National Space Strategies: Building Thailand's LEO Industry Cluster

Watanyoo Suksa-ngiam* Ussanai Nithirochananont** Pornthep Navakitkanok***
Atipat Wattanuntachai**** and Panom Intarussamee*****

Received: July 2, 2023 *Revised: March 22, 2024* *Accepted: April 9, 2024*

Abstract

Technological advancement is a crucial driver of economic growth. Thailand, aiming to escape the middle-income trap, requires robust science, technology, and innovation policies to enhance competitiveness. Embracing the new space economy, mainly focusing on low-Earth orbit (LEO) technology, can significantly contribute to national economic development. This paper offers policy recommendations to the Thai government

* School of Information Technology, King Mongkut's University of Technology Thonburi
126 Pracha Uthit Road, Bang Mot, Thung Khru, Bangkok 10140, THAILAND
E-mail: watanyoo.suks@kmutt.ac.th

** Space Technology Development Office, Geo-Informatics and Space Technology Development Agency
196 Phaholyothin Road, Chatuchak, Bangkok 10900, THAILAND
E-mail: ussanai@gistda.or.th

*** THEOS-2 Project Management Office, Geo-Informatics and Space Technology Development Agency
196 Phaholyothin Road, Chatuchak, Bangkok 10900, THAILAND
E-mail: pornthep@gistda.or.th

**** THEOS-2 Project Management Office, Geo-Informatics and Space Technology Development Agency
196 Phaholyothin Road, Chatuchak, Bangkok 10900, THAILAND
E-mail: atipat@gistda.or.th

**** Space Operations Center, Royal Thai Air Force
171 Thanon Dechathungkha, Si Kan, Don Mueang, Bangkok 10210, THAILAND
E-mail: panom@heroaviation.com

and outlines a conceptual model for future research. Specifically, this examines how Thailand can advance its LEO industry cluster, drawing insights from the Diamond Model, the current body of knowledge in the relevant literature. Hence, the study provides eight policy recommendations for government actions. Moreover, future research must validate the proposed model and assess economic feasibility through cost-benefit analysis. Empirical evidence from future research will strengthen government recommendations from this study. Furthermore, mixed methods research, action research, and design science approaches can facilitate the development of evidence-based policies derived from the validated model.

Keywords: New Space Economy, Industry Cluster, Low Earth Orbit, Space Policy, Thailand

ยุทธศาสตร์อวกาศชาติ: การสร้างคลัสเตอร์อุตสาหกรรมดาวเทียมวงโคจรต่ำของไทย

วทัญญู สุขเสงี่ยม* อัศนัย นิธิโรจนานนท์** พรเทพ นวกิจกนก***
อธิภัทร วรรธอนันตชัย**** และ พนม อินทรัศมี*****

รับวันที่ 2 กรกฎาคม 2566 *ส่งแก้ไขวันที่ 22 มีนาคม 2567* *ตอบรับตีพิมพ์วันที่ 9 เมษายน 2567*

บทคัดย่อ

ความก้าวหน้าทางเทคโนโลยีเป็นตัวขับเคลื่อนที่สำคัญของการเติบโตทางเศรษฐกิจ ประเทศไทยมีเป้าหมายที่จะก้าวพ้นกับดักรายได้ปานกลาง ดังนั้นจำเป็นต้องมีนโยบายด้านวิทยาศาสตร์ เทคโนโลยีและนวัตกรรมที่แข็งแกร่งเพื่อเพิ่มขีดความสามารถในการแข่งขัน การเปิดรับเศรษฐกิจอวกาศรูปแบบใหม่โดยมุ่งเน้นไปที่เทคโนโลยีวงโคจรโลกต่ำ (low-Earth orbit: LEO) เป็นหลัก ซึ่งสามารถมีส่วนช่วยในการพัฒนาเศรษฐกิจของประเทศได้อย่างมาก บทความนี้เสนอข้อเสนอแนะเชิงนโยบายแก่รัฐบาลไทยและสรุปโมเดลแนวคิดสำหรับการวิจัยในอนาคต โดยเฉพาะอย่างยิ่ง การศึกษานี้จะตรวจสอบว่าประเทศไทย

* คณะเทคโนโลยีสารสนเทศ มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี
เลขที่ 126 ถนนประชาอุทิศ แขวงบางมด เขตทุ่งครุ กรุงเทพฯ 10140
อีเมล: watanyoo.suks@kmutt.ac.th

** สำนักพัฒนาเทคโนโลยีกิจการอวกาศ สำนักงานพัฒนาเทคโนโลยีอวกาศและภูมิสารสนเทศ (องค์การมหาชน)
เลขที่ 196 ถนนพหลโยธิน จตุจักร กรุงเทพฯ 10900
อีเมล: ussanai@gistda.or.th

*** สำนักบริหารโครงการ THEOS-2 สำนักงานพัฒนาเทคโนโลยีอวกาศและภูมิสารสนเทศ (องค์การมหาชน)
เลขที่ 196 ถนนพหลโยธิน จตุจักร กรุงเทพฯ 10900
อีเมล: pornthep@gistda.or.th

**** สำนักบริหารโครงการ THEOS-2 สำนักงานพัฒนาเทคโนโลยีอวกาศและภูมิสารสนเทศ (องค์การมหาชน)
เลขที่ 196 ถนนพหลโยธิน จตุจักร กรุงเทพฯ 10900
อีเมล: atipat@gistda.or.th

***** ศูนย์ปฏิบัติการทางอวกาศกองทัพอากาศ
เลขที่ 171 ถนนเดชะตุงคะ แขวงสีกัน เขตดอนเมือง กรุงเทพฯ 10210
อีเมล: panom@heroaviation.com

สามารถพัฒนากลุ่มอุตสาหกรรมดาวเทียมวงโคจรต่ำได้อย่างไร โดยดึงข้อมูลเชิงลึกจากแบบจำลองเพชร (Diamond Model) องค์ความรู้ปัจจุบันจากวรรณกรรมที่เกี่ยวข้อง ดังนั้น การศึกษาจึงให้คำแนะนำเชิงนโยบายแปดประการสำหรับการดำเนินการของรัฐบาล นอกจากนี้การวิจัยในอนาคตจะต้องตรวจสอบแบบจำลองที่นำเสนอและประเมินความเป็นไปได้ทางเศรษฐกิจผ่านการวิเคราะห์ต้นทุนและผลประโยชน์ หลักฐานเชิงประจักษ์จากการวิจัยในอนาคตจะเสริมสร้างข้อเสนอแนะของรัฐบาลจากการศึกษานี้ นอกจากนี้การวิจัยด้วยวิธีผสมผสาน การวิจัยเชิงปฏิบัติการ และการวิจัยวิทยาศาสตร์การออกแบบ สามารถอำนวยความสะดวกในการพัฒนานโยบายตามหลักฐานเชิงประจักษ์ที่ได้มาจากแบบจำลองที่ได้รับการตรวจสอบแล้ว

คำสำคัญ: เศรษฐกิจอวกาศใหม่ คลัสเตอร์อุตสาหกรรม วงโคจรต่ำ นโยบายอวกาศ ประเทศไทย

Introduction

Technological progress drives economic growth. Thailand must implement policies focused on science, technology, and innovation (STI) to improve its competitiveness and economy. LEO technology innovation in the new space economy will be a crucial driver of this growth. In the past, technical advancements accounted for 87.5% of the increase in US per capita growth between 1909 and 1949 (Solow, 1957). Technological change is integral to economic growth, as seen in the Industrial Revolution (Romer, 1994). Governments worldwide have designed SIT policies to promote economic development. Porter (1990, 1998) proposed ideas to organize regional economic systems for new technological changes.

Great technology waves have boosted the economy. Economic growth factors of the past included steam engines, electricity, telephones, and cars. The digital revolution has been sweeping the global analog economy. Morgan Stanley (2020) surprisingly speculated that the space economy will reach $1 trillion by 2040 worldwide, including its significant second-order impact on other sectors (e.g., information technology and automobiles). Moreover, the National Aeronautics and Space Administration (NASA) ceased its Space shuttle programs and outsourced to new space startups like SpaceX. The costs of satellite manufacturing and launching have considerably declined, and the reusable rocket booster reduced the cost of transportation, and space devices are faster, better, and cheaper than before. Thus, space technology could be a new economic booster.

There are three types of satellites, categorized by their distance from Earth. The first type is Low-Earth Orbit (LEO) satellites, between 160 and 2,000 kilometers above sea level. The second type is Medium-Earth Orbit (MEO) satellites, which are between 2,000 and 35,786 kilometers away. The third type is geostationary orbiting satellites, also known as Geostationary Orbit (GEO) satellites, which are more than 35,786 kilometers from Earth (Garrity & Husar, 2021).

The LEO technology will be the next technological shift. Data from Statista publicized the giant pie of the space sector, consumer broadband, which will reach $ 94.85 billion globally in 2040 with an 18.71 % accumulative growth rate (CAGR) between 2018 and 2040. The LEO, an altitude between 160 and 2,000 km from Earth's surface, will play an imperative role as the communication satellite has moved from the fixed satellite orbit to LEO due to Earth's closeness and low latency. Starlink and OneWeb may disrupt the telecommunication industry by providing a low-latency communication network compared to fiber optics and fixed satellite communication networks. A low-latency communication network is critical for investment bankers. Also, the Earth Observation (EO) will reach $ 25.27 billion in 2040 at 10.7% CAGR, as revealed by Statista. The IT field – Space Big Data – will rapidly drive this expansion with high-resolution data, allowing machine learning (ML) to gain insights. Also, NASA permitted private investors to be part of its LEO International Space Station (ISS) ecosystem, fueling the LEO economy (Mazzucato & Robinson, 2018).

