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SWOT-AHP analysis of the Korean satellite and space industry: Strategy recommendations for development

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ABSTRACT

The global satellite industry is growing in the private market with the advent of SpaceX Corp., Planet Labs Corp., and so forth. Following this trend, the Korean government established the National Space Commission to construct a space development plan that encourages private companies' participation. Korea has the potential to create various satellite services based on its information technology and semiconductor industries. Thus, this study aims to present strategies to accelerate the growth of the satellite industry by considering various internal and external factors, such as the limitations and strengths of the Korean space and satellite industry. This study employs the SWOT-AHP method, to measure these items factors priorities' and suggest in-depth strategies. The SWOT matrix is constructed based on prior research. Then, an AHP survey of 32 experts is conducted, and strength-threat and strength-opportunity strategies are developed using the top eight relatively important items. The analysis finds that opportunity items have high priorities. Thus, a strategy is devised to meet demand in the public sector and vitalize private businesses. Lastly, topics are collected using latent Dirichlet allocation topic modeling to identify the media's perspective, which we find is similar to the opinions of the experts chosen for this study.

1. Introduction

Since the space race began accelerating in the 1950s, Russia and the U.S. monopolized the space industry (Devezas et al., 2012). Although space projects were initially implemented in only a few countries, however, the global industry is now highly competitive because it is perceived as a "blue ocean" in which projects generate high value despite entailing heavy costs (Yang, 2012). According to the Second Global Plan for Satellite Information Utilization, 28 countries had invested in space development in 1996, but this number increased to 70 by 2016, deepening the competition. Moreover, this competition has been intensifying since 2017 owing to the resumption of U.S. defense space projects, an economic recovery in Russia, and increased investments by emerging countries.

The satellite business accounts for the largest share of the space industry. Sales in the satellite industry have been increasing annually; in fact, global satellite industry sales have more than doubled over the last decade (Yang et al., 2018). Since Planet Labs started to operate cluster satellites and provide various services in 2014, interest in the utilization of cube satellites has increased. As a result, many governments and private companies have begun to operate small satellites, and 8588 cube satellites are expected to be launched in the ten years after 2019 (Hwang et al., 2020). Using multiple small satellite groups rather than one large satellite helps to improve time resolution and ground coverage (Sandau, 2010).

As the number of satellites increases, the market for satellite information is also expanding. According to the 3rd Basic Plan for Space Development, announced by the Korean Aerospace Research Institute (KARI), the size of the satellite information market is expected to grow from $2722 million in 2015 to $4637 million in 2025. As the market grows, many private companies are entering. Orbital Insight Corp. uses satellite images to analyze oil tank storage and provide crude oil price forecasting services. SpaceKnow Corp. provides satellite manufacturing index services by observing Chinese production facilities (Lee et al., 2019).

In addition, private companies' participation is expanding not only in the satellite information market but also in the projectile and telecommunication sectors. SpaceX is working on a project called "Starlink" that aims to build a global internet network and has developed a projectile production and operation system for space exploration. Amazon

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is also trying to build a global internet network using small satellites within a project called "Kuiper." As these cases show, the growth in private-led satellite service development is becoming a trend in the satellite industry (Kim, 2018).

Given these trends in the global satellite industry, South Korea has also worked to establish itself as a space power by building a space rocket (KITSAT-1), a science and technology satellite (STSAT), a multipurpose satellite (KOMPSAT), and a celestial satellite (COMEASAT). However, Korea is still not a technologically developed country because advanced nations (e.g., the U.S., Russia, and Japan) are reluctant to transfer technologies (Yang, 2012). Thus, Korea established its National Space Commission and announced the 3rd Space Development Promotion Plan and the 2nd Satellite Information Utilization Comprehensive Plan. Based on these plans, Korea is implementing policies to reduce technological gaps with developed countries and activate private businesses. For example, the multipurpose satellite Arirang 3A has a private participation rate of 46 percent, whereas that of Arirang 1 was 20 percent.

However, Korea's satellite industry has less investment, less manpower, and fewer activities relative to the satellite industries in developed countries. In 2019, KARI had 967 employees, fewer than the corresponding agencies in the U.S. (17,373), Japan (1520), and Europe (2342) have. In the same year, none of the 114 space activities worldwide took place in South Korea. South Korea's space development budget was 803.7 billion won in 2016 but decreased to 644.9 billion won in 2018. Furthermore, the ratio of Korea's space development budget to its GDP is 0.032%, which is small compared to those of the U.S. (0.236%), Russia (0.175%), and China (0.062%) (KASP, 2019). Thus, Korea's industry must use its resources, such as its budget and manpower, more efficiently.

Moreover, Korea's private space companies are not competitive. According to a Korean government report about the Korean space industry (KASP, 2019), the $3.3 billion in sales by Korean private space companies is equivalent to 1.25% of the world's total. The number of workers in the Korean space industry has been decreasing since 2017. In addition, 78.1% of private companies have fewer than 100 employees, and 64% of them have low sales.

However, Korea was the first country to commercialize 5 G communication technology and has potential in information technology fields, such as the semiconductor and battery industries. Korea's strength in information technology gives it the potential to create a variety of satellite services.

Given these strengths, weaknesses, and external factors, it is necessary to activate private business in Korea's space and satellite industry, which is one of the main goals of the Korean government's current policy. In this regard, this study aims to present strategies to overcome the limitations of the Korean space and satellite industry and accelerate the development of the satellite industry. To achieve this goal, this study uses strengths, weaknesses, opportunities, and threats (SWOT) analysis to identify the major factors in Korea's satellite industry and private business. Additionally, this study combines the SWOT analysis with the analytical hierarchy process (AHP) to evaluate factors' relative importance.

The rest of this paper is organized as follows. Section 2 presents relevant prior research, and the study methodology is introduced in Section 3. The results are presented in Section 4, and the conclusion is presented along with a discussion in Section 5.

2. Literature review

2.1. SWOT analysis

SWOT analysis is a type of contextual analysis used to present strategies based on an evaluation of internal capabilities (i.e., strategies, strengths, and weaknesses) together with external factors (i.e., opportunities and threats) (Noh, 2006). Internal and external factors are crucial for mapping future business strategies, and SWOT analysis enables the framing of basic but relevant strategies. This type of analysis has been used to set directions and make strategic decisions in many industries (D'Adamo et al., 2020; Rauch et al., 2015; Wang et al., 2020), including the satellite industry. For example, Carayannis and Alexander (2001) conducted a SWOT analysis for the broadband satellite industry to propose strategies for introducing next-generation satellite technologies to the market. Additionally, Dede and Akçay (2016) developed a strategy for achieving Turkey's space vision by building a SWOT matrix based on a survey. Chen and Li (2020) used SWOT analysis to make suggestions regarding China's development plans in the field of satellite navigation. SWOT analysis has been used to present strategies for some time and continues to be used today.

2.2. AHP

The AHP method is a theory for prioritizing the factors and layers that belong to a hierarchy that is distinguished by common criteria or attributes (Saaty, 1994). It uses pairwise comparisons to rank the relative importance of alternative options in a certain order (Saaty, 2008), and it can be applied to a wide range of problems, from simple personal choices to complex, capital-intensive decisions. This method is widely utilized for decision making owing to its simplicity, clarity, ease of use, and general theoretical purpose. Moreover, research on its theoretical structure is being actively conducted (Song et al., 2010). AHP analysis has been used in models to assess risk factors in the satellite assembly process (Tian and Yan, 2013) and to assess the security risk of satellite constellations (Yulong et al., 2008).

