged as a significant concern. Operators noted that regulatory frameworks have not kept pace with technological advancements and certification processes are often described as time-consuming and costly. Even though many drone operators have the technical capability to conduct flights up to 100 km between cities, they are unable to progress due to regulatory bottlenecks. As a result, firms are actively collaborating with regulatory authorities on unmanned traffic management, with 2025 identified as a transitional year for BVLOS and cross-border flights.

At the organizational level, the B2B interface between warehouse operators and drone delivery providers raised two important governance questions. First, whether warehouses should develop in-house drone capabilities or rely on third-party service providers. Second, whether the same drones should serve both internal warehouse operations and last-mile delivery or whether specialized drones should handle each separately, requiring structured coordination at the handoff point. Informants indicated that both economic factors, particularly return on investment and operational factors, including maintenance requirements, personnel training and regulatory compliance, shape these decisions. To manage these, warehouse and drone delivery operators are structuring their relationships through service-level agreements and performance-based contracts (Purtell *et al.*, 2025). These findings highlight that successful drone adoption at the warehouse and last-mile delivery interface depends on how organizations structure their roles, responsibilities and relationships.

From an environmental perspective, regulatory barriers have emerged as the most significant challenge affecting drone adoption, particularly regarding BVLOS operations. To enable BVLOS at scale, an LAAM system would need to be introduced to safely coordinate commercial drone operations in increasingly congested airspaces, as proposed by Merkert *et al.* (2021). Additional environmental pressures include understaffing at regulatory bodies and the reluctance of current aviation stakeholders to allocate funds toward drone infrastructure. These factors have been identified as major bottlenecks that slow down certification and approval processes. Our findings support broader calls in the literature for regulatory frameworks to evolve alongside technological developments to unlock the potential benefits of drones in retail logistics (Clothier *et al.*, 2015; Rejeb *et al.*, 2023).

Moreover, our results highlight the necessity for ecosystem-level coordination across warehousing and delivery. Operators indicated that drone integration within retail logistics cannot progress through isolated organizational efforts alone. Instead, it requires collaborative development among logistics operators, drone service providers, regulatory authorities and supporting industries. Our findings also reveal a knowledge gap between logistics expertise and aviation knowledge, with operators noting the challenges faced by organizations whose leaders understand logistics but have limited understanding of drone technology. The interdependence between flight operations and service design was also emphasized in our discussions. Operators argued that these functions must be co-developed rather than treated separately. Consistent with evidence that successful technology adoption in complex logistics ecosystems relies on collaborative governance arrangements (Bushell *et al.*, 2025), our findings suggest that the advancement of drone logistics will be most effective through shared ecosystem development rather than siloed efforts.

A comparison of warehouse manager and drone operator perspectives across the major themes identified through our interview program is provided in Appendix C.

6.2 Large-scale adoption of drone technology in logistics depends on collaboration

Our findings also suggest that large-scale adoption depends on how warehouses and service providers organize themselves within the broader logistics ecosystem. This raises an important question of whether warehouses and service providers will continue to operate in fragmented and siloed configurations (Maghazei *et al.*, 2022; Purtell *et al.*, 2025). During our interviews, key stakeholders indicated that standalone experimental implementations of drones for warehouse activities and last-mile delivery services are largely seen as underperforming due to poor ecosystem alignment. These findings highlight the importance of examining interactions between TOE dimensions when studying inter-organizational systems and collaborative adoption of emerging technologies like drones. Governance decisions cannot be understood through isolated analysis of organizational or environmental factors alone; rather, they emerge from the dynamic interplay between organizational capabilities (O) and environmental ecosystem (Ali *et al.*, 2021) requirements (E). This underscores the value of TOE as an integrative framework that captures multidimensional adoption dynamics.

6.3 Potential governance models at the warehouse–last-mile interface

As indicated in Section 5.2.2, a central question emerging from the interview findings and worth discussing in further detail is the choice of governance model for drone adoption: whether vertical integration represents a viable and strategic option for logistics firms or whether collaborative models offer a more suitable pathway. Our analysis identifies three distinct configurations: vertical integration, inter-organizational collaboration and partial deployment with intra-organizational collaboration (see Table 3).

This governance choice reflects a key interaction between the organizational (O) and environmental (E) dimensions of the TOE framework. While the decision is made at the organizational level, it is influenced by environmental factors, including ecosystem maturity, partner availability, regulatory frameworks and infrastructure dependencies. As such, it is inherently inter-organizational, highlighting the need to examine drone adoption beyond individual firm boundaries.

The following three subsections discuss how governance models may drive the integration of drones into the broader logistics chain. We define each governance model and discuss its application at the warehouse–last-mile delivery interface, highlighting illustrative examples as well as associated benefits and risks, thereby positioning governance as a boundary-spanning mechanism linking organizational decision-making with environmental constraints.

6.3.1 Vertical integration. The vertical integration governance model aligns with a central multi-use platform where a single actor maintains full control over multiple stages of its supply chain (Beal-Partyka and Laureano-Paiva, 2024). In drone operations, a vertically integrated company would operate its own drone fleet and related infrastructure as part of its logistics operations. These operations include inventory tasks, route optimization, last-mile delivery and customer experience.