The low Earth orbit is a common pool resource, which means if Thailand does not use the orbit, other nations could utilize it (Weeden, 2012). The LEO region is tiny and is running out of space. Companies have occupied and will occupy the best commercial orbit for their businesses' competitive advantage. Consequently, the orbit will need more usefulness. If Thailand acts fast, the door to building sustainable LEO space competitiveness will remain open. The availability of the LEO is decreasing as the number of satellites continues to increase spontaneously (including increasing amounts of space junk Due to the collision of space objects); Starlink alone plans to deliver up to 42,000 satellites (Mann, 2021).

Thailand's economy is not mainly dependent on STI, so the country is in the middle-income trap. Transitioning from a middle-income trapped country to an innovation-driven country requires STI policies to drive the economy. This paper aims to develop a research model for future theoretical testing and provide initial recommendations for the Thai government. Thus, this paper answers the question of how Thailand can build its LEO industry cluster (Porter, 1990, 1998).

The Overview of the Space Economy

The global space economy is estimated to reach $1 trillion by 2040. In 2015, according to the National Institute of Development Administration (2019), Thailand gained a share of the global space economy at 0.121 % (34 Baht per US Dollar). The draft of Thailand's National Space Master Plan estimated that Thailand may gain its performance of the space economy from 0.121 to 0.200 % between 2028 and 2032 and from 0.200 to 0.250% between 2023 and 2037 (Geo-Informatics and Space Technology Development Agency, 2022). Figure 1 shows the global space economy and Thailand’s shares. The value of Thailand's new space economy could surpass 200 billion US Dollars by 2037, according to the master plan, and depending on the context of global competition, other nations may rush to the space economy faster than Thailand.

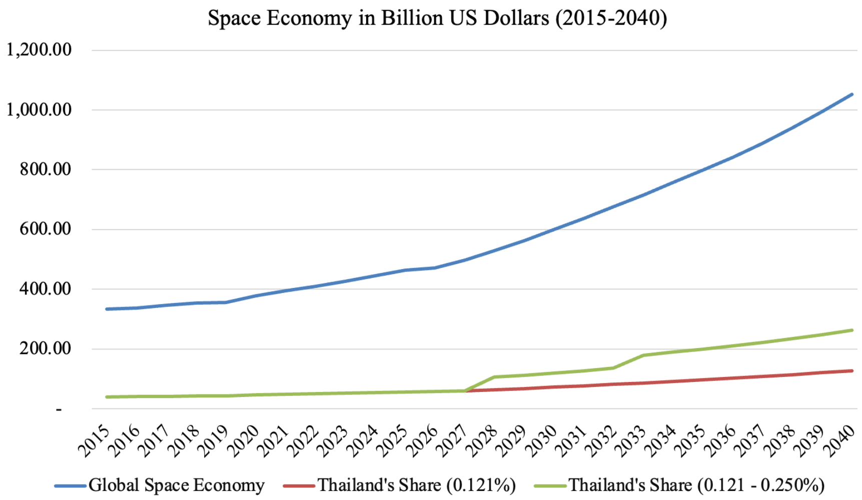

Figure 1: Space Economy in Billion US Dollars (2015 - 2040).

Note: Data from Statista.com

Figure 2 breaks down the sectors of the space economy. The second-order impacts are estimated to be the most considerable portion of the global space economy. Economies can benefit from the space economy by just utilizing space technologies. New downstream industries such as digital, national defense, autonomous vehicles, aviation, and agriculture industries are key Thai industries that potentially benefit from the space industry. Thus, the first and foremost initiative is encouraging Thai citizens, businesses, government agencies, and other users to use space technologies. The satellite services industry is the second most significant portion of the space economy. Major space companies such as SpaceX, Inmarsat, Viasat, Intelsat, Eutelsat, Iridium Communications, and Maxar Technologies operate in this sector. In Thailand, Thaicom and Geo-Informatics and Space Technology Development Agency (GISTDA) are two well-known entities in this sector. The third sector is the ground equipment sector, which includes Global Navigation Satellite System (GNSS) chipsets, navigation devices, satellite antenna producers, and satellite ground stations. Significant global players in the GNSS chipsets include Qualcomm Technologies Inc., Intel Corporation, and Thales Group. GNSS chipsets are core components of smartphones and navigation devices. Samart Group is a Thai conglomeration capable of producing satellite antennae. Amazon Web Services (AWS) and Microsoft Corporation, which provide a ground station network as a service, are challenging traditional ground station providers. The IT companies offer business models from the ground station as a product to a service. In addition, information captured by the satellite can automatically move to the cloud.

Fourth, the non-satellite industry covers space military operations, research, tourism, mining, energy, and manufacturing. The critical movement of this sector is space tourism, where technologies for human space flights are commercially possible. SpaceX, Blue Origin, and Virgin Galactic are developing products and services to carry tourists to space. In addition, the retirement of the International Space Station in 2031 will pave the way for private space stations and hotels. These objects are in LEO—Axiom Space Inc. and Mitsui & Co. plan jointly to develop a space hotel. Scientists and tourists can benefit from private space stations and hotels to experience lives in space and conduct research. However, government spending and activities are still vital sectoral contributions.

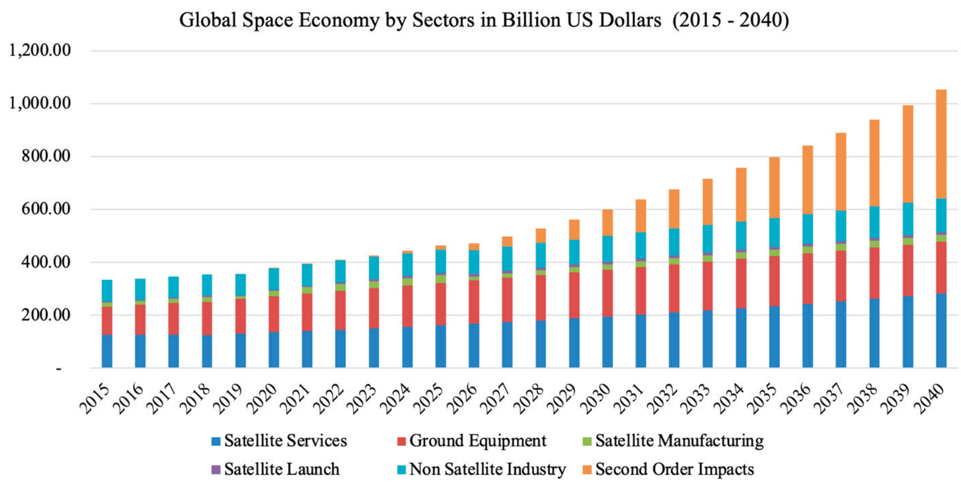

Figure 2: Global Space Economy by Sectors in Billion US Dollars (2015-2040)

Note: Data from Statista.com

The fifth-largest portion of the space economy is satellite manufacturing. SpaceX, Maxar Technologies, Lockheed Martin Corporation, Northrop Grumman, the Boeing Company, and Airbus Space and Defence are global players in this domain. Thailand also has satellite part manufacturers such as RV Connect, C.C.S. Group, Senior Aerospace, Jinpao, Gravitech, Lenso, Synergy, Aeroworks, Cherry Tech, Ducommun, Asia Recision, Cherrytech, and Toray Carbon Magi Co, ltd, Carbon Magi (Thailand) Co., ltd (Geo-Informatics and Space Technology Development Agency, 2021). These companies are players in other industries, such as electronics and aviation, but can move to the satellite manufacturing industries.

The satellite launch industry is the ground, air, and space gateway. SpaceX, Arianespace, Rocket Lab, and United Launch Alliance are examples of satellite launchers. Thailand has yet to have a satellite launcher due to its technical capability, market demand, and launch infrastructure, such as a spaceport. In comparison, the sub-sector is very small when companies are with the others. Other nations control space transportation, making self-access unsustainable. Figure 3 shows the space supply chain. Thailand has not had any players in the satellite launch industry. Thailand needs more satellite launchers and spaceport technology providers. Thus, this missing link is a strategic concern for developing the new space economy.

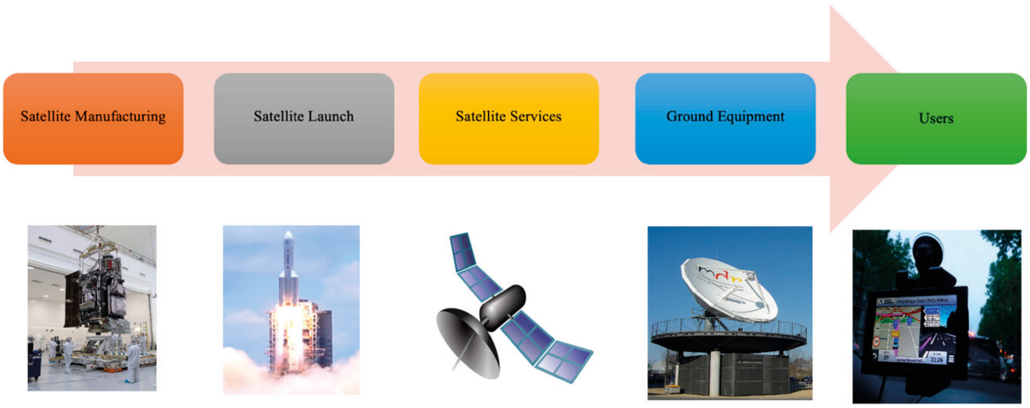

Image from:
https://commons.wikimedia.org/wiki/File:Processing_of_GOES-S_at_Astrotech_Space_Operations_(KSC-20171206-PH_LCH01_0105).jpg
https://commons.wikimedia.org/wiki/File:Tianwen-1_launch_04_(cropped-2).jpg
https://freesvg.org/vector-drawing-of-blue-space-satellite
https://commons.wikimedia.org/wiki/File:Mdr_big_satellite_dish.JPG
https://commons.wikimedia.org/wiki/File:Paris-PorteMolitor-GPS.jpg

Figure 3: Space Supply Chain

Figure 4 shows the global compound annual growth rate by sector between 2015 and 2040. The satellite services sector will lead the space economy with a size and growth rate of 3.28 %. Ground equipment is large but grows slower than the satellite services sector. The growth rate of ground equipment is 2.49 %.

