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Small Satellites in Southeast Asia: Status, Challenges, and Implications for China — A Hebei Perspective

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Abstract

With the rapid iteration of microelectronics, artificial intelligence (AI), and aerospace technologies, small satellites—leveraging their advantages of low cost, short development cycles, high functional density, and constellation-based deployment—have become a core driving force in the global space industry. Due to its unique archipelagic geographic characteristics, frequent natural disasters, and rapidly growing digital economy, Southeast Asia has emerged as an important emerging market for small satellite applications. This paper systematically reviews the technical features and global development trends of small satellites, analyzes the motivations and foundational conditions for Southeast Asian countries to develop small satellites, and focuses on their application scenarios in remote sensing monitoring, communications support, disaster response, and marine resource management. In-depth case studies are conducted on Singapore, Malaysia, and Vietnam as representative countries. On this basis, the paper identifies challenges facing small satellite development in Southeast Asia, including technological dependence, funding and talent shortages, inadequate policy and regulatory frameworks, and fragmented international cooperation. Finally, in light of China's small satellite industry development, the paper proposes macro-level strategic insights from three dimensions—technological autonomy, industrial ecosystem, and scenario-based application—and uses Hebei Province as a case study to explore differentiated pathways and practical measures for integrating the regional small satellite industry into the Beijing-Tianjin-Hebei coordinated development framework, providing reference for both the international expansion of China's small satellite industry and regional high-quality development.

INTRODUCTION

Since the beginning of the 21st century, the global space industry has been undergoing a profound transformation from government-led to being commercially driven. The maturation and proliferation of small satellite technology have significantly lowered the barrier to space access. According to statistics, small satellites have accounted for over 95% of global satellite launches by number since 2020, with their share of launch mass exceeding 80% in 2023

[Cui Yufu et al., 2024]. Large-scale low Earth orbit (LEO) constellation construction has become a central focus in the space sector. Small satellites are not only used in scientific experiments and technology verification but have also penetrated extensively into civil and military applications such as communications, remote sensing, and navigation, serving as critical space infrastructure supporting the digital economy.

Located at the key hub of the 21st-Century Maritime Silk Road, Southeast Asia comprises 11 countries with a population of 670 million. The region is characterized by archipelagic geography, interwoven land and sea territories, frequent natural disasters, insufficient communication coverage in remote areas, and pressing needs for marine resource development and management. Traditional large satellites, with their high costs and long revisit cycles, struggle to meet the diverse, low-cost spatial information needs of Southeast Asian countries. The technical characteristics of small satellites, however, are highly compatible with the region's application scenarios. In recent years, Southeast Asian countries have successively formulated space development strategies and accelerated the introduction and indigenous development of small satellites, making the region one of the fastest-growing small satellite markets globally [Chen Xiang, 2017].

Against this backdrop, studying the application status and development challenges of small satellites in Southeast Asia not only helps to grasp the regional development trends of the global small satellite industry but also provides important reference for China's small satellite industry to engage in international cooperation and explore overseas markets. Meanwhile, Hebei Province, as an integral part of the Beijing-Tianjin-Hebei coordinated development strategy, is actively laying out its space industry. Drawing on the experiences and lessons of small satellite development in Southeast Asia to explore development pathways suited to regional characteristics holds significant practical relevance for promoting Hebei's industrial transformation and upgrading and integrating into the national aerospace development strategy.

LITERATURE REVIEW

Scholars have conducted systematic research on small satellite technology development, regional applications, and international cooperation across three major dimensions, yielding rich theoretical achievements and practical experience.

