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Development of a Designation System for Supercomputing Specialized Centers by Application Field

Hyungwook Shim and Jaegyoon Hahm*
National Supercomputer Department, Korea Institute of Science and Technology Information, Daejeon, Republic of Korea
shw@kisti.re.kr, jaehahm@kisti.re.kr

Abstract
This study identified institutional gaps and improvement measures to correlate the "3rd Supercomputing Fostering Master Plan" established in 2023 with lower-level implementation plans. Institutional gaps were identified through matrix analysis of the major tasks. The analysis revealed the lack of planning for resource utilization, expansion of infrastructure, and dissemination of research results in the action plan. Hence, a joint utilization system should be established based on the law and a specialized center should be operated to establish specialized resources for each field. An evaluation system for the redesignation of a specialized center was selected as a necessary improvement. Evaluation items and points were adjusted through network centrality analysis using the existing evaluation result data. The improved evaluation model is expected to guide the development of a joint utilization system for supercomputers in Korea by enabling the effective redesignation of specialized centers. We plan an evaluation to determine whether to redesignate the seven specialized centers in Korea by applying the results of this study.

Category: Cloud Computing / High Performance Computing

Keywords: Supercomputer; Master plan; Innovation strategy; Comparative analysis; Roadmap; Matrix

I. INTRODUCTION

In 2023, the "3rd National Supercomputing Fostering Master Plan" (referred to as the "Master Plan"), the highest statutory plan in the supercomputing field in Korea, was established. Unlike the previous "2nd Master Plan," the latest master plan proposed new key directions and strategies in areas such as resource construction and utilization, technology development, and human resources. At a time when it is necessary to revise and supplement the sub-implementation plans established based on the "2nd Master Plan," the government must improve the "National Supercomputing Innovation Strategy" (hereinafter referred to as "Innovation Strategy"), which serves as a guide for the national supercomputing industry. This Innovation Strategy is the first mid- to long-term roadmap established by the Ministry of Science and ICT to expand supercomputer resources, which form the core equipment for the future competitiveness of the country in the technology sector, and to dominate key technologies and foster experts. All government research and development (R&D) projects related to supercomputers are undertaken based on this roadmap, and tasks are promoted sequentially according to the priorities of the technology classification system and strategy presented in the roadmap. It also presents the macro-governance and micro-collaboration systems of the domestic industry. The improvement plan for the "Innovation Strategy" is to find institutional gaps

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*Corresponding Author

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in major tasks presented in the “3rd Master Plan.” A gap refers to a case where there is no specific action plan for major tasks of the “3rd Master Plan” or the related content is contrary to the strategic direction.

The remaining part of this paper is organized as follows. Sections I and II explain the academic value of this study based on the background and previous research. Section III provides an overview of Korea's supercomputing policy governance. Sections IV and V describe the details of the “National Supercomputing Master Plan” and “National Supercomputing Innovation Strategy” and derive the institutional gaps. Section VI explains the methodology for improving the reassignment evaluation system, and Section VII presents a case study. Finally, Section VIII summarizes the results and their implications. It also clarifies the limitations of this study and proposes plans for future research.

II. LITERATURE REVIEW

Most studies on supercomputer-related evaluation systems focus on system performance. Jackson et al. [1] evaluated the performance of supercomputer applications in a cloud environment. Veiga et al. [2] evaluated the writing performance and energy efficiency of MapReduce programs. Hu et al. [3] proposed a supercomputing development index (SCDI) to evaluate the effect of supercomputing in situations where only the performance of the existing supercomputer is being evaluated. The SCDI quantitatively evaluates the degree of supercomputing development and proves the rationality of the evaluation indicator system using data collected from 130 Chinese institutions. Additionally, evaluation studies have been conducted in the supercomputer industry. Kim et al. [4] estimated the annual and future economic values based on the supercomputing demand of small and medium-sized enterprises (SMEs). Regarding economic value, the reduction in the development time, cost, and market preoccupation were selected as direct values, and indirect values were estimated using an industry correlation analysis. Economic value estimation suggests the necessity of discovering service models for domestic SMEs, inducing the participation of potential companies, and continuously expanding the list of beneficiary companies. Ko et al. [5] analyzed the economic ripple effect of the supercomputing simulation sector on other sectors using data from the Bank of Korea. Regarding the ripple effect, the production, value addition, and employment inducement effects were estimated for Korean manufacturers based on the supercomputing simulation budget of the National Supercomputing Center (Korea Institute of Science and Technology Information).

