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Original Paper

Study on technical issues related to the introduction of maritime autonomous surface ship

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Abstract: Recently, the introduction of Industry 4.0 (the Fourth Industrial Revolution) has led to major changes in industry and the emergence of new technologies and services. Maritime autonomous surface ship (MASS) industries are also striving to develop technologies to gain positions as shipbuilding powerhouses, as an opportunity to change the paradigm of the shipbuilding industry. This study conducted an analysis of recent trends in the shipbuilding industry, and analyzed the technical issues concerning the introduction of autonomous ships through in-depth interviews with experts from companies, universities, and research institutes related to the shipbuilding industry. According to the results of the study, the development of technologies such as those for safe navigation, economic maneuvering, and automatic maintenance for autonomous ships should precede development, along with early participation in the preparation of technical standards necessary for International Maritime Organization (IMO) performance requirements, design standards, and manufacturing standards. This research is meaningful by gathering and analyzing opinions from experts in the shipbuilding sector who possess the world's best technologies to present effective technical policy implications.

Keywords: Autonomous ship, Safe navigation, Economic maneuvering, Automatic maintenance, IMO performance requirements

1. Introduction

1.1 Background and Purpose of Study

Currently, large changes are occurring across industries owing to a paradigm shift called the Fourth Industrial Revolution and the emergence of new technologies and services. South Korea is also seeing large industrial transformations in the shipbuilding industry (one of the pillars of South Korea's manufacturing industries), through changes in products and factories using the Internet of Things, artificial intelligence, sensors, and big data analysis. The shipbuilding industry is now in the midst of the Fourth Industrial Revolution and a recession, and the importance of maritime autonomous surface ship (Mass) is drawing global attention as a means to address these challenges.

The European Union has established the Horizon 2020 strategy to strengthen research, development, and innovation, and to expand investments. According to this strategy, governments and public organizations focus on their roles as ecosystem creators, and the private sector takes the leadership in technology development. Thus, the actual users actively participate in technology development.

China, a major competitor to South Korea in the shipbuilding industry, formed the Unmanned Ship Cargo Alliance for the development of Mass, and began developing them with leading companies such as DNV-GL and ABB. In addition, Japan is promoting the projects at the national level, and has completed step 2 of a project for a smart ship application platform with the participation of shipyards, equipment vendors, shipping companies, and classification societies **[1]**. This indicates that South Korea's competitors are already ahead in regard to demonstration tests, international standards, and equipment preoccupation. Although South Korea's large shipbuilders (Daewoo Shipbuilding & Marine Engineering, Samsung Heavy Industries, and Hyundai Heavy Industries) have established development roadmaps and are conducting research, cooperation between the government and industry remains insufficient.

Since 2018, a smart MASS shipping and port operation service development project (fund: 584.77 billion KRW) has been

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Table 1: Analytic hierarchy process (AHP) results for pre-feasibility study for maritime autonomous surface ship development in 2019

Assess-ment	Total		Scientific and technological feasibility		Policy feasibility		Economic feasibility	
	Implementa-tion	No implemen-tation	Implementa-tion	No implemen-tation	Implementa-tion	No implemen-tation	Implementa-tion	No implemen-tation
Total score	0.736	0.264	0.794	0.206	0.696	0.304	0.680	0.320
Assess-ment index	10	0	10	0	9	1	7	2

conducted for developing medium-sized Mass, through the development of autonomous navigation equipment and systems under the planning of government ministries (Ministry of Trade, Industry and Energy and Ministry of Oceans and Fisheries). However, a preliminary feasibility study has concluded that it should not be implemented.

In 2019, a pre-feasibility study on a MASS technology development project (fund: 160.32 billion KRW) was conducted through re-planning, with a goal of the early establishment of a commercialization foundation, through the development of MASS core technologies and systematic verifications. Consequently, the scientific, technological, policy, and economic feasibilities were all derived for the project implementation, as shown in **Table 1**.

Recently, many policy studies have been conducted on issues regarding Mass. Park *et al.* **[2]** conducted an analytic hierarchy process (AHP), and reported that the industries that would be affected by the introduction of MASS were those concerning ship safety, responsibility/compensation, cargo management, crew, ship equipment, shipping, and ports and logistics. They derived the major issues in each area.

