Developing a Strategic Roadmap for Logistics 4.0 in South Korea: An Integrated QFD and SERVQUAL Approach

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Abstract

The rapid advancement of technology has significantly increased the complexity of logistics planning, necessitating enhanced collaboration among diverse sectors, including urban planning, ports, aviation, and railways. This study presents an integrated approach to establishing technology priorities and developing a roadmap for implementing Logistics 4.0 in South Korea's urban environments. The methodology begins with identifying key logistics technologies and trends through a comprehensive literature analysis. Customer needs are then assessed using the SERVQUAL model, which has been restructured to better reflect logistics service characteristics. Finally, the Quality Function Deployment (QFD) methodology is applied to prioritize technologies through expert surveys, leading to the development of a strategic roadmap. This roadmap outlines sequential development paths within each group while highlighting inter-group relationships, providing practical guidelines for implementing smart city logistics systems. The analysis identifies three top-priority technologies: Smart Last-Mile Delivery Hubs, Smart Logistics Terminals, and Delivery Robots. The research reveals four distinct technology groups: logistics hub technologies, air logistics technologies, ground-based logistics technologies, and digital environment technologies. This lays the groundwork for integrating various sectors and technologies to provide a unified vision for the future of logistics.

1.0 INTRODUCTION

Urbanization—the increasing concentration of people in urban areas—is one of the most significant trends shaping the future of logistics. According to a UN report, 55% of the global population currently lives in urban areas, and this proportion is expected to increase to 68% by 2050. Additionally, the number of megacities (urban areas with populations of over 10 million) is projected to increase from 33 in 2018 to 43 by 2030 (UN, 2018). This rapid urbanization is driving freight demand growth and creating new challenges for urban logistics. The growth of e-commerce has substantially increased parcel movement and delivery service demand. By 2027, e-commerce will constitute 41% of global retail sales, driving the demand for diverse delivery services and greater visibility in product flows (Boston Consulting Group, 2023). As urban freight demand increases, cities face critical challenges such as insufficient parking spaces, traffic congestion, and limited urban land for logistics facilities. Addressing these issues requires an integrated approach that combines Logistics 4.0 with smart city concepts.

Logistics 4.0 represents the application of Industry 4.0 technologies to logistics systems, incorporating advanced technologies such as artificial intelligence (AI), the Internet of Things (IoT), and autonomous vehicles (AVs). When integrated with smart-city concepts, these technologies provide more effective urban logistics solutions (Pan et al., 2024). Smart cities utilize ICT-based technologies to optimize resource usage through infrastructure that collects, integrates, and analyzes data using physical and digital twins (Harrison et al., 2010). The combination of Logistics 4.0 and smart city frameworks improves urban logistics efficiency through various innovations, such as AVs, automated warehouse operations with robotics, drone-based last-mile delivery, and micro-fulfillment centers. These solutions offer multiple benefits including reduced costs, shortened delivery times, reduced traffic congestion, and improved operational efficiency. Moreover, real-time tracking and personalized services enhance customer satisfaction.

The advancement of Logistics 4.0 and smart cities requires interdisciplinary research across management, information systems, and computer science. This development requires the coordinated involvement of multiple stakeholders (Pan et al., 2024). Defining clear priorities and sequences for development and adoption is crucial for effectively implementing advanced logistics technologies in urban logistics. This study aims to establish technology priorities for the Logistics 4.0 era and develop a roadmap for South Korea. It has three main objectives: (1) Define future technology requirements for urban logistics systems, (2) Evaluate service quality criteria using the service quality (SERVQUAL) model, and (3) Establish technology priorities using the QFD methodology. This integrated approach will provide practical guidelines for implementing smart cities with logistics systems.

2.0 LITERATURE REVIEW

2.1 Global Trends Shaping Future Logistics

The Fourth Industrial Revolution is transforming the logistics sector from traditional operations into a complex ecosystem involving multiple stakeholders. As Industry 4.0 reshapes all industries, the logistics paradigm is rapidly evolving into Logistics 4.0, which integrates technologies such as the IoT, AI, Big Data, and Cloud Computing. This transformation is enabling hyper-intelligence and hyper-connectivity, while making unmanned logistics through robots and drones a reality (Jeong et al., 2020). Unmanned automation technologies are being developed and commercialized across all transportation modes, including roads, railways, aviation, and maritime. New transportation modes and services are emerging, including Advanced Air Mobility (AAM) and delivery robots. While advanced technologies are being widely applied in logistics, efficient development requires the proper allocation of limited resources. To achieve this, it is necessary to reach a social consensus on priority areas through collaboration among various sectors, including urban planning, ports, aviation, roads, and railways. A review of domestic and international literature highlights an increasing focus on future logistics strategies and national R&D investment, emphasizing the importance of continued investment in Logistics 4.0.

The U.S. National Blueprint for Transportation Decarbonization outlines a comprehensive strategy for eliminating greenhouse gas emissions from the transportation sector by the year 2050. The short-term goal is to lay the foundation for the adoption of smart logistics technologies, whereas the long-term goal is to expand automation technologies and smart logistics systems to build a sustainable logistics ecosystem (U.S. Department of Energy, 2023). Similarly, the EU Green Deal targets a 90% reduction in transport emissions by

2050, emphasizing a shift to energy-efficient modes such as rail, maritime, and inland waterways (European Commission, 2021). The EU Commission's mobility strategy specifically aims to double rail freight volumes by 2050, while promoting the deployment of drones and unmanned aircraft. Furthermore, the EU is establishing a European Common Mobility Data Space to enhance innovation through data sharing and AI implementation (European Commission, 2020).

Similarly, Germany's Logistics 2030 Vision aims to support autonomous delivery systems using 5G networks and to establish decentralized micro-depots within cities through public-private partnerships (PPP). Additionally, the plan emphasizes the adoption of last-mile delivery methods such as drones and cargo bikes. This initiative seeks to create a sustainable and efficient logistics ecosystem through collaborations between city authorities and the private sector (Roland, 2018). Similarly, Australia's National Freight and Supply Chain Strategy (2019–2024) aims to build an efficient and sustainable logistics system. It focuses on enhancing smart infrastructure investment and data-driven decision-making, while promoting workforce development and sustainable operations to minimize environmental impacts. This focus on workforce development is particularly crucial, as labor shortages continue to challenge the logistics sector globally (Transport and Infrastructure Council, 2019). In parallel, Japan is implementing the Comprehensive Logistics Policy Outline (2021–2025) to address labor shortages, with projections showing a 34% shortfall in truck drivers by 2030. One of its key initiatives is the construction of dedicated autonomous driving lanes, with commercialization targeted for 2025 (MLIT, 2021). Likewise, the EU's Alliance for Logistics Innovation through Collaboration in Europe (ALICE) project aims to improve supply chain efficiency by 30% by 2030. ALICE Working Groups are developing detailed roadmaps focusing on key areas such as sustainability, digitalization, urban logistics, and cost reduction in logistics and supply chains (European Union, 2022).

In December 2023, South Korea's Ministry of Land, Infrastructure, and Transport announced the 'Second Spatial Information Technology Development (R&D) Mid-to-Long-term Roadmap (2025-2034),' allocating 360 billion won for implementation. This roadmap includes technology development plans for future industries such as autonomous driving, Urban Air Mobility (UAM), drones, robots, smart buildings, and digital twins. The ministry is also developing a three-dimensional positioning system that integrates ground, underground, indoor, and aerial spaces. This system will enable seamless communication in challenging environments such as tunnels and underground facilities, while ensuring personal information security for digital twin applications (MOLIT, 2024). This initiative aligns with 'The 5th National Logistics Master Plan (2021–2030),' which emphasizes digital transformation and smart logistics systems. The Master Plan focuses on establishing an integrated national logistics platform, promoting standardization, and implementing advanced technologies, including robotics, underground logistics, and autonomous systems (MOLIT, 2023).

Based on a review of major countries' logistics policies, the following four trends can be identified. The emergence of autonomous driving technology is transforming traditional freight transportation and introducing new transportation modes previously unused for freight. This shift toward autonomous systems necessitates substantial infrastructure upgrades and development. Additionally, rapid digital transformation is occurring across the entire logistics environment.

2.2 Technology Domains Based on Future Trends

Table 1 and Figure 1 illustrate four major trends in the logistics sector and their associated 20 representative technology areas. Autonomous driving technology has been integrated into five key areas of transportation: aircraft, airships, ships, trains, and trucks. By combining advanced autonomous systems with these existing modes of transport, a new logistics system is emerging.

The development of autonomous aircraft has reached a significant milestone with Airbus's ATTOL project, which successfully demonstrated fully autonomous operations using advanced image recognition and machine learning. Through extensive testing, this technology has shown promise for enhancing aviation efficiency while maintaining crucial safety standards (Miller et al., 2020). Building on these autonomous capabilities, the Hybrid Cargo Airship (HCA) represents another advancement in aviation technology, combining helium-based aerodynamics with Vertical Take-Off and Landing (VTOL) capabilities. HCAs offer unique advantages in disaster relief operations, enabling the swift delivery of supplies even when ground infrastructure is damaged (Owen-Jones, 2017; Tatham et al., 2017) Autonomous ships offer two major advantages: they enhance service delivery to remote coastal areas while simultaneously reducing the environmental footprint of maritime

logistics operations (Gu et al., 2021). Autonomous Train Control Systems (ATCS) enhance train autonomy by enabling real-time, independent decision-making using advanced sensors and control algorithms. In South Korea, the LTE-based Korean Train Control System (KTCS-2) has shown remarkable improvements in both safety and operational efficiency, reducing service headways and increasing transport capacity. These advancements represent a significant step toward the broader integration of autonomous technologies in rail systems (Song et al., 2022; Briginshaw, 2024). Autonomous trucks represent a key innovation in logistics, combining AI, sensors, and autonomous driving capabilities. By enabling continuous 24/7 operation, they address challenges such as driver fatigue, an aging workforce, and high transportation costs, while also reducing accidents and environmental impacts (Kim et al., 2022).