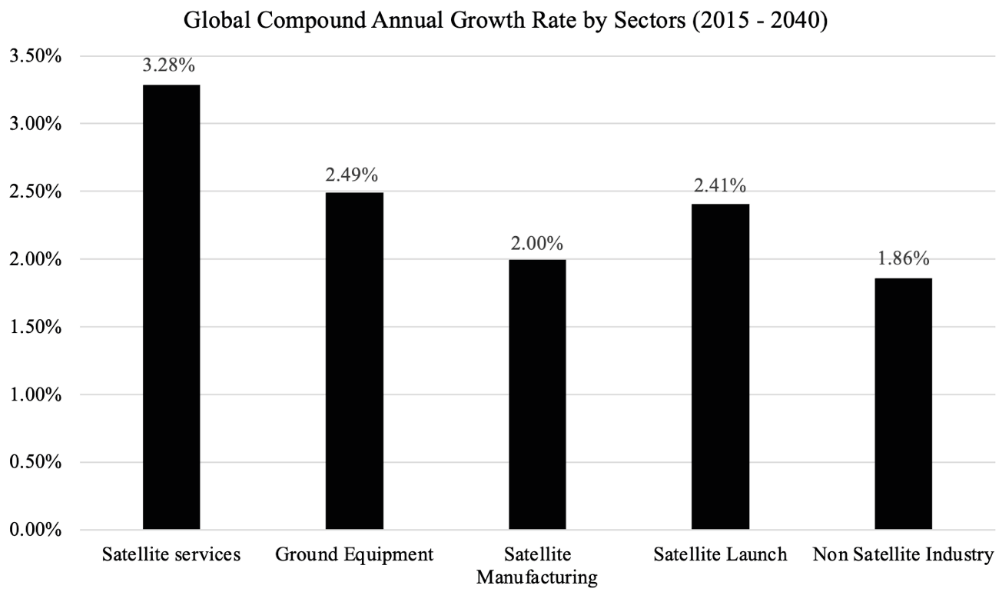

Figure 4: Global Compound Annual Growth Rate by Sectors (2015 - 2040)

Note: Data from Statista.com

However, despite all the fantastic dreams of new space industries, the satellite services industry is still the largest. Also, the satellite services industry connects to the ground equipment industry, which supports the services industry. Figure 5 shows the satellite services industry by sub-sectors in billion US Dollars between 2015 and 2040.

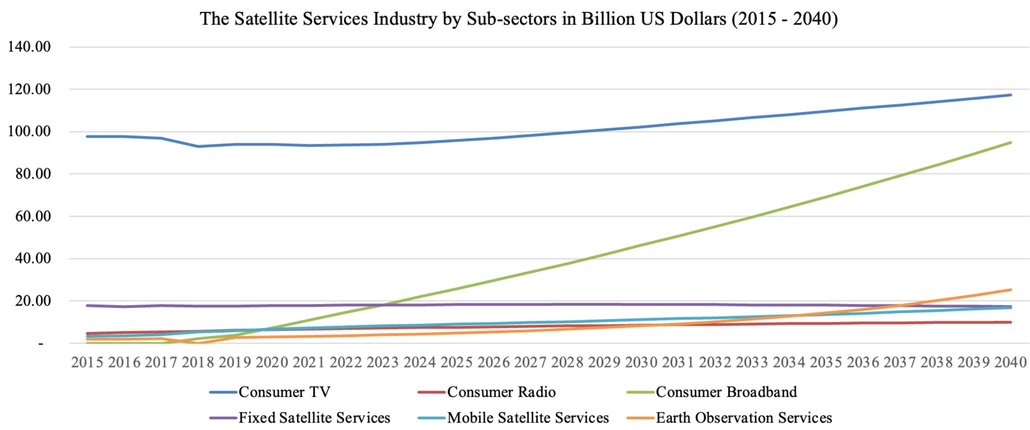

Figure 5: The Satellite Services Industry by Sub-sectors in Billion US Dollars (2015 - 2040)

Note: Data from Statista.com

Figure 6 shows the growth rate of the satellite services sub-sectors. The highest growth rate is the consumer broadband industry, at 13.63 %. The pattern indicates that the consumer broadband sub-sector is rising rapidly due to the new LEO satellite broadband Internet. Companies such as Starlink (SpaceX), OneWeb, Amazon Kuiper, Telesat Lightspeed, and China SatNet GuoWong are rushing to send their satellites into LEO. The main advantages of the LEO satellite are its latency and speed of Internet over that of the GEO satellite. In addition, the demand for broadband internet access of digital platforms such as Netflix, Amazon Prime, Xbox, and Sony PlayStation is pushing the need for high-speed Internet in remote areas. Also, new industries such as self-driving cars, drones, self-driving vessels, and the Internet of Things (IoT) are potential customers for LEO satellite companies.

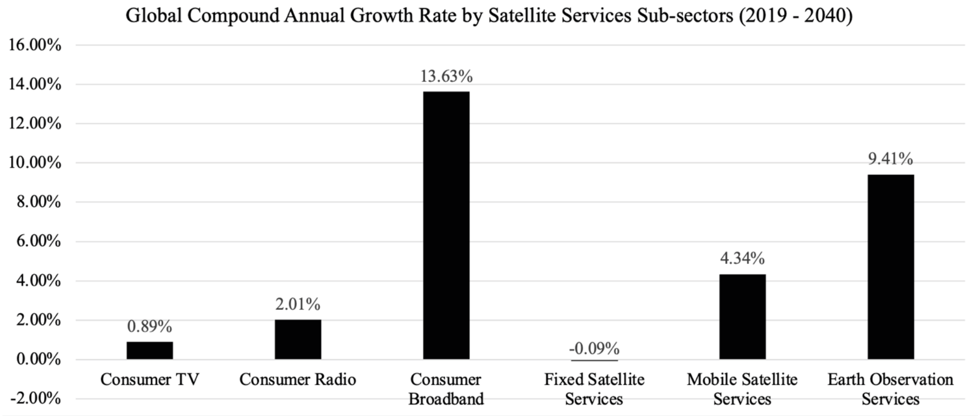

Figure 6: Global Compound Annual Growth Rate by Satellite Services Sub-sectors (2019 - 2040)

Note: Data from Statista.com

Following the consumer broadband sub-sector, the Earth observation is also expanding rapidly. The main reason is the growth of the big data and artificial intelligence industries. The use of satellite imagery with the capability of advanced deep learning algorithms yields digital applications for national defense intelligence gathering, smart farming, precision agriculture, and smart cities. The Earth observation sub-sector will grow at 9.41%. Although the other sub-sectors are growing (except the fixed satellite services), their applications for Thailand are limited.

Therefore, the critical strategic move of Thailand's space economy is to focus on the LEO industries that contain LEO internet broadband satellites, Earth observation satellites, space stations, launchers, and spaceports.

The Industry Cluster

Cluster Definition

Industry clusters are firms with common behaviors like location, innovation sources, and suppliers. They guide global industrial and regional development planning (Bergman & Feser, 2020). Porter (1998, p. 199) defined an industry cluster as “a geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities,” a dynamic interactive and interconnected system. Industries cannot sustain themselves individually as they feed on each other. For example, the LEO industry requires aerospace manufacturing and space transportation as supplier industries and the information technology industry as customers. The aerospace and defense cluster has a connection with the IT cluster. This paper focuses on the LEO industry cluster as a part of the aerospace and defense cluster.

Aerospace, Defense, and IT Clusters

Aerospace, defense, and IT clusters are closely collaborative through various means (Clustermapping.us, 2014). These clusters rely heavily on the same core technological innovations. Advancements in missiles in the defense sector have paved the way for the development of satellite transportation in the aerospace sector and vice versa (Labbé et al., 2022; Nair, 2006; Tugnoli et al., 2019). The core concept of spy satellites is also shared with that of EO satellites for remote sensing (Johnston, 2013). The advancement of space technology can enhance national security by improving surveillance, communication, and navigation systems.

As part of the aerospace cluster, satellite internet broadband will experience significant growth in the LEO cluster due to the improved speed and latency of LEO satellites. The lower production costs of satellites and innovative business models have made them more accessible, leading to growth in digital industries. Combining digital and space domains has created opportunities for big data analytics and geospatial technology. While developing economies face challenges in catching up, Thailand is leveraging digital space innovation to boost its economy. They plan to establish a non-geostationary satellite business. However, concerns persist regarding the impact on the ICT ecosystem. There is a need for international standards to ensure data flow between Earth and space (Suksa-Ngiam et al., 2023).