Thus far, in the field of supercomputing, few studies have been conducted to correlate upper- and lower-level policies. Moreover, most studies on evaluation systems have focused on the system’s performance. In Korea, this is because the policy has been implemented only through the upper-level plan (Master Plan), and the lower-level plan (Innovation Strategy) was first established as late as 2021. However, as the standard of the upper-level plan increased in 2023, improvements to the lower-level plan became necessary. Therefore, this study is the first to correlate the upper- and lower-level policies targeting the redesignation evaluation system related to the operation of a specialized center.

III. SUPERCOMPUTING POLICY GOVERNANCE

As shown in Fig. 1, domestic supercomputing policy governance is based on the “Act on Utilization and Fostering of National Supercomputers” (referred to as the “Supercomputing Act”), the highest degree in supercomputing established in 2011. Enforcement decrees and rules exist under the “Supercomputing Act,” which focuses on the national supercomputing fostering and development promotion system, laying of a solid foundation, and vitalization for efficient construction and systematic management of national supercomputers. The “Master Plan” and the annual “Implementation Plan” were established based on the “Supercomputing Act.” The “Master Plan” is established every 5 years; it includes the basic direction and goals of the national supercomputing fostering policy and matters related to securing/distributing/jointly utilizing resources. The “Implementation Plan” includes the performance of the previous year and the action plan for the following year and is subject to submission by the national center and specialized centers. Apart from the above plan, an “Innovation Strategy” was established in 2021. This plan was established to respond preemptively to the exascale technology transition period and lack of mid-to-long-term implementation strategies in the existing plans. According to this model, subordinate statutes and plans must be based on the “Master Plan,” and continuous revision is required to efficiently promote tasks and generate effective results [6].

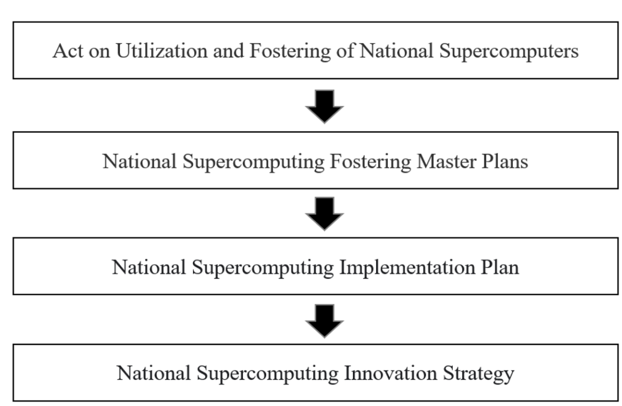

Fig. 1. Policy governance.

A. Third National Supercomputing Fostering Master Plan

The "Master Plan" involves four directions of promotion: leadership in technology, enhanced commercial utilization of supercomputing, total amount of national resources, and creation of professional manpower. The first direction is to promote leading global technologies in the country. The second direction is to increase the number of companies using supercomputers in the country. The third direction is to expand the number of national resources to a world-class level. The final direction is to produce skilled professionals in developing, operating, and using supercomputing technologies. These main directions were divided into 10 strategies, including technological independence in supercomputing, advancement of application support systems,

Table 1. Master plan promotion tasks [7]