Vertical integration requires seamless integration of drones, minimizing interoperability issues and reliance on technology from external providers. For example, a warehouse could have drone launch pads on the roof or vertiports where orders are dispatched for last-mile delivery. Amazon is a good example of a vertically integrated firm with significant capital resources and advanced technological capabilities. From the service provider side, Wing, Zipline and Speedbird Aero have end-to-end control over their flight operations.

The vertical integration model with in-house drone operation reflects a firm's strategic commitment to automation, which in our context would require significant restructuring. Companies such as Amazon may prioritize confidentiality and competitive positioning favoring internal control over collaboration with external providers. Workflows would change, and firms would have to introduce new protocols. Employees would need to be trained to ensure they can handle drone operations smoothly, as any disruptive technological change creates significant uncertainty and risk.

Vertical integrations would present a higher regulatory burden for warehouses, as aviation certifications are required, which our findings suggest is no easy feat. BVLOS operations are critical for last-mile delivery; however, they are currently only permitted in low-risk areas, limiting the scalability of these operations (Purtell *et al.*, 2025). In constrained urban airspaces or sensitive biopharma delivery corridors, predictability, regulatory compliance and rapid decision-making processes are important. The vertical integration model provides the clearest line of accountability in this regard, as drones equipped with AI enable real-time data flows that remain within a unified feedback architecture, reducing latency in optimization. Vertical integration may be advantageous at this stage, as the ecosystem may not yet be sufficiently mature to support multiple specialized operators across both drone operations and regulatory compliance. Aviation authorities also tend to prefer engaging with a single responsible entity, valuing consistency in procedures and risk assessment.

Drone operators should move beyond functioning solely as transport providers and expand their control across multiple stages, including in-house drone manufacturing, route planning software development, fulfillment center operations, vertiport management, selected warehouse functions and engagement with last-mile delivery customers. Such integration may facilitate scalability in delivery operations while enabling closer alignment between drone capabilities and logistics requirements. However, this model requires substantial resources and is therefore more feasible for larger firms with advanced capabilities and access to regulatory environments that support BVLOS operations. High capital intensity, combined with limited in-house technical expertise, presents a significant barrier for smaller logistics operators (Maghazei *et al.*, 2022).

6.3.2 Partial adoption with intra-organizational collaboration. Firms that implement the partial adoption model use drones to enhance operational efficiency within their own logistics chains that include inventory management, cycle counting, order picking and last-mile delivery. Unlike vertical integration, the focus is on using drones for specific tasks rather than automating all operational functions and drone operations do not cross organizational boundaries. For example, a warehouse might deploy drones for stocktaking, but not for last-mile deliveries. Walmart has used drones to automate internal inventory management, GEODIS initially collaborated with DELTA DRONE prior to bringing operations fully in-house, and DHL has tested and deployed drones for inventory counting globally (Abrams, 2016; GEODIS, 2018; Yigit *et al.*, 2024).

For last-mile delivery, the idea behind the partial adoption model is a network where multiple delivery mechanisms work together in a mesh. Rather than drones handling the entire process from end-to-end, mesh delivery involves smaller interconnected hops. For example, the Amazon Prime Air model involves human drivers delivering parcels to drone dispatch hubs, which tend to be located close to customers, and the last mile of delivery is provided by drones (Tarasov, 2023). In such systems, human–drone transitions must be tightly coordinated to ensure smooth and reliable operations. The partial adoption model may be a pragmatic approach that better captures how the industry will leverage existing last-mile delivery networks. It also offers a solution for deliveries in dense areas with many apartment and office buildings as opposed to suburban areas.

However, the partial adoption of drone deliveries does require a cultural shift where staff are trained on drone operations. Rather than replacing human labor, drones are intended to augment or complement existing logistics staff. In-house operations would be controlled primarily by managers within the firm, but flights beyond the premises would require staff to obtain certifications such as BVLOS approvals or remote pilot licenses. In practice, the partial adoption model is primarily driven by economic optimization.

Partial adoption is likely to be more suitable where full integration is constrained by regulatory uncertainty, infrastructure limitations or investment risk. It allows organizations to gradually build drone capabilities within selected warehouse functions or delivery segments, while maintaining operational flexibility and adapting to evolving regulatory and ecosystem conditions.

6.3.3 Inter-organizational collaboration. The inter-organizational collaboration model involves independent organizations establishing partnerships and pooling capabilities to implement specialized drone operations. For example, a warehouse could outsource last-mile delivery to operators offering drone-delivery-as-a-service (DDaaS) or outsource other core functions, such as inventory management or order picking. Given the novelty of the technology, warehouses often lack the organizational structure required for integrating drones (Maghazei *et al.*, 2022), making third-party collaboration a practical path forward (Purtell *et al.*, 2025). Inter-organizational models would become more prominent with increasing specialization, consolidation and the formation of accepted standards between stakeholders.