Additionally, IT advancements such as artificial intelligence find numerous applications in aerospace and defense clusters, including computer vision systems, navigation systems, cybersecurity, autonomous systems, and electronic warfare systems (Andås, 2020; Falco & AIAA Member, 2018; Labbé et al., 2022). Satellites also operate as part of the Internet of Things (IoT) network (Centenario et al., 2021; Huang et al., 2019). Collaborations between these sectors extend to research and development efforts, particularly in cybersecurity and unmanned systems.

These clusters often depend on government contracts and funding, with IT companies supporting defense contractors and aerospace companies collaborating on defense-related projects. Moreover, the interconnectedness among these clusters underscores their symbiotic relationships in the innovation ecosystem, where advancements in one sector often lead to innovations in the other sectors. This fosters collaboration and drives economic and innovation progress.

Figure 7 shows the vertical and horizontal integration between the aerospace and IT industries. Aerospace manufacturing and services cover upstream satellite manufacturing, launch vehicles, and aircraft and unmanned aerial vehicles (UAVs). Then, satellites, aircraft, and UAV platforms communicate and deliver data to ground stations.

Upstream	**Aerospace Manufacturing and launch services**			
Vertical Integration ⇓	**Ground Equipment & Communication Network**			
	Sat data and communication	**LBS & GNSS**	**Aerial**	**IoT**
	Spatial Analytics	**Data mining**	**ML**	**Cloud Computing**
	Agriculture solution	**Healthcare solution**	**Automobile solution**	**Defense solution**
Downstream	**Mobile**	**Web**	**Desktop**	**AR/VR**
Users	**Civil agencies**	**Companies**	**Citizen**	**Military**

⇔ Horizontal Integration

Figure 7: Aerospace and IT Vertical-Horizontal Integration.

Then, communication, GNSS, EO satellite, Location-Based Service (LBS), and aerial platforms merge with IT. Developers require complementary data from IoT to develop applications. Geospatial analysis, data mining, ML, and cloud computing are IT tools that add value to data. The merger between aerospace and IT advances solutions in many sectors, such as agriculture (smart farming and precision farming), automobile (self-driving vehicles), healthcare (remote healthcare), and defense (precision-guided missiles and surveillance). User experiences and user interface technologies like mobile, web, desktop, and spatial computing (Virtual Reality and Augmented Reality: VR and AR) enhance the value of LEO devices. As a result of the democratization of space, private companies, and citizens, in addition to government agencies, have become clients.

The LEO Cluster

Adapted from Ketels (2003), Figure 8 shows that the LEO cluster has three assemblers: EO, Communication Satellite (Com), and Space Station (SS). EO is the satellite system used to sense the changes in the Earth's surface. THEOS1, 2, and 2A are examples of Thailand's Earth Observation satellites. Communication satellites are essential for the telecommunication industry. Thaicom geostationary (GEO) satellites series has played significant roles in the Thai telecommunication industry and faces the challenge from LEO communication satellites like Starlink, OneWeb, Amazon Kuiper, Globalstar, and Galaxy Space due to better latency rate and upload and download internet bandwidth. The last sector is the space station sector. Axiom Space and Mitsui & Co. Ltd have developed the business idea of space hotels to respond to the retirement of the International Space Station (ISS). Thailand is well-known as a hospitality nation and may partner with other countries to explore the potential of the space tourism industry. Thus, the space station is one of the three key LEO space sectors.

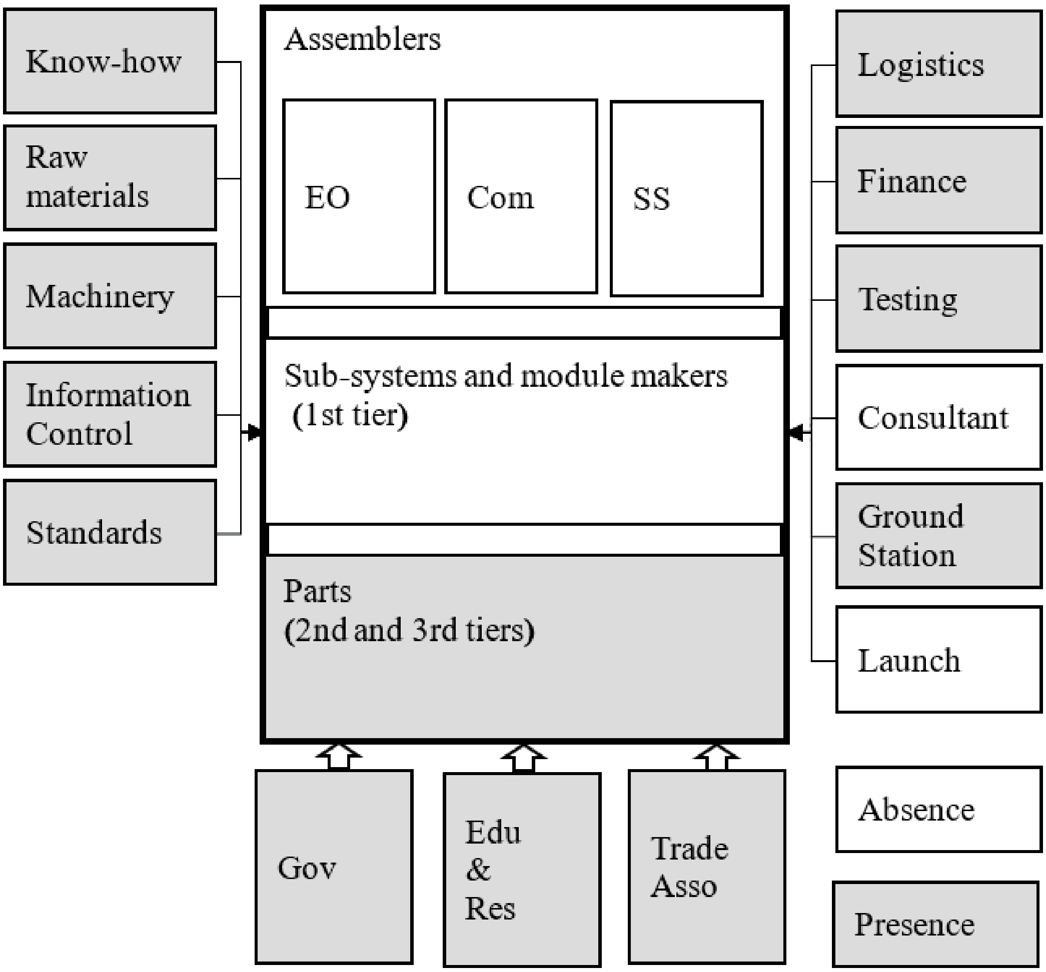

Figure 8: The LEO Cluster.

Thailand does not have commercial assemblers and sub-systems. However, these companies have experienced LEO by becoming satellite part manufacturers. Thailand has potential production capacities in many areas, such as metallic parts, composite parts, printed circuit boards (PCB), and PCB assemblies. Other possible areas are services in distribution, financing, testing, consultants, and information controls. Most services still need to be well developed and need support and guidance from the government and leading space agencies. Although Thailand has the know-how to create satellites in education and early invention stages, know-how at the commercialization level still needs to be added.

The Thai government has GISTDA, the National Space Operations Division (NSOD), the National Broadcasting and Telecommunications Commission (NBTC), the National Astronomical Research Institute of Thailand (NARIT), and the Royal Thai Airforce (RTAF) potentially relating to LEO businesses. Several Thai universities and research institutions (Edu & Res) have provided aerospace education in native and international programs. Raw materials for satellites, such as metal alloy, graphite fiber, aluminum, or composite materials, are available in Thailand. Various aerospace industries readily share the machinery required to manufacture satellite components. Information control is a government process service that attempts to regulate the flow of satellites and parts due to military control. Standards include standard service availability for international organizations such as the International Organization for Standardization (ISO), International Telecommunication Union (ITU), United States Military Standard (MIL), and Aerospace Standards (AS). These international organizations control standards of space devices and thus enhance demand sophistication.

The current Thai Aerospace Industry consists primarily of aircraft maintenance repair and overhaul (MRO) companies and aircraft components manufacturers, such as tires, seats, and catering trolleys. However, the space component needs to be included by 1st-tier suppliers. Recently, GISTDA set a goal to support and promote the aerospace industry. More than 40 companies from various industry sectors are interested in being involved. Lenso Aerospace extended its business from an automotive part supplier to an aerospace supplier, showing its commitment to the space-related industry. Also, Thailand has excellent ground logistics and transportation, financial systems, and ground stations (GISTDA and Thaicom). GISTDA recently invested in the nation's first small satellite assembly integration and test (AIT) facility, capable of testing satellites for up to 500 kilograms. However, Thailand still needs to have successful consultants and launch service companies.

The LEO Diamond Model

Porter's (1990, 1998) Diamond Model is a framework that analyzes the competitive advantage of nations or regions in specific industries, consisting of four key factors: Factor Conditions, Demand Conditions, Related and Supporting Industries, and Firm Strategy, Structure, and Rivalry. These factors interact with each other. By understanding and addressing these determinants, countries can create environments conducive to industry growth and innovation, ultimately improving their global competitiveness and guiding how the government formulates policies for a new technology industry or cluster.