Moreover, the AHP method has been used in combination with other analytical methods. For example, a study of landslide risk zones combined logistic regression and AHP techniques (Lee et al., 2006), and another study combined AHP and fuzzy analytics to calculate the relative importance of industrial sectors under a national free trade agreement (FTA) (Mo and Kim, 2012).

2.3. SWOT-AHP

SWOT analysis enables the framing of basic but relevant strategies. However, its ability to reflect the importance of each factor in decision making is limited (Kurttila et al., 2000), as these factors are manifested in the generality and brevity of the SWOT factor characteristics. According to Hill and Westbrook (1997), only three of twenty companies studied used SWOT analysis to formulate their strategies.

However, when SWOT is coupled with AHP, the importance of each factor in decision making can be quantitatively estimated (Song, 2007). Kurttila et al. (2000) described SWOT-AHP analysis in four steps. In step one, the external and internal factors are identified and used for SWOT analysis. The number of factors within a SWOT group should not exceed ten. In step two, all of the SWOT groups are prioritized by pairing their components. In step three, relative comparisons are made, and then the weights are calculated. Finally, a consistency index is estimated to check whether respondents' answers are arbitrary.

SWOT-AHP techniques have been used in a variety of areas in many countries, including in manufacturing companies' decision making (Görener et al., 2012), e-government strategy prioritization (Kahraman et al., 2008), electric and electronic industry analysis (Şeker and Özgürler, 2012), and tourism revival strategy planning (Wickramasinghe and Takano, 2009). SWOT-AHP techniques have also been used in satellite-related studies, including a study of the establishment of a Chinese satellite navigation system strategy (Du, 2018) and an analysis of the prospects and challenges of geographic information systems in developing countries (Taleai et al., 2009). However, no global SWOT-AHP study directly related to the satellite and space industry has been conducted. In Korea, Park and Park (2015) used the SWOT-AHP method to enhance the image of urban tourism in Gwangju, and Son (2011) developed a strategy for developing Gwangyang Port. This

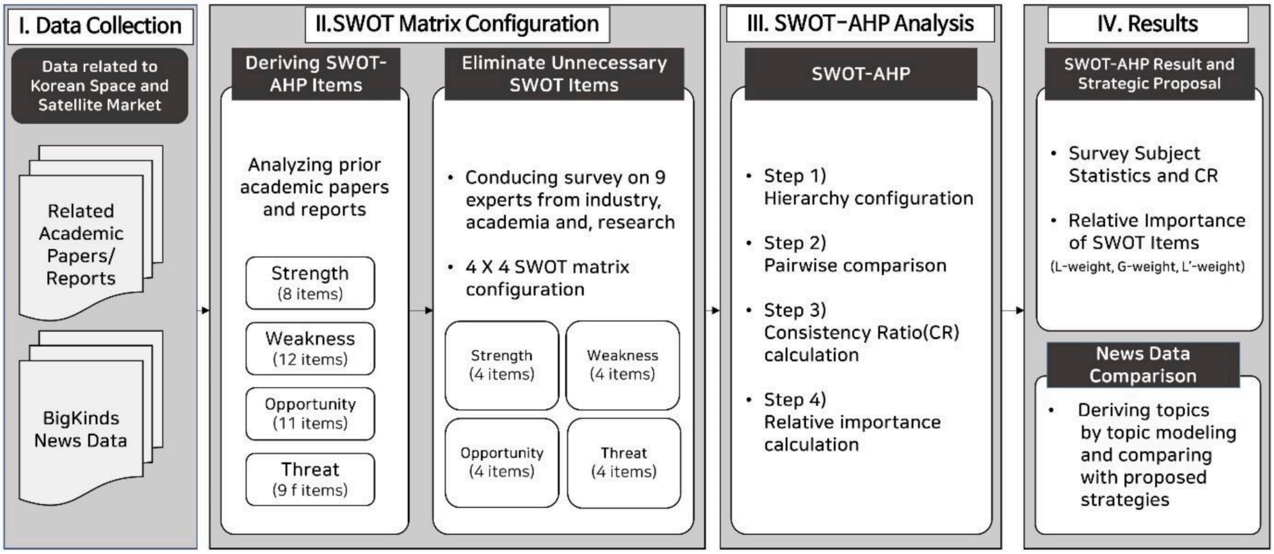

Fig. 1. Research procedure.

method has also been used to establish strategies for developing specific industries, such as the air logistics industry (Kim and Chung, 2012), infrastructure for the hydrogen energy industry (Han et al., 2016), the restaurant industry (including franchise competitiveness) (Choi and Lee, 2019), and social commerce (Choi and Kim, 2014). Thus, research on the satellite and space industry in Korea is lacking.

2.4. *Prior studies on development strategies for the satellite and space industry*

Lim and Ahn (2013) analyzed current and future trends in satellite synthetic aperture radar (SAR) technology through SWOT analysis to provide an understanding of its development trends. They analyzed the strengths and weaknesses of SAR technologies, discussed opportunities and threats facing the technological environment, and made recommendations regarding the direction of innovation in research and development (R&D), industrial policies, and research planning and management. Kim et al. (2015) studied satellite payloads by analyzing the current state of satellite industrialization and presenting a vision for the future. They flagged as a weakness of Korea's domestic industry that only three or four of the one hundred space-related companies in the industry are radio payload companies with actual development capability. They suggested that the links among industry, academia, research, and government are important to address these weaknesses.

Choo (2013) presented a development strategy for the aerospace industry by analyzing internal and external crises in Korea. The country faced challenges in fostering its space industry owing to a small domestic market and a high percentage of investment in defense costs. Choo (2013) proposed a strategy to achieve export-oriented industrial development by building core technologies that foster R&D industries. Hong and Ahn (2015) presented strategies for entering the space launch service market to develop Korea's space launch vehicle industry. They derived three key trends in the global space launch service sector: increasing demand for large high-performance space launch vehicles, an increasing number of low-cost space launch vehicles, and an increasing number of dual/multi-launch vehicles. They used binary analysis to propose strategies to address these trends. Ahn et al. (2018) presented the past and present states of the aerospace technology industry and analyzed the emergence of a new space industry ecosystem beyond the existing space industry structure and its effects. They presented strategies for successful entry into this newly emerging space industry ecosystem with respect to the future, growth, and convergence.

Landoni and Ogilvie (2019) analyzed the development of the space industry through a comparative case study of the aerospace industries in France, Italy, and the United Kingdom. By analyzing each country's development process in time order, they developed common strategies for the space industry's development, such as technological innovation, privatization, and the integration of the space agencies. Cobb (2011) conducted a study using the General Social Survey to analyze the public nature of U.S. space policy based on age, party supported, education level, social status, and gender. The study showed that the proponents of space activity tend to be younger, Republican, and male and have higher education levels and socioeconomic statuses. However, because the proportion of the U.S. population with these characteristics is small, the study found that U.S. space policy needs a strategy to enhance its publicness.

Additional prior studies about internal and external strategic items in the satellite and space industry are described in Section 3.2.

3. Research method

3.1. *Research procedure and methodology*

The purpose of this study is to increase the Korean space and satellite industry's strengths and overcome its limitations and to present strategies for accelerating the satellite industry's development. SWOT-AHP analysis is a method designed to assign weights to SWOT items and factors, allowing decision makers to analyze a given situation more precisely and in more detail (Kurttila et al., 2000). Thus, this study adopts the SWOT-AHP analysis method, which can consider experts' opinions and present strategies based on internal and external factors.