Emerging freight transportation modes are revolutionizing logistics through innovative technologies and systems. Underground Freight Transportation (UFT) is a novel logistics solution that moves goods through underground tunnels using electrically powered vehicles, offering improved efficiency and environmental benefits in urban areas. Studies show significant potential benefits, including a 40% cost reduction compared to traditional delivery models and the ability to remove up to 42% of packages from road networks with just 45 miles of tunnels (Powell et al., 2024). UAM and drone technologies are driving innovation in transportation and logistics, with UAM focusing on operational efficiency and infrastructure compatibility. The drone market is projected to grow from $30.2 billion in 2024 to $48.5 billion in 2029. These technologies are expected to significantly contribute to solving urban transportation challenges and improving logistics efficiency, with UAM particularly evolving as a safe and efficient air transportation system for passengers and cargo in low-altitude urban and suburban areas (Garrow et al., 2021; Unmanned Airspace, 2024). The hyperloop is an innovative high-speed transport system for passengers and freight that has attracted significant interest from stakeholders in Europe and Asia. The hyperloop system faces key technical and infrastructural requirements. Despite these challenges, recent developments by companies such as Swisspod have shown successful test runs and growing investor interest (Mitropoulos et al., 2021; McMillin, 2024). Autonomous Delivery Robots (ADRs) are revolutionizing last-mile logistics by addressing labor shortages, reducing costs, and promoting sustainability. While advancing in route optimization and fleet management, ADRs face challenges related to regulations, public acceptance, and integration with existing delivery systems (Srinivas et al., 2022). Space logistics is experiencing rapid growth, with the global market projected to expand by 18.3% annually from 2024 to 2034. The industry is evolving toward more connected and adaptable systems, with developments in satellite servicing, debris removal, and space-based logistics hubs shaping the future of space operations (Global Market Insights, 2024).

New infrastructure represents a significant trend in logistics innovation, encompassing eight key technologies that are reshaping the future of the industry. The tunnel market is expected to grow to $31.22 billion by 2028. This growth is exemplified by two major projects: the 18 km Fehmarnbelt Tunnel between Denmark and Germany and Norway's 26 km Boknafjord Tunnel, both of which significantly reduce travel times in their regions (Research and Markets, 2024; Mokran, 2024; Symons, 2024). Vertical and horizontal cargo elevators optimize urban logistics through multi-level underground transport systems. By integrating automation and IoT technologies, these systems can enhance space utilization and reduce surface traffic, thereby offering sustainable solutions for dense urban areas (Rho et al., 2021). Smart ports leverage automation and innovative technologies that focus on the integration of the IoT, cybersecurity, and cloud computing for optimized maritime operations (Li et al., 2023). Smart airports represent the evolution from traditional airports (Airport 1.0) to fully automated facilities (Airport 4.0). Key features include automated baggage-handling systems, intelligent routing, and comprehensive security measures, all of which are supported by autonomous robots with real-time monitoring capabilities (Göçmen, 2021). Vertiports are emerging as crucial infrastructure for UAM, with various scales under development—from medium-sized Vertiports to large-scale Vertihubs—to support electric VTOL operations (Schweiger & Preis, 2022). Smart Logistics Terminals combine physical infrastructure with digital systems, enabling automated operations, supported by digital infrastructure that facilitates seamless communication and operational efficiency (Brunetti et al., 2024). Smart Last-Mile Delivery Hubs are strategic urban locations where shipments are consolidated by postal operators for last-mile delivery using sustainable modes, such as cargo bikes. These hubs optimize urban logistics through micro-hub networks and automated delivery systems, focusing on sustainable urban solutions and efficient distribution (Novotná et al., 2022). Aerial/Underwater Last-Mile Delivery Hubs are evolving through innovations such as Amazon's Airborne Fulfillment Centers (AFCs). AFCs function as flying warehouses stationed approximately 45,000 feet above metropolitan areas, improving logistics efficiency by reducing delivery times and costs, while also

minimizing environmental impact through automated, optimized operations (Jeong et al., 2022).

Digital transformation has emerged as a key trend in logistics, particularly through the development of integrated information platforms and digital marketplaces. FENIX (European Federated Network of Information Exchange in Future Logistics) is Europe's federated logistics data-sharing platform, enabling Business-to-Business (B2B) exchanges across 11 pilot sites. KAIA's National Logistics Digital Platform integrates digital twin technology to monitor and analyze real-time logistics operations nationwide through comprehensive data collection and analysis of facilities, cargo, and transportation (Catana, 2022; KAIA, 2023). Blockchain-based digital marketplaces enable secure and transparent data exchange in last-mile logistics through transparent micro-hub operations and automated smart contracts (Hribernik et al., 2020).

Table 1. Four Major Trends and 20 Representative Technology Areas in the Logistics Sector.

Category	Technology	Source
Autonomous Driving	Autonomous Aircraft	(Miller et al., 2020)
	Autonomous Airship	(Owen-Jones, 2017; Tatham et al., 2017)
	Autonomous ship	(Gu et al., 2021)
	Autonomous Train	(Song et al., 2022; Briginshaw, 2024)
	Autonomous Truck	(Kim et al., 2022)
Emerging Freight Transportation Modes	Underground Logistics	(Powell et al., 2024)
	AAM & Drones	(Garrow et al., 2021; (Unmanned Airspace, 2024)
	Hyperloop	(Mitropoulos et al., 2021; McMillin, 2024)
	Delivery Robots	(Srinivas et al., 2022)
	Space Logistics	(Global Market Insights, 2024)
New Infrastructure	Underwater Tunnel	(Research and Markets, 2024; Mokran, 2024; Symons, 2024)
	Vertical/Horizontal Cargo Elevators	(Rho et al., 2021)
	Smart Ports	(Li et al., 2023)
	Smart Airports	(Göçmen, 2021)
	Vertiport	(Schweiger & Preis, 2022)
	Smart Logistics Terminals	(Brunetti et al., 2024)
	Smart Last-Mile Delivery Hubs	(Novotná et al., 2022)
	Aerial/Underwater Last-Mile Delivery Hubs	(Jeong et al., 2022)
Digital Transformation	National Logistics Integrated Information Platform	(Catana, 2022; KAIA, 2023)
	Digital marketplace	(Hribernik et al., 2020)

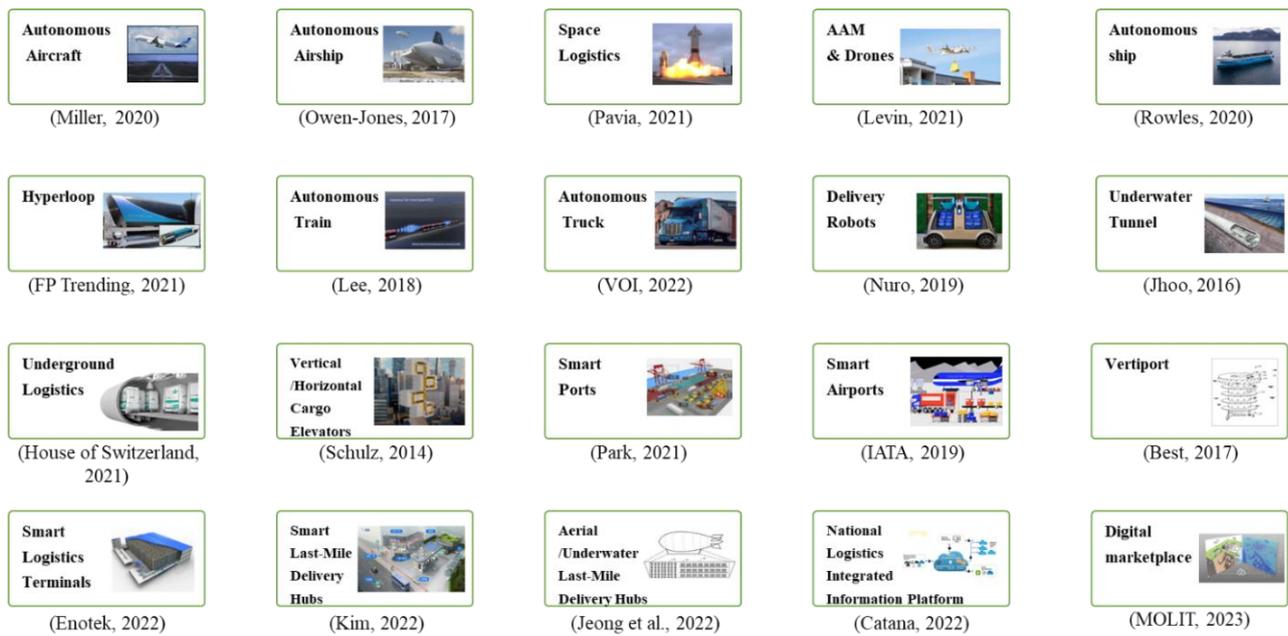| Autonomous Aircraft	Autonomous Airship	Space Logistics	AAM & Drones	Autonomous ship
(Miller, 2020)	(Owen-Jones, 2017)	(Pavia, 2021)	(Levin, 2021)	(Rowles, 2020)
Hyperloop	Autonomous Train	Autonomous Truck	Delivery Robots	Underwater Tunnel
(FP Trending, 2021)	(Lee, 2018)	(VOI, 2022)	(Nuro, 2019)	(Jhoo, 2016)
Underground Logistics	Vertical /Horizontal Cargo Elevators	Smart Ports	Smart Airports	Vertiport
(House of Switzerland, 2021)	(Schulz, 2014)	(Park, 2021)	(IATA, 2019)	(Best, 2017)
Smart Logistics Terminals	Smart Last-Mile Delivery Hubs	Aerial /Underwater Last-Mile Delivery Hubs	National Logistics Integrated Information Platform	Digital marketplace
(Enotek, 2022)	(Kim, 2022)	(Jeong et al., 2022)	(Catana, 2022)	(MOLIT, 2023)

Figure 1. An illustration of the 20 representative technologies.