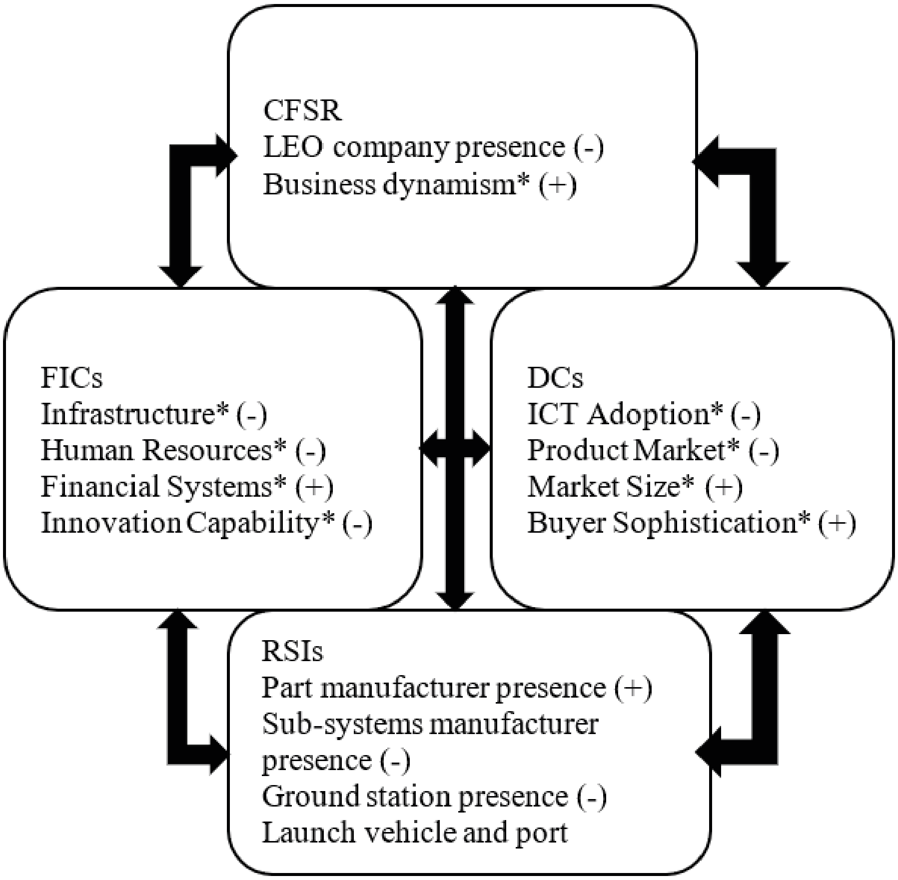

Figure 9: The Diamond Model

Adapted from Ketels (2003), Figure 9 shows the LEO Diamond Model. The data with * are from the World Economic Forum (WEF) (Schwab, 2018). The first quartile is considered positive (+), and others negative (-) as the LEO cluster is a global value chain requiring a high global competitive advantage. The model represents the interaction among four exogenous factors: Factor Input Conditions (FICs), Demand Conditions (DCs), The Context for Firm Strategy and Rivalry (CFSR), Related and Supporting Industries (RSIs), and Industry Cluster Concentration (ICC). These factors reinforce each other to aggregate an industry together in a region. Industry cluster or aggregation is an exciting phenomenon for governments worldwide to bring lucrative jobs to a region.

Factor Input Conditions (FICs)

FICs are factors required for production, including 1) land, 2) labor, 3) capital, 4) infrastructure, 5) natural resources, and 6) science and technology knowledge (Porter, 1998). Skilled labor is difficult to find, as indicated in labor skills and market indices (Schwab, 2018), and the overall infrastructure requires improvement. Human capital boosts innovation, particularly in clusters with more spinoffs (You et al., 2021). Under the THEOS-2 project, Thailand will gain about 22 custom satellite engineers and 1,000 remote sensing experts. In addition, Thai universities and colleges can produce about 2,040 graduates a year for the aerospace industry, but their main focus is on the aviation industry. Mahanakorn University of Technology exclusively provides an M.Eng program in Satellite Engineering. (National Institute of Development Administration, 2019). GISTDA expects to establish new training centers and programs to increase the skilled workforce. The attempt to develop the Eastern Economic Corridor (EEC) and Space Krenovation Park (SKP) equipped with AIT may improve the overall LEO competitiveness. Thailand is also excellent in its financial system for supporting new projects.

Demand Conditions (DCs)

DCs refer to “Sophisticated, demanding buyers pressure companies to meet high standards, provide a window into evolving customer needs, and prod companies into innovate and move to more advanced segments” (Porter, 1998, p. 327). DCs cover domestic and international demands if foreign countries can fulfill the demand of the Thai LEO cluster (Porter, 1990). Although ICT adoption, the downstream of LEO industries, could be more impressive, Thailand has a large market size and buyer sophistication. However, Thailand still has a more secondary product market when compared with Singapore (Schwab, 2018).

The Context for Firm Strategy and Rivalry (CFSR)

CFSR influences and regulates domestic competition. These factors include rules and regulations, social norms and incentives, tax systems, macroeconomic stability, and the political environment (Porter, 1998). The absence of domestic and international assembler companies is a serious concern of the LEO cluster as most Thai companies are part manufacturers. Thai innovation and investment agencies such as GISTDA and the Thailand Board of Investment (BOI) must attract world-class companies such as Airbus or Lockheed Martin to invest in Thailand significantly. Another key benefit of being a world-class player is the knowledge spillover to other regional actors. The government should organize the locations of agencies relating to aerospace and defense around the cluster with export promotion (Porter, 1998). However, Thai firms' business dynamics are excellent, implying that Thai companies and entrepreneurs can catch up with the LEO business trend.

Related and Supporting Industries (RSIs)

RSIs refer to "the local presence of capable specialized suppliers and related industries." (Porter, 1998, p. 328). National Institute of Development Administration (2019) showed that Thailand has 15,031 operating companies in the aerospace industry, including part and ground equipment. However, none of these companies are assemblers and sub-systems for the space industry. Porter (1998) recommended a cluster with high quality and quantity of RSIs and actor closeness in the cluster to access resources and collaboration. This idea has turned to science or industrial parks. The THEOS-2 project pushed Thai satellite part manufacturers to provide products and services to Surrey Satellite Technology Ltd (SSTL), such as Gravitech Thailand, Synergy Technology, Aeroworks, Senior Aerospace, and Lenso Aerospace. These companies and others have experience in automotive, electronics and other RSIs burned to gain experience in space products. Thailand has no LEO sub-system and module manufacturers, not to mention space vehicles.

Even though Thailand already has ground stations, ground station operators and equipment manufacturers must be involved. Space technology demands a workforce with advanced skills. Developing such a workforce benefits the space industry and extends its advantages to other high-tech sectors, as these skills are transferable across various industries.

Figure 10 shows the research model derived from Porter (1998). The research model posits that four exogenous factors influence industry cluster concentration, leading to economic growth through regional industry aggregation.

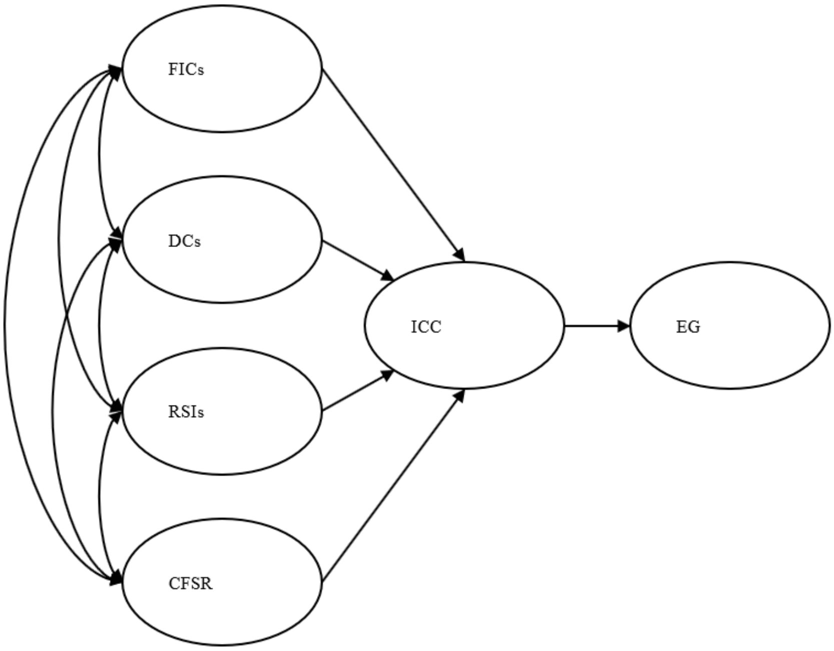

Figure 10: The Research Model

Industry Cluster Concentration (ICC)

ICC is a phenomenon in which firms operate in the same industry or RSIs in the same region. This phenomenon has occurred in many areas in the world, such as Silicon Valley (USA) for IT, Denver, Colorado (USA), and Toulouse (France) for aerospace and defense. The Thai aerospace and defense industries are clustered within the EEC, while the Thai space cluster is in SKP, a part of the EEC. FICs, DCs, RSIs, and CFSR should raise the region's ICC. EEC also promotes advanced industries, such as next-generation automotive, intelligent electronics, advanced agriculture, automation and robotics, aviation, logistics, digital, and defense, which could be customers or suppliers of the LEO industry.