Direction	Strategy	Task
1. Leap forward as a technological powerhouse	1.1 Promotion of technology independence in supercomputing	1.1.1 Promoting the establishment of a supercomputing system using own technology
		1.1.2 Narrowing the next-generation computing technology gap and securing future technology capabilities
	1.2 Establishment of foundation for industrial growth	1.2.1 Creating government-led demand for dissemination of R&D achievements
		1.2.2 Promotion Support of commercialization for market development of domestic technology
2. Innovation support by application field	2.1 Advancement of Utilization Support System	2.1.1 Reorganization of the support system to expand the use of national supercomputing
		2.1.2 Development and distribution of supercomputing application software
	2.2 Innovative usability and creation	2.2.1 Expansion of use to solve public and individual issues
		2.2.2 Fostering new growth engines and expanding support for large-scale public research
	2.3 Industrial utilization support	2.3.1 Development and dissemination of supercomputing utilization technology leading to digital transformation
		2.3.2 Fostering specialized industries to support the use of supercomputing by various companies and researchers
3. Strengthening access to supercomputing	3.1 Expansion of supercomputing infrastructure	3.1.1 Establishment of world-class national center for supercomputing resources
		3.1.2 Building specialized centers for each field to provide specialized services
		3.1.3 Reinforcement of supercomputing linkage infrastructure
	3.2 Establishment of a national joint utilization service system	3.2.1 Establishment of user-customized one-stop co-utilization service system and platform
		3.2.2 Expanding the base of joint utilization by improving the supercomputing equipment introduction system
4. Establishment of Industry Ecosystem Foundation	4.1 Nurturing skilled personnel	4.1.1 Implementation of professional education to produce talented people with theoretical and practical knowledge
		4.1.2 Vitalization of competency-building programs to improve the expertise of field personnel
	4.2 Expansion of supercomputing manpower	4.2.1 Expansion of learning experience opportunities to meet the demand of future generations
		4.2.2 Promotion of scientific and cultural activities to spread awareness on supercomputing
	4.3 Formation of research base	4.3.1 Establishment of a collaboration platform to vitalize industry- and university-affiliated community exchanges
		4.3.2 Securing ecosystem status data for effective policy establishment

infrastructure expansion, and cultivation of skilled talent. A summary of the results is presented in Table 1 [7]. These tasks are discussed in detail below.

1) Leap Forward as a Technological Powerhouse

The policy direction of the goal "leap forward as a technological powerhouse" focuses on making Korea a technological powerhouse. The related tasks can be divided into two categories: supercomputing technology independence and the creation of an industrial growth foundation. Technology-independent promotion involves building a supercomputing system by applying its technology, preparing a long-term technology-independence roadmap, and securing a heterogeneous, low-power hardware (HW) technology for exascale computing. To promote independent system development led by the industry, an industry–academia–research institute consortium was formed. The first stage was elemental technology and system integration, and the second stage was the development of its system. In addition, to bridge the gap in the next-generation computing technology and secure future technology capabilities, we plan to develop quantum-computing source technology and conduct empirical research on six items by 2035. To create a foundation for industrial growth, domestically developed products were first introduced into government projects and then transferred to developing countries overseas to spread the results of government-led R&D. An industry–academia–research ecosystem was created by matching demand and supply through a network comprising companies and researchers. Commercialization was promoted by preparing a test certification system for products developed with new technologies.

2) Innovation Support by Application Field

The policy direction of the performance goal "innovation support by application field" supports innovation based on the field of utilization. The related tasks can be divided into advancement of the utilization support system, creation of innovative utilization results, and support for the vitalization of technology utilization in the industry. During upgrade of the utilization support system, the allocation of national center resources is planned to be strategically divided into four categories: basic source, public society limit, industrial use, and joint use, and the selection evaluation system for R&D tasks is improved. In addition, it plans to develop software (SW) optimized for the exacomputing system and customized for emerging fields, such as medical biology, drug development, and energy environment. To ensure innovative utilization results, we plan to create solutions for pending public and individual issues and expand dedicated projects that utilize supercomputing. The expansion of challenging R&D centered on specialized centers and creating representative achievements to discover and nurture new growth engines is another focus area. Finally, to support the vitalization of industrial use, the policy plans to disseminate the modeling & simulation (M&S) technology in the manufacturing industry using artificial intelligence (AI) and deep learning. It plans to develop core technologies, such as simulation complexity reduction techniques and user interfaces, to discover potential demands related to digital twin technology, such as in healthcare, energy, construction, and national defense, and to develop and disseminate technology according to the demand.

3) Strengthening Access to Supercomputing

The policy direction of "strengthening access to supercomputing" is to strengthen access to ultra-high-performance computing resources. The related tasks can be divided into expansion of supercomputing infrastructure and establishment of a national joint utilization service system. In terms of supercomputing infrastructure expansion, the 6th supercomputer (600PF) will be built by 2023 to expand the technological capability of the national center, and business planning for the introduction of the 7th supercomputer will begin in 2025. Specialized centers should be established for each field to provide specialized services. By utilizing the resources of the specialized center at the level of approximately 490PF, customized services are provided by diversifying resource types, such as CPU-centered, GPU-centered, CPU-only, and GPU-only. To strengthen the connectivity of the supercomputing infrastructure, the research network will be advanced, and integrated storage will be established. Further, to establish a national joint utilization service system, a one-stop service for cloud-based technical support will be provided and the concept of joint utilization will be expanded by improving the supercomputing equipment introduction system.

