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A SECTORAL STRATEGIC ROADMAPPING FRAMEWORK FOR COMBINING REGULATORY AND INDUSTRY PERSPECTIVES: THE CASE OF ADVANCED AIR MOBILITY IN CANADA

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Abstract. This paper presents a sectoral roadmap development framework-testing process for the Canadian Advanced Air Mobility (AAM) industry, to evaluate a methodology for expanding technological roadmaps into comprehensive sectoral frameworks. The procedural framework incorporates the regulatory perspective to the technological, infrastructural, social, and economic ones, using the S-PLAN framework to identify important strategies and practical actions. Insights were gathered from interviews with cross-disciplinary experts in the public (regulatory) and private (industry) sectors across the industry using the Delphi method to consolidate strategic topics and crucial tactical insights for the sector evolution. The research aims at proposing a methodology for broadening the scope of existing technological roadmaps, applying it in the case of Canada. This methodology is then illustrated in its application to establish the foundation for iterative advancements in the AAM sector, emphasizing a collaborative approach to address the identified challenges. The concluding strategic topics, classified by Advanced Air Mobility Maturity Levels, serve as foundations for the ongoing transformation of Canada's aviation landscape from its current state towards a more autonomous and expansive future. While this study focuses on the AAM sector, the framework's design offers broader applicability, providing a valuable tool for other emerging, complex, and rigidly regulated industries.

Keywords: strategic roadmapping, regulatory framework, advanced air mobility, sectoral strategic planning, aviation.

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1. Introduction

The evolution of Advanced Air Mobility (AAM) marks a major shift in logistics and urban transportation. AAM provides safer, more efficient, and environmentally friendly alternatives to traditional methods. These advances are supported by improvements in battery technology, navigation systems, and communication networks, which together enable new possibilities for transportation in cities and remote areas (Birinci et al., 2025; Straubinger et al., 2020; Booz-Allen & Hamilton, 2018; Fu et al., 2019; Kasliwal et al., 2019).

Despite these advances, regulatory challenges remain a key obstacle. Madusanka et al. (2022) and Skjong (2009) explain that aligning new technology with safety standards can be difficult, especially in industries like aerospace where rules are strict. This issue is also seen in other fields, such as energy, where slow regulatory updates have delayed progress (Nelson, 2017), and in clean technologies and nanotechnology, where rigid rules have limited innovation (Romasheva & Ilinova, 2019; Amutha et al., 2024). These examples show the need for flexible regulations that can adapt to fast-developing technologies.

The global regulatory environment adds further complexity. Differences between national regulations create challenges for scaling AAM technology and ensuring compatibility across borders. Wiedemann highlight how this lack of alignment makes it harder for companies to expand internationally (Wiedemann et al., 2024). Organizations like ICAO are working to develop common standards, but balancing local priorities with international goals remains a challenge, as noted by Skjong (2009).

This study addresses these issues by introducing a method to create a strategic roadmap for Canada's AAM sector. This approach combines insights from experts with advanced planning techniques to connect technical and regulatory perspectives. Instead of providing a completed roadmap, the study offers a flexible framework that can be adapted to different needs and priorities while tackling complex challenges in rigidly regulated sectors.

The study integrates the Delphi method and the S-PLAN framework (Phaal et al., 2007) to identify important strategies and practical actions. Guided by the Advanced Air Mobility Maturity Levels (AMLs) framework (Goodrich & Theodore, 2021), it outlines a phased strategic planning process for sector development, moving from basic operations to high-risk, autonomous systems. By focusing on regulatory flexibility, market growth, and public acceptance, this framework provides a clear path for advancing AAM in Canada and offers a model for other countries facing similar challenges.

2. Literature review

2.1. Regulatory challenges in emerging sectors

Regulatory frameworks in emerging sectors often struggle to keep pace with technological advancements, creating barriers to innovation (Birinci et al., 2025). This misalignment is particularly evident in industries such as energy, artificial intelligence, and advanced materials, where outdated or rigid regulations limit the potential of new developments (Blind, 2010; Roca et al., 2021; Cortez, 2014). In the aerospace domain, these challenges are magnified by the necessity to prioritize public safety and international interoperability, which both demand stringent regulatory oversight (Le & Lappas, 2015).

The aviation sector illustrates this tension clearly. Certification processes for new technologies, such as Beyond Visual Line of Sight (BVLOS) operations in unmanned aircraft, highlight the slow adaptation of existing systems to innovation (Henderson, 2022; Andersen et al., 2020). While regulatory stability ensures safety and public trust, it can also stifle innovation by creating lengthy approval cycles. Adaptive approaches like "regulatory sandboxes" have emerged as solutions, providing controlled environments to test new technologies under flexible regulatory conditions (Ranchordas & Vinci, 2024; Ford, 2021).

The International Civil Aviation Organization (ICAO) plays a key role in addressing these regulatory challenges, offering a global platform for standardizing airspace management practices. ICAO's initiatives, such as the development of a global Remotely Piloted Aircraft System (RPAS) registry, and the implementation of performance-based regulations, aim to reduce regulatory fragmentation and promote a unified approach to integrating advanced technologies like AAM into global airspace systems (Yang et al., 2022). Research highlights how ICAO's efforts encourage alignment between national standards and international benchmarks, fostering interoperability and collaboration across jurisdictions (Nakamura & Kajikawa, 2018; Le & Lappas, 2015).

However, balancing innovation with safety, safeguarding privacy, and managing an increasingly crowded airspace require ongoing dialogue between stakeholders. The rapid pace of technological development often outpaces regulatory updates, delaying the establishment of international standards (Gössling & Humpe, 2024). Despite ICAO's contributions, achieving harmonization while accommodating regional differences continues to be a significant challenge in the aerospace industry.

2.2. Strategic roadmapping and foresighting: concepts and applications

Strategic roadmapping is an essential tool for aligning technological, regulatory, and market objectives in dynamic industries. Initially developed for the manufacturing sector, roadmapping has evolved into a versatile methodology applicable to various fields, offering structured approaches to long-term planning and coordination (Phaal et al., 2004; Geum et al., 2023; Siqueira et al., 2025). Early roadmaps primarily focused on technological milestones, but recent developments emphasize integrating regulatory and societal perspectives to address multifaceted challenges (Park et al., 2020).

In the context of AAM, strategic roadmapping facilitates the alignment of innovation with regulatory and market needs. Frameworks like the S-PLAN are particularly well suited for industries marked by complexity and rapid change. The S-PLAN framework incorporates a phased approach aimed at assessing the strategic landscape, selecting value elements, exploring emerging topics, and agreeing on actionable pathways (Phaal et al., 2007). This iterative method enables stakeholders to refine roadmaps over time, ensuring that both immediate and long-term goals remain achievable despite shifting external conditions.

The ability to integrate diverse viewpoints makes strategic roadmapping an indispensable tool for AAM development. By fostering collaboration among regulators, industry leaders, and researchers, roadmaps provide a shared framework for navigating challenges and seizing opportunities. The inclusion of regulatory perspectives alongside technological and societal considerations ensures that the resulting plans are robust, adaptable, and actionable.

Consensus building and managing uncertainty in strategizing is not a trivial task, and numerous approaches have been proposed in the literature, each one offering distinct strengths depending on the context (Bradfield et al., 2005). They often consist of a combination of a strategic planning tool (e.g. roadmapping) and a structured communication technique for synthesizing expert opinions (e.g. Delphi). In fact, the Delphi method has proven effective in various disciplines for building consensus and managing complexity in uncertain domains (Landeta Rodríguez, 2006). For instance, Schmalz et al. (2021) applied the Delphi method in a two-round scenario-based study, focusing on identifying future challenges and opportunities in complex mobility ecosystems. The research illustrated how iterative expert consultations could anticipate trends, address uncertainties, and align stakeholder priorities. In the first round, open-ended questions allowed experts to share broad insights, laying the groundwork for identifying key themes. The second round used these themes to develop more focused and structured questions, ensuring that the consensus reflected informed and contextualized perspectives. Schmalz et al. (2021) highlighted the value of this approach in aligning diverse viewpoints and informing actionable strategies, particularly in emerging sectors like

AAM, where rapid technological advancements require constant regulatory adaptation.