2.3 Comparison of Technology Prioritization Methods

The prioritization of technologies has become essential as logistics systems and Industry 4.0 continue to evolve rapidly. Current literature presents various methodologies for analyzing, prioritizing, and implementing advanced technologies across industries, each with distinct advantages and limitations. These methodologies can be broadly categorized into several approaches for identifying technological trends, including fuzzy logic, hierarchical structuring, and patent analysis. Understanding these frameworks is crucial for developing effective technology prioritization strategies that balance technical capabilities with market demand and operational requirements. Table 2 compares these technology prioritization methods and highlights the strengths of QFD and SERVQUAL.

Callefi et al. (2024) utilized fuzzy DEMATEL to identify causal relationships between technological elements within complex systems and to determine which technologies serve as foundations for others. The model's strength lies in its ability to address uncertainty in expert judgments through fuzzy set theory, thereby overcoming the limitations of subjective assessments. Hsu et al. (2024) used FISM-MICMAC to categorize factors into driving and dependent groups, enabling the identification of influential elements. While effective for determining key factors, it lacks specific guidance for improvement strategies. To address this, they developed a strategic roadmap for implementing Industry 5.0-driven smart logistics based on expert opinions. Kwon et al. (2022) applied Latent Dirichlet Allocation (LDA) to cluster patents into topics, revealing technological patterns and trends over time. Although LDA is effective for analyzing unstructured text data, it is limited in directly capturing customer needs. On the other hand, Lu et al. (2022) utilized the Kano model to categorize service attributes based on their impact on customer satisfaction. This method helps prioritize features based on their potential impact, while SERVQUAL and QFD provide the technical frameworks to implement these priorities effectively. This method helps prioritize features but does not translate customer expectations into technical requirements, as QFD does. Trappey et al. (2017) used a patent-analysis-based roadmap methodology, leveraging objective patent data to analyze trends and strategies. However, this approach primarily focuses on technical aspects and does not reflect customer needs or market demands. Awasthi et al. (2012) combined the Affinity Diagram, Fuzzy TOPSIS, and SERVQUAL to organize data, evaluate alternatives, and align customer needs with market demands.

QFD and SERVQUAL are particularly effective in aligning customer needs with technical requirements, offering a comprehensive and systematic approach to prioritizing technologies. SERVQUAL measures customer expectations and perceptions, and identifies gaps in service quality, while QFD translates these needs into actionable technical specifications using tools such as the House of Quality (HOQ). These methods use matrix calculations to establish direct relationships between customer needs and technical requirements,

thereby providing a transparent and systematic process for determining priorities based on weighted calculations. While these methods may require additional time and resources for expert consensus-building, they effectively integrate customer needs and market demands into the planning process. In this study, QFD and SERVQUAL were chosen for their ability to align customer needs with technical requirements, thus offering a practical and customer-centric approach to roadmap development. Their integration provides a systematic framework for addressing these changes by evaluating service quality expectations and perceptions, translating customer requirements into technical specifications, and developing a prioritized roadmap for adopting new technologies.

Table 2. Comparison of different technology prioritization methods.

Source	Research Objectives	Methods	Main Findings
Callefi et al. (2024)	To develop a roadmap for adopting ICTs to enhance road freight transportation (RFT) management.	Fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL).	- Identified 12 technologies to improve RFT management, prioritizing real-time data exchange and tracking technologies. - Conducted relationship analysis to develop a roadmap.
Hsu et al. (2024)	To identify key enablers for adopting smart logistics and develop a strategic roadmap suitable for the Industry 5.0 era.	Fuzzy Interpretative Structural Model - Matrices Impacts Croises-Multiplication Appliance Classement (FISM-MICMAC)	Underscored the significant roles of "Active support from the government" and "Human-centric manufacturing and logistics" as the most critical enablers of Industry 5.0.
Kwon et al. (2022)	To establish a methodology that predicts technological changes in the logistics sector through patent analysis.	Latent Dirichlet Allocation & Patent analysis	Classification of patent data into 15 distinct topics, with Micro-fulfillment and Logistics and Packaging Technology emerging as the most promising areas.
Lu et al. (2022)	To determine which smart transportation initiatives should be prioritized to effectively meet public needs and contribute to sustainable urban development.	Kano model & Customer satisfaction coefficient	- Utilized the Kano model to classify 24 smart transportation items into three categories based on user needs: Attractive, One-dimensional, and Indifferent - Identified public transport payment and real-time information system as top priorities.
Trappey et al. (2017)	To analyze technology roadmaps for the adoption of IoT technologies in smart logistics services.	Patent analysis	IBM focuses on technologies adaptable to diverse industries, while UPS emphasizes logistics transportation and tracking.
Awasthi et al. (2012)	To develop a hybrid approach that integrates Affinity Diagram, Analytic Hierarchy Process (AHP), and fuzzy TOPSIS for sustainable city logistics planning.	Affinity Diagram & AHP & Fuzzy TOPSIS	- Affinity Diagram was used to derive 16 evaluation criteria from four dimensions and AHP determined their importance and weights - Fuzzy TOPSIS evaluated and ranked four city logistics initiatives - Identified time restrictions as the most effective city logistics initiative

3.0 METHODOLOGY

3.1 Research Framework

The process began by identifying key logistics technologies and trends through a comprehensive literature review. Next, customer needs related to logistics service quality were derived using two complementary frameworks: the 7Rs theory and national transportation policy. In the second step, the SERVQUAL model was applied to assess these identified needs across restructured dimensions that better reflect logistics service characteristics. In the third step, the QFD methodology, particularly the HOQ matrix, was used to guide the prioritization process through expert surveys. These surveys gathered insights from logistics and transportation experts to ensure that the prioritization process was both practical and aligned with market demands. Experts first ranked customer needs based on their importance, then evaluated how well each technology addresses these prioritized needs, and finally assessed the interrelationships between technologies. Based on these evaluations, importance weights were assigned to technologies, ultimately leading to the development of a strategic roadmap. Figure 2 illustrates the research framework.
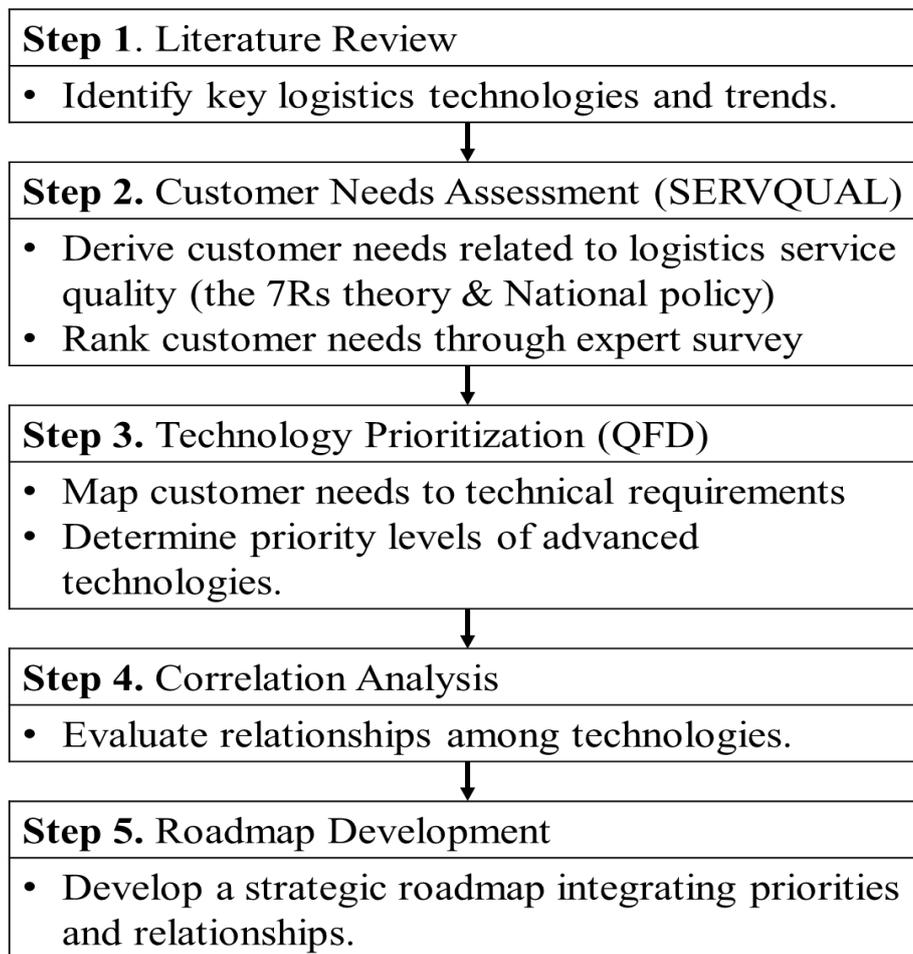
Step 1. Literature Review

- Identify key logistics technologies and trends.