4) Establishment of Foundation of Industry–Academia–Research Institute Ecosystem

The policy direction for the performance goal "establishment of industry–academia–research institute ecosystem foundation" supports the establishment of the foundation for the ecosystem. The related promotion tasks are divided as follows: (i) fostering excellent talent with expertise, (ii) expanding the base of supercomputing manpower, and (iii) creating a research base. Regarding the cultivation of excellent talent, a supercomputer graduate school has been newly established to provide opportunities to secure hands-on experience, produce talent with both theoretical and practical knowledge, and provide educational programs to develop the professionalism of field personnel. Career path management for researchers is also supported. Expanding the human resource base provides an opportunity to attract future generations by preparing a suitable curriculum for elementary, middle, and high schools, and expanding out-of-town youth experience programs. Other approaches include discovering publicity content and promoting popularization through online and offline publicity and exhibitions in science and cultural spaces. To create a research base, a comprehensive evaluation index system to check the effectiveness of related policies was established using "the Korea Supercomputing Forum." The objective is to manage the quality of statistical data based on fact-finding surveys and promote the designation of nationally approved statistics.

B. National Supercomputing Innovation Strategy

The goals of the Innovation Strategy are presented as quantitative figures for the three areas of computing power, discovery of leading technologies, and creation of new services. The number of new services created was set to 10. This goal focuses on the 10 national strategic areas shown in Table 2, such as material/nano and ICT (information and communication technology), and plans to create an ecosystem for mutual growth, such as the designation of specialized centers, development of specialized technologies, and research on the development and utilization of software in the areas of infrastructure and technology [8].

Table 2. Ten national strategic areas

Material/nano
Life/health
ICT (information and communication technology)
Weather/climate/environment
Autonomous driving
Space
Nuclear fusion/accelerator
Manufacturing base technology
Disaster
Defense security

Table 3. Key tasks

Direction	Strategy	Task
1. Strategic infrastructure expansion	1.1 Fostering a national center equipped with world-class infrastructure	1.1.1 Establishment and operation of national flagship supercomputer
		1.1.2 Expansion of small-scale supercomputer operation
		1.1.3 Establishment of an integrated operating system for supercomputing resources
	1.2 Designation and development of specialized centers by field	1.2.1 Designation of specialized centers
		1.2.2 Operation of supercomputing center incubation program
	1.3 Establishment of Supercomputing Resource Joint Utilization System 2.0	1.3.1 Establishment of supercomputer joint utilization system
		1.3.2 Building a supercomputing data hub
2. Securing independent technology and laying the foundation for industrialization	2.1 Securing core original technology based on strategic technology portfolio	2.1.1 Development of strategic technologies in four areas: processor, platform technology, data-intensive technology, and application-based technology
	2.2 Development and construction of an exaclass supercomputer with its processor	2.2.1 Independent development and construction of full exaclass supercomputer system using own parts, such as processor
	2.3 Eliminating barriers to technology commercialization and establishing a foundation for sustainable growth	2.3.1 Pilot introduction and diffusion of domestically developed products
		2.3.2 Demand–supply linkage new technology/new product development support
		2.3.3 Improvement of reliability of domestic parts, etc.
3. Activation of innovative utilization	3.1 Reinforcing demand-tailored support centered on national strategic areas	3.1.1 Strategic support for national supercomputing resources
		3.1.2 Customer-customized support
		3.1.3 Building a customized service environment
	3.2 Building an open utilization ecosystem based on expertise	3.2.1 Provision of specialized application SW development/sharing service
		3.2.2 Fostering supercomputing R&D service industry
		3.2.3 Fostering specialized manpower for supercomputing

As shown in Table 3, three key directions were selected: strategic infrastructure expansion, independent technological prowess and industrialization, and active utilization of innovation.