The study procedure is shown in Fig. 1. First, the study analyzes prior research (i.e., academic papers and reports) on the domestic satellite industry to derive items within the SWOT factors (Section 3.2). A group of experts from industry, academia, and research performed an assessment in which relatively low-priority items are eliminated to formulate a SWOT-AHP analysis model (Section 3.3). Based on the selected items, an AHP survey is conducted to measure each item's relative importance, and SWOT strategies are derived using the survey results (Section 3.4). Additionally, news data related to the domestic satellite industry are collected from *Big Kinds*, a Korean news data platform, and topic modeling is conducted to compare the identified topics with the results of the SWOT-AHP analysis (Section 3.5). The results obtained from this research process are presented in Section 4.

Table 1
SWOT factors for the Korean satellite and space industry.

SWOT	Description	Reference
Strength (S)	IS1-Accumulated know-how of professional research institutes IS2-Good performance by private satellite export companies IS3-Continuous expansion of satellite information user groups IS4-Plan to increase private companies' participation in government-led space development IS5-Success of satellite series that minimized the dependency on foreign companies IS6-Necessity of defense satellite communication owing to ceasefire IS7-Hardware and software development IS8-Launching a project to build Korean precision positioning system (KASS) infrastructure using global positioning systems (GPS)	Science_and_ICT (2018), Cho et al., (2011); Tak et al., (2001); Han et al., (2016); Lee et al., (2017); Landoni and Ogilvie (2019); Mazzucato and Robinson (2018); Perosanz (2019); Vos et al., (2019)
Weakness (W)	IW1-High dependency on government policy and investment IW2-The small size of the domestic market IW3-The absence of global space companies IW4-Landscape unfavorable to ground base station installation IW5-Lack of payload specialized companies IW6-The absence of systematic space legislation IW7-Lack of diversity in private cooperative business models IW8-Lack of expansion in satellite communication applications IW9-Difficulty in localization of satellite technology owing to low technology maturity IW10-Provider-centric satellite development without user consideration IW11-High dependence on foreign technology IW12-Lack of space- and satellite-related expertise	Science_and_ICT (2018), Kim et al., (2015); Park (2017); Yang (2012); Youn and Kim (2015); Choi and Lee (2019); Lee et al., (2017); Lim and Ahn (2013); Jakhu (2009); Winthrop et al., (2002); van der Heiden et al. (2015); Landoni and Ogilvie (2019)
Opportunity (O)	IO1-Demand for satellite images through the establishment of a national satellite information service support center IO2-Expansion of investment through government support IO3-Potential of the space industry market IO4-Import substitution effect by the development of domestic satellites IO5-Expanded utilization of the public sector (ocean, environment, agriculture, and fisheries) IO6-Existence of a continuous domestic satellite launch plan IO7-Increased interest in global satellite technology development on environmental changes IO8-Convergence of information and communication technologies (5 G, autonomous driving, 6 G) IO9-The universalization of satellites owing to the development of cube satellites IO10-Growth in the space debris removal industry IO11-Continuous increase in private enterprise participation	Science_and_ICT (2018), Science_and_ICT (2019), Choi (2016); Han et al., (2016); Hwang et al., (2016); Collins and Autino (2010); Ferrús et al., (2016); Millan et al., (2019); Papadimitriou et al., (2019); Włodzimierz and Iwona (2019)
Threat (T)	IT1-Increasing entry barriers with technological advances IT2-Policies of advanced countries to increase entry barriers IT3-Slow development rate of satellite communication technology owing to the attributes of the national territory IT4-Arrival of emerging countries in the global space market IT5-Small space development budget relative to economic size IT6-Intensified monopoly of large global space companies IT7-Rapid growth in China's space technology IT8-Reduction of industry due to increasing space debris IT9-Advanced countries' tendency to avoid technology transfer	Science_and_ICT (2018), Baek (2017); Kwon et al., (2018); Lee and Kim (2016); Choi (2016); Choi and Lee (2019); Landoni and Ogilvie (2019); Nolan and Zhang (2003); Santos et al., (2019)

We now explain the four major items within the SWOT factors.

3.2. Deriving SWOT-AHP items

To derive appropriate SWOT factors for the domestic satellite and space industry, we analyzed the internal and external attributes that appear in relevant research, Korea Aerospace Research Institute (KARI) reports, and government documents. The results are shown in Table 1. The table denotes the strength factors as IS1 to IS8, the weakness factors as IW1 to IW13, the opportunity factors as IO1 to IO11, and the threat factors as IT1 to IT9. The labels indicate that they are initial factors that will be pared down in the next step, described in Section 3.3.

3.2.1. Strength (S) factor

Among the eight items derived for the strength (S) factor, four main items were identified, the first of which is "accumulated know-how of professional research institutes." For many years, the KARI has led South Korea's development of space technology, including the Arirang satellite, a world-class, high-resolution earth observation satellite; the Chollian satellite, a weather and ocean observation satellite; and the successful launch of the Naro projectile. Professional research institutes have been supporting space industry development not only in Korea but also in Europe (Landoni and Ogilvie, 2019). The second item is "continuous expansion of satellite information user groups." Satellite information systems that provide free access to the public, such as Google Earth engines, lead to the formation of user groups, thus increasing the use of satellite information (Vos et al., 2019). As such, groups of public users continue to be fostered in the domestic satellite industry, creating an environment in which public users can access satellite information (Cho et al., 2011).

"Plan to increase private companies' participation in government-led space development" is the third main item. According to Mazzucato and Robinson (2018), NASA established a partnership with the private sector in developing low-earth orbit systems, contributing to the formation of a market with several stakeholders. In Korea, the private participation rate in the development of the multipurpose satellite 3A is 46%, an improvement over a previous project's rate of 20%. This rate is gradually increasing owing to private sector's role in designing platforms that share and utilize satellite information (Lee et al., 2017). The final item is "launching a project to build a Korean precision positioning system (KASS) infrastructure using global positioning systems (GPS)." Global navigation satellite systems (GNSS) are expected to be more sophisticated, real-time, and better at post-processing services than the existing global positioning systems are (Perosanz, 2019). Korea started developing the Korean GNSS in 2014 with the aim of providing services by 2022.

3.2.2. Weakness (W) factor

For weaknesses (W), 12 factors were derived. The first main item is "high dependency on government policy and investment." Research has found a positive correlation between the development of the U.S. space industry and NASA's R&D budget (Winthrop et al., 2002). Thus, professional research institutes highly depend on government policies and investments. Similarly, the Korean satellite industry also relies on government policies and investments because the satellite image market is marginal and emerging (Youn and Kim, 2015). The second item is "the absence of systematic space legislation." According to Jakhu (2009), space-related legislation and regulations are an essential part of the process, from the operation to the development of the space industry. Yang (2012) stated that two laws closely related to the Korean satellite industry—the Space Development Promotion Act and the Aerospace Industry Development Promotion Act—operate under the jurisdiction of the Ministry of Education, Science and Technology and the Ministry of Knowledge Economy, but confusion arises owing to the absence of systematic legislation. Additionally, "lack of diversity in private cooperative business models" is a major item. Whereas European countries exhibit synergy among companies, space research institutes, and governments through the expansion of private sector cooperation, Korean private companies have never been given the opportunity to run a space project because most projects are led by KARI (Science_and_ICT, 2018). The last item is "lack of space- and satellite-related expertise." According to the Third Basic Plan for the Promotion of Space Development (Science_and_ICT, 2018), the Korean aerospace institute has only 844 employees, whereas the Japan Aerospace Exploration Agency and the European Space Agency (ESA) both have more than 1500 employees, and NASA and the Indian Space Research Organization both have about 17,000 employees.