Although this model is intellectually rich, it is most prone to interface entropy. From a technological perspective, the major challenge to overcome is the drone-to-drone or drone-to-infrastructure handoff, which becomes a site of friction unless both actors have harmonized protocols, shared telemetry standards and real-time negotiation capabilities. Early-stage trials of this interoperability have been successfully conducted in Shenzhen (China) and Rotterdam (The Netherlands) in the context of coordinating ports' inbound drone freight with private last-mile drone operators. Organizationally, this model relies on flexible contracting arrangements, particularly for standardized or low-margin delivery segments. Large firms may outsource last-mile delivery where goods are of low value and customer information is not commercially sensitive, reducing the need for exclusive arrangements between warehouse operators and drone service providers. This points to a market-based coordination model, in which drone operators function as specialist carriers rather than being fully embedded within warehouse operations.

Such an arrangement may also reduce the need for immediate warehouse transformation, as dedicated sorting centers could enable drone carriers to dispatch goods more efficiently without requiring costly modifications to existing facilities. However, this model remains exposed to inter-organizational risks. Misaligned incentives, delayed information sharing, fragmented liability and differences in organizational culture can weaken resilience and reduce operational efficiency across the warehouse–drone interface. These risks are less pronounced in fully integrated models, where firms develop tightly coupled systems without relying on standardized application programming interfaces (APIs).

Inter-organizational models may offer efficiency gains for warehouse operators by optimizing delivery networks while introducing competition for last-mile delivery. For example, Amazon's road delivery operations rely on a network of delivery service partners (DSPs). An important design consideration concerns whether the interface or handover point between the two parties is fixed or mobile. For example, UPS has experimented with "motherships" concepts, using hybrid-electric delivery trucks equipped with drone launch and retrieval systems.

Inter-organizational collaboration is particularly pertinent where ecosystem coordination and specialized capabilities are required across multiple actors. It enables logistics providers and drone operators to leverage complementary expertise while reducing investment burden and technological risk. Collaborative arrangements also support shared infrastructure development and help organizations to adapt to evolving operational and airspace management requirements.

7. Conclusions

7.1 Theoretical implications

Our paper shows that successful adoption will require warehouses and drone operators to transform work practices across technological, organizational, environmental and inter-organizational–ecosystem domains. While barriers such as infrastructural constraints and regulatory coordination exist, both warehouse managers and drone operators see potential to integrate drone operations across the warehouse–last-mile delivery interface.

Our study makes several theoretical contributions to the literature on technology adoption in retail logistics. Following Makadok *et al.* (2018), we frame these contributions around the phenomenon examined, the level of analysis adopted, the constructs identified, the mechanisms explaining adoption and the boundary conditions under which drone-enabled logistics becomes more plausible and feasible.

First, our study conceptualizes drone adoption at the warehouse–last-mile delivery interface as an independent logistics phenomenon and an ecosystem-level coordination problem. Prior studies on technology adoption in logistics have largely focused on adoption within single firms or by individual users. While useful for firm-level technologies, these approaches do not fully capture drone adoption, as the latter cannot be explained without considering the wider network of actors involved (Maghazei *et al.*, 2022; Purtell *et al.*, 2025). Our findings show that drone logistics are inherently interdependent: adoption at the warehouse–last-mile interface depends not only on a focal firm's technological readiness but also on the alignment of supply chain partners, regulatory authorities and technology providers.

The second theoretical implication is that our study positions drone-enabled logistics at the inter-organizational level of analysis, where logistics service providers, drone service providers and regulatory actors must coordinate across operational boundaries. Applying the TOE framework to the warehouse–last-mile delivery interface reveals how organizational dependencies in drone adoption are shaped by ecosystem dynamics that extend beyond individual firm boundaries. Within the environmental dimension, drone adoption at the warehouse–last-mile delivery interface is shaped not only by exogenous factors (e.g. regulations, market trends) but also by endogenous variables such as infrastructural enablers and active collaboration between organizations. This highlights important interactions between the organizational and environmental dimensions of the TOE framework when innovations require coordination across multiple actors in the logistics ecosystem. This observation resonates with recent extensions of network theory (Bushell *et al.*, 2025), which emphasizes the importance of stakeholder interdependencies, and with calls for further development of TOE theory to incorporate inter-organizational collaboration (Baker, 2011). Our results indicate that active stakeholder engagement with policymakers, supply chain partners and airspace regulators can lead to more realistic policies and pricing structures at the warehouse–last-mile delivery interface and the interconnected logistics ecosystem more generally.

The third implication is the identification of key constructs that shape drone adoption in logistics. Contributing to the literature on advancing TOE theory (Adade and De Vries, 2024; Ali *et al.*, 2021; Wang and Zhang, 2024), our findings emphasize the significance of inter-organizational and ecosystem coordination in the context of logistics innovations. In particular, the findings identify stakeholder alignment, trust, collaboration, infrastructural readiness, regulatory engagement and governance model suitability as important constructs shaping drone adoption at the warehouse–last-mile delivery interface. Deploying TOE theory beyond static firm boundaries, our analysis demonstrates how technological, organizational and environmental dimensions interact in contexts where multiple actors must collaborate to adopt innovations. These findings capture the inter-organizational dependencies involved in adopting innovations in logistics, addressing a notable gap in the literature (Asare *et al.*, 2016). By focusing on ecosystem coordination, our study moves beyond a firm-centric view of adoption and demonstrates how collective alignment, trust and coordination among multiple actors can influence the success or failure of drone adoption in retail logistics.