1) Strategic Infrastructure Expansion

Regarding the strategic infrastructure expansion task, the first supercomputing ecosystem is systematized into a national center, a specialized center, and unit centers. The national center manages world-class resources and the joint utilization and operation of advanced research networks, whereas the specialized center supports the establishment and operation of resources through field and applied research. Specialized and unit centers are selected through a designation review conducted by the Ministry of Science and ICT. The unit center is an independent supercomputing center operated by an individual research institute or company, and operates and manages the demand from resource-operating organizations and companies. The national center plans to expand into the world's 5th-class infrastructure by 2030, and the number of specialized and unit centers will increase to 10 and 60, respectively. Supercomputers 6 and 7 were built as flagship resources. Unit 6 is scheduled to commence in December 2023 and will operate until 2027. Unit 7 is an exascale resource and business planning is underway to build it by 2028. A system for the joint utilization of supercomputing resources will also established. The joint utilization system utilizes the resources of national centers, specialized centers, and unit centers as joint resources at the national level, and provides integrated services by applying a cloud-based platform.

2) Securing Independent Technology and Laying the Foundation for Industrialization

To secure independent technology and lay the groundwork for industrialization, a strategic technology portfolio was established for technology leadership. It derives 24-core technologies for supercomputing, and prepares detailed promotional strategies for four areas: processor, platform technology, data-intensive technology, and application-based technology. We plan to secure independent chip design and manufacturing capabilities with open ISA-based CPU cores for processors by 2030, to foster supercomputer manufacturing companies such as Cray Inc. (United States), main board design and manufacturing technology, high-density packaging, and development of system-based technologies. Data-intensive technology involves the development of core technologies for managing and processing data, such as memory management, parallel file systems, and AI framework technologies, based on the technological competitiveness of memory semiconductors. Finally, utilization-based technology focuses on developing core-based SW such as exascale numerical libraries and programming models.

3) Activation of Innovative Utilization

The task of revitalizing innovative use is to derive 10 strategic areas that have a large ripple effect by using supercomputing and to promote customized support for the demands of the industry–academia–research institute in consideration of future demands and trends. In addition, we intend to prepare data management regulations to allow private companies to safely use public infrastructure, strengthen security technology systems, and establish a one-stop service system that enhances user accessibility.

IV. COMPARATIVE ANALYSIS RESULTS

A. Institutional Gap

The tasks of the “Master Plan” and “Innovation Strategy” were compared. The standards for the comparison were set based on the similarity between the tasks of the “Master Plan” and those of the “Innovation Strategy,” and the level of correlation was evaluated. Table 4 presents the results of the analysis. Overall, most of the “Master Plan” tasks were included in the “Innovation Strategy,” showing a certain level of correlation. However, for some

Table 4. Results of detailed comparison analysis

Master plan	Innovation strategy	Institutional gap
1.1.2 Narrowing the next-generation computing technology gap and securing future technology capabilities	-	Absence of content on quantum computing in the innovation strategy
2.2.1 Expansion of use to solve public and individual issues	-	Absence of a plan to expand the utilization of social issues within the innovation strategy
3.2.2 Expanding the base of joint utilization by improving the supercomputing equipment introduction system	-	Absence of information on improving the equipment introduction system in the innovation strategy
4.2.2 Promotion of scientific and cultural activities to spread awareness on supercomputing	-	Absence of science and cultural activities within the innovation strategy
4.3.1 Establishment of a collaboration platform to vitalize industry- and university-affiliated community exchanges	-	Absence of plans to promote industry- and academia-related community exchanges within the innovation strategy

promotional tasks, the contents not included in the “Innovation Strategy” were derived. The contents related to “Master Plan” tasks 1.1.2, 2.2.1, 3.2.2, 4.2.2, and 4.3.1 were insufficient in the “Innovation Strategy.” The “Master Plan” contained plans to secure materials, HW, system SW, and algorithm technology for quantum computers by 2035 to secure next-generation computing technology, but the “Innovation Strategy” was limited to supercomputers and does not contain information about quantum computers. To improve the usability of supercomputers, the “Master Plan” includes using it as an alternative for solving problems related to people's lives, such as weather, health, marine, and national defense fields. Regarding the introduction of supercomputer-related equipment, the “Master Plan” included information on institutional improvement, but the “Innovation Strategy” lacks relevant content. Finally, a strategy for establishing an open utilization ecosystem for science, cultural activities, and community exchange was available; however, the details are insufficient.