In the field of global small satellite technology and industry development, research has shifted from foundational conceptual definitions to technological evolution and trend forecasting. Lu Zhen (2018) was the first to systematically construct a small satellite classification system, defining a five-tier classification standard for spacecraft under 1000 kg and comprehensively mapping their application boundaries in military and commercial domains, laying the conceptual foundation for subsequent research. Jiang Jun et al. (2024), by analyzing global launch data from 2018–2023, quantitatively confirmed that small satellites have become the dominant force in space development, identifying constellation deployment as their core development model, and projected market size and technology iteration directions for the next decade. Li et al. (2024) further supplemented the literature on the regional distribution characteristics of the global market, revealing the rapid rise of emerging economies in the small satellite industry. In key technology research, Cui Yufu et al. (2024) and Chen et al. (2025) systematically elaborated on the application of artificial intelligence and digital twin technologies throughout the small satellite lifecycle from the perspectives of ground-based development and on-orbit application, respectively, proposing the development direction of integrated satellite-ground intelligence. Dou Jiao et al. (2024) focused on bottleneck issues constraining industry development, conducting in-depth analysis of global small satellite spectrum congestion, coordination difficulties, and electromagnetic compatibility issues. Miao Siwei and Liu Jun (2025) specifically examined the latest advances in chemical propulsion technology, clarifying its irreplaceable role in high-dynamic mission scenarios. In addition, Li Xin et al. (2025) provided international reference for China's technological breakthroughs through their tracking research on advanced US small satellite technologies.

In the field of small satellite application and development in Southeast Asia, research has focused on the two aspects of development drivers and application scenarios. Tan et al. (2023) systematically analyzed the intrinsic driving forces behind Southeast Asian countries' development of small satellites from geographic, economic, and policy dimensions, identifying archipelagic geography and frequent disasters as the core demand foundations. Nguyen et al. (2022) focused on sustainable development goals, providing detailed evidence of the application value of small satellites in agriculture, forestry, water resource management, and other fields in Southeast Asia, with practical cases from multiple countries. In specialized application research, Chen et al. (2024) quantitatively evaluated the effectiveness of small satellite constellations in disaster risk reduction in Southeast Asia, demonstrating their critical role in early warning and rescue stages. Sutrisno et al. (2023) explored the application of Automatic Identification System (AIS)-enabled small satellites for maritime domain awareness in Southeast Asian waters, providing technical pathways for marine resource management and security. Chen Xiang (2017), as the earliest domestic scholar to study Southeast Asian space affairs, systematically reviewed the evolution of various countries' space development strategies, providing a foundational framework for subsequent regional research.

In the field of China-Southeast Asia space international cooperation, research has shifted from summarizing cooperation outcomes to exploring strategies and models. Chen Xiang (2017) systematically summarized early cooperation achievements between China and Southeast Asian countries in satellite exports, navigation system deployment, data sharing, and talent training, analyzing the commercial, diplomatic, and political drivers behind such cooperation. Wang et al. (2024) further conducted in-depth analysis of the current competitive landscape of major powers in the Southeast Asian space market, noting that technology transfer and localized services constitute the core competitive advantages of Chinese enterprises. Ren Mingzhe (2024) explored the role of small satellites as space public goods in the Belt and Road Initiative from the macro perspective of China's new-era international space cooperation. Zhang et al. (2023) explicitly proposed that small satellites serve as an important catalyst for Belt and Road space cooperation, effectively promoting regional connectivity and shared development.

In the field of regional space industry collaborative development, Liu et al. (2024) conducted specialized research on the Beijing-Tianjin-Hebei region, analyzing the resource endowments and comparative advantages of the small satellite industry across the three areas and proposing development pathways of differentiated positioning and collaborative innovation, providing direct reference for the positioning of Hebei Province's small satellite industry.

In summary, existing research has made significant progress in global small satellite technology development, Southeast Asian application foundations, and international cooperation. However, two notable research gaps remain: first, there is insufficient systematic analysis of small satellite application scenarios in Southeast Asian countries, lacking in-depth comparison of differentiated development models across countries; second, few studies have combined the experience and lessons of Southeast Asian small satellite development with China's regional industrial development, particularly lacking specific pathway exploration for Hebei Province and other regions undertaking industrial transfer. This paper aims to address these two gaps, providing more targeted reference for both the internationalization of China's small satellite industry and regional high-quality development.