A further theoretical implication of our study is the identification of mechanisms and the boundary conditions that interact to shape the viability of drone adoption at the warehouse–last-mile delivery interface. Our findings suggest that the success of drone integration in logistics is not solely a function of one firm's technology, organizational capacity or external environment alone, but a collaborative outcome across the logistics chain. These mechanisms are reflected in three governance models for drone logistics: vertical integration, inter-organizational collaboration and partial adoption with intra-organizational collaboration.

Examining these governance models through the interaction between the organizational and environmental dimensions of the TOE framework enables scholars to assess misalignment risks, identify where to focus primary coordination efforts and provide managers with guidance on selecting governance models based on adoption maturity and regulatory context. We have shown that the success of drone logistics relies not only on technological readiness or regulatory progress, but also on how firms organize themselves and collaborate across operational boundaries. Using real-world cases and drawing on our informants' experiences, we have considered the logistics chain as a whole rather than isolated segments, enabling us to explore the adoption and integration of drones in end-to-end logistics.

Our study also contributes to the retail and technology adoption literature by examining drone-enabled logistics as a B2B coordination problem at the warehouse–last-mile delivery interface. In the retail literature, prior work has emphasized the growing complexity of fulfillment models, increasing customer expectation and the role of technology adoption in improving warehousing and last-mile delivery performance. Our findings extend this discussion by showing that drone adoption in retail logistics depends not only on technological capability but also on effective collaboration among stakeholders. Our findings move beyond isolated warehouse use cases and technical demonstrations to examine how decision-makers assess the practical demand, risks, timing and implementation conditions for drone adoption at this crucial interface. In doing so, our study connects drone applications in warehouse functions with drone-enabled last-mile delivery, positioning the warehouse–last-mile delivery interface as a critical point of adoption, coordination and governance in retail logistics.

7.2 Managerial implications

Our findings provide practical insights and actionable guidance for managers who are considering implementing drone technology at the warehouse–last-mile delivery interface. Building on Guan *et al.* (2023), we have shown that successful adoption to function effectively across stakeholders requires both formal management mechanisms (contracts, regulatory compliance, licensing and low-altitude airspace management integration) and informal management mechanisms (trust, shared risk management and cooperative planning). We show that drone adoption in retail logistics is constrained not by a lack of technical feasibility, but by the absence of shared operational standards and effective coordination among relevant stakeholders. For drone operations to create real value, drone company managers should aim to integrate their firms more deeply into logistics operations rather than functioning merely as transport providers. Warehouse operations managers should explore drone technology regarding current workflows, not just as a future concept and should avoid adopting drones solely for technological novelty. It is evident that drone operations cannot exist in a silo. Rather than solution spotting, there is a need to translate the great potential of drones into practical applications (Maghazei *et al.*, 2022). We have further identified that collaboration between operators, such as by sharing real-time information about when a package is ready for collection, is important.

Regulatory constraints continue to be major barriers to scalability in drone delivery operations. Operators are subject to restrictions when flying in low-altitude airspaces. Collaborating with regulatory authorities and co-developing practical solutions would accelerate the adoption of drone delivery systems. As such, operators should not focus solely on the compliance aspect of regulation, but embrace solutions such as a low-altitude airspace management system to practically manage congestion in a network of their own aerial drones and perhaps more importantly, competitive and potentially non-cooperative, hostile drone operations.

In discussing governance models for the warehouse–last-mile delivery interface, regardless of the model pursued, an important consideration is how to fit drones into the broader logistics chain. Our findings suggest that the choice of governance model should align with firm size, adoption maturity and regulatory environment. Echoing one of our informants, we conclude that due to the complexities and the importance of local context, no single model will dominate globally. What we anticipate, and what aligns with the "*ontological plurality*" observed in other domains, is that deployment models will vary depending on legal maturity and cultural infrastructure (Pfaff *et al.*, 2023; Tong *et al.*, 2025). Aerial drone operations are not just a technology deployment problem; they involve the complex orchestration of trust, territory and transaction. Models that account for that multiplicity, especially those that allow flexible switching between modes based on context (congestion, load type, urgency, etc.), will likely emerge as more resilient. While vertical integration may be attractive to some large firms, many smaller operators and new entrants, and indeed, many large firms, may rely on successful intra- or inter-organizational collaboration to make drone operations work at the warehouse–last-mile delivery interface.

7.3 Limitations and future research

While our research has identified both enablers and barriers to drone adoption and integration at the warehouse–last-mile delivery interface, technology is advancing rapidly, and perceptions are changing. Our findings represent a snapshot in time. In addition, while our sample is global, some markets and use cases have not been covered. The cost of drone adoption and integration at the warehouse–last-mile delivery interface should be evaluated further for commercial viability. From a theoretical perspective, future research could further develop the application of the TOE framework, particularly from a longitudinal perspective. Investigating how organizational and environmental conditions evolve, especially in relation to governance models and inter-organizational coordination, represents a promising research avenue in the context of retail logistics and supply chains.

Acknowledgments

We thank the two anonymous reviewers and the Editors for their constructive comments and patience throughout the review process. We are also grateful to iMOVE Australia and Thales Australia for their financial support.

Supplementary material

The supplementary material for this article can be found online.