In the mobility sector, Delphi has been used to predict technological trends and identify strategic challenges. Studies have demonstrated its utility in forecasting hydrogen adoption pathways and evaluating door-to-door travel scenarios (Kluge et al., 2020; Leypoldt et al., 2024; Jittrapirom et al., 2018; Melander et al., 2019; Liimatainen et al., 2014). Integrating Delphi insights into frameworks like S-PLAN enhances the roadmap's ability to address high-complexity environments by embedding expert-driven strategies into its foundational stages.

This combined methodology offers a comprehensive approach for creating sectoral roadmaps. Delphi provides the critical insights needed to define strategic priorities, while S-PLAN translates these insights into actionable pathways. Together, they offer a structured yet flexible framework for aligning regulatory, technological, and societal goals, addressing the unique challenges of AAM development.

3. Research background: prior studies about the status of AAM in Canada

Developing AAM in Canada requires balancing technological progress with strict regulations. The country's unique conditions make this process particularly demanding. Vast, sparsely populated areas, remote communities, and harsh weather create challenges that require tailored solutions (Sluijs et al., 2023). While global organizations like the International Civil Aviation Organization (ICAO) work to establish common standards, Canada must adapt these rules to its specific needs. This dual need for global alignment and local customization underscores the importance of approaches that address both international guidelines and Canada's distinct realities.

The RPAS sector, an essential part of AAM, faces many of the same issues. Both RPAS and AAM depend on advancements in safety systems, airspace integration, and public trust. Research aimed at solving RPAS challenges, such as operating BVLOS, also supports the broader development of AAM. For this reason, the RPAS sector provides a foundation for understanding and addressing the broader challenges of AAM in Canada (Canadian Advanced Air Mobility Consortium, 2021).

In line with these challenges, the National Research Council Canada (NRC), in collaboration with Polytechnique Montréal, Transport Canada, NAV Canada, and the Canadian Advanced Air Mobility (CAAM) organization, has been actively supporting the efficient emergence of AAM in the country. To this end, the NRC initiated two key studies, in which we were involved, prior to the research outlined in this paper. Two reports were prepared, addressing the integration of RPAS into Canadian airspace. These reports focused on understanding regulatory and technological requirements while ensuring compliance with strict safety standards, while the sectoral strategic roadmap aimed at in this research paper focuses on broadening the scope to include other critical perspectives, such as economic, social, and environmental dimensions, that need to be considered in sectoral strategic planning.

The first report, summarized in the next subsection, examines the specific challenges associated with BVLOS operations in Canada (National Research Council Canada, n.d.-a). It highlights the critical need for collaboration among operators, manufacturers, and regulators to define performance requirements for practical use cases, such as medical supply delivery. This report also explores how the integration of RPAS into airspace demands customized solutions tailored to Canada's unique geographic and climatic conditions. The second report, discussed in the subsequent subsection, extends the findings by identifying current technological gaps and proposing a strategic roadmap for the sector (National Research Council Canada, n.d.-b). It emphasizes the importance of aligning technological advancements with regulatory frameworks to enable the safe and scalable integration of AAM technologies in Canada.

Together, these reports underscore the complexity of establishing a robust AAM ecosystem in Canada. They also highlight the need for a broader strategic planning approach that incorporates regulatory, economic, social, and infrastructural considerations to ensure the sector's successful emergence and long-term viability on a global scale. This study builds on these findings to propose solutions that align with Canada's unique challenges while remaining consistent with international goals.

3.1. Canadian regulatory framework and requirements assessment

The first report initiated by the National Research Council Canada (NRC) examined the challenges of integrating RPAS into Canadian airspace, with a specific focus on BVLOS operations. To provide actionable insights, the study is centered on a practical use case: the delivery of medical supplies to remote communities. This scenario was chosen because it highlighted the operational, regulatory, and technological hurdles of deploying RPAS in complex and high-stake conditions, such as those found in Canada's vast and sparsely populated regions.

The report outlined the importance of aligning regulatory requirements with operational goals. By employing a structured framework inspired by the Systems Engineering V-Model (SAE International, 2023; Taibi et al., 2015), the study systematically analyzed the collaborative requirements among operators, manufacturers, and regulators to ensure safe and scalable BVLOS operations.

Regulatory landscape in Canada

The integration of BVLOS operations into airspace required adapting established methodologies to address the unique challenges presented by stringent regulatory frameworks and operational demands. To tackle these complexities, the first NRC report employed a modified

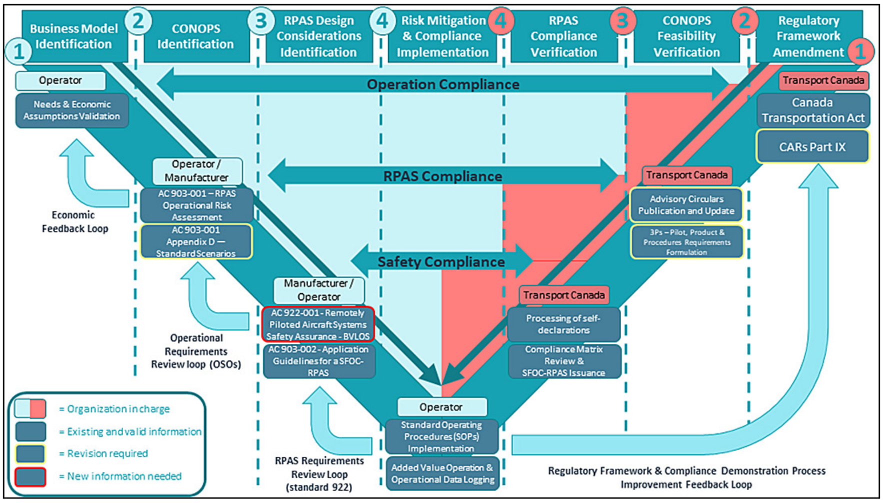

Figure 1. BVLOS RPAS cargo delivery operations development process

V-Model framework, traditionally used in aviation and other high-stake industries to guide system certification and compliance (Taibi et al., 2015). This adaptation emphasized collaboration between operators and regulators, ensuring alignment between operational needs and regulatory expectations at each stage of development.

Developed from the Canadian regulatory framework, this modified process aligns well with international regulatory environments characterized by similar challenges, making it adaptable to other countries. Figure 1 illustrates this collaborative and iterative process, inspired by the V-Model (Lind, 2015), showcasing its applicability to integrating BVLOS operations into regulated airspace.

The modified V-Model process consists of four iterative and collaborative stages, fostering mutual understanding and continuous refinement between operators and regulators.

In the first stage, operators evaluate the feasibility of BVLOS missions, both operationally and economically. This involves refining business models through iterative feedback loops, incorporating insights from experimental data and regulatory feedback. Concurrently, regulators work to adapt and improve regulatory frameworks based on industry input, ensuring public safety remains the priority.

The second stage focuses on the development and validation of the Concept of Operations (CONOPS). Operators and manufacturers collaborate to define operational boundaries, mission objectives, and system performance requirements. These CONOPS are aligned with regulatory guidelines, such as advisory circulars like AC 903-001, which offer standardized scenarios and criteria (Transport Canada, 2021a). Regulators review the feasibility of the proposed CONOPS to ensure compliance with safety standards while simplifying the approval process where appropriate.

The third stage addresses system design considerations and regulatory compliance. Operators and manufacturers align on the configuration of systems required for BVLOS missions, including safety features and communication systems. Manufacturers conduct self-declarations of performance, which are subsequently verified by regulators through compliance matrices submitted with Special Flight Operations Certificate (SFOC) applications. This stage also addresses challenges like the absence of explicit BVLOS performance standards in some regulatory documents, highlighting the importance of adaptive collaboration.

The final stage emphasizes risk mitigation and operational validation. Operators implement comprehensive risk management strategies, identifying and addressing operational hazards while documenting anomalies for continuous improvement. Regulators validate operational data and oversee testing phases to ensure compliance with safety and performance standards throughout the operational lifecycle.

This structured process not only facilitates the integration of BVLOS operations into regulated airspace but also provides a scalable and adaptable model that can be generalized to other regulatory contexts with similar complexities.

Specific technological challenges: Closing the gaps

The NRC's first report identified a range of technological challenges specific to the operationalization of BVLOS missions in Canada. These challenges highlight the need for innovations in design, communication systems, and operational procedures to meet stringent safety and performance standards.