Step 2. Customer Needs Assessment (SERVQUAL)

- Derive customer needs related to logistics service quality (the 7Rs theory & National policy)
- Rank customer needs through expert survey

Step 3. Technology Prioritization (QFD)

- Map customer needs to technical requirements
- Determine priority levels of advanced technologies.

Step 4. Correlation Analysis

- Evaluate relationships among technologies.

Step 5. Roadmap Development

- Develop a strategic roadmap integrating priorities and relationships.

Figure 2. Research framework.

As summarized in Table 3, the expert panel comprised highly qualified professionals with diverse academic backgrounds and extensive logistics and transportation experience. The panel included nine experts, most of whom held doctoral degrees in fields, such as Maritime Business & Logistics, Transportation Engineering, Geography, and Industrial and Systems Engineering. Their roles ranged from assistant and associate professors to senior researchers. With an average of 15 years of experience in logistics and transportation-related disciplines, these experts brought substantial expertise to this study. This diverse and experienced panel provided a robust foundation for ensuring the validity and reliability of the expert surveys and prioritization processes used in this research.

<div align="center">Table 3. Profile of experts.</div>

Experts	Position	Academic education	Experience with logistics/transportation
1	Senior Researcher	Ph.D. in Maritime Business & Logistics	24 years
2	Senior Researcher	Ph.D. in Logistics	21 years
3	Senior Researcher	Ph.D. in Transportation Engineering	20 years
4	Assistant Professor	Ph.D. in Transportation Engineering	15 years
5	Assistant Professor	Ph.D. in Transportation Engineering	15 years
6	Assistant Professor	Ph.D. in Transportation Engineering	14 years
7	Researcher	Ph.D. in Geography	10 years
8	Associate Professor	Ph.D. in Transportation Engineering	10 years
9	Assistant Professor	Ph.D. in Industrial and Systems Engineering	9 years

3.2 Customer Needs and Service Quality Analysis

3.2.1   Customer Needs Identification

Table 4 illustrates the advanced logistics needs derived from the 7Rs theory and the perspective of national transportation policy. Core logistics needs were identified by examining the 7Rs, which focus on key aspects such as location, time, and quantity, facilitating the assessment and optimization of corporate logistics systems (Perreault & Russ, 1974). To clarify the scope of this study, we focused on identifying future directions for logistics in South Korea. Accordingly, customer needs were derived by analyzing South Korea's logistics policy framework, considering the key directions outlined in the "2nd Comprehensive Plan for National Territorial and Transport R&D (2023–2032)" issued by the Ministry of Land, Infrastructure, and Transport (MOLIT). This approach aligns with South Korea's national logistics and transportation vision, enhancing the study's relevance to the South Korean context.

<div align="center">Table 4. Advanced logistics needs.</div>

Category	Advanced Logistics Needs
7Rs theory (Core Logistics Values)	(1) (Right time) Is the logistics service provided within the required schedule?
	(2) (Right place) Is the logistics service provided at the appropriate location?
	(3) (Right price) Is the logistics service provided at the appropriate cost?
	(4) (Right product) Is accurate logistics service provided for the required products?
	(5) (Right quantity) Is the logistics service provided for the required quantity?
	(6) (Right customer) Is the logistics service provided to the appropriate customer?
	(7) (Right condition) Is the logistics service provided while maintaining product condition?
National Transportation Policy	(8) Is it an advanced intelligent logistics system for digital transformation?
	(9) Is it a carbon-neutral logistics system in response to climate change?
	(10) Is it an inclusive and safe logistics system for public safety and convenience?

3.2.2   Derivation of SERVQUAL Dimensions

The SERVQUAL model, developed by Parasuraman (1988), is a multidimensional scale designed to measure service quality by assessing the gap between customer expectations and perceptions across five dimensions: tangibles, reliability, responsiveness, assurance, and empathy. Based on a comprehensive literature review of Logistics Service Quality (LSQ), this study proposes specialized dimensions that better reflect the characteristics of advanced logistics services. Gulc (2017) provided a comprehensive review of LSQ dimensions, while Arabelen and Kaya (2021) noted the evolution of LSQ dimensions from physical attributes to a more customer-centric approach. They proposed an LSQ framework consisting of five dimensions and 24

factors, derived from a synthesis of literature analysis and expert interviews. In a recent study, Jamkhaneh et al. (2022) focused on identifying key factors influencing Logistics 4.0 service quality. Our study proposes six evaluation criteria as the dimensions of LSQ: economic efficiency, logistics efficiency, environmental friendliness, technological innovation, security and safety, and ripple effects. Detailed descriptions of these dimensions and their corresponding sub-dimensions are presented in Table 5.

Table 5. Dimensions and sub-dimensions of logistics service quality

Dimensions	Sub-dimensions
Economic efficiency	Easy negotiation with suppliers/purchasers
	Easy acquisition of facilities/workforce
	Easy procurement of capital/materials and components
	High possibility of investing public resources
	High input of public goods and government participation
	High possibility of mass production
	High market growth and preference in the market
	Easy entry into the industrial market
	Low intensity of competition between companies
	High labor productivity
	High quality competitiveness
	High diversity and establishment of sales channels
	High future logistics needs and potential (density)
	High possibility of creating added value
Logistics efficiency	High reduction effect on total logistics costs (storage costs, transportation costs, etc.)
	Short waiting time for entry and exit at logistics hub facilities
	High on-time delivery rate for transportation
	Low empty vehicle distance rate for cargo trucks
	High transportation time efficiency
	High spatial efficiency
	High contribution to technology standardization
	High contribution to automation
	High contribution to informatization
	High contribution to logistics collaboration
Environmental friendliness	High energy efficiency
	Low air pollution emissions
	Low water pollution emissions
	High waste recycling effect
	High utilization of environmentally friendly technologies
	Low vibration/noise levels
Technological innovation	Superior technology
	High technological maturity
	Differentiated technology compared to others (originality)
	Developed as a pure domestic technology with high potential for overseas expansion
	Low possibility of emergence of alternative technologies
	Advantageous compared to substitutes
	Long-term sustainability in terms of technology life cycle
Security and safety	Low annual number of theft cases
	High number of accident-free days
	Low number of casualties

	Low annual number of accidents
	Low cargo damage rate
	Low compensation amount for damages
	High stability or securement possibility of rights
Ripple effects	Wide range of beneficiaries from technology development
	High potential for technology application and extension
	Significant industrial ripple effect
	Alignment with relevant industry trends
	High potential for expansion of related infrastructure

Equations (1) and (2) describe the process used to calculate the importance weights for the six evaluation criteria based on expert evaluations. Each expert assigned scores to the criteria (denoted as j), with the total score for all criteria summing up to 100 points. The scores from all participating experts were then averaged to calculate the mean score m_j for each criterion, as shown in Equation (1):

$$m_j = \frac{\sum_{i=1}^{N} x_{ij}}{N_{allj}} \qquad (1)$$

Here, x_{ij} represents the score given by the i-th expert to the j-th criterion, and N_{allj} is the total number of respondents who provided the data. The calculated mean scores m_j were normalized to derive the relative importance weights for each criterion, as shown in Equation (2):

$$Critera\ weights_j = \frac{m_j}{\sum_{j=1}^{N} m_j} \qquad (2)$$

This normalization ensured that the sum of all weights equaled 1, allowing for a standardized comparison of the importance assigned to each criterion. As a result, economic efficiency (0.2411) emerged as the most important, followed by logistics efficiency (0.2156), environmental friendliness (0.1700), security and safety (0.1367), technological innovation (0.1211), and ripple effects (0.1156). The relative importance of these criteria was used to evaluate the previously identified Advanced Logistics Needs, ensuring alignment between each need and the corresponding SERVQUAL dimensions.

3.2.3   Prioritization of Advanced Logistics Needs

Table 6 illustrates the correlation scores between each advanced logistics need and the evaluation criteria. Each value represents the average score across all respondents. The evaluation criteria weights, calculated earlier, are presented in the first row. Subsequent rows show the average scores assigned to each need by respondents on a ten-point scale. The shaded values indicate the three highest scores in each column, identifying the needs that are most closely aligned with the prioritized evaluation criteria.

Table 6. Correlation scores between advanced logistics needs and evaluation criteria.

Evaluation items	economic efficiency (0.2411)	logistics efficiency (0.2156)	environmental friendliness (0.1700)	security & safety (0.1211)	technological innovation (0.1367)	ripple effects (0.1156)
Needs1	7.4	9.6	3.9	6.7	7.2	5.1
Needs2	7.6	9.0	4.7	6.9	6.0	5.3
Needs3	9.9	9.1	4.6	3.8	7.0	5.7
Needs4	7.1	8.1	4.0	7.8	7.9	6.6
Needs5	8.4	9.0	4.1	5.3	6.9	5.0
Needs6	7.9	8.9	4.3	6.2	6.1	7.0
Needs7	7.9	8.7	5.6	8.4	6.7	6.1
Needs8	7.1	8.6	5.7	7.6	9.1	7.6
Needs9	5.4	7.6	10.0	4.0	8.1	7.6
Needs10	6.0	6.2	6.3	9.6	6.3	7.6

The weighted scores were calculated by multiplying each value in Table 6 with its corresponding evaluation criterion weight. For example, the first cell (7.4) was multiplied by the weight of the first criterion (0.2411), while the second cell (9.6) was multiplied by the weight of the second criterion (0.2156). This calculation was performed for all cells, creating a new matrix of weighted scores. The overall importance of each need was then determined by calculating the mean of the weighted scores across each row. These final importance scores are presented in Table 7. This process ensured that the relative importance of each need aligned with the weights of the evaluation criteria. These calculated need weights served as the foundation for the subsequent application of the QFD methodology.