References

Abrams, R. (2016), "Walmart looks to drones to speed distribution", available at: https://www.nytimes.com/2016/06/03/business/walmart-looks-to-drones-to-speed-distribution.html (accessed 2 April 2024).

Adade, D. and De Vries, W.T. (2024), "An extended TOE framework for local government technology adoption for citizen participation: insights for city digital twins for collaborative planning", *Transforming Government: People, Process and Policy*, Vol. 19 No. 1, pp. 53-73, doi: 10.1108/tg-01-2024-0025.

Afandi, M., Dewi, T.K., Widianingrum, S., Farizki, M.A.A., Endrasari, F., Saptaji, K., Hadisujoto, I.B.S. and Djamari, D.W. (2024), "Warehouse drone inventory management system using OpenCV", in *2024 International Seminar on Intelligent Technology and its Applications (ISITIA)*, IEEE, pp. 172-177.

Agatz, N., Bouman, P. and Schmidt, M. (2018), "Optimization approaches for the traveling salesman problem with drone", *Transportation Science*, Vol. 52 No. 4, pp. 965-981, doi: 10.1287/trsc.2017.0791.

Ali, S.S., Kaur, R., Gupta, H., Ahmad, Z. and Elnaggar, G. (2021), "Determinants of an organization's readiness for drone technologies adoption", *IEEE Transactions on Engineering Management*, Vol. 71, pp. 43-57, doi: 10.1109/tem.2021.3083138.

Ali, S.S., Khan, S., Fatma, N., Ozel, C. and Hussain, A. (2024), "Utilisation of drones in achieving various applications in smart warehouse management", *Benchmarking: An International Journal*, Vol. 31 No. 3, pp. 920-954, doi: 10.1108/bij-01-2023-0039.

Arkabaev, N., Doolotbek-kyzy, G. and Amanbaev, S. (2024), "Optimizing logistic processes and transport challenges in the dynamic landscape of online commerce", *Bulletin of Science and Practice*, Vol. 10 No. 1, pp. 292-298.

Asare, A.K., Brashear-Alejandro, T.G. and Kang, J. (2016), "B2B technology adoption in customer driven supply chains", *Journal of Business and Industrial Marketing*, Vol. 31 No. 1, pp. 1-12, doi: 10.1108/jbim-02-2015-0022.

Aurambout, J.P., Gkoumas, K. and Ciuffo, B. (2019), "Last mile delivery by drones: an estimation of viable market potential and access to citizens across European cities", *European Transport Research Review*, Vol. 11 No. 1, pp. 1-21, doi: 10.1186/s12544-019-0368-2.

Autry, C.W., Grawe, S.J., Daugherty, P.J. and Richey, R.G. (2010), "The effects of technological turbulence and breadth on supply chain technology acceptance and adoption", *Journal of Operations Management*, Vol. 28 No. 6, pp. 522-536, doi: 10.1016/j.jom.2010.03.001.

Awa, H.O., Ojiabo, O. and Orokor, L. (2017), "Integrated Technology-Organization- Environment (T-O-E) taxonomies for technology adoption", *Journal of Enterprise Information Management*, Vol. 30 No. 6, pp. 893-921, doi: 10.1108/jeim-03-2016-0079.

Baker, J. (2011), "The Technology–Organization–Environment framework", *Information Systems Theory*, Vol. 1, pp. 231-245.

Beal-Partyka, R. and Laureano-Paiva, E. (2024), "Bridging the gap: state-of-the-art on vertical integration", *RAUSP Management Journal*, Vol. 59 No. 3, pp. 229-255, doi: 10.1108/rausp-03-2023-0041.

Benchis, M.P., Shahzad, K. and Dan, S. (2025), "Comparative analysis of blockchain adoption in the public and private sectors. A Technology-Organization-Environment (TOE) framework approach", *Journal of Innovation and Knowledge*, Vol. 10 No. 4, 100746, doi: 10.1016/j.jik.2025.100746.

Boysen, N., Briskorn, D., Fedtke, S. and Schwerdfeger, S. (2018), "Drone delivery from trucks: drone scheduling for given truck routes", *Networks*, Vol. 72 No. 4, pp. 506-527, doi: 10.1002/net.21847.

Braun, V. and Clarke, V. (2006), "Using thematic analysis in psychology", *Qualitative Research in Psychology*, Vol. 3 No. 2, pp. 77-101, doi: 10.1191/1478088706qp063oa.

Bushell, J., Merkert, R. and Sutton-Brady, C. (2025), "Mind the gap: expanding proximity theory to understand network failure in transport systems", *Industrial Marketing Management*, Vol. 126, pp. 131-145, doi: 10.1016/j.indmarman.2025.02.012.

Chittipaka, V., Kumar, S., Sivarajah, U., Bowden, J.L.H. and Baral, M.M. (2023), "Blockchain technology for supply chains operating in emerging markets: an empirical examination of Technology-Organization-Environment (TOE) framework", *Annals of Operations Research*, Vol. 327 No. 1, pp. 465-492, doi: 10.1007/s10479-022-04801-5.

Chour, K., Pradeep, P., Munishkin, A.A. and Kalyanam, K.M. (2023), "Aerial vehicle routing and scheduling for UAS traffic management: a hybrid Monte Carlo tree search approach", *2023 IEEE/AIAA 42nd Digital Avionics Systems Conference (DASC)*, pp. 1-9.