3.2.3. Opportunity (O) factor

For the opportunity (O) factor, 11 items were derived. The first main item is "expansion of investment through government support." The International Committee for Space Science announced a roadmap for small satellites in 2016, highlighting governments' roles in realizing the goal (Millan et al., 2019). In Korea, the government-led investment policy was carried out by announcing two plans to utilize satellite information and three basic plans to promote space development under the supervision of the Ministry of Science, Technology, Information, and Communication. The second item is the "potential of the space industry market." The space industry began with space exploration in 1940, followed by advanced technologies for building projectiles and telecommunications spacecraft and, finally, space travel. The fact that the space industry, which was previously part of national research agendas, has developed into a business is an emerging opportunity for many space researchers and businesses (Collins and Autino, 2010).

The third item is "expanded utilization of the public sector (ocean, environment, agriculture, and fisheries)." With satellite technology diversifying, its use in the public sector (i.e., oceans, environment, agriculture, and fisheries) is expanding both in Korea and abroad. One example is the ESA's agreement with the European Maritime Safety Agency to develop a space system that assists with marine activities (Papadimitriou et al., 2019). In Korea, the second Global Satellite Information Utilization Plan (Science_and_ICT, 2019) also emphasizes the expansion of satellite information usage in various fields, including weather, the environment, oceans, land, and agriculture. The last item is the "convergence of information and communication technologies (5 G, autonomous driving, 6 G)." According to Devezas et al. (2012), satellites, which play an important role in global communication, were introduced to the world because of information and communication technology (ICT). Now, satellite technology has improved to provide high-speed and accurate communication. Włodzimierz and Iwona (2019) and Ferrús et al. (2016) reported that the development of self-driving cars and 5 G communication technologies will utilize satellites, and Yang et al. (2018) stated that the Korean satellite industry will grow owing to 5 G technologies.

I-1. Unnecessary items within the strength factor for the domestic satellite industry (check unnecessary elements, leaving 4 to 5 unchecked)

No.	IS1	IS2	IS3	IS4
Item	Accumulated know-how of professional research institutes	Good performance by private satellite export companies	Continuous expansion of satellite information user groups	Plan to increase private companies' participation in government-led space development
No.	**IS5**	**IS6**	**IS7**	**IS8**
Item	Success of satellite series that minimized the dependency on foreign companies	Necessity of defense satellite communication owing to ceasefire	Hardware and software development	Launching a project to build Korean precision positioning system (KASS) infrastructure using global positioning systems (GPS)

I-2. Feel free to describe any strength items in the domestic satellite industry that you think are essential other than the existing ones.

Fig. 2. Example section from the unnecessary factor removal survey (strength factor).

Table 2
Voting frequency table for unnecessary SWOT items.

	IS1	IS2	IS3	IS4	IS5	IS6	IS7	IS8
Industry	0	1	1	0	2	3	1	1
Academia	0	2	1	0	3	2	1	2
Research	0	2	1	2	1	2	2	1
Total	0	5	3	2	6	7	4	4

	IW1	IW2	IW3	IW4	IW5	IW6	IW7	IW8	IW9	IW10	IW11	IW12
Industry	0	2	2	2	0	0	2	3	2	2	2	0
Academia	0	3	2	3	2	2	0	2	2	1	3	0
Research	1	4	3	3	2	2	1	2	3	1	2	1
Total	1	9	7	8	4	4	3	7	7	4	7	1

	IO1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11
Industry	1	1	0	2	0	0	0	2	1	1	3
Academia	2	1	1	3	0	2	3	0	1	1	3
Research	2	1	1	3	1	2	1	3	0	3	3
Total	5	3	2	8	1	4	4	5	2	5	9

	IT1	IT2	IT3	IT4	IT5	IT6	IT7	IT8	T9
Industry	0	0	3	1	0	1	2	3	1
Academia	0	1	3	2	0	1	3	3	2
Research	1	2	2	3	1	0	2	2	2
Total	1	3	8	6	1	2	7	8	5

3.2.4. Threat (T) factor

Nine threat (T) items were derived. The first is "expanding entry barriers with technological advances." According to Santos et al. (2019), the space industry is considered to have very high entry barriers, as advanced countries have developed their technologies through specialized agencies. They also noted that it is becoming increasingly difficult to enter this market, as many countries, such as China, Russia, and India, have joined the competition along with existing superpowers. The next item is "policies of advanced countries to increase entry barriers." From 1960 to 2000, France, Italy, and the United Kingdom developed innovative policies that were tailored to adapt to technological and institutional changes through their research institutes. All three succeeded in privatizing state research institutes while lowering government dependency and attracting large investments (Landoni and Ogilvie, 2019). The U.S. also enacted the Remote Exploration Commercialization Act for the Commercial Use of Satellite Data in 1984, and, in 2015, a domestic legal device was established allowing the individual ownership of space resources despite international legal disputes (Kwon et al., 2018).

The third item is "small space development budget relative to economic size." In 2016, Korea's space investment was 2% of that of the U. S., 20% of that of Japan, and 60% of that of India. Moreover, accumulated investment since 1990 was only 0.5% in the U.S., 7.5% in Japan, 7.5%, and 30% in India (Science_and_ICT, 2018). The space development budget accounted for 3.9% of South Korea's R&D budget, which is very low compared to 25.8% in the U.S. and 7.9% in Japan. The last item is "intensified monopoly of large global space companies." The growth of U.S. and European space companies has intensified the industry's entry barriers, and space companies in developing countries have struggled to keep up with market-leading global companies. In particular, the monopoly of large global space companies has continued, as American and European companies hold 60% of the military procurement market (Nolan and Zhang, 2003).

3.3. Eliminate unnecessary swot-ahp items

In SWOT-AHP analysis, it is best to have no more than ten items for each factor (Saaty, 1980). Thus, the AHP questionnaire aims to construct a four-by-four SWOT matrix for easier assessment. To eliminate derived items within the SWOT factors that are unnecessary, we enlisted nine experts from industry, academia, and research to respond to survey questions from September 11 to September 17, 2019. Subjective questions were used to identify the necessary items that were missing from the questionnaire. Three experts from CONTEC Co., Ltd., three professors from Satellite Information Convergence Application Service (SICAS), and three experts from KARI were surveyed.

Table 3
Selected SWOT factors.

Factor	Items
Strength (S)	S1 - Accumulated know-how of professional research institutes S2 - Continuous expansion of satellite information user groups S3 - Plan to increase private companies' participation in government-led space development S4 - Launching a project to build a Korean precision positioning system (KASS) infrastructure using global positioning systems (GPS)
Weakness (W)	W1 - High dependency on government policies and investments W2 – The absence of systematic legislation W3 - Lack of diversity in private cooperative business models W4 - Lack of space- and satellite-related expertise
Opportunity (O)	O1 - Expansion of investment through government support O2 - Potential of the space industry market O3 - Expanded utilization of the public sector O4 - Convergence of information and communication technologies
Threat (T)	T1 - Increasing entry barriers with technological advances T2 - Policies of advanced countries to increase entry barriers T3 - Small space development budget relative to economic size T4 - Intensified monopoly of large global space companies

As shown in Fig. 2, the questionnaire was constructed such that the experts removed unnecessary elements, leaving only four to five necessary elements. The questionnaire consisted of nine parts, and short answer questions were used to identify necessary items that were missing from the questionnaire. The survey results are shown in Table 2.

Based on the survey results, unnecessary items are removed, leaving four items for each SWOT factor. Ties are decided through an internal vote by the researchers. The SWOT factors that are ultimately selected are shown in Table 3.