To organize and analyze these challenges, the report utilized Transport Canada's categorization of requirements into three areas: The Pilot, The Product, and Procedures. This categorization helped to clearly identify the technological gaps that need to be addressed to achieve scalable and compliant BVLOS operations. Each category highlights a critical area for aligning technological solutions with operational and regulatory expectations. See Table A1 in Appendix A, extracted from this first report.

The insights derived from this analysis emphasize the need for targeted technological advancements to address these challenges. By focusing on operator training, system reliability, and procedural improvements, the report lays the groundwork for a more robust and scalable BVLOS operational model. These findings also serve as a critical input for the second NRC report, which evaluates broader technological gaps and proposes a roadmap for addressing them within the context of AAM.

In the Canadian context, infrastructural readiness differs significantly between electric and hydrogen-based propulsion systems. While electric propulsion can partially leverage existing electrical grid infrastructure, hydrogen deployment faces additional challenges related to production capacity, storage, transportation, and certification. These infrastructural constraints reinforce the need for localized regulatory and technological roadmapping approaches that reflect national conditions rather than relying on generic international models.

3.2. General technological gaps assessment and technological roadmapping

Building on the findings from the first report, the second phase of the study extended its focus to identify broader technological gaps within the RPAS sector and outline a technological and operational roadmap. This phase incorporated insights from the International Forum for Aviation Research (IFAR), which provided a global perspective on the technological and operational challenges in AAM. By aligning IFAR's global insights with Canada's unique needs, the roadmap synthesizes specific gaps and proposes strategic solutions for the sector (International Forum for Aviation Research, 2023).

To bridge the gaps identified in the first report, the second phase employed a detailed analysis of key technological and operational focus areas. These areas were categorized into two broad domains: technological challenges and operational priorities. This categorization ensured a comprehensive approach to addressing the multifaceted requirements for advancing RPAS and AAM in Canada.

Appendix B presents a table (Table A2), extracted from this second report, that summarizes the IFAR evaluation of critical technological and operational areas, linking them to the specific requirements identified in the Canadian context. This synthesis highlights how global insights align with the challenges identified in the first phase, reinforcing the need for a cohesive and structured roadmap.

The technological roadmap developed in this earlier phase offers a strategic vision for the integration and scaling of AAM systems in Canada, extending from 2023 to 2035, as summarized in Table 1, extracted from the 2nd report. This roadmap is not exhaustive but serves as a practical guide to align technological advancements with regulatory developments and operational goals. By incorporating phased milestones, it provides a framework for the gradual evolution of RPAS and AAM capabilities, focusing on areas such as infrastructure development, regulatory alignment, and public acceptance.

The roadmap not only addresses the immediate regulatory and technological challenges identified in the two reports but also emphasizes the broader infrastructural, social, and economic dimensions essential for the successful integration of AAM in Canada. By aligning these diverse perspectives, this roadmap underscores the complexity of establishing a sustainable and inclusive AAM

Table 1. Simplified technological and regulatory roadmap for the AAM sector in Canada (2023–2035) (source: National Research Council Canada, n.d.-b)

Timeline	Technological priorities	Key actions	Regulatory alignment
2025 (Short Term)	Development of simulators and training tools for BVLOS pilots.	Implement tests in secure temporary corridors.	Integration of Remote Identification (Remote ID) regulations planned for 2025. (sources: Canada Gazette Part 1: Vol. 157 (2023), Transport Canada[1]; RPAS Traffic Management (RTM) System: Concept of Operations, NAV Canada[2])
	Standardization of Communication and Control (C2) systems.	Deploy temporary vertiports for tests and limited operations.	Preparation of requirements for drone integration into regulated airspace. (source: RPAS Traffic Management (RTM) System: Concept of Operations, NAV Canada[2])
	Initial development of Detect and Avoid (DAA) systems and secure data architectures.	Collaborate with Transport Canada to validate new regulatory requirements.	Partial adoption of Canadian regulations planned for 2025. (source: Canada Gazette Part 1: Vol. 157 (2023), Transport Canada[1])
	Establish digital platforms for real-time operations monitoring.	N/A	Continued adoption of specific recommendations for safe integration into controlled airspace. (source: RPAS Traffic Management (RTM) System: Concept of Operations, NAV Canada[2])

[1] Available: https://canadagazette.gc.ca/rp-pr/p1/2023/2023-06-24/html/reg6-eng.html (last access on 2024/11/15)
[2] Available: https://www.navcanada.ca/en/rpas-conops.pdf (last access on 2024/11/15)

End of Table 1

Timeline	Technological priorities	Key actions	Regulatory alignment
2030 (Medium Term)	Integration of semi-autonomous systems for BVLOS operations in low-complexity semi-urban environments.	Expand operations to dedicated suburban and interurban corridors.	Full implementation of Canadian regulations planned for 2026. (source: Canada Gazette Part 1: Vol. 157 (2023), Transport Canada[1])
	Development of multifunctional infrastructure (vertiports adapted for goods and passengers).	Create advanced prototypes for electric and hydrogen-powered vertiports.	Validation of U-Space management systems for integrated air traffic control. (source: RPAS Traffic Management (RTM) System: Concept of Operations, NAV Canada[2])
	Optimization of thermal management and batteries for medium-range routes.	Test hybrid and electric solutions for regional services.	N/A
	Strengthening cybersecurity to protect BVLOS networks from intrusions.	Conduct pilot projects during high-visibility events (e.g., international competitions).	N/A
2035 (Long Term)	Development and integration of fully autonomous aircraft for high-density operations in complex urban environments.	Launch large-scale commercial services with flexible, dynamic corridors.	Finalization of international standards for full autonomy with compliance to integrated traffic management protocols.
	Adoption of hydrogen-powered systems for regional and inter-urban routes.	Build high capacity vertiports for complex commercial operations.	Alignment international standards on eVTOLs safety and performance.
	Full automation of U-Space systems for advanced air traffic management.	Deploy integrated platforms to plan, supervise, and optimize large-scale operations.	N/A
	Monitoring the environmental impacts of technologies throughout their lifecycle.	Conduct full-scale demonstrations to validate safety and performance of automated systems.	N/A

ecosystem. In this vein, the procedural framework that is the focus of this current paper builds directly upon these findings to propose a sectoral strategic roadmap that integrates these additional multifaceted challenges, beyond technological and regulatory issues, with the aim of offering a comprehensive methodology to guide the phased development of AAM while addressing the unique needs, challenges and priorities of Canada.

4. Research methodology

This study aims to develop a strategic roadmapping framework, specifically tailored to the Canadian context of AAM but flexible enough to be adapted to other contexts. By integrating expert consensus and structured planning methods, the research combines the Delphi method with the S-PLAN framework (Phaal et al., 2007) to address regulatory, technological, and societal challenges. This approach ensures a phased, adaptable roadmap designed to meet both immediate priorities and long-term goals.

The methodology is built upon two complementary components. The Delphi method was used to gather and refine expert multidimensional insights across sectors, while the S-PLAN framework structured these findings into a roadmap for guiding sectoral development. Together, these methodologies form a robust basis for aligning regulatory and technological advancements within the AAM ecosystem.

4.1. The Delphi method: expert opinion and consensus building

This study adapted the Delphi method into three targeted phases – Preparing, Conducting, and Analyzing. These phases systematically collected and refined expert insights, supporting the comprehensive development of a roadmap for Canada's AAM sector. Each phase was designed to build upon the insights gathered in the previous step, fostering a progressive and structured development process. Figure 2 illustrates this adapted Delphi process, showing how each phase contributes to refining expert inputs and translating them into actionable insights for the strategic roadmap.