Table 7. Priority ranking of weights for each advanced logistics need.

Needs	Weights	Rankings
(1) (Right time) Is the logistics service provided within the required schedule?	0.098	7
(2) (Right place) Is the logistics service provided at the appropriate location?	0.097	9
(3) (Right price) Is the service provided at the appropriate cost (resources)?	0.102	3
(4) (Right product) Is the logistics service provided for the required product, including accurate information?	0.098	6
(5) (Right quantity) Is the logistics service provided for the required quantity?	0.097	8
(6) (Right customer) Is the logistics service provided to the appropriate customer?	0.099	5
(7) (Right condition) Is the logistics service provided while maintaining the required condition of the product?	0.104	2
(8) Is it an advanced intelligent logistics system for digital transformation?	0.107	1
(9) Is it a carbon-neutral logistics system in response to climate change?	0.101	4
(10) Is it an inclusive and safe logistics system for public safety and convenience?	0.096	10

3.2.4   QFD-based Technology Evaluation

The technology prioritization process consisted of two main phases, as illustrated in Figure 3. In the first phase, as previously detailed in Section 3.2.3, correlation scores between advanced logistics needs and evaluation criteria were calculated to determine the relative importance of each need. In the second phase, the focus shifted to evaluating the relationships between these needs and candidate technologies using the QFD methodology, specifically the HOQ.
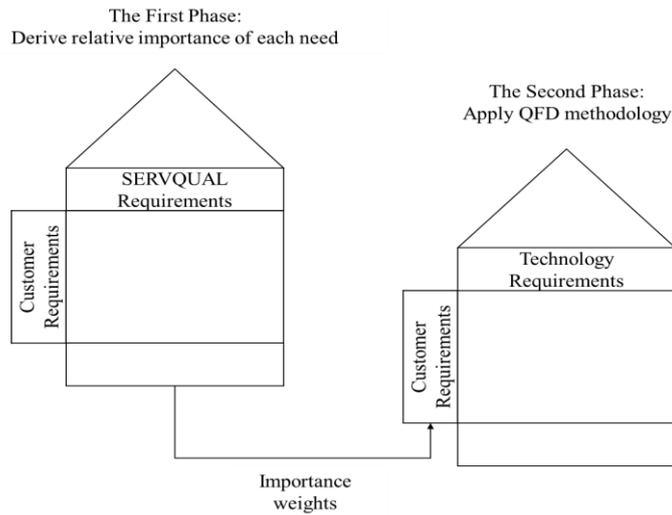
Figure 3. Two phases in the process used to prioritize advanced logistics technology.

The HOQ is a matrix-based tool that translates customer needs into technical equirements. It provides a structured framework that relates 20 candidate technologies to ten customer needs, as shown in Figure 4. Technologies with higher total scores were identified as better suited for meeting needs and ensuring a comprehensive roadmap for technology implementation.
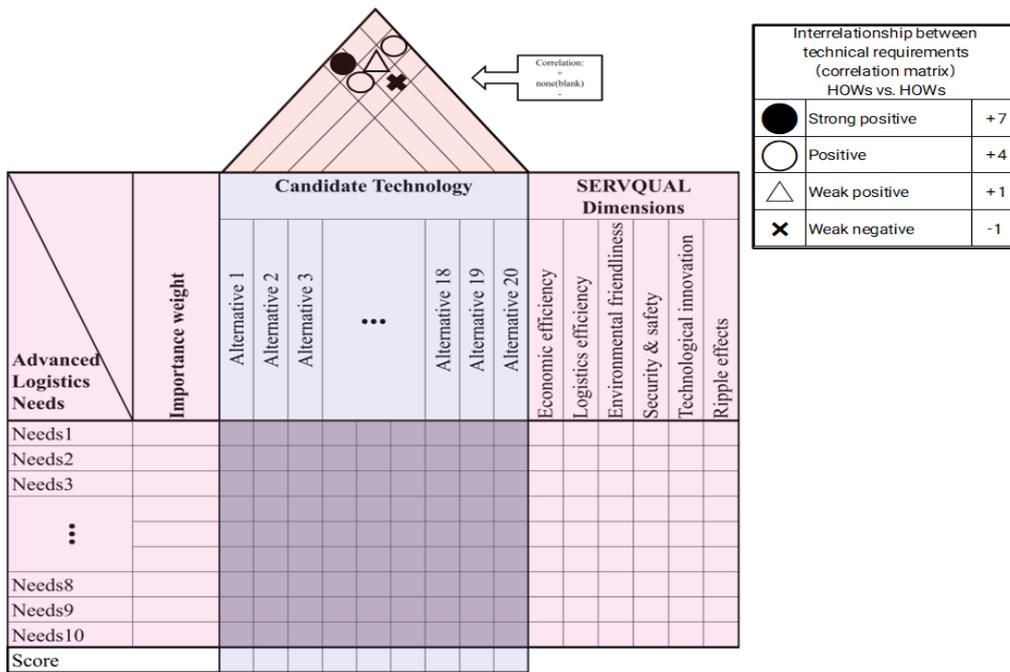

Figure 4. Structure of the House of Quality (HOQ) used in this study.

This process comprised the following steps. Nine respondents assessed the correlation between each technology (k) and need. Individual scores (x_{ijk}) were aggregated and averaged, as shown in Equation (3):

$$m_{jk} = \frac{\sum_{i=1}^{N} x_{ijk}}{N_{alljk}} \qquad (3)$$

For each candidate technology, each correlation value (m_{jk}) was multiplied by the corresponding need weight (w_j). Weighted scores were summed to obtain the overall technology score (s_k), as shown in Equation (4):

$$s_k = \sum_{j=1}^{10}(w_j \times m_{jk}) \qquad (4)$$

The Arithmetic Mean of Means (AMM) was implicitly used in this process by averaging individual scores (x_{ijk}) for each correlation (m_{jk}), ensuring that group-level data were reflected in the technology scoring. This approach effectively integrated the opinions of all respondents, providing a foundational assessment for comparing candidate technologies.

While the AMM offers group-level aggregation, the Arithmetic Mean (AM) and Geometric Mean (GM) were employed to effectively evaluate and prioritize candidate technologies. Before introducing the AM formula, it was essential to understand the comprehensive evaluation score for each candidate technology (s_{ik}). This score represents the weighted sum of the correlation scores (m_{ijk}) between each technology (k) and need (j), as assessed by each respondent (i), and the corresponding weights of the needs (w_{ij}), as shown in Equation (5):

$$s_{ik} = \sum_{j=1}^{10}(w_{ij} \times m_{ijk}) \qquad (5)$$

The s_{ik} values formed the basis for calculating both the AM and GM. The AM aggregated the comprehensive scores (s_{ik}) across all respondents to calculate the average technology score, as shown in Equation (6):

$$AM_k = \frac{\sum_{i=1}^{N} s_{ik}}{N_{allk}} \qquad (6)$$

The AM treated each expert's evaluation equally, ensuring that every opinion was reflected in the results, even if one evaluation differed significantly from the others. When expert evaluations were similar, the AM effectively represented the group's central tendency. However, the AM is sensitive to extreme values (outliers), meaning that a single expert's evaluation could disproportionately influence the overall average (Fleming et al., 1986). In contrast, the GM handles extreme values better by using multiplication and roots. If an expert assigned a very high or very low score, the GM reduced the effect of outliers to better reflect the overall trend. However, the GM cannot process zero values and may become distorted with very small values (Jacquier et al., 2003). The GM was computed by multiplying all individual scores ($s_{1k} \times s_{2k} \ldots \times s_{Nk}$) and taking the N-th root, as shown in Equation (7):

$$GM_k = \sqrt[N_{all}]{s_{1k} \times s_{2k} \ldots \times s_{Nk}} \qquad (7)$$

Figure 5 presents a comprehensive view of the AMM, AM, and GM methodologies. The combination of the three methods provides a more reliable way to rank technologies. The AMM captures group consensus, the AM reflects individual variations, and the GM shows relative differences between scores. This comprehensive approach supports better decision-making regarding which technologies to prioritize.
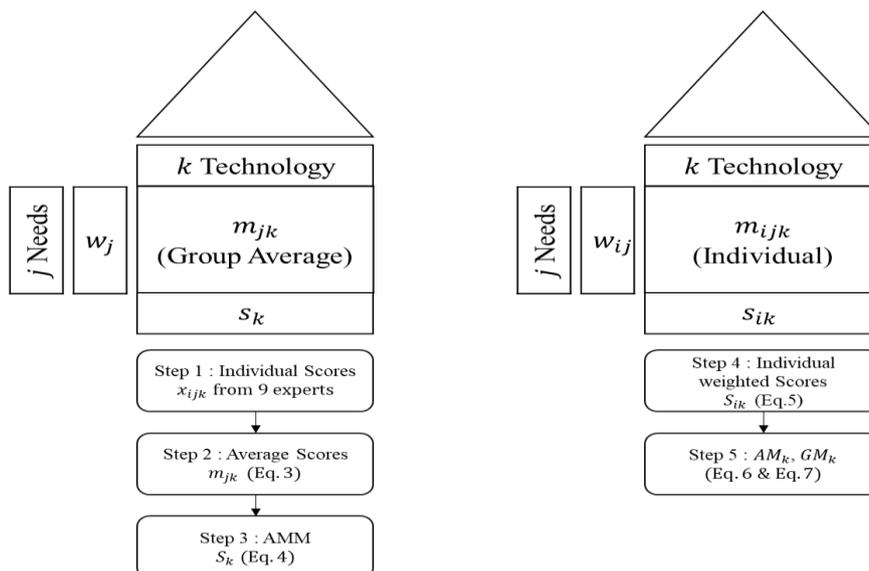

Figure 5. Comparison of mathematical methods (the AMM, AM, GM).