3.4. SWOT- Analytical Hierarchy process (SWOT-AHP)

The SWOT-AHP method is composed of four steps, as shown in Fig. 3. In step 1, a hierarchy is built based on the selected SWOT items and factors. In step 2, experts perform pairwise comparisons to derive the priorities of factors and items. In step 3, consistency ratios (CRs) are considered to identify consistent surveys that are appropriate for

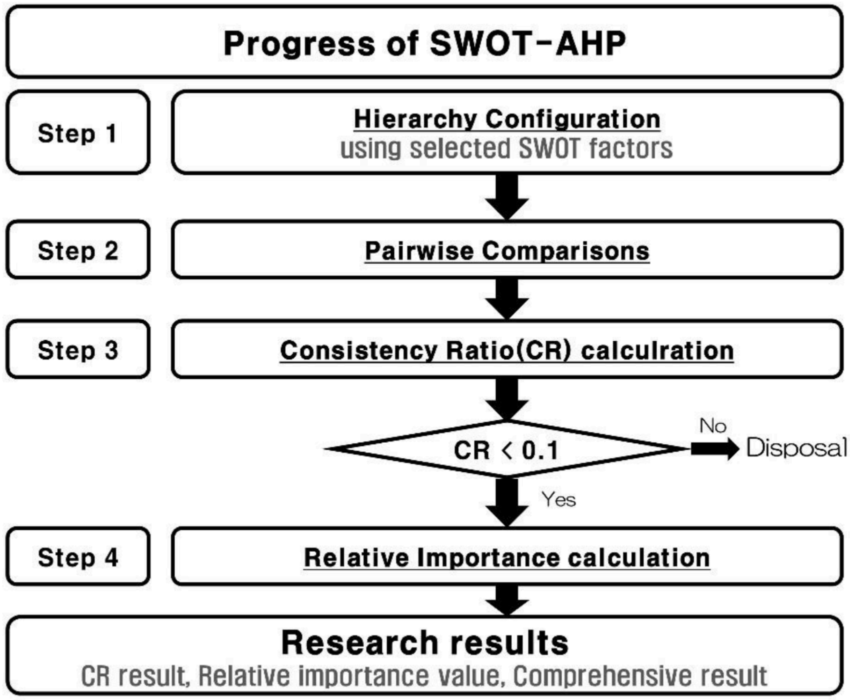

Fig. 3. Steps for the SWOT-AHP method in this study.

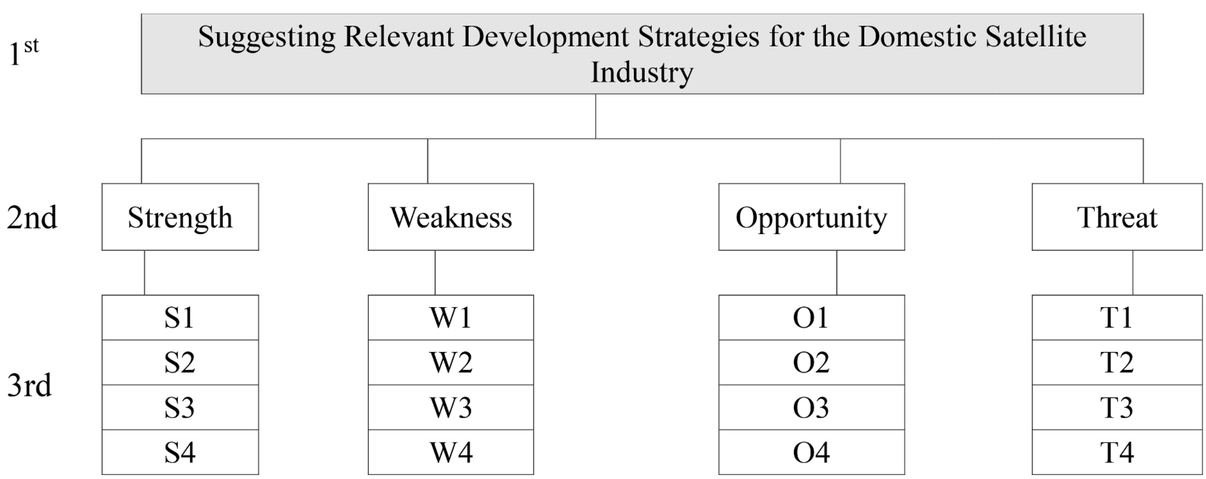

Fig. 4. Hierarchy of the SWOT-AHP factors.

analysis. In step 4, the relative importance of SWOT items and factors (i.e., L-weights and G-weights) is calculated. Furthermore, the relative importance is illustrated by calculating L'-weights. Finally, the results of the study are presented in Section 4.

3.4.1. Step 1: hierarchy configuration

Based on the selected items within the SWOT factors, the SWOT-AHP hierarchy is designed. The SWOT-AHP method includes three levels, as shown in Fig. 4. The top level involves suggesting strategies for the development of the domestic satellite industry. The second level consists of the four SWOT factors, and the third level consists of four items for each factor in the second level.

3.4.2. Step 2: pairwise comparisons

After the hierarchical structure is constructed, the questionnaire is designed to enable the use of double contrast bridges on a nine-point scale for each layer. The experts were asked to respond to the questionnaire from September 25 to October 2, 2019, via an online survey platform, and data were collected from 32 respondents. The industrial field was represented by ten experts from CONTEC Inc., and the academic field was represented by twelve experts from the SICAS research team, which is currently conducting research on satellite services. Ten experts from KARI also participated in the surveys, representing the research field. We conduct six pairwise comparisons for the

Table 4
Two-step pairwise comparison sets of SWOT factors.

Step 1 (6 Pairwise Comparisons)	(S:W), (S:O), (S,T), (W,O), (W:T), (O:T)
Step 2 (24 Pairwise Comparisons)	(S_1:S_2), (S_1:S_3), (S_1:S_4), (S_2:S_3), (S_2:S_4), (S_3:S_4)
	(W_1:W_2), (W_1:W_3), (W_1:W_4), (W_2:W_3), (W_2:W_4), (W_3:W_4)
	(O_1:O_2), (O_1:O_3), (O_1:O_4), (O_2:O_3), (O_2:O_4), (O_3:O_4)
	(T_1:T_2), (T_1:T_3), (T_1:T_4), (T_2:T_3), (T_2:T_4), (T_3:T_4)

II-1. Which of the SWOT attributes do you think is more important when comparing the four sub-factors of the strength (S) attribute with each other?

Item	Weight ←								Same								→ Weight	Item
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
S1																		S2
S1																		S3
S1																		S4
S2																		S3
S2																		S4
S3																		S4

Fig. 5. Example pairwise comparison question (strength factor).

four SWOT factors, followed by 24 pairwise comparisons among the four items from each of the four factors, as shown in Table 4. The pairwise comparison questions are constructed as shown in Fig. 5.

3.4.3. Step 3: CR calculation

Expert Choice 2000, a tool for AHP analysis, is used for steps 3 to 5. For a more accurate analysis, the pairwise comparison questionnaire's CR value, which reflects consistency, should be less than 0.1 (Kurttila, 2000). Thus, surveys with CR values of 0.1 or greater are not included. The consistency verification procedure is as follows.

First, to verify consistency, each pairwise comparison result must be converted into a matrix, as shown in formula (1). This matrix is formed based on the assumption that if A is preferred X times more than B is, then B should be preferred 1/X times more than A is (Vargas, 1990).

$$A = (a_{ij}) = \begin{bmatrix} 1 & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & 1 & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \cdots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & 1 \end{bmatrix} \quad (1)$$

The weight vector is then obtained based on the Saaty method, and the maximum lambda value (λ_{max}) is calculated. A consistency index (CI) for each matrix is then calculated using formula (2).

$$CI = \frac{(\lambda_{max} - n)}{n - 1} \quad (2)$$

Based on the calculated CI value, the CR is calculated using formula (3) to determine the degree of consistency. The random index (RI) value refers to the random index table proposed by Saaty.

$$CR = \frac{CI}{RI} \quad (3)$$

3.4.4. Step 4: Relative importance calculation

Depending on the number of valid surveys that are determined to be consistent, the final L-weights are calculated using the geometric mean of each element. G-weights are then calculated by multiplying the L-weights and the weights of the SWOT factors to measure the priorities of all the elements.