RESEARCH METHODOLOGY

This paper adopts a combination of literature research, case analysis, and comparative study. First, by reviewing relevant domestic and international literature and industry reports, it summarizes the technical features and global development trends of small satellites. Second, it analyzes the geographic, economic, and policy foundations for Southeast Asian countries to develop small satellites, summarizes their main application scenarios, and selects Singapore, Malaysia, and Vietnam as three representative countries for case analysis. Third, it summarizes the challenges facing small satellite development in Southeast Asia from four dimensions: technology, funding, policy, and international cooperation. Finally, in light of China's small satellite industry development, it proposes macro-level strategic insights and, using Hebei Province as a case study, explores development pathways for the regional small satellite industry.

RESEARCH FINDING

1. Application Foundations and Development Status of Small Satellites in Southeast Asia

1.1 Technical Features and Development Trends of Small Satellites

Small satellites generally refer to spacecraft with a mass of less than 1000 kg, which can be further classified by mass into: small satellites (100–1000 kg), microsatellites (10–100 kg), nanosatellites (1–10 kg), picosatellites (0.1–1 kg), and femtosatellites (below 0.1 kg) [Lu Zhen, 2018]. Compared with traditional large satellites, small satellites possess the following core technical features:

a) High Functional Density: Benefiting from advances in microelectronics, MEMS (Micro-Electro-Mechanical Systems), and integration technologies, small satellites integrate multiple functions such as communications, remote sensing, and navigation within limited volume and mass. Some 100 kg-class small satellites have already achieved sub-meter resolution remote sensing and high-throughput communications [Jiang Jun et al., 2024].
b) Low Cost and Short Development Cycle: Small satellites adopt modular design and commercial off-the-shelf (COTS) components. The development cost of a single satellite has decreased from hundreds of millions of US dollars for traditional large satellites to hundreds of thousands to tens of millions of US dollars, and the development cycle has been shortened from several years to several months. Furthermore, multi-satellite launch methods can significantly reduce launch costs.
c) Constellation and Cluster Deployment: A single small satellite has limited coverage. By forming constellations of tens to tens of thousands of satellites, global seamless coverage and high temporal resolution observation can be achieved, meeting the demands of real-time communications, dynamic monitoring, and other applications [Lu Zhen, 2018].
d) Rapid Iteration and Fault Tolerance: Small satellites typically have a lifespan of 1–5 years, allowing for technology updates through rapid launches. Constellations also exhibit “graceful degradation” characteristics, where the failure of individual satellites does not affect the overall service capability of the

system. In addition, small satellite propulsion technology has made substantial progress. Chemical propulsion, offering high instantaneous thrust, has advantages in high-dynamic mission scenarios such as rapid orbital transfer and emergency collision avoidance maneuvers [Miao Siwei and Liu Jun, 2025]. According to statistics, small satellites have accounted for over 95% of global launches since 2020, with their launch mass share exceeding 80% in 2023 [Li et al., 2024]. Currently, small satellite technology is advancing toward intelligence, mass production, and integration. In terms of intelligence, AI technology is applied to onboard data processing, autonomous mission planning, and fault diagnosis, enhancing satellites' autonomous on-orbit operation capabilities [Chen et al., 2025]. In mass production, assembly line and smart manufacturing technologies enable large-scale rapid satellite fabrication [Cui Yufu et al., 2024]. In integration, satellite-ground integrated design is promoted, shifting ground-based data processing capabilities to the satellite to optimize overall system efficiency [Jiang Jun et al., 2024]. Meanwhile, at the application level, combining AI, big data, and other technologies with small satellites to develop intelligent remote sensing satellite systems—achieving a leap from Earth observation satellites to an "Earth observation brain"—represents another important development direction.