Based on existing studies using a quantitative approach (e.g., AHP), studies on qualitative aspects are required. In this context, this study interviews experts in the industry, education, and research fields of the shipbuilding industry in regards to practical technical research problems, using an in-depth interview method. We analyze the opinions of these experts to derive development directions and implementation strategies for the introduction of Mass in Korea, and present strategic implications.

1.2 Literature review

An examination of previous works reveals that studies on control management and operation technologies for Mass are mixed with studies on systems and policies, and there is confusion regarding terminology. Various terms are used for a MASS, such as smart ship, digital ship, remote control ship, unmanned ship, and automation ship. However, the 99th Maritime Safety Committee of the International Maritime Organization (IMO) began to establish the regulatory scope for the introduction of the MASS, and tentatively defined MASS as follows:

"Maritime Autonomous Surface Ship (MASS) is defined as a ship which, to a varying degree, can operate independently of human interaction." **[3]**

The present study analyzed previous domestic research (2016–2019) on Mass, and the results are outlined in **Table 2**.

Table 2: Previous research on maritime autonomous surface ship

Researcher	Main contents
In-Hyeon Kim (2016)	A study on legislative issues regarding maritime laws for containers, SPCs, and unmanned ships in the new shipping environment of the 21st century
Jeong Won Lee (2018)	Analyzes laws and regulations on unmanned ships and obligation to pay attention to airworthiness
Hyo Jun Lim (2018)	Analyzes recent trends in the shipbuilding and shipping industries, new strategic plans of the IMO, and the main agenda and issues presented in the Maritime Safety Committee and the Maritime Law Committee.
Jeong Hwan Choi (2018)	Analyzes the status and roles of remote operators of MASS as a different concept from captain or sailor based on international conventions and domestic maritime laws.
Hyeon Gyun Lee (2019)	Analyzes liability issues that may arise in relation to MASS operations around the current commercial laws in accordance with the development stage of MASS suggested by the IMO.

To summarize the previous studies, they investigated the introduction, directions, and main issues in MASS, generally from a legal perspective. It appears that these previous works focused on a specific perspective and are somewhat insufficient for a syntactic approach to Mass. Research on Mass needs to be conducted from social and technical perspectives for introduction and activation, as well as from a legal perspective.

2. Research Design and Analysis Method

2.1 Research on in-depth interview method

An in-depth interview is a qualitative research method in empirical social science research. The representative method of social science research can be said to be statistics, and it has developed greatly in the United States, as a methodology called "social research." This method has developed as a quantitative analysis and structured survey method. In contrast, qualitative research methods have the advantage that they can extract subjective and subjective positions or ideas in specialized fields that are missed by statistics **[4]**. In other words, whereas quantitative research emphasizes accuracy in quantifying linguistic (symbolic) tests, qualitative research is related to the understanding of texts. These methods have been developed with significant effort directed to identifying the true meanings behind external structures, under the belief that not only language can be understood or reconstructed linguistically, but also all things derived from humans **[5]**. The differences between qualitative and quantitative research are outlined in **Table 3**.

Table 3: Comparison of qualitative and quantitative research

Classification	Qualitative research	Quantitative research
Social theory	Action	Structure
Reality awareness	Various realities derived subjectively	Objective reality
Research method	Observation and interview	Experiment and survey
Inference method	Inductive	Deductive
Sampling	Theoretical	Statistical
Language type	Personal, informal, and context-dependent	Official and rule-based sentences
Role of researcher	Interaction with the researched phenomena	Work in isolation and independently from research variables
Main features	Accuracy and validity	Reliability
	Identification of the primary meaning of data	Attention to generalization
	Non-standardization	Standardization
	Research subjects are grasped in general terms	The effects of specific variables are separated

In-depth interviews can be classified into group and individual interviews. The individual interview method used in this study was for the researcher to ask and then listen to the opinions of individuals, and was mainly used to gather in-depth and professional opinions from experts in specific fields. Thus, it had an advantage in its ability to collect expert opinions that might have been difficult to obtain from the general public. However, it had disadvantages, e.g., it was difficult to select and contact interviewees, and required a significant amount of time **[6]**.

Interview methods are largely classified into four types: informal interviews, unstructured interviews, semi-structured interviews, and structured interviews.