Economic Growth (EG)

EG is the outcome construct. ICC influences EG because the concentration of firms leads to well-paid employment, household consumption of employees and investors, and import and export trade activities, which increases the Gross Domestic Product (GDP). Investing in space tech can fuel economic growth by creating new industries like satellite manufacturing and space tourism and improving existing sectors such as telecommunications, smart agriculture, and logistics. Acquiring knowledge and infrastructure through space tech development may attract foreign investors to Thailand to use resources.

The Role of Chance

Change events can disrupt an incumbent firm and create a new firm (Porter, 1990). Moore's Law states that the number of transistors in a microchip doubles yearly while the cost halves. The phenomenon has led to an increase in satellites, resolution and a decline in production cost and size. The cost of satellite production can be from 50,000 to several hundred million US Dollars. Additionally, the sharing economy has led to a smaller fee for a launcher. For instance, SpaceX launched a marketing campaign, “rocket rideshares,” bringing the cost down to about $1 million for a 200 kg satellite (SpaceX.com, 2021). For EO, the decline in the cost of a satellite means data explosion. A large satellite constellation results in a fast-revisit time. For instance, Planet Labs provides a 50-centimeter optical resolution with 12 daily revisits. Satellogic will possess more than 300 EO satellites. Black Sky Global has operated over 60 EO satellites (Denis et al., 2017). Landsat and Sentinel Series have provided free and open data.

Moreover, computer vision and deep-learning technologies have added value to satellite data as massive data are available to train, validate, and test ML algorithms. The advancement of sensors for multiple bands and SAR is essential for object classification and detection, leading to change, ship, airplane, and car detection. Big data and cloud computing technologies organize and process high volume, velocity, and variety of space data.

A large LEO constellation might disrupt fiber optics and fixed orbit satellites for the communication satellite. The LEO communication satellites take advantage of orbiting near Earth, resulting in lower latency. Starlink has launched a swarm of satellites in LEO. Also, 6G will be another game-changer the communication satellite and will open up the communication between aerospace and ground devices: IoT, aircraft, UAV, ground stations, mobile phones, household antennae, and satellites, which might result in remote healthcare, industrial automation, precision agriculture, autonomous vehicles, large intelligent surfaces, holographic teleportation, blockchain-based spectrum sharing, molecular communication, the Internet of Space Things, and the Internet of Nano-Things (Akyildiz et al., 2020; Zhang et al., 2019).

The Role of Government

Governments can attribute to a cluster's success or failure. Governments develop favorable conditions for firms in their areas, which can determine government decisions (Porter, 1990). The government can, for example, subsidize and issue new policies regarding capital markets and the space economy, step up industry standards, enhance sophisticated customer demands, and improve product development.

Space warfare is a government's concern, fueling the space race. When war machines connect to space devices such as satellites, they turn space into a battlefield. A nation with advantages of battlefields on space, air, surface, and sub-surface (i.e., underwater) is likely to win the war, and 6G will connect all devices in all four war domains (Zhang et al., 2019). The government has joined the space race, but if a war were to disrupt the nation that invented the low Earth orbit (LEO) companies and technologies, Thailand would be unable to access them, leaving the government without space warfare capabilities against the adversary nation (Intarussamee, 2020). Foreign companies manufactured most of Thailand's satellites, putting Thailand at a disadvantage in times of war against the country's manufacturing sector.

Interaction Effects

Interaction 1: FICs interact with RSIs. To serve the primary industries, the talent pool determines RSIs via skills, knowledge, and technology (Porter, 1990). Also, highly skilled labor, knowledge transfer, and specialized infrastructure in the primary industry can diffuse to the entire group of RSIs (Porter, 1990). In addition to skilled labor, infrastructure such as public research laboratories often used by the leading industry can also be used by the RSIs. Shared resources can be dynamic and transferable, benefiting the cluster community and knowledge spillover. RSIs form or incite factor input dynamics. These industries share common FICs with the leading industry, so they often push government agencies and educational institutions to invest in their favorable FICs (Porter, 1990; Suksa-Ngiam et al., 2023).

Interaction 2: FICs interact with DCs. International students and researchers can bring demands for the product to their home countries (Porter, 1990). The internal use of satellite imagery is from researchers in dominant satellite countries such as the US, creating international markets. On the other end, the appropriate level of DCs leads to investment in the education and infrastructure of the cluster. Advanced technology and infrastructure serve the needs of cluster's DCs (Porter, 1990). DCs drive public education, research, and development. Looking at Thailand's Aerospace and Defense Cluster, there is demand for commercial aircraft but little for LEO communication satellites.

Interaction 3: FICs interact with CFSR. FICs lead to a startup, spinoff, or new enterprise, shaping the incumbent's strategy, rivalry, and industry structure (Porter, 1990; Suksa-Ngiam et al., 2023). In the THEOS-2 project, the investment in customer engineers is the starting point for specialized engineers who may become entrepreneurs or work for enterprises. CFSR develops infrastructure, human resources, and knowledge for competition (Porter, 1990; Suksa-Ngiam et al., 2023).

Interaction 4: CFSR interacts with DCs. Intense competition drives innovation, improves quality, lowers prices, and expands consumer choices, enhancing domestic demands and benefiting businesses and consumers (Porter, 1990). When DCs are abundant and sophisticated, there is likely that world-class players will access the region (Porter, 1990). For example, Airbus, a world-class player, planned to enter Thailand as an aircraft maintenance hub because Airbus has a strong presence in Thailand, serving as an important customer base for its commercial aircraft, defence, space and helicopter product lines. The company has a Flight Operations Services Centre and a regional helicopter maintenance, repair and overhaul (MRO) facility in Thailand (airbus.com, 2021). Also, world-class players can benefit from early technology adoption from abundant and sophisticated technology users. If the DCs are high, bringing world-class players to Thailand is easier.

Interaction 5: CFSR interacts with RSIs. Incumbents can formulate partnerships or establish subsidiaries as specialized suppliers and related companies and industries (Porter, 1990), known as backward vertical integration. On the other hand, new rivals can come from RSIs (Porter, 1990). Suppliers can move forward to the primary industry.

Interaction 6: DCs interact with RSIs. Extensive and sophisticated home demands create a market for supplier industries. Industries producing excellent supplies and complementary products expand the international market of the nation's products by transferring their reputations (Porter, 1990).

Recommendations

Investing in space technology in Thailand can drive economic growth by fostering new industries like satellite manufacturing and space tourism while also enhancing existing sectors such as telecommunications and agriculture. Integrating space-derived technologies boosts efficiency and competitiveness. Additionally, advancements attract foreign investors, showcasing innovation capabilities and creating opportunities for collaboration with international space agencies. This strategic investment diversifies industries, creates jobs, and strengthens Thailand's global competitiveness, leading to long-term economic prosperity (Romer, 1994; Solow, 1957).

Developing the LEO industry cluster in Thailand drives technological innovation across industries. Space innovations like satellites have revolutionized telecommunications, enabling global communication networks and navigation systems. In agriculture, space-derived data aids crop monitoring and resource management, leading to practices like precision agriculture (Mbugua & Suksa-ngiam, 2018). Environmental science benefits from space observations, informing climate change, deforestation, and pollution research. Technologies developed for space missions, such as remote sensing and data analysis tools, also find applications in studying and managing Earth's ecosystems. Moreover, space missions spur advancements in medical technology to address astronaut health, which translates to benefits like remote monitoring and telemedicine in healthcare (Scarpa et al., 2023). Overall, space technology catalyzes innovation, with its impacts extending beyond space exploration to benefit industries such as telecommunications, agriculture, environmental science, and healthcare, driving progress and societal advancement.

Thailand has a small GDP compared with space giants (e.g., China, the EU, Japan, India, Russia, and the US). The Thai government should spend public money wisely. Moreover, where Thailand should go in space is the central argument of the space public policy debate, and commercial benefits must be answered from such a policy.

Table 1 shows the policy recommendation prioritization based on prior recommendations required and the number of factors supported.

Table 1: Policy Recommendation Prioritization

Recommendation	Recommendations Required	FICs	DCs	CFSR	RSIs
1	No	■			
2	1		■	■	
3	1,2			■	
4	1, 2, and 3	■			■
5	1, 2, 3, and 4	■	■		
6	3	■			
7	2 and 3		■		
8	2 and 3		■		

Porter's (1990, 1998) Diamond Model provides a framework for analyzing the competitiveness of nations and can be used to prioritize recommendations for investing in space technology in Thailand. Recommendations that enhance the four-factor conditions. By aligning recommendations with these factors, policymakers can strengthen Thailand's competitive advantage in the space technology sector and drive economic growth and innovation. Additionally, policymakers should consider the interconnectedness of these factors and how investments in one area can positively influence others. Also, some recommendations are conditions of subsequent recommendations.

The following initial policies must proceed accordingly.

Recommendation 1: Space infrastructure supports space innovation. Space infrastructure also serves upstream and downstream industries, such as digital, defense, aviation, manufacturing, and government. Space infrastructure covers 1.1) Physical infrastructure, 1.2) Information infrastructure, 1.3) Scientific laboratory, and 1.4) Laws and regulations.

Recommendation 1.1: The government should invest in physical space infrastructure as the base of space enterprises or startups (satellites, launch systems, assembly integration, and testing (AIT) facilities). A launch site is essential for both commercial and military purposes. The government can own a launch site but allows private entities to use it. GISTDA and DTI (Defence Technology Institute) are collaborating with a foreign space agency to study Thailand's potential to establish a spaceport and launch system for LEO.