1.2 Motivations and Foundational Conditions for Southeast Asian Countries to Develop Small Satellites

The motivation for Southeast Asian countries to develop small satellites stems from their unique geographic endowments and pressing practical needs, with geographic environmental characteristics being the primary foundational factor driving small satellite application deployment.

a) Geographic and Demand Characteristics

The unique geography of Southeast Asia determines its urgent need for small satellites. First, the region consists of the Indochina Peninsula and the Malay Archipelago, with over 25,000 islands and complex land terrain. Traditional ground-based communication and monitoring methods struggle to cover remote islands and mountainous areas, while small satellite constellations can provide low-cost, wide-coverage communication and remote sensing services [Chen Xiang, 2017]. Second, Southeast Asia is one of the most natural disaster-prone regions globally, experiencing dozens of typhoons, earthquakes, tsunamis, and volcanic eruptions annually. Small satellites' rapid response capability and high revisit frequency can provide timely spatial information support for disaster monitoring, early warning, and post-disaster rescue. Furthermore, Southeast Asia boasts abundant marine resources, with sea areas exceeding 5 million square kilometers. Marine fisheries, oil and gas development, and maritime shipping are vital economic pillars for these countries. Small satellites can be used for marine environmental monitoring, vessel tracking, and illegal activity surveillance, enhancing marine resource management capabilities.

b) Economic and Policy Foundations

In recent years, Southeast Asian economies have maintained relatively rapid growth, with digital economies developing quickly and demand for spatial information services continuously increasing. Governments have gradually recognized the strategic significance of space technology for economic and social development, successively introducing policies to support the development of the small satellite industry [Tan et al., 2023]. Indonesia enacted the Space Law in 2013, setting the goal of achieving independent launch vehicle capability by 2024 and planning to build its own remote sensing and communication satellite constellation. Singapore established the Singapore Space and Technology Agency (SSTA), investing substantial funds to support commercial space enterprises, with a focus on small satellite manufacturing, launch services, and application solutions. Vietnam formulated the 2020 Strategy for Space Technology Research and Application in 2006, explicitly setting the goal of independently developing small satellites and cultivating space talent through international cooperation. Malaysia, Thailand, the Philippines, and other countries have also successively launched space development plans, promoting the development and application of small satellites through government investment and international cooperation [Chen Xiang, 2017].

2. Main Application Scenarios of Small Satellites in Southeast Asia

2.1 Remote Sensing Monitoring

Remote sensing is the most widely applied field of small satellites in Southeast Asia, mainly serving agriculture, forestry, land resources, and urban planning. Thailand uses remote sensing satellites for rice planting area monitoring and yield prediction, providing data support for agricultural policy formulation and food security assurance. Indonesia uses small satellites to monitor forest fires on Sumatra and Kalimantan, detecting fire points in a timely manner and assessing fire damage, providing a scientific basis for forest fire prevention and environmental management. Singapore uses high-resolution small satellites for urban land use surveys and infrastructure monitoring, enhancing urban fine-grained management. In addition, small satellites are used for transboundary river monitoring, mineral resource exploration, and illegal mining surveillance, providing important tools for resource management and environmental protection across countries [Nguyen et al., 2022].

2.2 Communications Support

Communications is one of the core areas of small satellite application in Southeast Asia, focusing on solving communication coverage issues in remote areas and at sea. In 2015, China successfully launched the LaoSat-1 communications satellite, the first satellite exported to an ASEAN country, providing television broadcasting, broadband communications, and distance education services across Laos [Chen Xiang, 2017]. Indonesia has built multiple communications satellites through cooperation with China, Russia, and other countries, covering its main islands and maritime areas. In recent years, LEO communications small satellite constellations have become a major development trend. Their low-latency, high-bandwidth characteristics can provide high-speed internet access for maritime vessels, aircraft, and users in remote areas, compensating for the deficiencies of traditional ground communication networks. The rapid development of large LEO constellations such as SpaceX's Starlink has also provided new ideas and solutions for Southeast Asian countries to address communication coverage challenges.