Table 4: AHP analysis result of maritime autonomous surface ship introduction issues

Classification	Policy elements	Weight	Ranking
Ship design and operation technology	Ship structure and design technology	9.5%	5
	Autonomous navigation/control and maintenance technologies	17.8%	1
Ship safety and management	Ship security systems such as preparation for piracy and cyber terrorism	13.0%	2
	Equipment and devices for ships (e.g., cargo management, life safety)	9.2%	6
Employment and education	Forms of education and employment of maritime operators	7.4%	9
	Training and education system for professional personnel	8.0%	7
Liabilities and insurance for accidents	Changes in marine accident types	10.7%	3
	Liability and insurance system	10.0%	4
Shipping, port, and logistics systems	Shipping, port, and logistics connection system	7.7%	8
	Changes in related industries (shipbuilding, equipment, shipping, port, and logistics)	6.7%	10
Total		100%	

2.2 Research model and survey design

This study performed semi-structured individual in-depth interviews, and tried to induce responses and collect data from the interviewees as appropriate for the research purposes in a natural communication process, while using only the minimum number of questions. As the main theme of the interview, we adopted a significant research problem, i.e., technical issues when introducing a MASS. Then, we approached a smaller problem in the previous research, the “priority of the analysis results from using an AHP among the five major issues when introducing a MASS”. The results of the priority analysis for policy elements are outlined in **Table 4**.

In the priority analysis results, ① autonomous navigation, control, and maintenance technologies showed the highest weight of 17.8%, followed by ② ship security systems, such as preparation for piracy and cyber terrorism at 13.0%, and ③ changes in marine accident types, at 10.7%.

The in-depth interview was performed such that the researcher asked questions, and requested opinions based on a prepared questionnaire. After the interview, additional questions were asked again in writing, to revisit the large and small research issues. In this way, the research was designed to enable cross-checking, by allowing views not yet drawn from the interviewees during the interview process to be mentioned again. The research model of this study is illustrated in **Figure 1**.

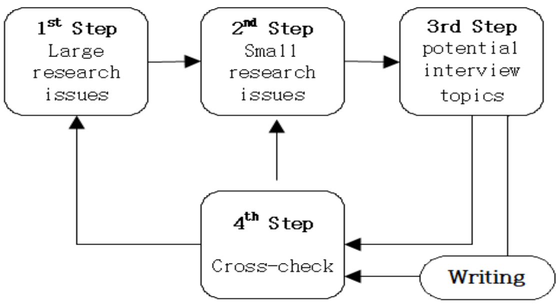

Figure 1: Research Model

The specific research problems addressed in the in-depth interview in this study are as follows.

- ◆ First, what are the major issues in terms of autonomous navigation, control, and maintenance technologies in the introduction of a MASS?
- ◆ Second, what are the major issues in terms of ship security systems (such as preparation for piracy and cyber terrorism) in the introduction of the MASS?
- ◆ Third, what are the major issues in terms of changes in marine accident types in the introduction of the MASS?

Before the interview, a brief explanation of the research model was given to the interviewee. If the interviewee moved away from the topic, the interviewee was naturally guided to return to the research problem at hand, and the answer to the research problem was cross-checked (4th step). For the in-depth interviewees, experts in the shipbuilding industry were selected in such a way as to reflect the viewpoints of the industrial, educational, and research circles. The selected companies and organizations are outlined in **Table 5**.

Table 5: Configuration of in-depth interviews

Classification	Organization	No. of Interviewees
Industry	Shipyards	2
	Inspection agencies	1
Education	Universities	2
	Training institute	1
Research	Laboratory	1
	Association	2
Total	8 companies and organizations	9

Table 6: In-depth interviewees and details

Interviewees	Organization	Career	Position	Remarks
Expert 1	A Heavy Industries	32 years	General Manager	
Expert 2	B Heavy Industries	20 years	Deputy Manager	
Expert 3	C Classification Society	27 years	Senior Researcher	Writing
Expert 4	D University	10 years	Professor	
Expert 5	E University	21 years	Professor	Writing
Expert 6	F training institute	12 years	Professor	
Expert 7	E laboratory	12 years	Senior Researcher	Writing
Expert 8	F Association	18 years	General Manager	
Expert 9	G Association	17 years	Deputy Manager	
Average career of interviewees: Approximately 18.7 years				