B. Improvement Plans

In the previous section, we identified institutional gaps. Excluding 1.1.2, the remaining four tasks must be implemented by a specialized center that constitutes the joint utilization system, and these can be improved through the operation of the specialized center. Therefore, according to Article 9-2 of the Supercomputing Act, specialized centers must build computing resources for each field and provide related services. Additionally, efforts should be made to revitalize supercomputers by conducting basic and applied research and disseminating the research results. The legal implementation matters of the specialized center are related to most of the main contents of this law, including Master Plan 3.2.2 (construction of resources), 2.2.1, 4.2.2 (basic/applied research), and 4.3.1 (diffusion of research results). Therefore, the government is making efforts to operate an efficient specialized center to improve the completeness of policy governance. The best way to achieve this with superior performance is to designate an institution as a specialized center. To achieve this, the government introduced a reasonable evaluation system that is based on several evaluation results [9]. When evaluating the redesignation of a specialized center for the first time, it is important to set appropriate evaluation indicators and point distributions.

V. EVALUATION SYSTEM FOR DESIGNATION OF SPECIALIZED CENTER

A specialized center is designated based on the evaluation system. Every 5 years, comprehensive evaluations are conducted, and centers that received a score of 70 or more in the comprehensive evaluation were re-designated. The design procedure is illustrated in Fig. 2.

The evaluation items are listed in Table 5. The items for designation are related to performance, validity of operation purpose and plan, suitability of center manpower, facility, and equipment securement plan. The comprehensive evaluation items for redesignation are goal achievement (mid), operational performance (mid), internal and external collaboration performance (mid), operational performance (final), publicity, and joint utilization performance. Operational achievement (mid), operational performance (mid), and internal and external collaboration performance (mid), which are the evaluation items for the comprehensive evaluation, are related to mid-evaluation.

A comprehensive evaluation of the redesignation must be linked to the preceding evaluation. This is because the operational performance in a comprehensive evaluation is influenced by the initially designated evaluation items, such as business promotion plans, manpower, and

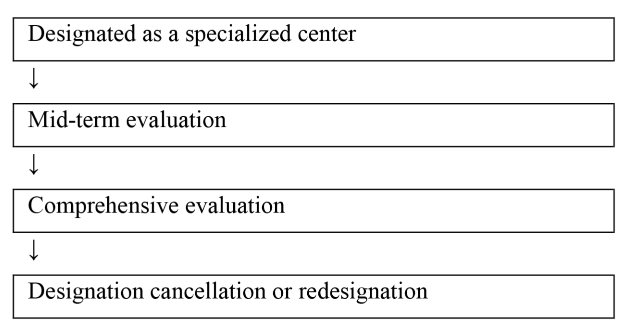

Fig. 2. Evaluation system.

Table 5. Evaluation items

Designated evaluation		Comprehensive evaluation	
Item	Points	Item	Points
Related performance	20	Goal achievement (Mid)	20
Validity of operation purpose and plan	40	Operational performance (Mid)	16
Suitability of center manpower	20	Internal and external collaboration performance (Mid)	4
Facility and equipment securing plan	20	Operational performance (Final)	40
-	-	Joint utilization performance	20

infrastructure operation plans. In addition, because the redesignation evaluation should re-evaluate whether the institution can continue as a specialized center during the next operating period, it is necessary to evaluate whether the next operating plan can be appropriately established. Therefore, it is necessary to improve the joint utilization system evaluation model to ensure full-cycle connectivity.

VI. METHODOLOGY

This study applied a network analysis methodology to improve the evaluation model, which is designated as a specialized center. The research procedure is illustrated in Fig. 3. First, the survey results are used to calculate the weight index and create a matrix. Subsequently, the matrix is applied to a network analysis to analyze the network strength and derive quantitative centrality values. Improved evaluation items and points are estimated by applying the proposed algorithm. Network analysis is performed again to review the improvement effect. Finally, a comparative analysis of the descriptive statistical results is performed.

Network analysis is a method of systematically evaluating and explaining the relationships and connection structures between objects. It is widely used in social sciences, engineering, and big data analysis because the complex relationships between objects can be mathematically quantified and visualized. Indicators representing network cohesion and centrality are typical measurement indicators used in network analysis; indicators of centralization and connectivity are also used. The indicators of solidarity include degree of connection, density, and inclusiveness, whereas representative centralities include connection, proximity, mediation, and prestige centrality. Centrality indicators are classified as shown in Table 6 according to analysis factors, such as the number of connections between nodes, distance, and route.