2.3 Disaster Response

Southeast Asian countries place high importance on the application of small satellites in disaster response. The Asia-Pacific Space Cooperation Organization (APSCO) has established a regional disaster monitoring and emergency response mechanism, utilizing member states' small satellite resources to provide rapid remote sensing imagery and communication support for typhoons, earthquakes, and other disasters. Following the 2004 Indian Ocean tsunami, Thailand, Indonesia, and other countries strengthened their disaster early warning systems, using small satellites to monitor sea level changes and meteorological conditions in real time, enhancing tsunami and typhoon early warning capabilities. In the post-disaster rescue phase, small satellites can rapidly acquire disaster area imagery, assess building damage and road disruptions, and provide decision-making support for rescue force deployment and material allocation [Chen et al., 2024]. Furthermore, emergency communications small satellites can provide temporary communication links when ground communication facilities are damaged, ensuring smooth rescue command operations.

2.4 Marine and Resource Management

Marine resource management is a distinctive area of small satellite application in Southeast Asia. Countries use LEO small satellites equipped with Automatic Identification System (AIS) receivers to track maritime vessel positions in real time, monitor illegal fishing, smuggling, and piracy, and enhance maritime security capabilities [Sutrisno et al., 2023]. Malaysia and Vietnam use small satellites to monitor offshore oil and gas field development, preventing illegal extraction. The Philippines uses small satellites for coral reef ecological monitoring, protecting marine biodiversity. In addition, small satellites are used for marine environmental monitoring, tracking seawater temperature, salinity, red tides, and other marine disasters in real time, providing data support for marine fisheries production and ecological conservation.

2.5 Case Studies of Representative Countries

To provide a concrete representation of the differentiated development landscape of the small satellite industry in Southeast Asia, this paper selects three representative countries—Singapore, Malaysia, and Vietnam—for in-depth analysis. Singapore serves as the benchmark with the most mature space technology and highest degree of commercialization in Southeast Asia.

a) Singapore: A Technology-Leading Commercial Space Hub
   Singapore is the most developed country in terms of space technology in Southeast Asia. Leveraging its strong economic strength and technological foundation, it focuses on developing the commercial small satellite industry. Universities such as the National University of Singapore and Nanyang Technological University began developing small satellites as early as the 1990s, successively launching multiple remote sensing small satellites including X-Sat and TeLEOS-1. Among them, TeLEOS-1 is Southeast Asia's first commercial high-resolution remote sensing satellite, with a resolution of 1 meter. Singapore has also attracted numerous global space enterprises to establish operations, forming a complete industrial chain covering small satellite design, manufacturing, launch services, and application solutions. Currently, Singapore is actively promoting the construction of LEO communications small satellite constellations, aiming to become Southeast Asia's commercial space center.

b) Malaysia: Application Development Driven by International Cooperation
   Malaysia has rapidly developed small satellite applications through international cooperation. In 2000, Malaysia launched its first communications satellite, Measat-1, followed by multiple communications and remote sensing satellites. In 2019, the Malaysia-1 remote sensing satellite, developed in cooperation with China, was successfully launched with a resolution of 0.5 meters, primarily used for agriculture, forestry, and disaster monitoring. Malaysia also actively participates in projects under the Asia-Pacific Space Cooperation Organization, sharing satellite data resources to enhance its spatial information application capabilities. Currently, Malaysia is focusing on developing small satellite application services, promoting the deployment of space technology in agriculture, marine, and smart city domains.

c) Vietnam: Balancing Indigenous Development and International Cooperation
Vietnam follows a small satellite development path that combines indigenous development with international cooperation. In 2013, Vietnam's first domestically developed small satellite, VNREDSat-1, was successfully launched with a resolution of 2.5 meters, primarily used for land resource surveys and disaster monitoring. Subsequently, Vietnam launched multiple small satellites including VNREDSat-1B and MicroDragon, gradually improving its indigenous development capabilities. Meanwhile, Vietnam has engaged in extensive cooperation with Japan, France, Russia, and other countries, introducing advanced technology and talent while cultivating its own space workforce. Currently, Vietnam is planning to build a remote sensing constellation composed of multiple small satellites, aiming to achieve high-frequency coverage of its territory and maritime areas.