Table 7: Results of interviews regarding autonomous control and maintenance

Classification	Interviewees	Major issues and obstacles
Industry	Expert 1	To implement MASS, the following technologies must be developed sequentially: ① establishment of navigation plan, ② navigation monitoring, ③ navigation diagnosis, ④ navigation control, and ⑤ self-problem solving. A navigation planning system (weather routing) must be developed by assigning an objective function to minimize fuel consumption. A technology for active identification of external risks of ships must be developed using advanced sensor fusion technology of an advanced type based on maritime information and Lidar.
	Expert 2	Self-problem solving is the core technology to implement an unmanned ship. Abnormal operation need to be detected and the problem situation diagnosed or repaired by analyzing the data received from the equipment in the ship.
	Expert 3	The ship must be implemented as a complete electric propulsion ship as the prerequisite for technology. The land control center technology needs to be developed for the operation of MASS.
Education	Expert 4	The first priority of MASS is the establishment of criteria and standards. Participate from the early stage in the preparation of technical, institutional, and navigational standards required for the MASS performance, manufacturing, and design standards of the IMO.
	Expert 5	Various sensors and analysis technologies to effectively monitor the status of parts and equipment are critical.
	Expert 6	There will be many challenges to be solved for automation in the process of cargo and ballast management and equipment repair.
Research	Expert 7	The development and verification of technologies in the engine area such as electric propulsion engine and battery technology need to be carried out systematically.
	Expert 8	The development of safe navigation, collision avoidance, economic operation, and automatic maintenance and repair technologies using AI must be prioritized. The development of commissioning and demonstration technologies, and the development of commissioning and performance evaluation procedures and manuals
	Expert 9	We need to jointly respond to the changes in the global technology standards and conventions centered in Europe that has advanced technologies.

3. Analysis of Expert In-depth Interview Results

3.1 Overview of in-depth interviews

The interviewees selected for individual in-depth interviews in this study were nine experts from eight companies and organizations. The in-depth interviews were conducted twice in preset periods, by a researcher who visited the work sites of the companies and organizations. However, for some interviewees, interviews were replaced with written responses owing to time constraints.

The expertise of the interviewees was verified based on their careers and positions in the corresponding fields. The average work career of the nine interviewees was approximately 18.7 years. The careers and positions of the interviewees are outlined in **Table 6**.

3.2 Results of in-depth interviews

The opinions of the interviewees were summarized for each question of the study from the results of the individual in-depth interviews, and then were classified around common opinions that appeared frequently. In addition, the opinions of the industrial, educational, and research circles were analyzed using a visualization chart, and the frequency of opinions was analyzed using a word cloud technique with the R Program.

The expert opinions regarding autonomous navigation control and maintenance, which was the subject of the first question, are briefly outlined in **Table 7**.

An analysis of the in-depth interview results of the experts indicated that the main goal of industrial experts was to develop navigation control and monitoring technologies for autonomous navigation. It could be seen that they were establishing concrete development strategies in four categories: navigation planning, navigation monitoring, navigation control, and self-problem solving.

Meanwhile, the educational experts claimed that standardization must occur first. As Mass must be built for all ship owners worldwide, they suggested that we should participate in the early stages of preparation for the technical standards required for the IMO's performance, design, and production standards. The research experts suggested the importance of R&D tasks, such as determining international cooperation tasks for technical developments in commercialization, developing commi-

Table 8: Result of interviews regarding ship security system

Classification	Interviewees	Major issues and obstacles
Industry	Expert 1	Protections against pirates and cyber-attacks are divided. Implementation of outboard hazard detection method and faster pirate detection method
	Expert 2	Ship cybersecurity is a highly important issue. Respond with technology to install multiple network security devices from satellite communication network to onboard network terminals. Demonstrate through approval procedure related to cybersecurity of classification society.
	Expert 3	There are no security and management systems for maritime communication now. Fast growth is expected as a power country of ICT industry.
Education	Expert 4	For existing shipyards, hardware must be modified and improved with a focus on physical security. We should analyze and respond to the risks of cybersecurity appropriate for smart ships.
	Expert 5	Development of land and marine cybersecurity management systems Continuous improvement is required like financial security systems.
	Expert 6	The cybersecurity system should be developed considering its effects on the employee education and organizational culture.
Research	Expert 7	Systems and applications using data in the ship are increasing. Maritime data need to be encrypted for data security between ships and land.
	Expert 8	Development of new types of ship security equipment and devices, and preparation of a strict verification system for quality level.
	Expert 9	Development of software applications that satisfy national or international standards such as IEC 61508