4.0 RESULTS AND DISCUSSION

4.1 Technology Prioritization Using QFD

Table 9 presents the quantitative results comparing priorities across the three methods. Due to space constraints, Table 8 provides a cross-reference between the names and numbers associated with the candidate technologies.

Table 8. Corresponding numbers for the technologies.

No.	Technology	No.	Technology
1	Autonomous Aircraft	11	Underground Logistics
2	Autonomous Airship	12	Vertical/Horizontal Cargo Elevators
3	Space Logistics	13	Smart Ports
4	AAM & Drones	14	Smart Airports
5	Autonomous Ship	15	Vertiport
6	Hyperloop	16	Smart Logistics Terminals
7	Autonomous Train	17	Smart Last-Mile Delivery Hubs
8	Autonomous Truck	18	Aerial/Underwater Last-Mile Delivery Hubs
9	Delivery Robots	19	National Logistics Integrated Information Platform
10	Underwater Tunnel	20	Digital Marketplace

The analysis of the 20 candidate technologies identified the top three priorities: 1. Smart Last-Mile Delivery Hubs, 2. Smart Logistics Terminals, and 3. Delivery Robots. Although slight variations appeared in the rankings derived from the three methods, the overall priorities remained consistent. Some variations appeared in the lower-middle rankings due to different averaging methods and decimal place differences.

Table 10 illustrates the correlations between technologies, with values ranging from -2 to +2. A value of +2 indicates a strong positive correlation, suggesting that the two technologies strongly complement or enhance each other. A value of +1 represents a weak positive correlation, showing a complementary relationship between the two technologies. A correlation of 0 implies no relationship, indicating the two technologies do not influence each other. On the negative side, a value of -1 reflects a weak negative correlation, suggesting a minor conflict between the technologies. Lastly, a value of -2 indicates a strong negative correlation, where the two technologies significantly conflict or reduce each other's effectiveness.

The strongest positive correlations (+8 to +9) were found between AAM and drones with vertiport (+9), followed by three pairs with a +8 correlation: autonomous trains with underground logistics, smart logistics terminals with last-mile delivery hubs, and the National Logistics Integrated Information Platform with a digital marketplace. Moderate positive correlations (+6) were observed between several pairs: smart logistics terminals with smart ports, hyperloop with autonomous trains, autonomous ships with smart ports, smart ports with smart airports, and smart last-mile delivery hubs with aerial/underwater last-mile delivery hubs. Only one negative correlation (-2) was identified, between space logistics and delivery robots. The QFD- and SERVQUAL-based analyses, which integrated the findings from Tables 9 and 10, are presented in Figure 6.

Table 9. Prioritization of candidate technologies.

Needs	Weights	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.098	7.3	6.3	5.6	7.7	7.1	7.2	7.4	8.2	8.3	7.3	7.6	8.1	8.2	8.4	7.6	8.9	9.0	7.1	8.1	7.6
2	0.097	6.0	5.4	4.0	7.1	6.4	5.7	6.2	7.9	8.1	6.7	7.4	7.1	7.8	7.7	6.6	8.3	9.0	6.7	6.3	6.2
3	0.102	6.3	6.7	3.6	6.4	6.8	5.1	7.0	7.4	7.6	5.7	7.8	7.2	7.8	7.6	6.1	7.4	8.0	5.2	7.2	7.0
4	0.098	6.3	6.2	4.3	7.0	7.3	6.9	7.3	7.3	7.8	6.0	7.0	6.2	8.0	7.8	6.3	8.2	8.1	6.1	8.8	8.3
5	0.097	5.7	6.0	4.0	4.6	7.2	5.3	6.8	7.3	6.8	6.0	6.8	6.8	7.2	7.0	4.3	7.8	7.2	5.9	6.3	5.6
6	0.099	6.6	5.3	3.9	6.8	7.0	6.3	6.9	7.9	8.3	6.3	7.0	7.4	6.4	6.7	5.7	7.9	8.1	5.8	8.1	7.4
7	0.104	7.0	6.4	4.4	6.7	7.2	7.8	7.3	7.9	6.7	7.4	7.9	7.3	7.9	7.9	6.1	7.6	8.0	5.1	6.9	6.1
8	0.107	8.4	7.3	6.1	8.6	9.0	7.4	7.4	9.0	8.6	6.3	7.0	6.7	9.1	9.0	8.6	8.7	8.6	7.0	9.6	9.6
9	0.101	5.8	7.4	3.3	6.9	6.4	6.6	7.4	6.6	7.8	7.2	8.4	7.4	7.2	7.2	6.2	6.6	7.1	5.6	6.4	6.0
10	0.096	5.2	5.2	3.3	5.2	5.4	6.1	6.8	6.8	7.0	6.2	6.6	6.6	6.6	6.1	5.8	6.6	7.8	5.4	7.2	5.8
AAM		6.5	6.3	4.3	6.7	7.0	6.5	7.1	7.6	7.7	6.5	7.3	7.1	7.6	7.5	6.3	7.8	8.1	6.0	7.5	7.0
Rank		15	18	20	13	11	16	10	4	3	14	8	9	5	6	17	2	1	19	7	12
AM_k		6.5	6.3	4.3	6.7	7.0	6.5	7.1	7.6	7.7	6.5	7.3	7.1	7.6	7.6	6.4	7.8	8.1	6.0	7.6	7.0
rank		15	18	20	13	12	16	9	5	3	14	8	10	4	7	17	2	1	19	6	11
GM_k		6.3	6.1	3.9	6.6	6.9	6.4	7.0	7.6	7.6	6.3	7.3	7.0	7.5	7.4	6.2	7.7	8.0	5.6	7.4	6.9
rank		16	18	20	13	11	14	9	4	3	15	8	10	5	7	17	2	1	19	6	12

Table 10. Correlation Matrix of Advanced Logistics Technologies.

Technology	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1																				
2	4																			
3	1	1																		
4	6	6	1																	
5	1	1	0	1																
6	0	0	0	0	0															
7	0	0	0	0	0	6														
8	1	1	0	1	1	4	2													
9	1	1	-2	5	1	0	0	1												
10	0	0	0	0	0	5	4	4	0											
11	0	0	0	0	0	5	8	0	0	5										
12	0	0	0	0	0	2	2	0	0	0	5									
13	0	0	0	0	6	0	0	1	0	1	0	0								
14	4	2	0	2	0	0	0	1	0	1	0	0	6							
15	2	2	0	9	0	0	0	1	0	1	0	2	1	1						
16	0	0	0	0	0	0	0	2	0	1	0	3	6	6	2					
17	0	0	0	3	0	0	0	1	5	1	2	0	4	4	3	8				
18	0	1	0	4	0	0	0	1	2	1	0	0	2	2	5	4	6			
19	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	1	2	2		
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	
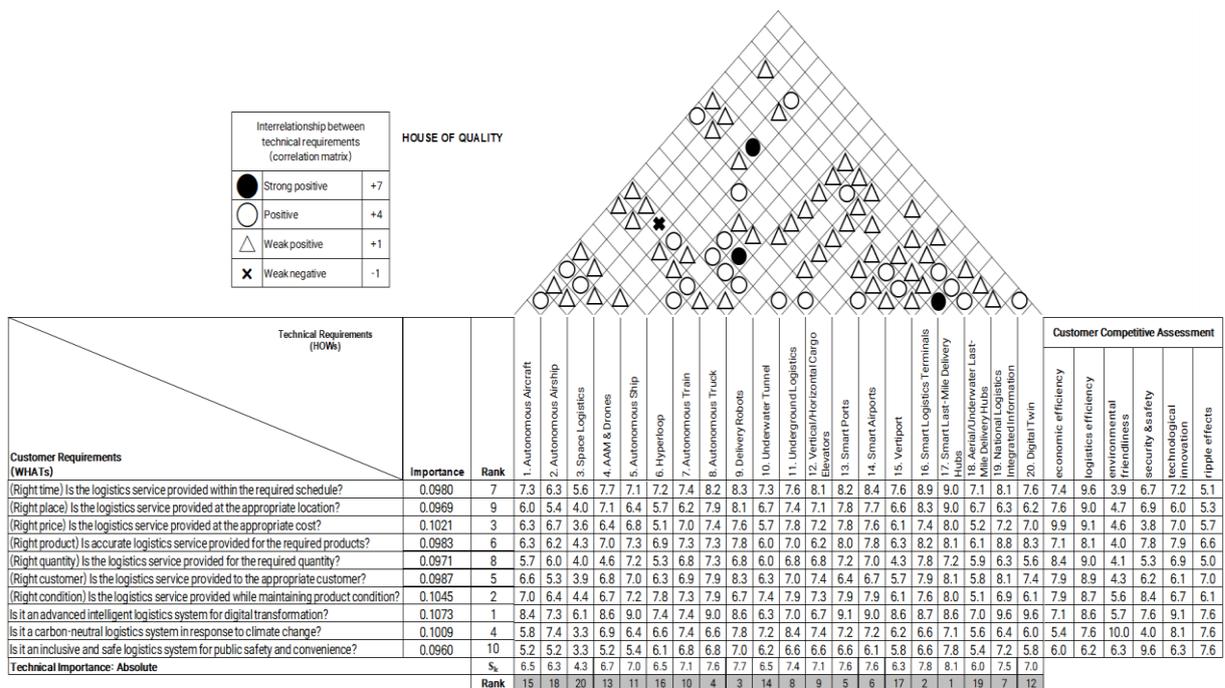
Figure 6. House of Quality for advanced logistics technology prioritization.