Recommendation 1.2: Information infrastructure is essential for the space industry, supporting and relating industries, and customer industries. Satellites provide data for artificial intelligence and machine learning and serve as the core technology of self-driving vehicles.

Recommendation 1.3: Education, scientific research, and engineering require scientific laboratories. Private companies can also share laboratories with the public sector.

Recommendation 1.4: Laws and regulations govern Thailand's space economy. By having a supportive rather than regulatory-oriented space law design paradigm, private companies can efficiently operate in Thailand; Otherwise, they may operate in other countries.

Recommendation 1 aims to strengthen FICs. The government must invest in space infrastructure the public and private sectors share. Recommendation 1 also serves Recommendation 2.

Recommendation 2: Increase the presence of national LEO Companies (state enterprises or hybrid enterprises). Cleary Thailand has no commercial LEO companies such as Airbus Space and Defense, Planet Labs, Starlink, OneWeb, and Amazon Kuiper. Thus, Thailand does not have forceful local space competition (CFSR). The government has two ways of making this happen. A strategy is to give financial incentives to foreign companies to relocate to Thailand. This strategy is complicated because the LEO companies interfere with the defense industry under the international market economic model (Weinzierl, 2018; Weinzierl & Sarang, 2021). The Thai government needs push-and-pull strategies to establish national space companies (Bonvillian, 2021; Bonvillian et al., 2019). The alternative is to build new enterprises, which (Intarussamee, 2020) called "Space Public Company" (p.90), or encourage existing ones, such as National Telecom Public Company Limited (NT), to pursue an LEO communication satellite constellation. A joint venture between government agencies (e.g., GISTDA and DTI) and private companies (e.g., Thaicom) could also be a state enterprise or startup to make satellites and serve civil and defense demands. Singapore Technologies Engineering Ltd is an example. Also, the government should encourage the backward and forward integration of the space supply chain by giving incentives for upstream and downstream industries to operate in the LEO space cluster. Large space enterprises can serve as the customers and investors of space startups. This recommendation serves Recommendation 3. This strategy stimulates CFSR and DCs.

Recommendation 3: While a space state or hybrid enterprise is the first step, Thailand requires private LEO startups to excel in the global value chain. Instead of direct investment in ventures, the government can support the research and development (R&D) of an LEO venture by funding a startup such as the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs in the US (sbir.gov, 2014). Thailand has recently initiated this through the National Innovation Agency (NIA)'s Space Economy Lifting Off 2021 and recently in 2023. However, this project requires ongoing support and maintenance to ensure its continued success. NIA also supports other industries that could be a part of the LEO downstream (e.g., healthcare) through the Medical Innovation District. In addition, the Digital Economy Promotion Agency (DEPA) could fund startups relating to space and IT domains. A startup can be an LEO assembler, sub-system, or part manufacturer. This strategy stimulates CFSR.

Recommendation 4: The government must allow foreign scientists, engineers, consultants, and managers to work for LEO enterprises and RSIs in Thailand. Thailand's labor market disadvantages home-grown scientists and engineers, who face quality and quantity concerns. Thus, Thailand must issue a new immigration policy to attract foreign-born scientists and engineers and strengthen its innovation capability, reinforcing FICs. Space technology demands a skilled workforce whose training benefits other high-tech sectors. Investing in space industry training supports its growth and cultivates innovative talent for broad economic development. The government should subsidize space education, including LEO technologies. Graduates must have strong science, technology, engineering, and mathematics (STEM) skills and English proficiency. These educational degrees must be supported to secure the competitive orbit advantage and strengthen FICs. Collaborations between industries and academia drive advancements, fueling economic growth and knowledge dissemination. The government must establish a world-class LEO research institute to produce world-class engineers and scientists. This strategy promotes FICs and RSIs. Human resources require infrastructure (Recommendation 1) to train students, researchers, scientists, and space entrepreneurs, as in Recommendations 2 and 3.

Recommendation 5: This addresses the problem of innovation capability. The government must set an agenda for research and development in this organization. The Defense Advanced Research Projects Agency (DARPA) has set target innovation and worked backward to basic research (Bonvillian et al., 2019). The government must transfer innovation to private partners. This strategy will reinforce both DCs and FICs. This recommendation requires Recommendations 1 - 4 as the basis. The role of the government is to invest in R&D, which the private sector cannot invest in.

Recommendation 6: The government should incentivize Thai venture capitalists (VCs) to invest in Thai LEO startups. Optionally, the government can establish funds for VCs to invest in startups. Although Thailand has a sound financial system, the government should encourage VCs to invest in startups by providing tax incentives. In addition, the government may consider the government-backed VCs that fund strategic space startups, strengthening FICs.

Recommendation 7: The government must change its procurement approach to stimulate domestic DCs. Defense industry use is the first and foremost priority in securing orbit. The procurement must allow Thai LEO companies to secure government contracts as NASA has developed its Orbital Transportation Services Program (COTS) and Commercial Crew Development Program (CCDev) (Mazzucato & Robinson, 2018). The Thai government must ensure that space technology made in Thailand must win a government contract first (Bonvillian, 2021; Bonvillian et al., 2019). Without Thai technology, the government can open foreign technology for contract bidding (Intarussamee, 2020). The US government has also used this strategy to ensure that US space and defense technology companies gain government contracts. Once space companies gain government contracts, investors and private customers, both domestic and foreign, can have confidence in space companies. Therefore, Thai government budgeting and military procurement policies lead to the success of Thai space innovations. This strategy promotes DCs. However, this strategy should be after Thailand has space enterprises (Recommendations 2 and 3).

Recommendation 8: The government should expand domestic demand to Southeast Asia and primary space nations to economic communities. Space technology needs international partnerships to provide access to resources and markets. By partnering with other nations to create demands for LEO and RSIs, DCs will become more sophisticated. The government must build diplomatic and trade relationships with foreign nations. For example, in another industry, South Korea and Brazil could co-develop and co-produce fighter jets with the assistance of foreign partners (Lee & Yoon, 2015). The government can employ bilateral or multilateral relationships with partner governments (Intarussamee, 2020). This recommendation promotes DCs. Like Recommendation 7, Recommendation 8 can happen if Thailand has space enterprises (Recommendations 2 and 3).

Theoretical implications

Applying Porter's (1990, 1998) Diamond Model to the space industry cluster reveals significant theoretical implications for understanding its competitiveness and driving factors:

The LEO industry cluster, particularly in Low Earth Orbit (LEO), relies on skilled labor, advanced technology, infrastructure, and financial capital. The cluster includes robust educational systems and research institutions to support a skilled workforce, technological innovation, and access to specialized materials and resources (Porter, 1990, 1998). Strong demand for space-related products and services, driven by LEO satellite communications and Earth observation data, fuels innovation within the cluster. Government policies and initiatives, such as space exploration missions and satellite procurement programs, further shape demand dynamics and industry growth.

Complementary industries, such as aerospace manufacturing, electronics, and telecommunications, strengthen the LEO industry cluster by fostering collaboration and knowledge sharing, ultimately enhancing the overall value chain. Strategic decisions and competitive dynamics among firms within the cluster are crucial, with factors like rivalry levels, dominant players, collaboration agreements, and regulatory environments impacting performance. Promoting healthy competition, fostering collaboration, and creating supportive regulatory frameworks are essential for enhancing competitiveness (Porter, 1990, 1998).

The LEO industry cluster flourishes when certain key factors create a favorable industry aggregation and innovation environment. By addressing weaknesses and leveraging strengths in relevant areas of Thailand, industry clusters can enhance their competitiveness and contribute to the country's long-term economic prosperity. Job creation, high salaries, consumption, investment, and trade with other regions determine the cluster's growth.

Exploring theoretical developments in industry clusters, particularly in emerging sectors like the space industry, can lead to innovation. Critical focus areas include explaining how industry clusters can address new technology challenges such as AI, blockchain, and quantum computing, researching sustainability concerns on Earth and in space (such as space debris), examining digital transformation, and studying global value chains (Lin, 2024). LEO technology advancements impact interdisciplinary fields, driving progress in diverse sectors such as agriculture, transportation, security, and medicine, with implications for space and terrestrial applications. Understanding LEO cluster resilience and promoting inclusive growth are crucial areas. These perspectives are needed to address evolving technology and economic and social challenges. These developments contribute to a deeper understanding of cluster dynamics, informing public policymaking in emerging technology-economic sectors.

Future research

The paper draws upon Porter's theories of competitive advantage and industry analysis (1990, 1998), emphasizing the need to quantify relationships between constructs and develop strong measures for future research. Future research must verify the strength of each relationship numerically and develop the measurement of each construct. Employing a mixed-methods research approach in this study enriches the comprehensiveness of its findings and can also provide valid relationships among constructs. This research gains depth and breadth by incorporating qualitative and quantitative data collection and analysis techniques, contributing to a more nuanced understanding of the subject matter. These should be done together with economic feasibility analysis, including the cost-benefit of each recommendation. We can then be more confident in the recommendations given to the government. Also, action research and design science can develop policies based on an adequate theoretical model.

Global industry clusters, studied through the Global Cluster Networks theory, reveal an increase in China's auto industry network scale and density. Intra-industry division affects R&D and buyer-supplier cooperation differently on varying spatial scales (Lin, 2024). Thus, building an understanding of an industry cluster can be done at a dynamic interplay between national and international levels.