Table 9: Results of interviews regarding changes of marine accident type

Classification	Interviewees	Major issues and obstacles
Industry	Expert 1	Preparation for collision accidents due to human error is necessary in the coast (e.g., recent collision of Russian cargo ship with Gwangan Daego Bridge)
	Expert 2	Development of outboard hazard detection technology using multiple sensor information
	Expert 3	Preparation for collision accidents due to failure of ship manipulation near the port
Education	Expert 4	It is difficult to predict the diversification of marine accidents. Ship owners and shippers are very passive, claiming cargo safety.
	Expert 5	The sensing technology can reduce human error if the technology development secures reliability.
	Expert 6	It is necessary to prepare for systems such as international maritime collision prevention regulations such as congestion in the coastal waters.
Research	Expert 7	Technology development considering the situation that the marine environment changes frequently.
	Expert 8	Development of new insurance and compensation systems according to the changes in marine accident type and liability
	Expert 9	Need for reviewing the new installation of ports dedicated to MASS

ssoning and demonstration technologies, and developing performance evaluation procedures and manuals.

For the second question, the expert opinions regarding ship security such as piracy or cyber terrorism, as well as the corresponding technology developments in terms of autonomous navigation control, are briefly outlined in **Table 8**. An analysis of the results of in-depth interviews with experts for the second question indicated that the industrial experts proposed responding with technology, i.e., installing multiple network security devices from a satellite communication network to the ship network terminals, while focusing on existing ship security approaches against pirates. The educational experts presented opinions from a macroscopic viewpoint of establishing and implementing cybersecurity systems, emphasizing that ship monitoring systems and network equipment are currently exposed to serious dangers owing to a lack of security. The research experts presented opinions regarding the development of new types of ship safety equipment and devices, preparation of a strict verification system for quality levels, and preparation for the safety management service industry, such as certification, inspection, and consultation regarding equipment and devices.

The third question was related to liability for accidents, rather than technical issues. The expert opinions on the changes caused by changes in the types of marine accidents are briefly summarized in **Table 9**.

An analysis of the in-depth interview results for the third question indicated that the industrial experts expected a need to develop outboard hazard detection technology based on the information of multiple sensors, owing to increasing numbers of accidents from human errors. The education experts mentioned that although sensing technology cannot identify wooden boats properly as it mainly relies on radar, human errors nevertheless can be reduced if this technology is developed reliably. However, they expected that it would take more time to apply it in the field, owing to the passive attitude of the shipping industry (including shipping companies and ship owners) regarding various accidents.

The research experts suggested that the establishment of dedicated ports for Mass would be more effective, as accommodating Mass and general ships together could make the related institutions and systems more complicated and difficult.

3.3 Results of word cloud frequency analysis

The results from the in-depth interviews with industry, education, and research experts were combined, and the frequency of key words was analyzed using a word cloud technique (a big data analysis method). The results are shown in **Figure 2**.