4.2 Understanding Technology Dependencies and Group Relationships

A Predecessor refers to a technology that exists before the development of a specific technology and serves as its foundation or basis. These technologies can influence or inspire the development of successor technologies. A successor technology builds upon or replaces the predecessor with more advanced features. Understanding the relationship between predecessor and successor technologies helps identify the flow and patterns of technological development, aiding future technology forecasting and strategic R&D planning. The fact that technologies are related does not imply that they will inevitably develop sequentially. Their developmental paths vary depending on circumstances, environment, and necessity (Guem et al., 2015).

In this study, predecessor-successor relationships were identified through expert surveys, with their frequencies counted and presented as "frequency" in Figure 7. This approach provided valuable insights into technological dependencies and priorities for advancement. The analysis revealed several key sequential relationships, with 50% of respondents indicating that smart ports should follow autonomous ships development. Other significant sequences included smart airports following autonomous aircraft development and smart last-mile delivery hubs following delivery robot development. This pattern suggests a general preference for developing transportation means before infrastructure. However, some exceptions exist, such as AAM and UAV development following vertiport construction, and vertical and horizontal cargo elevators following both underground logistics and smart last-mile delivery hubs development. These varying perspectives on infrastructure versus transportation development priorities indicate that sequential relationships may depend on specific circumstances and stakeholder viewpoints. Therefore, technology development planning requires a flexible approach that considers individual technology characteristics, interrelationships, contextual factors, and stakeholder perspectives to ensure more effective implementation of advanced logistics technologies.
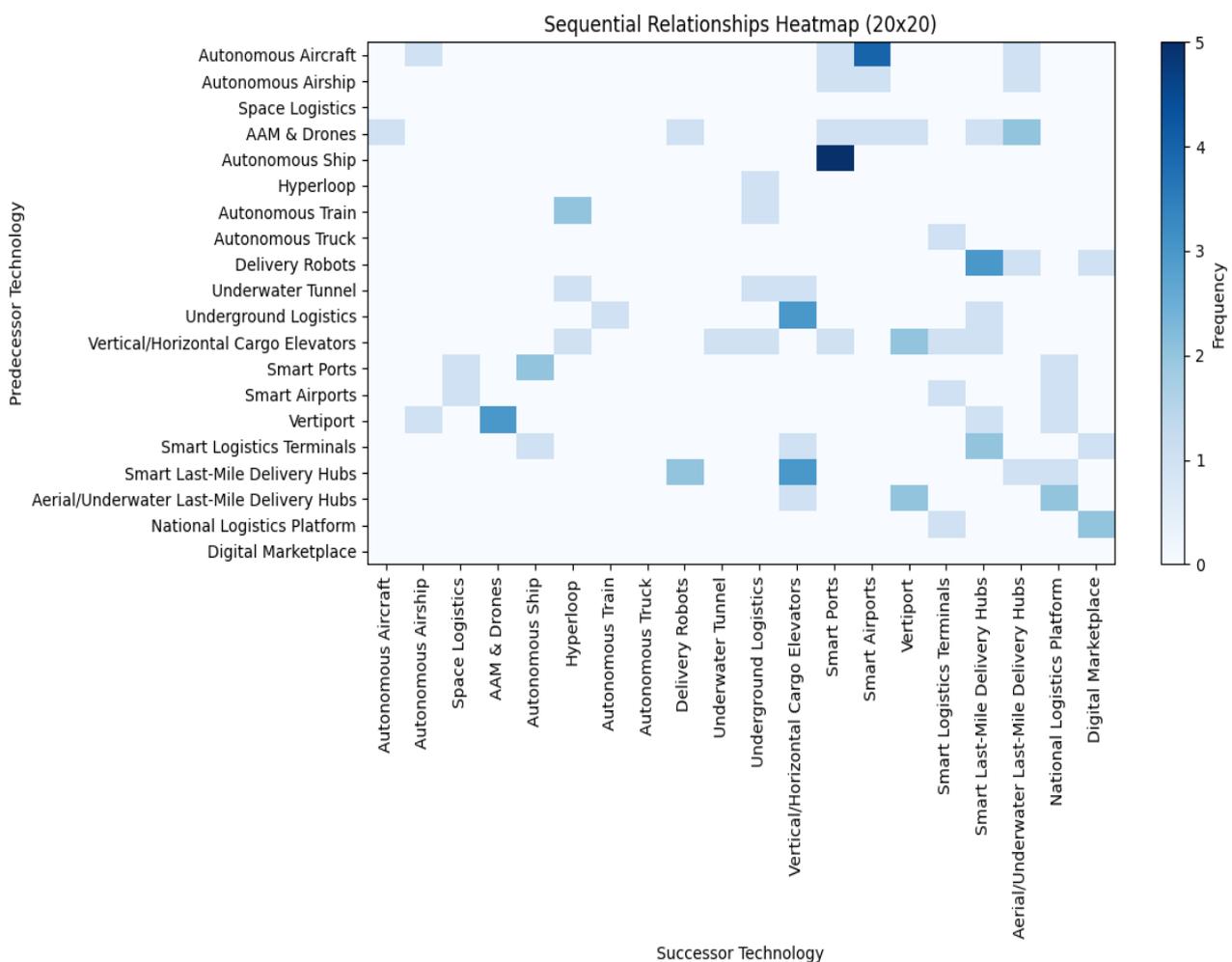

Figure 7. Sequential relationships in the development of advanced logistics technology.

Figure 8 presents technology groups based on an expert survey analysis of correlations and sequential relationships. Group A includes core technologies, such as smart last-mile delivery hubs, smart logistics terminals, smart airports and ports, and aerial/underwater last-mile delivery hubs, showing correlations of six points or higher. This group also includes autonomous ships due to their connection with smart-port technology. Group B encompasses AAM and drones, autonomous aircraft, and autonomous airships, and incorporates vertiport technology due to its strong correlation with AAM and drone systems. Additionally, space logistics was classified within Group B, although it shares a weaker technological relationship with AAM and drones than with other air transport technologies in the group. Group C contains autonomous trains, Hyperloop, and underground logistics, with a related subgroup (C') consisting of vertical/horizontal cargo elevators, autonomous trucks, and underwater tunnels, showing moderate correlations with underground logistics systems. Group D comprises the National Integrated Logistics Information Platform and Digital Twin Technology. Delivery robots showed moderate associations with multiple technologies across groups. Space logistics is an independent technology, with minimal connections to other groups. These groupings formed the basis of the technology roadmap shown in Figure 8. Figure 9 presents the resulting medium to long-term roadmap for future urban logistics.
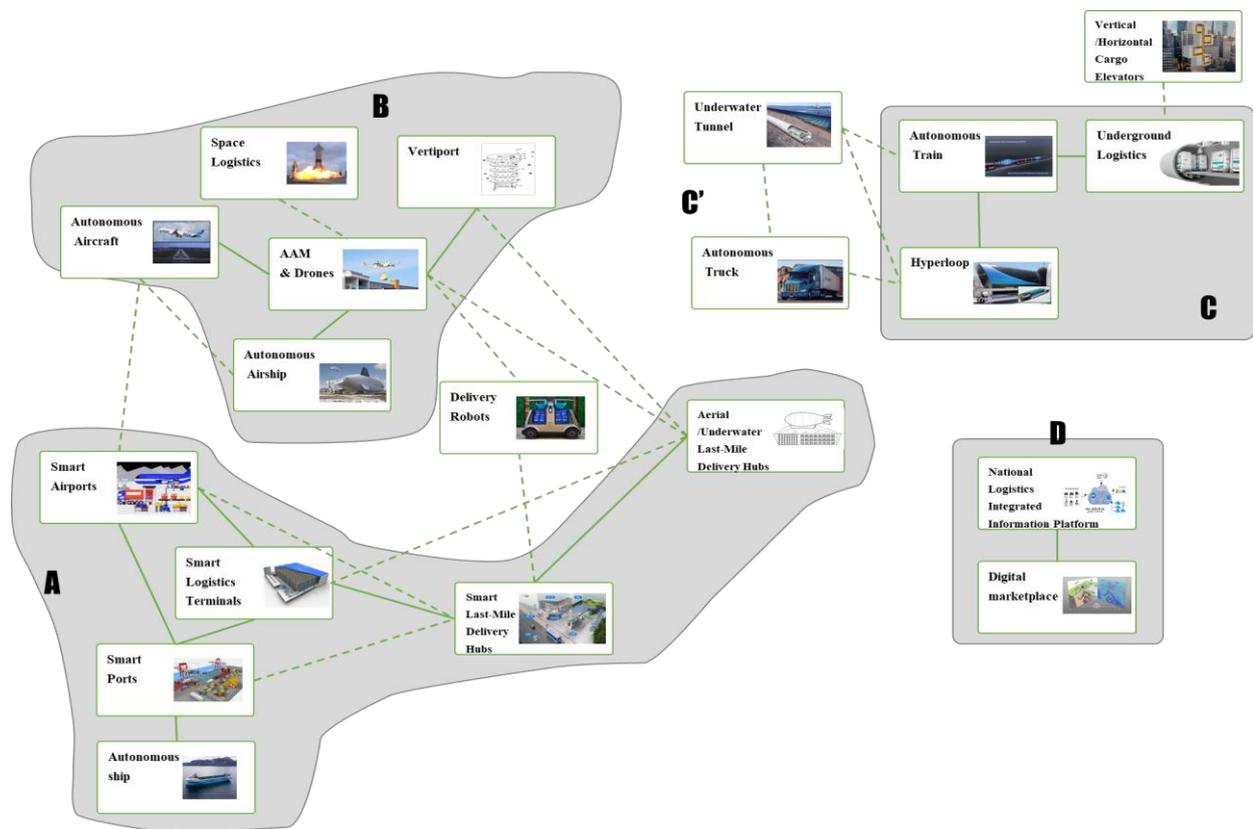

Figure 8. Classification of technology groups.