Conclusion

Technology is a driving force behind economic growth, and Thailand needs policies related to science, technology, and innovation (STI) to enhance its competitiveness and economy. The space economy is to reach $1 trillion by 2040, and the new space economy is a critical factor in national economic development. The low Earth orbit (LEO) technology drives the economy. Advancements in LEO technology drive interdisciplinary breakthroughs in physics, engineering, computer science, and beyond. From environmental monitoring to medical research, these innovations impact diverse sectors, fostering progress in agriculture, transportation, security, and medicine, with implications for space and terrestrial applications. This paper aims to provide initial policy recommendations to drive Thailand's LEO economy and establish a conceptual framework for theoretical testing. The study initially suggests that the Thai government should develop its LEO cluster with preliminary recommendations and suggests a conceptual model based on the Diamond Model for future theoretical testing. LEO technology will be the next major technological shift. Therefore, Thailand must implement STI policies to transition from a middle-income trap to an innovation-driven country.

References

Airbus.com. (2021, July 21). Airbus in Thailand. Retrieved April 1, 2024, from https://www.airbus.com/en/our-worldwide-presence/airbus-in-asia-pacific/airbus-in-thailand

Akyildiz, I. F., Kak, A., & Nie, S. (2020). 6G and beyond: The future of wireless communications systems. IEEE Access, 8, 133995-134030. https://doi.org/10.1109/ACCESS.2020.3010896

Andås, H. E. (2020). Emerging technology trends for defense and security. In 20/01050. Norwegian Defence Research Establishment (FFI). https://ffi-publikasjoner.archive.knowledgearc.net//handle/20.500.12242/2704

Bergman, E., & Feser, E. (2020). Industrial and Regional Clusters: Concepts and Comparative Applications (2nd ed.). Regional Research Institute, West Virginia University. https://researchrepository.wvu.edu/rri-web-book/5

Bonvillian, W. B. (2021). *Policy for Science, Technology, and Innovation.* https://learning.edx.org/course/course-v1:MITx+STS.081x+3T2020/home

Bonvillian, W. B., Van Atta, R., & Windham, P. (2019). *The DARPA Model for Transformative technologies perspectives on the US: Defense Advanced Research Projects Agency.* OpenBook Publishers. https://doi.org/10.11647/OBP.0184

Centenaro, M., Granelli, F., & Vangelista, L. (2021). A survey on technologies, standards and open challenges in satellite IoT. *IEEE Communications Surveys & Tutorials, 23*(3). https://ieeexplore.ieee.org/abstract/document/9442378

Clustermapping.us. (2014). *Aerospace vehicles and defense.* http://www.clustermapping.us/cluster/aerospace_vehicles_and_defense#related-clusters

Denis, G., Claverie, A., Pasco, X., Darnis, J.-P., de Maupeou, B., Lafaye, M., & Morel, E. (2017). Towards disruptions in Earth observation? New earth observation systems and markets evolution: Possible scenarios and impacts. *Acta Astronautica, 137,* 415-433. https://doi.org/10.1016/j.actaastro.2017.04.034

Falco, G., & AIAA Member. (2018). *The vacuum of space cybersecurity.* https://arc.aiaa.org/doi/abs/10.2514/6.2018-5275

Garrity, J., & Husar, A. (2021). Digital connectivity and low earth orbit satellite constellations: Opportunities for Asia and the Pacific (Issue 76). *Asian Development Bank.* Retrieved April 23, 2021, from https://www.adb.org/publications/digital-connectivity-low-earth-orbit-satellite-opportunities

Geo-Informatics and Space Technology Development Agency. (2021). *Thailand New Space Directory 2021: Space Industry.* Geo-Informatics and Space Technology Development Agency.

Geo-Informatics and Space Technology Development Agency. (2023). *The Draft of National Space Master Plan (2023-2037).* Geo-Informatics and Space Technology Development Agency.

Huang, H., Guo, S., Liang, W., & Zomaya, A. (2019). Green Data-Collection from Geo-Distributed IoT Networks Through Low-Earth-Orbit Satellites. 3, 806-816. https://doi.org/10.1109/TGCN.2019.2909140

Intarussamee, P. (2020). The development of space affairs supporting the national strategy. *Nopphayathipataya Journal, 4*(2).

Johnston, S. (2013). Technical Introduction to Satellite EO. In Evidence from Earth Observation Satellites (pp. 9–42). Brill Nijhoff. https://doi.org/10.1163/9789004234031_004

Ketels, C. H. M. (2003). *Thailand's competitiveness: Key issues in five clusters.* Retrieved April 21, 2021, from https://www.researchgate.net/publication/242784795_Thailand's_Competitiveness_Key_Issues_in_Five_Clusters

Labbé, P., Ghanmi, A., & Abdelazez, M. (2022). *Current and Future Hypersonic Threats, Scenarios and Defence Technologies for the Security of Canada.* Defense Research and Development Canada.

Lee, J. J., & Yoon, H. (2015). A comparative study of technological learning and organizational capability development in complex products systems: Distinctive paths of three latecomers in military aircraft industry. Research Policy, 44(7), 1296-1313. https://doi.org/10.1016/j.respol.2015.03.007

Lin, B. (2024). The Spatial-Temporal Evolution of China's Automobile Manufacturing Cluster Network and Its Influencing Factors. Journal of the Knowledge Economy. https://doi.org/10.1007/s13132-024-01735-0

Mbugua, J. K., & Suksa-ngiam, W. (2018). Predicting suitable areas for growing cassava using remote sensing and machine learning techniques: A study in Nakhon-Phanom Thailand. Issues in Informing Science and Information Technology, 15, 043-056. https://doi.org/10.28945/4024

Mann, A. (2021, May 29). *Starlink: SpaceX's satellite internet project.* Retrieved September 9, 2021, from https://www.space.com/spacex-starlink-satellites.html

Mazzucato, M., & Robinson, D. K. R. (2018). Co-creating and directing innovation ecosystems? NASA's changing approach to public-private partnerships in low-earth orbit. Technological Forecasting and Social Change, 136, 166-177. https://doi.org/10.1016/j.techfore.2017.03.034

Morgan Stanley. (2020). *Space: Investing in the final frontier. Morgan Stanley.* Retrieved July 12, 2020, from https://www.morganstanley.com/ideas/investing-in-space

National Institute of Development Administration. (2019). โครงการจ้างเหมาบริการวิชาการเพื่อศึกษาอุตสาหกรรมอวกาศในประเทศไทย [Academic Service Contracting Project to Study the Space Industry in Thailand]. National Institute of Development Administration.

Nair, K. K. (2006). *Space: The Frontiers of Modern Defence.* KnowledgeWorld.

Porter, M. E. (1990). *The Competitive Advantage of Nations.* The Free Press.

Porter, M. E. (1998). *On competition.* Harvard Business School Publishing.

Romer, P. M. (1994). The origins of endogenous growth. *Journal of Economic Perspectives, 8*(1), 3-22.

Scarpa, J., Parazynski, S., & Strangman, G. (2023). Space exploration as a catalyst for medical innovations. Frontiers in Medicine, 10, 1226531. https://doi.org/10.3389/fmed.2023.1226531

Schwab, K. (2018). *The Global Competitiveness Report 2018. World Economic Forum.* Retrieved May 3, 2021, from https://www.weforum.org/reports/the-global-competitveness-report-2018

Sbir.gov. (2014). The Small Business Innovation Research (SBIR) & Small Business Technology Transfer (STTR) Program Interagency Policy Committee Report to Congress. Environmental Protection Agency. https://www.sbir.gov/sites/default/files/2_commercialization-ipc_report_to_congress.pdf

Solow, R. M. (1957). Technical change and the aggregate production function. *The Review of Economics and Statistics, 39*(3), 312-320.

SpaceX.com. (2021). *SpaceX satellite rideshare.* Retrieved May 18, 2021, from https://rideshare.spacex.com/search?orbitClassification=1&launchDate=2021-09--18&payloadMass=200

Suksa-Ngiam, W., Vanijja, V., Watanapa, B., & Nithirochananont, U. (2023). Digital space economic transformation design: An innovation ecosystem approach. Proceedings of the 13th International Conference on Advances in Information Technology, 1-10. https://doi.org/10.1145/3628454.3630589

Tugnoli, M., Sarret, M., & Aliberti, M. (2019). *European Access to Space: Business and Policy Perspectives on Micro Launchers.* Springer International Publishing. https://doi.org/10.1007/978-3-319-78960-6

Weeden, B. (2012). The space review: The economics of space sustainability. Retrieved July 28, 2021, from https://www.thespacereview.com/article/2093/1

Weinzierl, M. (2018). Space, the final economic frontier. *Journal of Economic Perspectives, 32*(2), 173-192. https://doi.org/10.1257/jep.32.2.173

Weinzierl, M., & Sarang, M. (2021, February 12). The commercial space age is here. Harvard Business Review. https://hbr.org/2021/02/the-commercial-space-age-is-here

You, S., Zhou, K. Z., & Jia, L. (2021). How does human capital foster product innovation? The contingent roles of industry cluster features. *Journal of Business Research, 130,* 335-347. https://doi.org/10.1016/j.jbusres.2021.03.046

Zhang, Z., Xiao, Y., Ma, Z., Xiao, M., Ding, Z., Lei, X., Karagiannidis, G. K., & Fan, P. (2019). G wireless networks: Vision, requirements, architecture, and key technologies. IEEE Vehicular Technology Magazine, 14(3), 28–41. https://doi.org/10.1109/MVT.2019.2921208