First, degree centrality indicates the extent to which a node is connected to other nodes around it; the higher the number of connected nodes, the higher the centrality. The mathematical expression for connectivity centrality is given by Eq. (1),

$$C(x) = \Sigma n(i)\,, \tag{1}$$

where $n(i)$ is the number of nodes connected to node i.

1. Network analysis of the existing evaluation model
- Calculate the weight index
- Create matrix
- Network visualization
- Network centrality value

↓

2. Derivation of the improvement model
- Evaluation item
- Evaluation index point

↓

3. Network analysis of the improvement model
- Calculate the weight index
- Create matrix
- Network visualization
- Network centrality value

↓

4. Comparative analysis of descriptive statistical results
- Standard deviation, variance, etc.

Fig. 3. Research procedure.

Closeness centrality is defined as the reciprocal of the sum of the minimum distances required to reach another node from one node; the shorter the distance between the nodes, the higher the centrality. The mathematical expression for proximity centrality is the same as in Eq. (2):

$$C(x) = 1/\Sigma_y d(y,\, x)\,. \tag{2}$$

where x and y are nodes and d is the distance between the nodes.

The betweenness centrality increases when a node is located on most of the paths between other nodes in the network. The mathematical expression is shown in Eq. (3):

$$C(x) = \Sigma_{s \neq v \neq t \in V} \frac{\sigma_{st}(v)}{\sigma_{st}}\,, \tag{3}$$

$\sigma_{st}(v)$ denotes the number of shortest paths between

Table 6. Types of network centrality

Type	Note
Degree centrality	Number of links incident upon a node
Betweenness centrality	Number of times a node acts as a bridge along the shortest path between two other nodes
Closeness centrality	Average length of the shortest path between a node and all other nodes in the graph
Eigenvector centrality	Assigns relative scores to all nodes in the network based on the concept that connections to high-scoring nodes contribute more to the score of the node

node s and node t that pass through node V.

Eigenvector centrality is a method for analyzing centrality by weighting the centrality of another node. The mathematical expression is the same as in Eq. (4):

$$C_i = \frac{1}{\lambda}\Sigma_j \alpha_{if} C_j, \qquad (4)$$

where i and j are nodes, α is the connection relationship between the nodes (“1” if nodes i and j are connected, “0” otherwise), C_i is the centrality of the node, and λ denotes the maximum eigenvalue of the matrix between the nodes i and j.

This study used eigenvector centrality indicators that weigh the importance of connected nodes among the various centrality indices in the network analysis. This is because it is necessary to consider the influence of breaststroke items linked to the designated and comprehensive evaluation items because the entire cycle evaluation system is considered. Unlike existing network analyses, this study applied new weights to each evaluation item. The reason for applying the weight was to reflect the distribution of points for each evaluation item in the existing network analysis for each evaluation point. Because network analysis represents the relationship between the evaluation items as a matrix consisting of only 0 and 1, it is necessary to derive a more accurate level of improvement by applying points that represent the quantitative levels. The weight W_N considers the distribution of points for each evaluation item and is calculated as shown in Eqs. (5) and (6):

$$d_N = \frac{N}{S_1}(N \rightarrow A \sim D),$$

$$d_N = \frac{N}{S_2}(N \rightarrow E \sim I), \qquad (5)$$

$$W_N = \frac{d_N}{\Sigma d_N}, \qquad (6)$$

where N is the score of the evaluation item, S_1 is the total score of the designated evaluation item, and S_2 is the total score of the comprehensive evaluation item.

The calculated weight is reflected in the matrix value, as shown in Eq. (7). V is the existing matrix value, and V_M is a matrix value that considers the weights.

$$V_M = W_N \cdot V. \qquad (7)$$

VII. CASE STUDY

A. Data

The data for the network analysis are listed in Table 7. The designated and comprehensive evaluation items were assigned codes from A to I, and the results of the inter-item correlation investigation were entered into the matrix shown in Fig. 4. The survey was conducted with 50 supercomputer experts participating in the joint utilization system; the matrix with a correlation between the evaluation items was marked with 1, and those with no connectivity were marked with 0. The network analysis programs used were UCINET6 and NetDraw.