Clothier, R.A., Williams, B.P. and Fulton, N.L. (2015), "Structuring the safety case for unmanned aircraft system operations in non-segregated airspace", *Safety Science*, Vol. 79, pp. 213-228, doi: 10.1016/j.ssci.2015.06.007.

Companik, E., Gravier, M.J. and Farris II, M.T. (2018), "Feasibility of warehouse drone adoption and implementation", *Journal of Transportation Management*, Vol. 28 No. 2, pp. 5-48, doi: 10.22237/jotm/1541030640.

Dorling, K., Heinrichs, J., Messier, G.G. and Magierowski, S. (2017), "Vehicle routing problems for drone delivery", *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, Vol. 47 No. 1, pp. 70-85, doi: 10.1109/tsmc.2016.2582745.

Filiopoulou, E., Bardaki, C., Nikolaidou, M. and Michalakelis, C. (2025), “Drone-as-a-Service for last-mile delivery: evidence of economic viability”, *Economics of Transportation*, Vol. 41, 100398, doi: 10.1016/j.ecotra.2025.100398.

Fragapane, G., de Koster, R., Sgarbossa, F. and Strandhagen, J.O. (2021), “Planning and control of autonomous mobile robots for intralogistics: literature review and research agenda”, *European Journal of Operational Research*, Vol. 294 No. 2, pp. 405-426, doi: 10.1016/j.ejor.2021.01.019.

Fusch, P.I. and Ness, L.R. (2015), “Are we there yet? Data saturation in qualitative research”, *The Qualitative Report*, Vol. 20 No. 9, pp. 1408-1416, doi: 10.46743/2160-3715/2015.2281.

Garg, V., Niranjan, S., Prybutok, V., Pohlen, T. and Gligor, D. (2023), “Drones in last-mile delivery: a systematic review on efficiency, accessibility, and sustainability”, *Transportation Research Part D: Transport and Environment*, Vol. 123, 103831, doi: 10.1016/j.trd.2023.103831.

Geetha, D.M., Arunachalam, A.C., Deepikarani, K. and Shanmugam, K.B. (2023), “Autonomous cargo drone with collision avoidance and warehouse management IoT”, *2023 2nd International Conference on Automation, Computing and Renewable Systems (ICACRS)*, IEEE, pp. 1611-1617.

GEODIS (2018), “Warehouse inventory using drones: GEODIS and DELTA DRONE have entered the industrialization production phase of their completely automated solution”, available at: https://geodis.com/au-en/newsroom/press/warehouse-inventory-using-drones-geodis-and-delta-drone-have-entered (accessed 20 January 2025).

Gioia, D., Corley, K. and Hamilton, A. (2013), “Seeking qualitative rigor in inductive research”, *Organizational Research Methods*, Vol. 16 No. 1, pp. 15-31, doi: 10.1177/1094428112452151.

Goodchild, A. and Toy, J. (2018), “Delivery by drone: an evaluation of unmanned aerial vehicle technology in reducing CO2 emissions in the delivery service industry”, *Transportation Research Part D: Transport and Environment*, Vol. 61, pp. 58-67, doi: 10.1016/j.trd.2017.02.017.

Guan, W., Ding, W., Zhang, B., Verny, J. and Hao, R. (2023), “Do supply chain related factors enhance the prediction accuracy of blockchain adoption? A machine learning approach”, *Technological Forecasting and Social Change*, Vol. 192, 122552, doi: 10.1016/j.techfore.2023.122552.

Hofmann, E., Sternberg, H., Chen, H., Pflaum, A. and Prockl, G. (2019), “Supply chain management and Industry 4.0: conducting research in the digital age”, *International Journal of Physical Distribution and Logistics Management*, Vol. 49 No. 10, pp. 945-955, doi: 10.1108/ijpdlm-11-2019-399.

Kellermann, R., Biehle, T. and Fischer, L. (2020), “Drones for parcel and passenger transportation: a literature review”, *Transportation Research Interdisciplinary Perspectives*, Vol. 4, 100088, doi: 10.1016/j.trip.2019.100088.

Kembro, J. and Norrman, A. (2022), “The transformation from manual to smart warehousing: an exploratory study with Swedish retailers”, *International Journal of Logistics Management*, Vol. 33 No. 5, pp. 107-135, doi: 10.1108/ijlm-11-2021-0525.

Kumbhani, C. and Kant, R. (2024), “Ranking the benefits of drone-based last-mile delivery due to adoption of its enablers”, *Journal of Advances in Management Research*, Vol. 21 No. 5, pp. 805-836, doi: 10.1108/jamr-03-2024-0103.

Maghazei, O., Lewis, M.A. and Netland, T.H. (2022), “Emerging technologies and the use case: a multi-year study of drone adoption”, *Journal of Operations Management*, Vol. 68 Nos 6-7, pp. 560-591, doi: 10.1002/joom.1196.

Maher, C., Hadfield, M., Hutchings, M. and De Eyto, A. (2018), “Ensuring rigor in qualitative data analysis: a design research approach to coding combining NVivo with traditional material methods”, *International Journal of Qualitative Methods*, Vol. 17 No. 1, doi: 10.1177/1609406918786362.