5.0 DISCUSSION

The 20 technologies analyzed were closely interrelated and influenced one another. These relationships arose from the dual roles technologies play as both service means and supporting infrastructure. Additionally, these relationships were shaped by their common applications across different environments, such as ground, aviation, and maritime environments. The analysis in Section 4.2 revealed four distinct technology groups, as illustrated in Figure 8. Furthermore, these technologies can be prioritized for development based on societal demands, as discussed in Section 4.1. When prioritizing development, it is crucial to consider the sequential relationships between technologies, particularly in the interaction between transportation means and infrastructure, as detailed in Section 4.2. By combining prioritization analysis, sequential relationships, and technology groupings, we developed a comprehensive technology development roadmap, as presented in Figure 9.
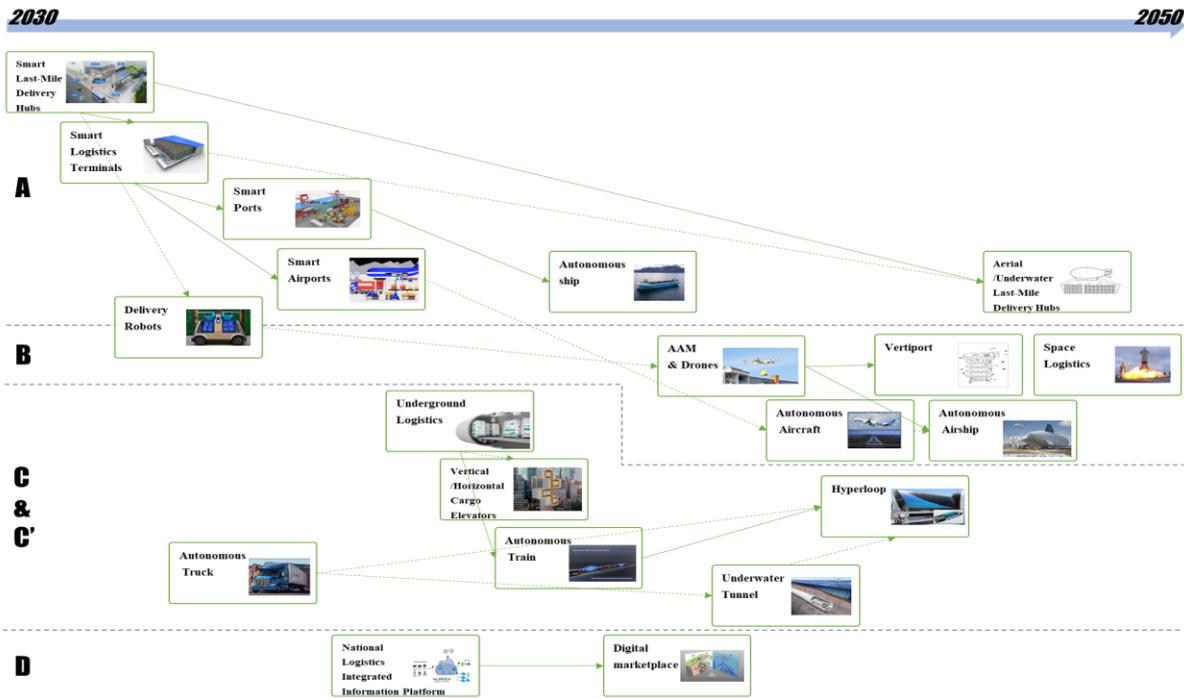
Figure 9. A medium to long-term roadmap.

This roadmap outlines the sequential development order of technologies within each group while showing their interconnections with other groups. For example, Group A comprises logistics hub technologies, while Group B focuses on air logistics technologies. Delivery robots, serving as last-mile transportation technology based on logistics hubs, connect with other logistics hub technologies in Group A and influence logistics technologies like "AAM & Drones" in Group B, thus acting as a bridge between groups. Groups C and C' focus on ground-based transportation means and network infrastructure technologies, specifically categorizing technologies with significant geographical or infrastructural overlaps. Group D encompasses logistics technologies in the digital environment and demonstrates sequential relationships that enable marketplace formation through information connectivity. The development and implementation of these technologies are expected to transform future urban logistics environments, providing a blueprint for future urban logistics, as shown in Figure 10.
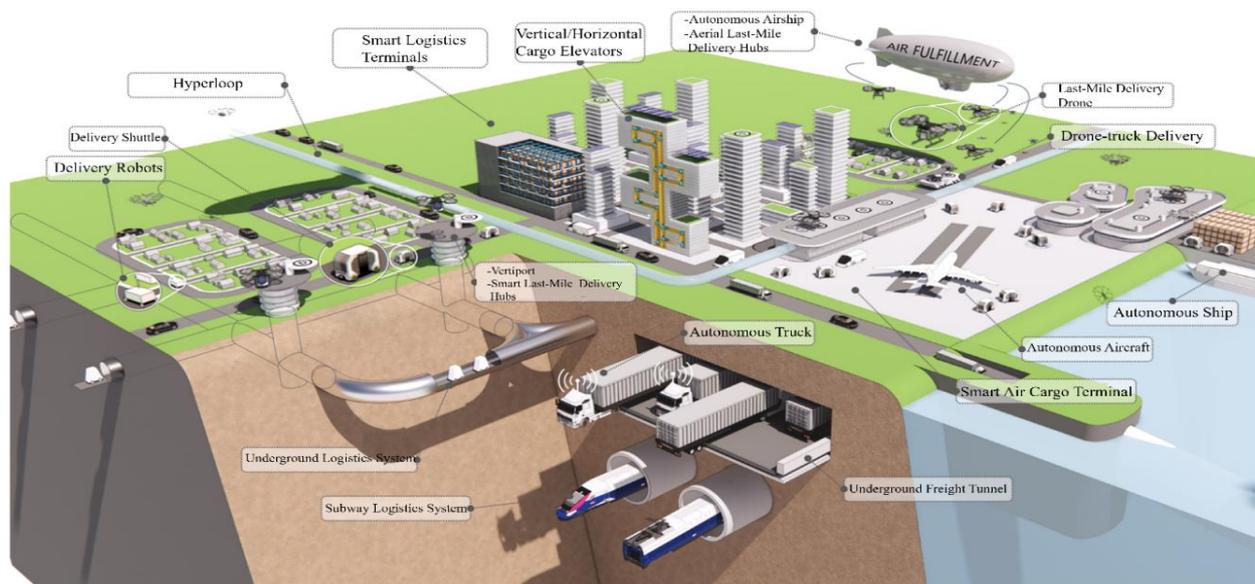

Figure 10. Future scenarios of urban logistics.

6.0 CONCLUSION

Advancements in IT have led to the development of unmanned, automated, and intelligent technologies across various sectors. These advancements have not only transformed existing transportation modes but have also redefined the forms and functions of logistics hubs. This study identified 20 promising logistics technologies expected to gain prominence between 2030 and 2050. Based on these identified technologies, an expert survey was conducted to analyze the interrelationships among them. SERVQUAL and QFD methodologies were applied to prioritize the identified technologies. An analysis of their interrelationships classified the technologies into four groups. A technology roadmap was then developed based on these classifications, reflecting their priorities and sequential development. By analyzing technological priorities and identifying sequential relationships, this study provides a strategic foundation for the efficient allocation of resources in logistics planning. The significance of this study lies in its integration of diverse stakeholders and technologies, thus offering a unified vision of the future of logistics. Furthermore, the resulting technology roadmap can serve as a valuable reference for governmental technology development policies. Governments supporting national technology development through direct investment or indirect support often pursue sequential development because of resource limitations. The technology groups identified in this study can guide the formulation of long-term development projects, wherein each technology within a group can be developed sequentially as part of a unit-level initiative. This study contributes to fostering innovation in urban logistics by providing a framework for establishing logistics-related technological development projects.

This study has several limitations. While the QFD methodology was employed to reflect customer needs, the survey was limited to experts, which may have failed to directly capture the diverse needs of the logistics industry. However, experts generally serve as effective proxies for customer demands, particularly in the early stages of emerging technologies when potential needs are not yet clearly defined. While expert judgment effectively substituted for direct customer input to a significant extent, this approach carries the risk of misalignment with the expectations of actual technology users. To better incorporate customer voices, several methods can be implemented. These include conducting surveys and interviews with logistics practitioners and end-users to gather specific needs and expectations. A more comprehensive analysis should integrate both qualitative and quantitative approaches to ensure well-rounded results. Qualitative methods, including expert surveys and customer feedback, should provide in-depth insights into user experiences, technological trends, and complex relationships between technologies. These should be complemented by quantitative methods such as patent and keyword analyses. Patent analysis helps track technological evolution and assess technology maturity stages, while keyword analysis using text analytics can reveal patterns in technological terminology and measure the relevance of technical concepts. This dual-method approach enables the cross-validation of findings, where qualitative insights help explain quantitative data and quantitative metrics validate qualitative findings. The combination of these methods would provide a more complete and reliable understanding of technology relationships and development priorities, leading to more accurate forecasting and strategic planning. Future research should focus on expanding and refining technology evaluations by incorporating emerging technologies. For example, smart highway systems should be evaluated, including their key features such as platoon driving capabilities, dedicated lanes for AVs, electric vehicle charging systems, and real-time road information networks. This broader and more comprehensive approach would enable a more accurate assessment of the practical applicability of each technology, ultimately contributing to the development of a more comprehensive and realistic technology roadmap.

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