3. Existing Challenges and Problems in Small Satellite Application Development in Southeast Asia

3.1 Technological Challenges

The core challenge facing small satellite development in Southeast Asian countries is reliance on imported core technologies. With the exception of Singapore, other countries' small satellite platforms, payloads, onboard electronic equipment, and tracking, telemetry, and command (TT&C) systems are primarily imported from China, the United States, Europe, and other countries and regions, with weak indigenous research and development capabilities. For example, although Vietnam and Malaysia participate in the design of their small satellites, core components and key technologies are still supplied by foreign countries. Furthermore, Southeast Asian countries lack comprehensive space infrastructure, with insufficient ground TT&C stations and limited data processing capabilities, making it difficult to fully leverage the application effectiveness of small satellites. In terms of spectrum and orbital resources, as the number of small satellites globally surges, commonly used frequency bands such as S-band and X-band are becoming increasingly congested, and frequency coordination is growing more difficult. Southeast Asian countries have relatively limited bargaining power in international frequency and orbital resource allocation, making it difficult to secure high-quality resources [Dou Jiao et al., 2024].

3.2 Funding and Talent Challenges

Small satellite development and constellation construction require substantial capital investment, yet the economic strength of most Southeast Asian countries is limited. Government space budgets are insufficient, and commercial capital remains cautious about investing in the space sector. For instance, the space budgets of Indonesia and the Philippines account for only about 0.01% of GDP, which is insufficient to support large-scale small satellite constellation construction. Talent shortage is another prominent issue. Southeast Asian countries lack comprehensive space education systems and are deficient in professional space engineers and technical personnel. Existing talent is mostly cultivated through international cooperation projects, with quantity and quality insufficient to meet industry development needs. Brain drain is also a serious problem, with many outstanding space professionals flowing to developed countries in Europe and America, further constraining their domestic space industry development.

3.3 Policy and Regulatory Challenges

Space policies and regulatory systems across Southeast Asian countries remain underdeveloped, lacking unified industry standards and norms. Legal and regulatory frameworks concerning satellite launches, frequency utilization, data sharing, and space security are incomplete, resulting in cumbersome approval processes for small satellite projects and unclear market access thresholds. In addition, countries pay insufficient attention to space debris issues, lacking effective deorbiting measures, with numerous end-of-life small satellites remaining in orbit, exacerbating the deterioration of the space environment. Regarding cross-border data flows, differences in data security and privacy protection policies among countries affect the regional sharing and collaborative application of satellite data.

3.4 International Cooperation Challenges

Small satellite development in Southeast Asian countries is highly dependent on international cooperation. However, current cooperation is mostly bilateral, lacking regional multilateral cooperation mechanisms. Countries lack coordination in space development strategies, resulting in redundant construction and resource waste. Meanwhile, competition among major powers in the Southeast Asian space sector is intensifying. The United States, Japan, Europe, and others are vying for market share in the Southeast Asian space market through technology exports, financial assistance, and project cooperation, posing certain challenges to China's space cooperation with Southeast Asia [Chen Xiang, 2017; Ren Mingzhe, 2024; Wang et al., 2024]. Furthermore, some countries, influenced by geopolitical factors, have reservations about space cooperation, affecting the depth and breadth of collaboration.

4 Implications of Southeast Asian Small Satellite Development Practices for China's Small Satellite Development

4.1 Macro-Level Strategic Insights

Drawing on the experiences, lessons, and practical challenges of small satellite development in Southeast Asia, China can derive macro-level strategic insights from three dimensions—technology, industry, and application—with technological autonomy and controllability serving as the fundamental prerequisite for overcoming development bottlenecks and building core competitiveness.