This study also uses the L'-weight formula developed by Kim and Chung (2012) to indicate the importance of the SWOT items on a four-part graph. L'-weights can be calculated by multiplying the L-weight of each item within each SWOT factor by the importance of the SWOT item at the higher level and dividing that product by the item with the highest L-weight within the SWOT factor.

$$L' = \frac{G_W \times f_L^n}{f_L^1} \quad (4)$$

Table 5
CR results.

Recover	Consistency Ratio Use <0.1	Not in use >=0.1, <0.2	>=0.2, <0.3	>=0.3, <0.4	>=0.5
32	21	2	2	2	5

- L': Location of SWOT factors on the graph
- G_W: Importance of SWOT factors
- f_L^1: L-weight of the most important item within a factor
- f_L^n: L-weight of items with n^th importance within a factor

The relative importance values, such as the L-weights and G-weights, are derived from the questionnaires that meet the CR criteria. The results are organized into a table, and graphs are also created based on the L'-weights. Strategies are then constructed for the items with the eight highest G-weights, as described in Section 4.

3.5. Analysis and comparison of news data topics

Finally, we compare the strategies with the perspectives disseminated by the media regarding the satellite industry. We collect 19,728 data observations that include the keywords "space" and "satellite" via the *Big Kinds* web service for the period from January 1, 1990, to December 17, 2019.

Latent Dirichlet allocation (LDA) topic modeling, which identifies topics or attributes based on keywords in massive sets of documents, is used to derive implications from large volumes of news data (Blei et al., 2003). Ten topics are extracted, and the five with the highest frequencies are reconstructed and compared with the media's perspective on the satellite industry.

4. Results

4.1. Survey subject statistics and CR

A total of 32 surveys were administered, all of which elicited responses. These surveys are used to conduct pairwise comparisons. Only surveys with CR values less than 0.1 are used for the analysis. The results of the consistency analysis are shown in Table 5.

4.2. Relative importance of SWOT factors

The analysis of the SWOT factors' relative importance shows that the factor with the highest relative importance is opportunity (O, 0.487), followed by strength, threat, and weakness, as shown in Fig. 6. The experts prioritize developing the satellite industry, which is receiving much attention globally, as an opportunity. They also emphasize the importance of using the strengths of the Korean satellite industry,

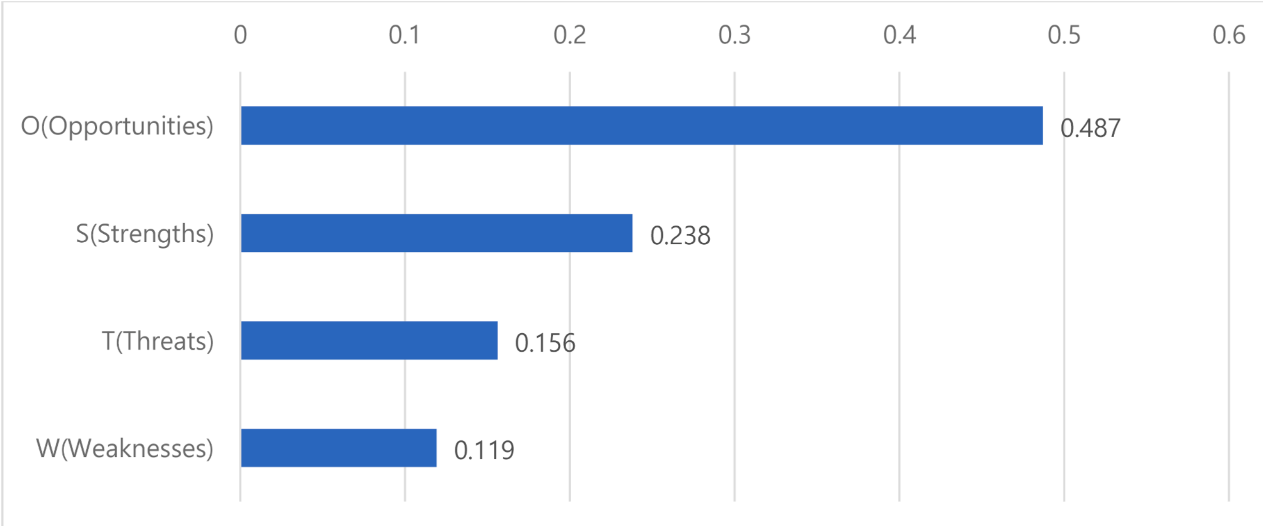

Fig. 6. Relative importance of SWOT factors.

Table 6
Relative importance of items within the SWOT factors.

Item	L-weight	Rank	G-weight	Rank	Item	L-weight	Rank	G-weight	Rank
S1	0.265	3	0.063	8	W1	0.134	3	0.016	15
S2	0.285	2	0.068	5	W2	0.116	4	0.014	16
S3	0.343	1	0.082	4	W3	0.319	2	0.038	11
S4	0.107	4	0.026	12	W4	0.432	1	0.051	9
O1	0.134	4	0.065	7	T1	0.137	3	0.021	13
O2	0.278	2	0.135	2	T2	0.134	4	0.021	14
O3	0.312	1	0.152	1	T3	0.419	1	0.066	6
O4	0.275	3	0.134	3	T4	0.310	2	0.048	10

Fig. 7. Top eight items of relative importance within the SWOT factors (G-weights).

handling threats from the external environment, and supplementing the weaknesses of the domestic satellite industry.

4.3. Relative importance of items within the SWOT factors

The analysis of the G-weights of the items in the third level, that is, the lowest level in the hierarchy, shows that O3 is the most important item, followed by O2 and O4. The G-weights of these three items are 0.1 or higher, whereas those of the other ranked items are less than 0.1. S3, S2, and T3 rank fourth, fifth, and sixth, respectively. O1 ranks seventh, and S1 ranks eighth. Thus, all four opportunity (O) items, three strength (S) items, and one threat (T) item are ranked as the top eight items.

The relative importance of the items within the SWOT factors is indicated by the L-weight values. The items with the greatest L-weight values within each SWOT factor are included among the items with the eight highest G-weight values, except in the case of weakness.

The L-weight and G-weight values are summarized in Table 6, and Fig. 7 presents the top eight items in order of importance.

4.4. SWOT-AHP comprehensive analysis results

Based on the results of the SWOT-AHP analysis, the relative

Table 7
SWOT-AHP comprehensive analysis results.

Factor	CR	Weight	Item	CR	L-weight	G-weight
S	0.00	0.238	S1 Accumulated know-how of professional research institutes	0.00	0.265	0.063
			S2 Continuous expansion of satellite information user groups		0.285	0.068
			S3 Plan to increase private companies' participation in government-led space development		0.343	0.082
			S4 Launching a project to build a Korean precision positioning system (KASS) infrastructure using global positioning systems (GPS)		0.107	0.026
W		0.119	W1 High dependency on government policies and investments	0.01	0.134	0.016
			W2 The absence of systematic legislation		0.116	0.014
			W3 Lack of diversity in private cooperative business models		0.319	0.038
			W4 Lack of space- and satellite-related expertise		0.432	0.051
O		0.487	O1 Expansion of investment through government support	0.00	0.134	0.065
			O2 Potential of the space industry market		0.278	0.135
			O3 Expanded utilization of the public sector		0.312	0.152
			O4 Convergence of information and communication technologies		0.275	0.134
T		0.156	T1 Increasing entry barriers with technological advances	0.00	0.137	0.021
			T2 Policies of advanced countries to increase entry barriers		0.134	0.021
			T3 Small space development budget relative to economic size		0.419	0.066
			T4 Intensified monopoly of large global space companies		0.310	0.048

Table 8
L'-weights of items within the SWOT factors.