Makadok, R., Burton, R. and Barney, J. (2018), “A practical guide for making theory contributions in strategic management”, *Strategic Management Journal*, Vol. 39 No. 6, pp. 1530-1545, doi: 10.1002/smj.2789.

Malik, S., Chadhar, M., Chetty, M. and Vatanasakdakul, S. (2022), "Adoption of blockchain technology: exploring the factors affecting organizational decision", *Human Behavior and Emerging Technologies*, 7320526, pp. 1-14.

McGowan, L.J., Powell, R. and French, D.P. (2020), "How can use of the theoretical domains framework be optimized in qualitative research? A rapid systematic review", *British Journal of Health Psychology*, Vol. 25 No. 3, pp. 677-694, doi: 10.1111/bjhp.12437.

Merkert, R. and Bushell, J. (2020), "Managing the drone revolution: a systematic literature review into the current use of airborne drones and future strategic directions for their effective control", *Journal of Air Transport Management*, Vol. 89, 101929, doi: 10.1016/j.jairtraman.2020.101929.

Merkert, R., Beck, M.J. and Bushell, J. (2021), "Will it fly? Adoption of the road pricing framework to manage drone use of airspace", *Transportation Research Part A: Policy and Practice*, Vol. 150, pp. 156-170, doi: 10.1016/j.tra.2021.06.001.

Merkert, R., Bliemer, M.C. and Fayyaz, M. (2022), "Consumer preferences for innovative and traditional last-mile parcel delivery", *International Journal of Physical Distribution and Logistics Management*, Vol. 52 No. 3, pp. 261-284, doi: 10.1108/ijpdlm-01-2021-0013.

Meydan, C.H. and Akkaş, H. (2024), "The role of triangulation in qualitative research: converging perspectives", in *Principles of Conducting Qualitative Research in Multicultural Settings*, IGI Global.

Moshref-Javadi, M., Hemmati, A. and Winkenbach, M. (2020), "A truck and drones model for last-mile delivery: a mathematical model and heuristic approach", *Applied Mathematical Modelling*, Vol. 80, pp. 290-318, doi: 10.1016/j.apm.2019.11.020.

Mourtzis, D., Angelopoulos, J. and Panopoulos, N. (2024), "Unmanned Aerial Vehicle (UAV) path planning and control assisted by Augmented Reality (AR): the case of indoor drones", *International Journal of Production Research*, Vol. 62 No. 9, pp. 3361-3382, doi: 10.1080/00207543.2023.2232470.

Murray, C.C. and Chu, A.G. (2015), "The flying sidekick traveling salesman problem: optimization of drone-assisted parcel delivery", *Transportation Research Part C: Emerging Technologies*, Vol. 54, pp. 86-109, doi: 10.1016/j.trc.2015.03.005.

Nguyen, D.D. and Dang, Q.D. (2024), "Developing an intelligent drone management system for smart city transportation networks", *Drones*, Vol. 8 No. 9, p. 512, doi: 10.3390/drones8090512.

Nguyen, T.N.M., Whitehead, L., Dermody, G. and Saunders, R. (2022), "The use of theory in qualitative research: challenges, development of a framework and exemplar", *Journal of Advanced Nursing*, Vol. 78 No. 1, pp. e21-e28, doi: 10.1111/jan.15053.

Oliveira, T. and Martins, M.F. (2011), "Literature review of information technology adoption models at firm level", *Electronic Journal of Information Systems Evaluation*, Vol. 14 No. 1.

Palmer, A. (2023), "Amazon's drone business can't get off the ground as regulations, weak demand stymie progress", *CNBC*, available at: https://www.cnbc.com/2023/03/11/amazon-prime-air-drone-business-stymied-by-regulations-weak-demand.html

Perotti, S., Bastidas Santacruz, R.F., Bremer, P. and Beer, J.E. (2022), "Logistics 4.0 in warehousing: a conceptual framework of influencing factors, benefits and barriers", *The International Journal of Logistics Management*, Vol. 33 No. 5, pp. 193-220, doi: 10.1108/ijlm-02-2022-0068.

Pfaff, Y.M., Birkel, H. and Hartmann, E. (2023), "Supply chain governance in the context of Industry 4.0: investigating implications of real-life implementations from a multi-tier perspective", *International Journal of Production Economics*, Vol. 260, 108862, doi: 10.1016/j.ijpe.2023.108862.

Principal Logistics Technologies (2015), *Warehouse Operation & Back Office Cost Savings Model*, available at: https://www.principallogisticstechnologies.com/warehousing-back-office-and-operational-cost-savings-model/ (accessed 20 March 2025).

Proudfoot, K. (2023), "Inductive/deductive hybrid thematic analysis in mixed methods research", *Journal of Mixed Methods Research*, Vol. 17 No. 3, pp. 308-326, doi: 10.1177/15586898221126816.

Purtell, C.T., Manuj, I., Pohlen, T.L., Garg, V., Porchia, J. and Hill, M.J. (2025), "Innovators and transformers: envisioning a revolution in middle mile logistics with extended range cargo drones", *International Journal of Physical Distribution and Logistics Management*, Vol. 55 No. 4, pp. 376-393, doi: 10.1108/ijpdlm-12-2023-0468.