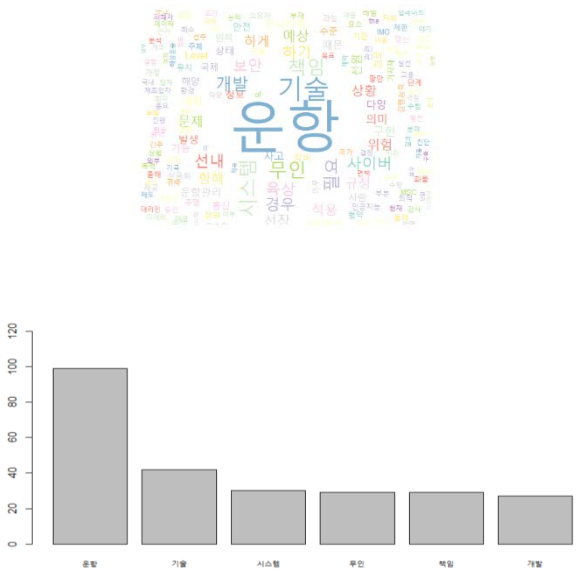

Figure 2: Text analysis result with word clouds

According to the word cloud analysis result, the word with the highest frequency was navigation, followed by technology, system, unmanned, liability, and development. The frequency of navigation (first) was dominantly high, accounting for approximately 9% of all keywords (101 times). This indicated that the navigational aspect of the MASS is a major interest; navigation control and navigation management were mainly mentioned. The frequencies of five keywords were similar, i.e., technology (42 times), system (33 times), unmanned (32 times), liability (32 times), and development (31 times). This result suggested that both technology and liability are major interests.

4. Conclusion

After a significant crisis in the shipbuilding industry, industry experts are carefully predicting an economic recovery centered on eco-friendly ships and liquid natural gas ships. MASS developers are also concentrating on technology developments, to become shipbuilding powerhouses by treating the current paradigm of the shipbuilding industry as an opportunity. Therefore, it is time to establish policies and development strategies while considering industrial characteristics, to thereby realize innovative growth in technologies in the shipbuilding and shipping industries concerning MASS.

Therefore, in this study, recent domestic and international industry and technology trends were analyzed based on previous studies and data obtained from research and discussion, and simple and plain questions were composed based on the priorities of AHP results from the Korea Maritime Institute. In addition, individual in-depth interviews were conducted with experts from private companies, universities, and research institutes related to the shipbuilding industry, to gather the free opinions of experts based on their experience and knowledge.

According to the interview results, the experts presented the same opinion: the autonomous navigation, control, and maintenance technologies of MASS are essential elements. They also insisted that technology developments for safe navigation (avoidance technology), economic navigation (optimal route), and automatic maintenance (self-problem solving) must occur before autonomous navigation can be implemented, and that we must participate in the early stages of the IMO’s preparation of performance, design, and production standards. In addition, they claimed that technology developments and demonstrations in the engine sector (such as electric propulsion engines and battery technologies) need to be promoted systematically. They also noted the criticality of various sensor and analysis technologies for effectively monitoring the status of components and equipment. Regarding cyberterrorism and security systems, the industry, academic, and research experts presented different opinions. However, they emphasized the current serious risks in ship security, and presented opinions from a macroscopic perspective regarding the construction of cybersecurity systems and preparations for the safety management service industry, including ship data encryption for data security between ships and land.

Furthermore, regarding the changes in the types and liabilities of marine accidents, they acknowledged the difficulties in predicting various marine accidents. However, they indicated that we must prepare for occurrences of collision accidents, owing to failures in ship control around ports owing to human error (such as the recent collision of a Russian cargo ship with the Gawngan Daegyo Bridge). They also indicated the need to develop technologies to overcome the frequently-changing marine environment, such as outboard hazard detection technology based on multiple sensor information.

In addition, the experts indicated that we should actively participate in the international discussion regarding the regulation scope under the initiative of the IMO and establish strategies for future domestic industry. We must secure seaworthiness for the safe operation of ships in terms of ship security systems and the changing types of marine accidents, establish a land support system and ship security system for unmanned ships, and develop new types of ship safety equipment and devices.

In this study, individual in-depth interviews were conducted with experts in the corresponding fields, to collect opinions on the technical issues regarding the introduction of Mass. However, owing to the limited time of the experts, the interviews took a significant amount of time, and the interview periods were somewhat dispersed. As a result, the in-depth interviews did not proceed as intended. Therefore, in the future, we need to prepare in advance to allow the experts to express their opinions sufficiently on the given questions, e.g., by contacting the interviewees in advance. However, despite these limitations, the present study is meaningful, in that it provides practical suggestions for technology policies by collecting and analyzing opinions from experts in the shipbuilding industry, with the world's best technology.

Author Contributions

Conceptualization, Y. G. Lee and Y. S. Ock; methodology, Y. G. Lee and Y. S. Ock; Software, Y. G. Lee ; Formal Analysis, Y. G. Lee ; Investigation, Y. G. Lee ; Writing-Original Draft Preparation, Y. G. Lee ; Writing-Review & Editing,Y. G. Lee and J. C. Bae; Supervision, Y. S. Ock; Funding Acquisition, All Authors.

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