4.2 Technology: Strengthening Full-Chain Autonomy and Building an Adaptive Technology Export System

The technological dependence issue in Southeast Asian small satellite development serves as a cautionary lesson, underscoring the need to strengthen full-chain technological autonomy in small satellites. China should increase R&D investment in core small satellite technologies, achieving breakthroughs in key areas such as high-resolution payloads, onboard intelligent processing, advanced propulsion, and laser communications, thereby enhancing the performance and reliability of small satellite platforms [Cui Yufu et al., 2024; Li Xin et al.]. At the same time, tailored to the application needs of Southeast Asian countries, China should build an adaptive technology export system, developing low-cost, highly reliable, and easy-to-operate small satellite products and solutions. For example, for Southeast Asia's disaster response needs, develop rapidly deployable emergency small satellites; for marine management needs, develop specialized small satellites equipped with AIS, Synthetic Aperture Radar (SAR), and other payloads. Furthermore, China should actively participate in international frequency and orbital resource allocation to secure more resources for the development of the small satellite industry [Dou Jiao et al., 2024].

4.3 Industry: Improving Investment, Financing, and Talent Systems to Overcome Development Bottlenecks

The funding and talent shortage problems faced by Southeast Asian countries also exist to varying degrees in some regions of China. China should improve the investment and financing system for the small satellite industry, establish space industry investment funds, and guide social capital to participate in small satellite development and constellation construction. Financial institutions should be encouraged to innovate financial products, offering services such as intellectual property pledge loans and equity financing to commercial space enterprises. In terms of talent cultivation, strengthen the development of space-related disciplines in universities, establish industry-education integrated training bases, and cultivate versatile talent with both technical expertise and market acumen. At the same time, improve talent introduction policies to attract overseas high-end space talent to return and start businesses. In addition, strengthen space science education to enhance public space literacy, laying the talent foundation for industry development.

4.4 Application: Deepening Scenario-Based Deployment and Building Sustainable Commercial Models

The successful experience of small satellite applications in Southeast Asia shows that scenario-based deployment is key to sustainable industrial development. China's small satellite industry should move away from the approach of emphasizing manufacturing over applications, deeply explore spatial information needs across various industries, and create satellite + industry application solutions. For example, in agriculture, develop precision agricultural remote sensing services; in the marine sector, provide vessel tracking and marine environmental monitoring services; in emergency response, establish an integrated space-ground disaster emergency response system [Jiang Jun et al., 2024]. At the same time, innovate business models, transitioning from pure satellite manufacturing and data sales to value-added data services and integrated solution provision, thereby increasing industrial added value. Furthermore, strengthen the development of international markets, leveraging the Belt and Road Initiative to promote China's mature small satellite technologies and application models to emerging markets such as Southeast Asia [Chen Xiang, 2017; Ren Mingzhe, 2024; Zhang et al., 2023].

5 Regional Implementation Practice—A Case Study of Hebei Province

The aforementioned macro-level strategic insights must be translated into concrete regional practices to achieve tangible results. This paper takes Hebei Province as a representative case study, first examining the current development status and core positioning of its small satellite industry.

5.1 Current Development Status and Positioning of Hebei Province's Small Satellite Industry

Hebei Province is an important industrial base in China, with a strong manufacturing foundation and abundant application scenarios. In recent years, with the in-depth implementation of the Beijing-Tianjin-Hebei coordinated development strategy, Hebei has actively undertaken the transfer of the space industry from Beijing, establishing space industry parks in Langfang, Baoding, and other areas, bringing together a cluster of small satellite manufacturing, application, and service enterprises. The positioning of Hebei's small satellite industry should be: leveraging the advantages of Beijing-Tianjin-Hebei coordinated development to build a Beijing-Tianjin-Hebei space industry collaborative innovation base and a small satellite application demonstration base, focusing on small satellite supporting manufacturing, spatial information application services, and space science education, forming an industrial pattern of differentiated development and complementary advantages with Beijing and Tianjin [Liu et al., 2024].