Rejeb, A., Rejeb, K., Simske, S.J. and Treiblmaier, H. (2023), "Drones for supply chain management and logistics: a review and research agenda", *International Journal of Logistics Research and Applications*, Vol. 26 No. 6, pp. 708-731, doi: 10.1080/13675567.2021.1981273.

Rogers, E.M. (2003), *Diffusion of Innovations*, 5th ed., Free Press.

Saldaña, J. (2021), *The Coding Manual for Qualitative Researchers*, SAGE Publication.

Sarraf-Yazdi, S., Pisupati, A., Goh, C.K., Ong, Y.T., Toh, Y.R., Goh, S.P.L. and Krishna, L.K.R. (2024), "A scoping review and theory-informed conceptual model of professional identity formation in medical education", *Medical Education*, Vol. 58 No. 10, pp. 1151-1165, doi: 10.1111/medu.15399.

Sides, R.R. and Skelly, L. (2021), "The retail profitability paradox", *MIT Sloan Management Review*, Vol. 62 No. 4, pp. 1-5.

Snoeck, A., Winkenbach, M. and Fransoo, J.C. (2023), "On-demand last-mile distribution network design with omnichannel inventory", *Transportation Research Part E: Logistics and Transportation Review*, Vol. 180, 103324, doi: 10.1016/j.tre.2023.103324.

Stanko, J., Stec, F. and Rodina, J. (2022), "Process automation of warehouse inspection using an autonomous unmanned aerial vehicle", *MM Science Journal*, Vol. 2022 No. 3, pp. 5864-5869, doi: 10.17973/mmsj.2022_10_2022063.

Stolaroff, J.K., Samaras, C., O'Neill, E.R., Lubers, A., Mitchell, A.S. and Ceperley, D. (2018), "Energy use and life cycle greenhouse gas emissions of drones for commercial package delivery", *Nature Communications*, Vol. 9 No. 1, p. 409, doi: 10.1038/s41467-017-02411-5.

Ta, H., Hofer, A.R., Jin, Y.H., Peinkofer, S.T. and Sodero, A. (2025), "Designing scenario-based experiments in retail SCM: methodological approaches and practical insights", *International Journal of Physical Distribution and Logistics Management*, Vol. 55 No. 1, pp. 94-117, doi: 10.1108/ijpdlm-10-2024-0392.

Tarasov, K. (2023), "Amazon's 100 drone deliveries puts Prime Air far behind Alphabet's Wing and Walmart partner Zipline", *CNBC Tech*, available at: https://www.cnbc.com/2023/05/18/amazons-100-drone-deliveries-puts-prime-air-behind-google-and-walmart.html

Thomaidis, N.C. and Zeimpekis, V. (2024), "Investigation of operational parameters that affect the use of drones in goods' stock count process: evidence from experimental results", *Journal of Industrial Engineering and Management*, Vol. 17 No. 1, pp. 115-132, doi: 10.3926/jiem.6446.

Tong, X., Wilhelm, M. and Wang, S. (2025), "Make, buy, and ally: can plural sourcing reconcile the tension between outsourcing and corporate social responsibility?", *Journal of Supply Chain Management*, Vol. 61 No. 3, pp. 77-94, doi: 10.1111/jscm.12348.

Tornatzky, L.G. and Fleischer, M. (1990), *The Processes of Technological Innovation*, Lexington Books.

Varpio, L., Paradis, E., Uijtdehaage, S. and Young, M. (2020), "The distinctions between theory, theoretical framework, and conceptual framework", *Academic Medicine*, Vol. 95 No. 7, pp. 989-994, doi: 10.1097/acm.0000000000003075.

Wang, S. and Zhang, H. (2024), "Inter-organizational cooperation in digital green supply chains: a catalyst for eco-innovations and sustainable business practices", *Journal of Cleaner Production*, Vol. 472, 143383, doi: 10.1016/j.jclepro.2024.143383.

Yigit, K.A., Dalkiran, A. and Karakoc, T.H. (2024), "Applications of drones in the health industry", in Karakoc, T.H. and Özbek, E. (Eds), *Unmanned Aerial Vehicle Design and Technology. Sustainable Aviation*, Springer, Cham, doi: 10.1007/978-3-031-45321-2_5.

Yurek, E.E. and Ozmutlu, H.C. (2018), "A decomposition-based iterative optimization algorithm for traveling salesman problem with drone", *Transportation Research Part C: Emerging Technologies*, Vol. 91, pp. 249-262, doi: 10.1016/j.trc.2018.04.009.

Zhang, T., Zhao, F., Zhang, J., Mendis, G., Ru, Y. and Sutherland, J.W. (2019), "An approximation of the customer waiting time for online restaurants owning delivery system", *Journal of Systems Science and Complexity*, Vol. 32 No. 3, pp. 907-931, doi: 10.1007/s11424-018-7316-4.

Zhang, J., Campbell, J.F., Sweeney II, D.C. and Hupman, A.C. (2021), "Energy consumption models for delivery drones: a comparison and assessment", *Transportation Research Part D: Transport and Environment*, Vol. 90, 102668, doi: 10.1016/j.trd.2020.102668.

Corresponding author
Rico Merkert can be contacted at: rico.merkert@sydney.edu.au