The first phase ("preparing") focuses on establishing the foundational elements of the study. Semi-structured interviews were conducted according to the guide presented in Appendix C (Table A3), with a carefully selected panel of experts to explore the key challenges and opportunities within the AAM sector. As highlighted by Beiderbeck et al. (2021), semi-structured interviews are particularly effective in rapidly evolving fields where flexibility and depth are critical for capturing nuanced perspectives. The experts selected represented a range of backgrounds,

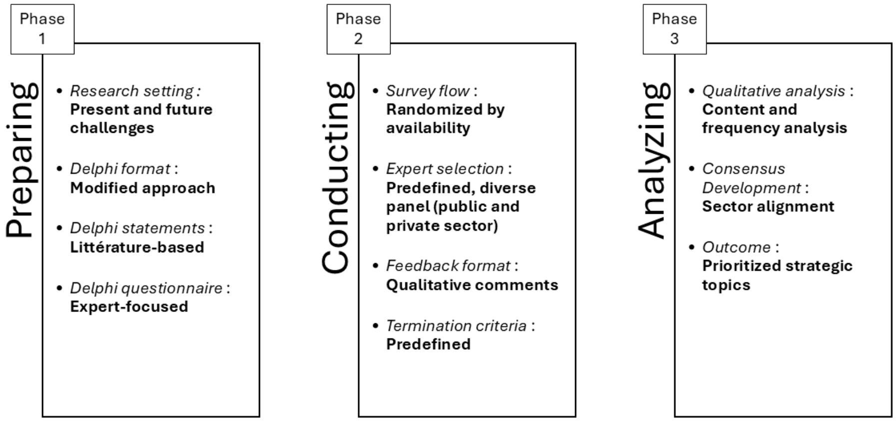

Figure 2. Overview of the three phases of the Delphi method applied in this research

including industry professionals, policymakers, academics, and end users, ensuring a diverse set of insights that reflect the multifaceted nature of the AAM ecosystem.

To further strengthen the transparency of the data collection process, the expert panel was intentionally composed to reflect the diversity of organizations shaping the Canadian RPAS and AAM ecosystem. Interviews were conducted exclusively with participants who confirmed their availability and completed the interview process.

The selected experts represented public, private, and hybrid organizations, including ministries, regulatory agencies, research bodies, industry players, airport and air navigation management organizations, AAM consulting firms, and academic or industry support organizations.

Rather than focusing on individual identities, the interview design emphasized functional roles and institutional perspectives, ensuring that insights captured strategic, regulatory, operational, and societal dimensions of AAM development in Canada.

Interviews were structured around four complementary roles, spanning both public and private sectors: (1) Strategy directors, (2) Industry consultants, (3) Government experts, and (4) Lawmakers in RPAS/AAM. This role-based approach enabled cross-validation of perspectives and helped balance technological ambitions with regulatory feasibility and public acceptance considerations.

Beyond public-sector representation, the Delphi panel included experts with industry, research, and system-level experience, whose work directly relates to societal adoption, operational integration, and public perception of AAM technologies. These perspectives contributed to addressing social acceptance issues from operational, economic, and user-oriented viewpoints, complementing regulatory considerations. Statements and questionnaires for this phase were crafted based on existing literature and prior research, with a focus on identifying the most pressing sectoral challenges and strategic opportunities.

The second phase ("conducting") was centered on systematically collecting and refining feedback from the expert panel. This phase objective was to broaden the scope of the study by incorporating a wider range of perspectives on regulatory, technological, and operational issues. Experts provided detailed qualitative responses, which were then used to expand and refine the roadmap's structure. The diversity of the expert panel, coupled with the iterative nature of the feedback process, ensured a well-rounded understanding of sectoral priorities. The importance of maintaining a diverse and inclusive panel for

Table 2. Interviewed organizations, roles, and experience (aggregated)

Organization type	Ecosystem category	Interview role	Experience in related field (years)
Industry (private)	Industry players	Strategy director	15
Industry (private)	Industry players	Strategy director	20
Industry (private)	Industry players	Industry consultant	12
Private	AAM consulting firms	Industry consultant	18
Private	AAM consulting firms	Industry consultant	15
Public	Airport & navigation management orgs	Government expert	20
Public	Ministries	Government expert	15
Public	Ministries	Lawmaker in RPAS/AAM	20
Public / hybrid	Agencies & research bodies	Strategy director	15
Public / hybrid	Academic & industry support orgs	Government expert	6

Delphi studies has been emphasized by von der Gracht (2012), who highlights that a balanced representation of expertise strengthens the validity and applicability of the outcomes. Feedback was carefully analyzed to identify recurring themes, ensuring that the roadmap reflected a comprehensive view of the sector's needs.

In the third and final phase ("analyzing"), the gathered expert input was synthesized and evaluated to prioritize strategic topics and establish a cohesive roadmap. This phase relied on detailed qualitative analysis techniques to identify key areas of consensus among experts. As noted by Rowe and Wright (1999), the robustness of Delphi studies is greatly enhanced when consensus metrics are rigorously applied, ensuring that the derived insights are both credible and actionable. The analysis emphasized the alignment of public and private sector priorities, balancing technological advancements with regulatory and societal considerations. The resulting roadmap provided a structured foundation for the next step using S-PLAN framework, integrating expert insights into a phased approach that aligns with Canada's regulatory and operational landscape.

Potential tensions between technological priorities and regulatory agility were explicitly discussed during the Delphi interviews. Experts were invited to reflect on trade-offs between innovation pace and regulatory robustness, leading to a shared understanding that regulatory agility should function as an enabling mechanism rather than a constraint. These discussions informed the alignment between technological roadmaps (Table 1) and strategic regulatory themes (Table 2).

By structuring the Delphi process into these three interconnected phases, the methodology facilitated the systematic integration of expert opinions into the strategic planning process. This iterative and consensus-driven approach not only addressed the specific challenges of the Canadian AAM sector but also demonstrated the versatility of the Delphi method in aligning stakeholder insights with actionable roadmaps. The insights gathered through this method served as a critical input for the subsequent application of the S-PLAN framework, ensuring a comprehensive and adaptable strategy for advancing AAM in Canada.

4.2. Strategic roadmapping: the S-PLAN framework

This study focuses on the first two steps of the S-PLAN framework, which lay the groundwork for aligning sectoral challenges with strategic solutions. The framework comprises four steps: (1) defining the strategic landscape, (2) selecting value elements, (3) exploring topics, and (4) agreeing on a strategic pathway. Nevertheless, the scope of this research is limited to the first two steps, ensuring a concentrated and actionable output. The latter steps are proposed as future work to be developed by stakeholders as sectoral conditions evolve.

Step 1: Define strategic landscape

The first step of the S-PLAN framework involves assessing the current state of the sector by examining regulatory frameworks, technological capabilities, and operational requirements (Phaal et al., 2007). This step establishes a foundational understanding of the existing landscape, enabling stakeholders to identify key challenges and opportunities. In the Canadian context, this step was informed by data from the two aforementioned NRC reports, enriched by several recognized regulatory and industry expert sources, including insights from Transport Canada and NAV Canada, and global perspectives such as those provided by the International Forum for Aviation Research (IFAR). This comprehensive analysis highlighted the critical regulatory and technological barriers to integrating BVLOS operations and advancing AAM in Canada.

Step 2: Select value elements

Step 2 of the S-PLAN framework focuses on identifying and prioritizing the sector's key challenges and opportunities (Phaal et al., 2007). By concentrating on regulatory barriers, technological gaps, and socio-economic factors, this step establishes a value-driven foundation for the roadmap. The integration of insights from the Delphi method was crucial in this stage, as expert feedback provided a nuanced understanding of sectoral needs. These insights were aligned with the findings from step 1 to ensure that the roadmap addressed Canada's unique regulatory, geographic, and climatic conditions, while assuring consistency with international best practices.

By concentrating on these initial steps, the study offers a streamlined yet impactful application of the S-PLAN framework, aligning it with the iterative and flexible nature of the Delphi method. Together, these methodologies create a structured yet adaptable roadmap that reflects the complexities of the AAM sector in Canada.

The outcomes from these two steps not only provide a foundation for future development but also underscore the importance of cross-sectoral alignment in addressing the challenges of AAM integration. The following two steps of the S-PLAN framework (not applied here) remain critical areas for further exploration, offering stakeholders a pathway to refine and expand the roadmap as new challenges and opportunities emerge.

4.3. Broadening the scope of roadmaps: integration of Delphi insights into S-PLAN framework

This section focuses on the methodological integration of Delphi insights with the S-PLAN framework, highlighting how the two approaches were applied systematically to create a comprehensive roadmap for Canada's AAM sector. This integration ensures that the roadmap addresses regulatory, technological, and societal challenges while remaining adaptable to the sector's evolving nature.

Improvements to Step 1: Define strategic landscape influenced by Delphi

Delphi insights contributed directly to defining the strategic landscape by gathering expert perspectives across essential dimensions such as regulatory, technological, and operational challenges. These perspectives, identified through iterative consultations, informed the foundational objectives of the S-PLAN framework. Specific challenges were mapped to this first step, such as regulatory hurdles and technological gaps, ensuring that the strategic landscape reflected both current sectoral realities and anticipated future developments.