5.2. Anchoring Differentiated Positioning and Integrating into the Beijing-Tianjin-Hebei coordinated development framework

Hebei Province should fully leverage its own advantages and anchor differentiated development directions. In the manufacturing segment, focus on developing supporting products such as small satellite structural components, power systems, and TT&C equipment, providing supporting services for satellite assembly enterprises in Beijing and Tianjin. In the application segment, develop specialized spatial information application services tailored to the needs of Hebei's agriculture, marine, environmental protection, and emergency response sectors. For example, use small satellites to monitor winter wheat cultivation in Hebei, conduct marine environmental monitoring in Bohai Bay, and monitor geological disasters in the Taihang Mountains. At the same time, strengthen cooperation with universities and research institutes in Beijing and Tianjin, jointly establishing space technology innovation platforms and collaborating on key technological breakthroughs to enhance industrial innovation capacity.

5.3 Deepening Beijing-Tianjin-Hebei Technology Synergy and Building an Autonomous and Controllable Industrial Ecosystem

Hebei Province should deepen technology synergy across the Beijing-Tianjin-Hebei region to build an autonomous and controllable small satellite industrial ecosystem. Relying on the Langfang Space Industry Base, establish a small satellite intelligent manufacturing center, introducing advanced intelligent manufacturing technologies and equipment to achieve batch production of small satellite supporting products [Cui Yufu et al., 2024]. Strengthen cooperation with leading enterprises such as the China Aerospace Science and Technology Corporation (CASC) and the China Aerospace Science and Industry Corporation (CASIC), taking on their industrial chain transfers and integrating into the national space industry system. At the same time, cultivate a group of local space enterprises, support small and medium-sized enterprises in technological innovation, forming an industrial pattern of collaborative development among enterprises of all sizes. In addition, improve industrial supporting facilities, build space data centers, ground TT&C stations, and application service platforms to provide support for the development of the small satellite industry.

5.4 Improving Industry-Education Integration and Investment/Financing Systems to Address Talent and Funding Bottlenecks

Hebei Province should improve the industry-education integrated talent cultivation system, supporting universities such as Hebei University of Technology and Yanshan University to establish space-related programs, jointly building internship and training bases with space enterprises to cultivate application-oriented space talent. Establish the Hebei Provincial Space Industry Development Fund to guide social capital to participate in small satellite project construction. Encourage financial institutions to increase credit support for space enterprises, offering financing services such as intellectual property pledges and equity pledges. At the same time, actively seek national policy support, incorporating Hebei's space industry into the national space development plan to secure more funding and project support [Ren Mingzhe, 2024].

CONCLUSION

In summary, the rapid development of small satellite technology provides Southeast Asian countries with a low-cost, high-efficiency pathway to access spatial information services, demonstrating broad application prospects in fields such as remote sensing monitoring, communications support, disaster response, and marine resource management. However, small satellite development in Southeast Asia still faces challenges including technological dependence, funding and talent shortages, inadequate policy and regulatory frameworks, and fragmented international cooperation.

As a major space power, China should draw on the experiences and lessons of small satellite development in Southeast Asia, strengthen full-chain technological autonomy and controllability, improve the investment, financing, and talent systems, deepen scenario-based applications, and build sustainable commercial models. At the same time, China should actively engage in space cooperation with Southeast Asian countries, exporting advanced small satellite technologies and application solutions to achieve mutual benefits [Chen Xiang, 2017]. For Hebei Province, it should seize the opportunity of Beijing-Tianjin-Hebei coordinated development, anchor differentiated positioning, deepen technology synergy, improve the industrial ecosystem, and promote high-quality development of the small satellite industry, contributing to regional economic transformation and upgrading as well as the national goal of becoming a space power.

This study still has certain limitations. The specific data and case analysis of small satellite applications in individual Southeast Asian countries are not sufficiently in-depth, and the concrete measures for the development of Hebei Province's small satellite industry require further refinement. Future research could obtain more detailed data through field surveys and enterprise interviews, conducting in-depth study of specific models for China-Southeast Asia small satellite cooperation and the development pathways of Hebei Province's small satellite industry.

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