Item	L'-weight	Item	L'-weight	Item	L'-weight	Item	L'-weight
S1	0.184	W1	0.037	O1	0.209	T1	0.051
S2	0.198	W2	0.032	O2	0.434	T2	0.050
S3	0.238	W3	0.088	O3	0.487	T3	0.156
S4	0.074	W4	0.119	O4	0.429	T4	0.115

importance of each SWOT factor is presented along with the relative importance of the items within each SWOT factor (L-weights). We also describe the relative importance of all the items within the SWOT factors (G-weights), reflecting the weights of the upper layers. Table 7 shows the results.

A graph can be plotted based on the L'-weights in Table 8, as shown in Fig. 8. Strength (S) and opportunity (O), the positive factors, are plotted in Sections 2 and 1, and weakness (W) and threat (T), the negative factors, are plotted in Sections 3 and 4. The lengths of the straight lines on the graph represent the importance of the SWOT items and their ratios to the total importance. The end points of the straight lines indicate the locations of the items with the highest importance (f_L^1) for each SWOT factor. The remaining items are plotted on the lines according to the values of their L'-weights.

This comprehensive analysis shows that opportunities O3, O2, O4, and O1 should be leveraged and that threat T3 should be dealt with. The findings also indicate that Korea's satellite and space industry should utilize strengths S3 and S1.

4.5. Strategies for the development of the satellite industry

Based on the comprehensive SWOT-AHP analysis, possible strategies for the development of the satellite industry are strength-threat (ST) and strength-opportunity (SO) strategies. These strategies are derived based on the relative importance of the SWOT factors, as shown in Fig. 9. Weakness-opportunity (WO) and weakness-threat (WT) strategies are not suggested because we consider only the top eight SWOT items based on their relative importance.

4.5.1. Strength-Opportunity (SO) strategy

S3 (plan to increase private companies' participation in government-led space development), S2 (continuous expansion of satellite information user groups), S1 (accumulated know-how of professional research institutes), O3 (expanded utilization of the public sector), O2 (potential of the space industry market), O4 (convergence of information and communication technologies), and O1 (expansion of investment through government support) are included in this strategic composition.

First, S3, the most important item within the strength factor, suggests that the government should initiate cooperation and support for private businesses and startups based on the KARI's knowledge. This strategy is illustrated by Buchen (2015) idea that the commercial sector's continued interest can lead to multi-billion dollar investments in satellite companies, such as OneWeb, SpaceX and other ventures.

Further, a SO strategy that combines S2 and O3 can be proposed to make the open API satellite information platform more public to expand the group of satellite information users and increase its utilization in the public sector. The importance of a public satellite information platform is best shown by the example of V-World, a virtual mapping and geographical information service covering the entire Korean peninsula. This platform, which KARI runs, is based on the high-resolution optical imagery of KOMPSAT-2 and 3 (Kim et al., 2015). V-World has provided public access to 3D maps of the Korean Peninsula, and various public satellite data open application programming interfaces (APIs) have been expanded, widening the base of the space and satellite industry. Likewise, more useful public satellite information platforms will lead to the growth of the Korean space and satellite industry.

It is also important for satellite industry to take advantage of Korea's strength in ICT. Many experts say that satellite-based industries can be the starting point for sixth generation (6 G) communication technology, which is expected to be a next-level communication technology because 6 G mobile and wireless networks can provide global coverage by integrating satellite and 5 G networks (Gawas, 2015). Because South Korea is a 5 G communication technology leader and plans to commercialize 6 G by 2028, it may be a good SO strategy to develop a satellite communication industry associated with 6 G.

4.5.2. Strength-Threat (ST) strategy

T3 (small space development budget relative to economic size) holds a high priority among the threat (T) items. Although Korea is developing its space industry on a national level, the budget for space development is insufficient compared to those of other advanced countries. If progress in the satellite and space industry is slow owing to low research costs,

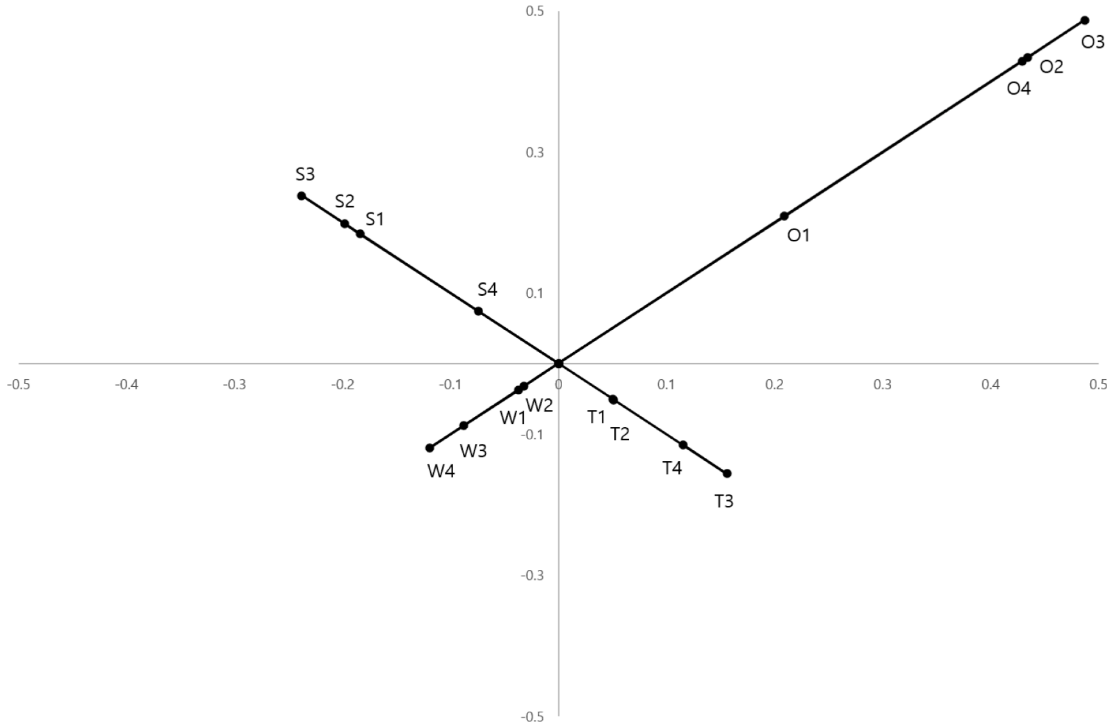

Fig. 8. L'-weights of each SWOT factor.