Improvements to Step 2: Select value elements influenced by Delphi

In S-PLAN's second step, Delphi findings were used to prioritize key sectoral topics based on expert consensus. This included actionable themes such as market viability, infrastructure development, and public acceptance. By synthesizing these insights, step 2 established a value-driven foundation for the roadmap that emphasized the most impactful sectoral challenges, ensuring alignment with both domestic needs and international trends.

An iterative and adaptive integration of S-Plan framework and Delphi insights

The integration of Delphi and S-PLAN followed a cyclical process, enabling continuous refinement of strategic priorities based on expert feedback. The iterative nature of Delphi complemented the phased structure of S-PLAN, allowing insights to be revisited and adjusted as sectoral conditions evolved. This methodological alignment ensured that steps 1 and 2 of S-PLAN were enriched by expert-driven insights, while also maintaining a flexible foundation for future iterations in steps 3 and 4.

The transition from qualitative Delphi themes to the tactical insights presented in Table 2 followed a structured analytical process. First, medium- and high-consensus strategic themes identified in Appendix D were clustered according to their regulatory, technological, and socio-economic nature. These clusters were then mapped onto the corresponding AAM Maturity Levels (AMLs), ensuring temporal and operational coherence. Tactical insights were subsequently formulated by translating recurrent expert recommendations into actionable measures aligned with each AML phase, consistent with the objectives of the S-PLAN framework.

Some tactical insights were explicitly articulated by experts during the Delphi interviews, while others were analytically inferred by the authors through consolidation of recurrent recommendations and alignment with the S-PLAN planning logic. This inferential step was guided by predefined analytical criteria to ensure consistency and traceability between expert input and proposed actions.

Together, these methods create a robust and flexible methodology for guiding the strategic integration of RPAS and AAM technologies in Canada, addressing the sector's unique challenges while aligning with international standards and trends. By grounding the roadmap in expert-driven insights and emphasizing flexibility, this approach offers a replicable model for other countries facing similar complexities in the development and deployment of AAM systems.

4.4. Data collection procedures

The development of the roadmap for Canada's RPAS and AAM sectors relied on a combination of primary and secondary data sources to ensure a thorough understanding of the regulatory, technological, and operational challenges within these sectors. The primary data was collected using the Delphi method, which involved engaging 11 Canadian experts from industry, regulatory bodies, and academia. These experts contributed through a structured, iterative process designed to gather and refine insights. The process began with a preparation phase where semi-structured interviews were conducted to establish foundational challenges, such as regulatory gaps and technological needs. This was followed by a systematic collection of feedback through structured questionnaires in subsequent rounds, focusing on emerging priorities related to infrastructure, social acceptance and economical perspectives. The final phase of the Delphi process involved analyzing qualitative responses to identify key areas of consensus and align them with the objectives of the S-PLAN framework.

In addition to the Delphi method, secondary data provided essential context and evidence-based support. This data included regulatory and industry reports, such as those from Transport Canada, NAV Canada, and ICAO (Transport Canada, 2021b), which offered critical insights into evolving frameworks like the RPAS Traffic Management Concept of Operations (NAV Canada, 2023), new regulations (Government of Canada, 2023) and advisory circulars such as AC 903-001 and AC 922-001 (Transport Canada, 2021a, 2021b). Market studies such as McKinsey's report on Urban Air Mobility (UAM) (McKinsey & Company, 2018) and BIS Research's executive summary on Global UAS traffic Management (UTM) System Market (BIS Research, 2019), further enriched the analysis by highlighting trends and advancements that contextualized expert insights within the broader landscape of AAM and RPAS. Comparative case studies from related sectors, such as autonomous vehicles (Transport Canada, 2019), were also reviewed to identify transferable strategies for addressing regulatory and social barriers.

The integration of primary and secondary data enabled a comprehensive approach to roadmap development. By combining expert-derived insights with evidence from regulatory, market, and case-study analyses, the resulting roadmap is both grounded in Canada's unique conditions and aligned with international trends and standards. This holistic methodology ensures the roadmap is robust, actionable, and adaptable to future developments.

5. Findings and discussion

This section presents the results of the study, structured to align with the combined insights from the Delphi method and the S-PLAN framework. The findings focus on strategic and tactical priorities essential for the development of the Canadian AAM sector. Through an iterative and integrative approach, these methodologies provided a roadmap that balances regulatory adaptation, technological innovation, and market readiness within the unique Canadian context.

5.1. Strategic insights from the Delphi process

Experts emphasized the importance of aligning technological advancements with regulatory frameworks to ensure safe and scalable operations. The Delphi process interviews also underscored the critical role of market viability, social acceptance, and workforce readiness in achieving successful commercialization of RPAS and AAM technologies. A consistent theme throughout the discussions was the necessity for cross-sectoral collaboration, which was seen as vital for driving innovation and addressing regulatory and infrastructural barriers.

Appendix D presents the Table A4 summarizing the Medium and High Consensus-level strategic themes, offering a detailed view of key priorities. These themes were derived directly from the structured interviews conducted during the Delphi study. It reflected their collective perspectives and priorities covering regulatory agility, infrastructure development, market expansion, and public acceptance, providing informed insights towards an integrated roadmap for addressing sectoral strategic challenges.

5.2. Alignment with AAM maturity levels (AMLs)

The identified strategic topics were categorized according to the Advanced Air Mobility Maturity Levels (AMLs) framework. This alignment ensures a phased and systematic progression in operational capabilities, reflecting the sector's evolution from foundational operations to high-risk, fully autonomous systems. Each AML phase focuses on specific strategic topics validated through expert feedback during the Delphi process.

The first AML phase (Horizon 2025) prioritizes low-risk operations, emphasizing regulatory agility and early-stage public engagement to build foundational capabilities. The second phase (Horizon 2030) introduces medium-risk operations, focusing on market expansion and intermediate-level technological integration. The third phase (Horizon 2035) addresses high-risk, high-density urban operations, highlighting the importance of advanced safety protocols and multi-stakeholder collaboration for achieving full autonomy and integration.

Table 3 illustrates this planned alignment over the next 10 years, mapping strategic themes to each AML phase while providing actionable tactical insights to guide the implementation.

5.3. Dependency of the evolution of AAM landscape on the regulatory context

The evolving regulatory context is a critical factor shaping the operational landscape of the Canadian AAM sector. Recent adjustments by Transport Canada aim to accommodate the rapid technological advancements within these sectors, demonstrating the dynamic interaction between regulatory updates and technological innovation. The dependency on regulatory adaptation is evident, as industry players must continually align with new frameworks to ensure compliance, operational safety, and scalability.

This regulatory dependency presents both opportunities and challenges. On the one hand, responsive and progressive regulations can accelerate industry growth by providing clear guidelines for emerging technologies. Conversely, if regulations are overly conservative or slow to adapt, they may slow progress by limiting the operational potential of advanced technologies. Thus, it is essential for Canada to foster a regulatory environment that is both

Table 3. AAM maturity levels (AMLs) and sectoral strategic themes and tactical insights

AMLs	Description	Strategic Themes	Tactical Insights
AML 1 – 2025: Low Risk CONOPS	Proof of concepts and test beds for low-risk operations are developed to establish foundational capabilities and ensure basic operational safety.	Regulatory Agility – Develop frameworks that adapt swiftly to emerging tech in AAM. Social Acceptance – Promote transparency and early engagement with public stakeholders.	Safety and Compliance Education – Launch early-stage educational campaigns to foster a safety-conscious culture. Regulatory Training Programs – Tailor training programs for regulatory bodies on low-risk drone operations.
AML 2 – Until 2030: Medium Risk CONOPS	This phase introduces operationally viable concepts, involving complex operations and integration into national airspace under medium-risk conditions.	Market Expansion – Broaden market reach by promoting intermediate risk applications. Collaborative R&D – Support joint R&D to tackle medium risk operational challenges.	Pilot Projects for Medium Risk – Initiate collaborative pilot projects to validate safety and efficiency. Public Awareness Campaigns – Enhance public confidence with community-based demonstrations.
AML 3 – Until 2035: High Risk CONOPS	High-risk, commercially viable concepts are developed, leading to full autonomy and integration across economic and public sectors.	Regulatory Agility & Market Expansion – Refine regulatory approaches to include high-risk operations while enabling market growth. Advanced Collaboration – Strengthen multi-stakeholder partnerships to support high-risk innovations.	Advanced Safety Protocols – Implement rigorous safety protocols for high-risk operations to ensure compliance and public trust. R&D Integration – Forge long-term partnerships with R&D institutions to sustain technological advancements.

agile and proactive, enabling the sector to capitalize on advancements while maintaining robust safety standards. Ongoing collaboration between regulatory authorities and industry stakeholders will be instrumental in shaping policies that support sector growth.

5.4. Methodological complementarity: integrating bottom-up and top-down approaches

One of the most notable aspects of this research is the complementarity between the Delphi method and the S-PLAN framework, which combines bottom-up and top-down approaches for strategic roadmapping (Pierre et al., 2024; Kim et al., 2014). Together, these methodologies offer a robust framework for aligning stakeholder insights with long-term planning objectives.

The Delphi method, with its bottom-up orientation, excels in gathering detailed, expert-driven insights through iterative consultations. This approach captures the nuanced, real-world complexities experienced by stakeholders across regulatory, technological, and operational domains. It ensures that strategic planning reflects the lived experiences of industry actors while addressing specific sectoral challenges.

Conversely, the S-PLAN framework applies a top-down perspective, structuring the planning process from high-level objectives to actionable implementation pathways. Its phased design facilitates the alignment of immediate priorities with long-term goals, such as regulatory compliance, technological scalability, and market readiness.

The strength of this integration lies in its ability to bridge granular insights with overarching strategic objectives. While Delphi validates and refines sector-specific priorities, S-PLAN organizes these priorities into a coherent roadmap. This synergy ensures that the roadmap is both adaptable to sectoral complexities and aligned with strategic milestones.

This dual approach is particularly valuable in navigating the dynamic and multidimensional nature of the AAM sector. By combining Delphi's adaptability with S-PLAN's structured planning, the roadmap becomes a replicable model for other industries facing similar regulatory and technological challenges. This integration emphasizes not only its applicability to AAM but also its potential to inform strategic planning in emergent sectors like autonomous vehicles and renewable energy.

6. Main results and limitations

This section synthesizes the practical and methodological outcomes of the study. The practical findings focus on the strategic topics essential for laying the foundation for a sectoral roadmap for the Canadian RPAS AAM sectors. Meanwhile, the methodological results highlight the benefits of integrating the Delphi Method and the S-PLAN framework, emphasizing their complimentary value in complex, emergent, and rigidly regulated sectors.

6.1. Practical results: strategic sectoral roadmap for AAM in Canada

The integration of expert feedback through the Delphi method and its alignment with the structured phases of the S-PLAN framework resulted in a clear set of strategic themes. These themes form the foundation for developing a comprehensive roadmap tailored to Canada's unique needs. The Advanced Air Mobility Maturity Levels (AMLs) framework was employed to organize these themes, reflecting a phased approach for sectoral growth and readiness.

The strategic themes identified include the need for regulatory agility to ensure that frameworks evolve in tandem with technological advancements. This adaptability supports innovation while maintaining robust safety and compliance standards. Another priority is market expansion, which emphasizes the importance of extending applications for RPAS technologies in both low- and high-risk operations. This ensures economic viability while demonstrating scalability across diverse operational contexts. Social acceptance was also highlighted as a critical component, requiring early and transparent engagement with stakeholders to foster trust and address public concerns regarding safety, noise, and privacy.

Collaborative research and development emerged as a key area for fostering multi-stakeholder innovation. Joint R&D initiatives, particularly in medium and high-risk operations, can address complex challenges while generating valuable insights for scaling technologies in AAM sector in Canada. Finally, the importance of safety and compliance education was emphasized, with tailored training programs aimed at building a culture of safety across all stakeholders, including industry and regulatory bodies. These educational efforts are crucial for equipping participants with the expertise required to manage evolving risks effectively.

The strategic themes, organized according to AML phases, ensure a logical progression for the industry. At the foundational level, low-risk operations focus on establishing core capabilities, regulatory alignment, and public engagement. Medium-risk operations expand market applications and technological integration, while high-risk operations prioritize advanced collaboration, comprehensive safety protocols, and complete autonomy. This phased approach ensures that foundational capabilities are solidified before progressing towards more complex, high-density operations. The result is a structured framework that aligns with Canada's regulatory, technological, and societal conditions, providing a robust basis for finalizing a comprehensive and actionable sectoral roadmap for the AAM sector in Canada.

6.2. Methodological results: towards a new sectoral strategic roadmapping framework

The integration of the Delphi method and the S-PLAN framework resulted in a comprehensive and adaptive methodology for addressing the complexities of Canada's AAM sector. By combining Delphi's iterative, expert-driven approach with the structured and phased design of S-PLAN, this framework effectively prioritized strategic challenges and opportunities while ensuring alignment with Advanced Air Mobility Maturity Levels (AMLs).

The Delphi method played a pivotal role in gathering diverse expert perspectives, capturing nuanced insights across regulatory, technological, and societal dimensions. Its iterative nature allowed for the refinement of these perspectives, ensuring the inclusion of well-rounded and actionable priorities. These insights were directly integrated into the S-PLAN framework, which provided a structured mechanism to organize and operationalize them within a phased roadmap. The S-PLAN framework ensured that strategic topics identified through Delphi, such as regulatory agility, market expansion, and public acceptance, were systematically aligned with Canada's unique context and long-term objectives.

This iterative and complementary integration resulted in a roadmap that balances immediate needs with future growth opportunities, offering stakeholders a robust foundation for decision-making. The framework not only reflects expert-driven insights but also maintains flexibility, enabling ongoing adaptation to technological advancements and evolving regulatory landscapes. The methodological integration underscores its potential as a replicable model for strategic planning in other emergent and complex sectors.

6.3. Limitations

This study recognizes several limitations in the proposed new framework for sectoral strategic roadmapping within the Canadian AAM. These limitations highlight areas for refinement and underscore the need for iterative updates to maintain the framework's relevance in a rapidly evolving context.

The fast-paced evolution of technologies and regulatory frameworks in the AAM and RPAS sectors poses a challenge to the longevity of the study's findings. While the proposed roadmap provides a robust starting point, the dynamic nature of the industry necessitates continual updates to reflect new advancements and policy changes. This volatility underscores the need for ongoing monitoring and adaptation to maintain alignment with emerging trends and sectoral shifts.

The findings and roadmap are tailored specifically to the Canadian context, reflecting the country's unique regulatory environment, geographic conditions, and market characteristics. While the framework provides valuable insights for similar sectors in other regions, adjustments would be required to account for differences in local regulatory, economic, and infrastructural conditions. This context dependency limits the direct applicability of the findings beyond Canada without careful adaptation.

Although efforts were made to ensure a diverse panel of experts representing the public, private, and academic sectors, the composition of the panel may still introduce biases. For example, majority opinions (strong signals) could overshadow minority perspectives (weak signals), which are particularly important in rapidly evolving industries (Zhao et al., 2024). The reliance on expert consensus, while central to the Delphi method, may limit the framework's ability to capture emerging, different, or unconventional insights that could prove valuable in the future.

For instance, several themes identified during the Delphi process reached a low level of consensus and were therefore not integrated into the final strategic roadmap. These included divergent views related to privacy concerns in urban drone operations, potential noise pollution impacts, alternative funding models for early-stage AAM initiatives, and the localization of supply chains. While these perspectives did not achieve sufficient convergence to inform the core tactical insights, they were documented as weak signals that may represent critical alternative scenarios for future research or context-specific AAM implementations.

Another potential limitation arises from researcher bias during the note-taking process in interviews. The interpretation of expert perspectives could inadvertently introduce errors or misrepresentations, particularly when dealing with complex or nuanced information (von der Gracht, 2012). To mitigate this risk, an objective criterion was established during the interviews to guide the analysis and ensure consistency and neutrality in the data collection process. This structured approach helped reduce subjectivity, providing a more reliable foundation for synthesizing insights across diverse expert contributions.

The iterative nature of the Delphi method, while effective for consensus building, requires significant time and resources, potentially limiting its responsiveness in fast-changing environments. Moreover, the structured design of the S-PLAN framework, while comprehensive, may lack the flexibility to address unexpected disruptions or paradigm shifts in the industry. For example, unexpected regulatory changes or technological breakthroughs could necessitate significant modifications to the roadmap, underscoring the importance of periodic evaluations and adjustments.