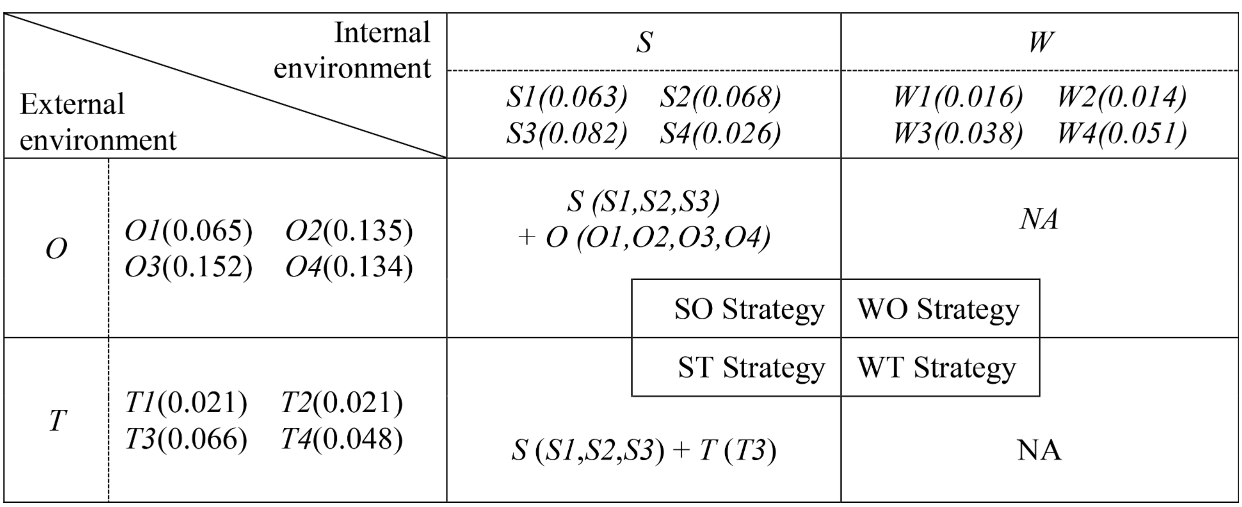

Fig. 9. Strategic composition based on the SWOT-AHP analysis.

Korea will lose its competitiveness. Thus, in the short term, it is necessary to engage a group of potential users in the satellite and space industry to effectively distribute budgets based on their requirements. In this way, S2 can be used to deal with T3. One way to effectively use a limited budget is to develop the Cube Sat, a mini satellite. More than 80 institutions around the world have used the Cube Sat for space research projects to reduce costs and to use satellites that fit their research in terms of size, mass, and power (Woellert et al., 2011). It is also important that this development be sustainable so that it can generate its own profits while reducing reliance on the government through collaboration and joint investment by KARI and the private sector. This strategy uses S1 to avoid T3. NASA Glenn Research Center initiated a request for information in September 2017 to gage commercial interest in forming public-private partnerships with NASA on shared satellite development, communication provision, navigation capabilities and services in and out of low Earth orbit, and the development and validation of technology (Stegeman et al., 2018). In this regard, KARI is important as NASA's commercial corporate investment accelerates the availability of new services and advances the American space and satellite industry. In the long run, the budget should be increased to make the space industry sustainable; simultaneously, the importance of the satellite industry must be recognized by the Korean public.

4.6. News data topic analysis

For the LDA topic modeling, we use the *Big Kinds* web service and identify the top five topics based on the frequency of their appearance in media. Table 9 shows the results.

Topics related to industry (three times), technology (one time), and government (one time) are identified. The industry topics are associated with the global satellite and space market related to O2 (potential of the space industry market) and T1 (expanding entry barriers with

Table 9
Results of LDA topic modeling and labeling.

Topic	Keywords
Industry; Satellite market	Market, export, dollar, company, outlook, sales, business, growth, increase, semiconductor, forecast, enterprise, investment, product, industry, production, company, expansion, record, scale
Industry; Satellite market	U.S., China, business, Korea, the world, industry, economy, think, Japan, investment, government, chairman, dollar, internet, change, person, company, degree, country, start
Government; Satellite-related government policy	support, sector, industry, business, promotion, planning, government, building, enterprise, nurturing, information, expansion, strengthening, cooperation, investment, country, utilization, creation, preparation, policy
Technology; Satellites and new technology	services, telecommunications, Internet, market, business, information, delivery, digital, satellite, KT, terminal, network, use, world, construction, sector, planning, industry, wireless, SK Telecom
Industry; Satellite and space industry	space, satellite, launch, projectile, rocket, rocket, satellite, plan, our country, success, world, U.S., business, aviation, Naro, industry, sector, Russia, earth, Japan, exploration

technological advances). Technology includes the convergence of satellites with various telecommunication technologies, which is related to O4 (convergence of information and telecommunication technologies) and T1 (increasing entry barriers with technological advances). Lastly, the topic of government deals with the role of government policy and investment in expanding the satellite industry and is related to W1 (high dependency on government policies and investments), O1 (expansion of investment through government support), and T2 (policies of advanced countries to increase entry barriers).

These results are within the same context as the SO strategy, which includes analyzing the potential of the satellite and space industry on a national level and developing innovative business models through convergence with ICT, and the ST strategy, which recommends that the government expand its investment in the satellite and space markets so that Korea is not left behind globally. The results show that experts' opinions and the media's coverage are similar, and the comparison between the strategies and topic modeling partially supports this result.

4.7. Discussion

This study aimed to analyze the Korean satellite and space industry and propose strategies for this industry. The analysis was conducted based on the opinions of experts in various fields. It has academic implications in that it reflects the stance of a private business, CONTEC CO., in line with the trend that the power of private business is increasing in the satellite and space industry. Considering that most of the existing research on the satellite and space industry, such as studies about the economic impact of government-led satellite projects in Korea (Park et al., 2020) and a roadmap of small satellites (Millan et al., 2019), has been conducted by state institutions or state-run research institutes or from the perspectives of such groups, this study is meaningful.

Moreover, this study was successful in being more data-driven than prior research using the SWOT-AHP method is. As big data and analytical methods are becoming more important, proper methodologies for data analysis are commonly used in suggesting strategies. Example studies include those of Li et al. (2020), who used a data-driven forecasting model to derive strategies for electricity usage by campus buildings, and Chen et al. (2020), who suggested a data-driven safety-enhancing strategy for construction sites. In this study, the LDA topic modeling results support the results of the SWOT-AHP analysis, which takes the opinions and experience of a comparatively small group of experts into account.

5. Conclusion

The world's first satellite was launched more than 60 years ago. Since then, many studies and projects have been conducted, and competition between countries has intensified. Korea has some competitiveness in the satellite and space industry, but it is insufficient compared to India, Japan, and China, which are leading Asia's space and satellite industry (Han et al., 2017).

Moreover, the satellite and space industry is actively privatizing. On May 30, 2020, SpaceX became the first private company to successfully launch a manned spacecraft carrying astronauts, and they returned safely two months later. This iconic event represents the privatization trend in the satellite and space industry, and this trend is inevitable in South Korea as well.

Under these circumstances, the study sought to propose strategies for South Korea's satellite and space industry by applying the SWOT-AHP analysis method to the opinions of experts from industry, academia, and research areas related to the Korean space and satellite industry.

This study has shown that appropriate strategies for the development of the satellite and space industry in Korea are SO strategies, which utilize strengths and opportunities, and ST strategies, which take advantage of strengths while dealing with threats. The SO strategies include providing state-led support for cooperation between KARI and private businesses and creating a business model using the strengths of the Korean IT sector while analyzing potential users' requirements. ST strategies include increasing the space development budget, reorganizing the distribution structure to improve efficiency, and fostering continuous potential users. Moreover, a strategy for reducing government dependence through collaboration and joint investment between KARI and the private sector is also presented. Finally, these strategies are very similar to the top five topics that were derived from news data topic modeling.

One of the limitations of this study is the identification of the items within the SWOT factors. During the process, the researchers' subjectivity may have affected the results. We believe that if the items were derived directly through interviews with experts and the top four items selected, we could secure objective results. Second, this study failed to present a specific strategy. Additional investigation is required to understand how the strategies can be applied to the Korean satellite and space industry based on the derived items within the SWOT factors.

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