Future research should focus on refining and updating the AAM roadmap as new data and insights become available. Periodic evaluations using both the Delphi method and S-PLAN framework will ensure that the roadmap remains aligned with sectoral developments. Additionally, exploring methods to incorporate minority perspectives within the Delphi process could enrich the diversity of insights and enhance the robustness of the framework.

While the proposed framework provides a valuable tool for guiding the Canadian AAM sector, its long-term success depends on continuous testing, iteration, and stakeholder engagement to address the evolving landscape of this transformative industry.

Furthermore, expanding the application of this methodology to other emergent, complex, and rigidly regulated sectors could test its adaptability and generalizability. By applying the framework to industries such as autonomous vehicles or renewable energy, researchers can evaluate its utility in addressing cross-sectoral challenges and refining its structure for broader applicability.

7. Conclusions

This study presents a comprehensive methodology for developing a strategic roadmap for the Canadian RPAS and AAM sectors, combining the Delphi method and the S-PLAN framework. The new roadmapping process was developed and applied in this use case and resulted in a strategic sectoral AAM roadmap based on expert insights, with strategic topics validated through iterative consultation. These topics, organized by AAM Maturity Levels (AMLs), address critical areas such as regulatory flexibility, market development, and workforce training, providing a structured approach to guide the sector's growth.

The findings have important implications for both theory and practice. For Canadian stakeholders, the roadmap offers practical guidance tailored to the country's unique regulatory and technological landscape, supporting immediate decision-making. Internationally, the study provides a model that other nations can adapt to align regulatory development with technological and operational goals in similarly complex sectors. For researchers, the integration of Delphi and S-PLAN demonstrates how iterative, expert-driven consensus-building can be combined with a flexible planning framework to support strategic alignment in sectors where technological and regulatory advancements must move together.

Future research should build on these findings to explore the broader applicability of the proposed methodology. One avenue is to refine and expand the roadmap for the Canadian RPAS and AAM sectors, validating its effectiveness through practical implementation and stakeholder feedback. Developing a detailed roadmap that addresses all stages of sectoral maturity could provide additional insights into the operationalization of strategic topics.

Testing this framework in other countries is another important direction for research. By applying the methodology in diverse regulatory and technological contexts, such as emerging AAM markets or regions with significantly different regulatory environments, researchers can evaluate its adaptability and robustness. This comparative analysis would help identify potential refinements to the framework and ensure its global relevance.

Additionally, the methodology could be applied to other emergent sectors characterized by high levels of complexity and strict regulatory oversight, such as autonomous vehicles, renewable energy systems, or advanced healthcare technologies. Such applications would test whether the framework can effectively support industries undergoing rapid technological evolution and market transformation, ensuring that it remains a versatile tool for addressing multifaceted challenges.

Finally, future studies could focus on assessing the proposed new roadmapping framework's capacity to support high-velocity evolution in emerging sectors. This includes evaluating how well the Delphi and S-PLAN integration handle rapid advancements in technology, regulatory changes, and shifting stakeholder priorities. By validating the framework's ability to adapt to fast-paced environments, researchers can ensure it remains a relevant and valuable tool for strategic planning in dynamic industries.

Beyond the aviation domain, this framework presents potential applicability to other highly regulated transport sectors, such as autonomous ground mobility or sustainable maritime logistics, where technological innovation must continuously align with evolving regulatory environments. Its emphasis on structured stakeholder alignment and iterative experimentation suggests a degree of transferability across international contexts, particularly in jurisdictions facing similar governance and policy coordination challenges. While sector-specific adaptations would be required, the framework offers a generic approach for navigating regulatory complexity in innovation-driven transport systems.

In conclusion, this research contributes to both practice and academic discourse by presenting a replicable framework that enables strategic alignment among diverse stakeholders. The proposed methodology not only equips Canada to lead in drone delivery and AAM but also provides a foundation that other nations and sectors can adapt to foster growth and innovation. By bridging regulatory, technological, and operational perspectives, this approach supports the safe and sustainable integration of advanced technologies into complex, evolving sector.

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Author contributions

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Appendix A

Table A1. Specific Canadian use case: Closing the technological gaps (source: National Research Council Canada, n.d.-a)

Category	Technological Gaps Identified	Closing the Gaps
Pilot	Warnings within the CS for operators	Enhanced warning systems within Control Stations (CS) are needed to alert operators of potential risks in real time, improving situational awareness in complex environments.
	Simulated training tools for operators	Development of scenario-based simulators and operator-specific training tools to refine skills and prepare operators for diverse BVLOS missions.
	Simulated environments (digital twin)	Virtual digital twin environments for realistic training and mission planning, helping operators simulate and practice decision-making for specific operational scenarios.
Product	Safety features impact on RPAS performance	Balancing additional safety features with RPAS performance demands, considering how redundancies and safety improvements might impact operational efficiency.
	Digital data link architecture for C2 Link	Standardization of digital data link architecture for Command and Control (C2) links to ensure stable, secure, and reliable BVLOS communication.
	Mitigation of cybersecurity hazards	Implementation of advanced cybersecurity protocols to prevent unauthorized access to RPAS systems, ensuring safe and secure operations in both public and restricted airspaces.
	End-to-end reliable DAA system	Development of robust Detect and Avoid (DAA) systems that meet all performance requirements, essential for collision avoidance in complex airspace.
	Multirotor vs. fixed-wing RPA for cargo	Analysis of multirotor versus fixed-wing RPAS configurations to optimize performance for short- to medium-distance cargo delivery missions.
	Cold weather operations	Addressing cold-weather challenges through technologies like low-power de-icing systems, ice-phobic coatings, and efficient battery thermal management.
	Urban wind flow modeling	Modeling urban wind patterns to better understand and mitigate the impact on RPAS stability and operational safety in populated areas.
	Noise management near populated areas	Developing noise reduction strategies to minimize RPAS noise impact, supporting public acceptance and regulatory compliance.
Procedures	Remote Identification (Remote ID)	Implementation of standardized Remote ID protocols for real-time RPAS tracking, facilitating accountability and security in BVLOS operations.
	Real Time Monitoring (RTM)	Real-Time Monitoring capabilities to dynamically oversee RPAS activities, enabling timely adjustments based on situational demands.
	Remote goods delivery methods	Development of effective remote delivery methods to ensure safe and efficient cargo transfer, improving the reliability of drone delivery services.
	In-Time Aviation Safety Management	An adaptable in-time Aviation Safety Management System (SMS) for proactive hazard management in real time, accommodating the dynamic nature of BVLOS conditions.
	Localization and identity tracking	Advanced tracking systems for precise localization and identification of RPAS in airspace, aiding seamless integration with other air traffic.
	Reliability in hazard identification	Enhanced reliability in hazard identification through predictive analytics, supporting proactive risk mitigation and operational resilience in BVLOS missions.

Appendix B

Table A2. Key technological and operational areas of focus for RPAS development in Canada (source: National Research Council Canada, n.d.-b)

Category	Identified technological Gap	Summary of key points needed to close the gaps	Link to the 3Ps
Technology	1. Vehicle Overview	The variety of vehicle configurations poses technological challenges. Key factors include flight safety and noise.	Product: Development of configurations adapted to specific environments.
	2. Propulsion and Energy	VTOL (Vertical Takeoff and Landing) aircraft require high energy for hovering. Hybrid-electric or hydrogen systems offer future potential but are limited by energy density.	Product: Thermal management, hybrid systems, and integration of alternative fuels (hydrogen, electric).
	3. Autonomy	Autonomous systems (AS) are essential for extending AAM operations but require technological and regulatory maturity, particularly for pilot roles and responsibilities.	Pilot: Simulators and training tools for operators. Procedures: Standards for autonomy and RPAS airspace integration.

End of Table A2

Category	Identified technological Gap	Summary of key points needed to close the gaps	Link to the 3Ps
	4. Airspace Integration	Effective integration with existing airspace requires standardized intent-sharing protocols and regional adaptation.	Procedures: Remote Identification (Remote ID), integration of U-Space systems.
	5. Safety Management	Predictive safety analysis and incident reporting are necessary for scaling UAM operations and ensuring safety in autonomous systems.	Procedures: Real-time Safety Management Systems (SMS).
	6. Infrastructure	Development of infrastructure, such as vertiports and charging stations, is critical for integration into urban environments and electrical grids.	Product: Design of robust and multifunctional vertiports.
	7. Security	Cybersecurity standards must be adapted for AAM, incorporating AI and machine learning to enhance operational security.	Product: Securing C2 systems and protecting against cyber threats.
	8. Communication, Navigation, Surveillance (CNS)	CNS requirements are underdeveloped; unique solutions are needed for interference-prone urban airspace.	Product: Standardized communication architectures for the C2 link.
	9. Weather Tolerance	Urban microclimates impact AAM stability; high-resolution weather prediction tools are necessary.	Product: Integration of tools for managing climate and thermal risks.
Operations	10a. Environment: Emissions	While some AAM vehicles are zero emission, lifecycle emissions need to be assessed, especially for electric and sustainable fuel options.	Product: Transition to low-emission technologies (hydrogen, batteries).
	10b. Environment: Noise	Noise reduction is essential; specific standards for urban and rural environments are required, along with adapted measurement methods.	Product: Technical solutions to reduce RPAS noise pollution.
	11. Maintenance	Standardized maintenance protocols are necessary for innovative systems such as hydrogen- or electric-powered vehicles to ensure safety.	Product: Development of protocols for maintaining new technologies.
	12. Safety and Security	UAM safety standards must be harmonized internationally, with emergency response procedures and operational standards.	Procedures: Standardized emergency response procedures.
	13. Infrastructure Interconnection	New infrastructure is needed to support AAM, considering societal and environmental impacts.	Product: Design of interconnected infrastructure (vertiports, charging stations).
	14. Data Protection and Security	Enhanced security measures are needed to protect sensitive data in urban environments.	Product: Implementation of data security protocols.

Appendix C

Table A3. Interview guide

Questions / Scenario	1: Strategy directors	2: Industry consultants	3: Government experts	4: Lawmakers in RPAS/AAM
Preliminary formalities	▪ Have you signed the information and consent form? ▪ Do you agree that I record this interview (this is purely for transcription purposes)?	Same as Scenario 1	Same as Scenario 1	Same as Scenario 1
Background and experience	Can you tell us a little bit about your background and experience in strategic planning or directing within companies aiming to participate in the drone delivery industry and AAM?	Can you tell us a little bit about your background and experience as a consultant in the drone delivery and advanced air mobility industry?	Can you tell us a little bit about your experience and background in research administration in aeronautics?	Can you tell us a little bit about your background and experience in the field of lawmaking and regulation for Remotely Piloted Aircraft Systems (RPAS) and Advanced Air Mobility (AAM)?

End of Table A3

Questions / Scenario	1: Strategy directors	2: Industry consultants	3: Government experts	4: Lawmakers in RPAS/AAM
Steps to commercialization	In your opinion, what are the steps needed to commercialize the drone delivery industry? How does this set the stage for the advent of AAM?	In your opinion, what are the steps needed to commercialize the advanced air mobility industry? How does the drone delivery industry play a role in this process?	What are the steps needed to commercialize drone delivery and advanced air mobility?	In your opinion, what are the steps needed to commercialize the drone delivery industry? How does lawmaking fit into this process?
Challenges and gaps	From your perspective, what are the main technological, regulatory, ethical, and social challenges that need to be overcome for drone delivery and advanced air mobility to become a reality?	What are some of the key technical, regulatory, ethical, and social challenges in the drone delivery and AAM sectors, based on your consulting experience, for it to become a reality?	What are the main technological, regulatory, ethical, and social challenges to overcome for advanced air mobility and drone delivery to become common options?	From your perspective, what are the main technological, regulatory, ethical, and social challenges that need to be overcome for drone delivery to become a reality?
Blockers and constraints	Where do you see the most significant blockers or constraints in current drone delivery and AAM technologies, regulations, or practices?	Where do you observe the most significant gaps or shortcomings in the current state of drone delivery and AAM technologies, regulations, or practices?	Where do you see the most significant gaps in the current technologies, regulations, or practices of drone delivery and AAM from a governmental or research perspective?	Where do you see the most significant blockers or constraints in current drone delivery and AAM technologies, regulations, or practices?
Underestimated challenges	In your experience, have there been instances where companies or organizations underestimated or overlooked certain challenges or gaps in drone delivery or AAM? Could you share such experiences without disclosing confidential information?	Same as Scenario 1	Same as Scenario 1	Same as Scenario 1
Importance of collaboration	How important is collaboration between industry, government, and academia in addressing the technological, regulatory, ethical, and social challenges in the drone delivery and AAM industry? What resources are available to support this collaboration?	Same as Scenario 1	Same as Scenario 1	Same as Scenario 1
Technology and commercial roadmaps	How do companies in this ecosystem develop their own technology and commercial roadmaps? What trends have you observed?	How do companies in this ecosystem develop their own technology and commercial roadmaps? What trends have you observed in advanced air mobility?	How do organizations in this ecosystem develop their own technology and commercial roadmaps? What trends have you observed in research administration in aeronautics?	How have companies in the drone delivery and AAM industry developed their technological and commercial roadmaps? Can you provide an example?
Future insights and contact	Are there any case studies outside of Canada that could be useful for my future analyses? Would you agree to stay in contact with me to complete a short survey summarizing the main points of our meeting and to receive the results of my work?	Same as Scenario 1	Same as Scenario 1	Same as Scenario 1

Appendix D

Table A4. Detailed summary of medium and high consensus level strategic themes

Interview Section	Theme	Content Analysis	Repetition Count	Expert Group	Consensus Level	Strategic Topics	Tactical Insights	Additional Notes
Steps to Commercialization	Regulatory and Safety Focus	Public sector experts emphasize a regulatory framework that ensures safety and compliance in AAM.	6	Public	High	Align regulatory frameworks with rapid tech advancements.	Implement continuous regulatory training for all stakeholders.	Regular inter-agency meetings help align priorities.
	Workforce and Skill Needs	Both public and private sectors agree on the importance of specialized training in new AAM tech.	5	Both	Medium	Develop workforce training programs to meet evolving sector needs.	Promote cross-training in both tech and regulatory practices.	Leverage existing aeronautics expertise to develop new skills.
	Market Viability	Private sector emphasizes the need for economically viable models and operational readiness in AAM.	5	Private	Medium	Develop market-responsive business models for sustained growth.	Showcase lower risk use cases to boost public and investor confidence.	Increase public campaigns for wider sector acceptance.
	Cost and Efficiency	High consensus on the need for cost-efficient systems and streamlined processes to support growth.	6	Both	High	Streamline certification processes to reduce time and costs.	Standardize low-risk BVLOS operations as a scalable entry model.	Build cost-sharing models for infrastructure with local governments.
Challenges and Gaps	Social Acceptance	High consensus on the need to build public trust and societal acceptance for drones in urban areas.	7	Both	High	Launch public awareness and education initiatives to boost acceptance.	Engage stakeholders through community-based pilot projects.	Use local projects to address public concerns about noise and safety.
	Standards and Interoperability	A focus on standards that ensure safe integration with traditional airspace and systems.	6	Public	High	Advocate for interoperable standards across platforms and regions.	Harmonize standards with international guidelines.	Collaborate with ICAO for unified airspace standards.
Technology and Roadmaps	Infrastructure Gaps	Emphasis on the need for infrastructure and Unmanned Traffic Management (UTM) systems for AAM.	4	Public	Medium	Strengthen infrastructure investments, particularly in UTM and AAM facilities.	Develop partnerships to address low-altitude airspace integration challenges.	Align with low-altitude airspace management standards globally.
	Data and Cybersecurity	Broad concern for robust data security measures and cybersecurity to protect AAM systems.	5	Both	High	Establish cybersecurity protocols for critical AAM infrastructure.	Develop a framework for secure data-sharing across sectors.	Prioritize cybersecurity training for all levels of staff.
Future Insights	Innovation Collaboration	Strong agreement on fostering collaboration between academia, industry, and government for AAM.	6	Both	High	Foster cross-sector partnerships to drive research and innovation.	Develop “sandbox” models for experimental collaboration.	Consider scaling collaborative frameworks to international standards.
	Environmental Sustainability	Emphasis on eco-friendly practices and infrastructure for the AAM sector’s long-term impact.	4	Both	Medium	Promote sustainable technology in all areas of AAM.	Encourage green energy for drone fleets and AAM infrastructure.	Integrate emissions reduction into strategic roadmaps.