Table 7. Dataset

Code	Evaluation item
A	Related performance
B	Validity of operation purpose and plan
C	Suitability of center manpower
D	Facility and equipment securement plan
E	Goal achievement (mid)
F	Operational performance (mid)
G	Internal and external collaboration performance (mid)
H	Operational performance (comprehensive)
I	Publicity and performance in the last year of the operating period

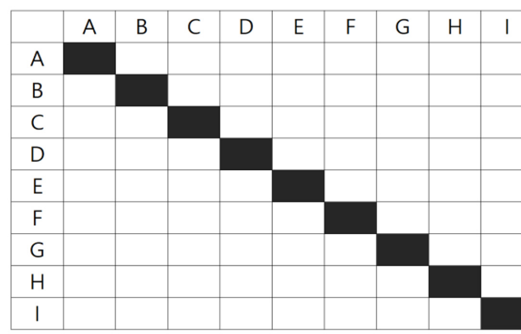

Fig. 4. Matrix.

B. Network Analysis Result

In network analysis, a matrix representing the relationships must first be derived. The matrix reflecting the results of the survey on the existing evaluation system and W_N (Table 8) is shown in Fig. 5.

Fig. 6 shows a schematic for the evaluation of the item network using this matrix. The lines indicate connections, and the thickness of a line indicates the strength of the connection. Item A is not strongly linked to other items. The items that were relatively strongly connected were C and D, which were all evaluation items in the designated evaluation. B was strongly connected to D, and the strength of the connection with the comprehensive evaluation items, such as F, E, and H, was also strong. However, the strength of the connection with the evaluation item I was relatively low. C showed a high connection strength with the comprehensive evaluation items E and F, and a low connection strength with I. D had a low connection strength with C and I, and showed a similar level of connection strength to the other items. E, the evaluation item of the comprehensive evaluation, was most strongly connected to H and showed relatively high connectivity to C, F, and G. F was most strongly linked to H and most weakly linked to A. G was very strongly connected to E, and H to F and E. I had the lowest connectivity with all evaluation items. The characteristics derived from the analysis results are as follows. Item A did not show any connection with the evaluation items of the comprehensive evaluation. According to the "operating guidelines," it denotes the performance before the designation; hence, the absence of a connection is expected. B had a correlation with the comprehensive evaluation items. Therefore, in the designated evaluation system, it was confirmed that the weight of the evaluation item B should be higher than that of the other evaluation items; this is reflected at an appropriate level in the operational guidelines. Similar to B, C also showed a connection with the comprehensive evaluation items, except with I, which was not correlated with any of the evaluation items. Therefore, I can be regarded as a relatively inappropriate evaluation item for redesignation.

Table 8. W_N list

N	W_N
A	0.2
B	0.4
C	0.2
D	0.2
E	0.2
F	0.16
G	0.04
H	0.4
I	0.2

	A	B	C	D	E	F	G	H	I
A		1	2	1	1	1	1	2	1
B			8	14	8	8	4	8	2
C				1	5	5	3	4	1
D					4	4	3	4	1
E						5	5	7	2
□F							3.2	4.8	1.6
G								0.6	0.2
H									2
I									

Fig. 5. Matrix results.

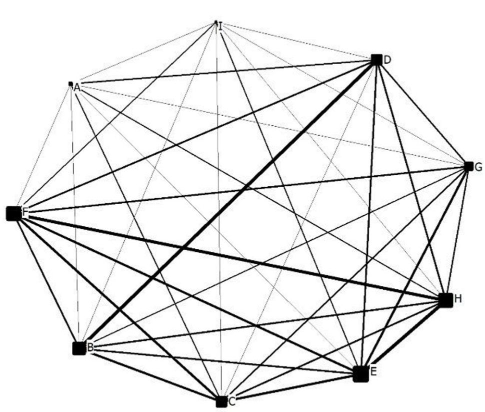

Fig. 6. Network of evaluation items.

A quantitative analysis was conducted using eigenvectors to derive improvement measures by considering the network characteristics. The eigenvector values and descriptive statistics for each evaluation item in the network are listed in Tables 9 and 10. The evaluation items were divided into three groups using the eigenvector values. Groups with a value of 2 or less with relatively low connection strength included A and I, and groups with a value of 2 or more and 4 or less with a medium level of connection strength included C, D, E, F, G, and H. B is an evaluation

Table 9. Eigenvector centrality value

Item	Value	Var
A	0.099	0.032
B	0.528	0.032
C	0.317	0.032
D	0.384	0.032
E	0.386	0.013
F	0.354	0.013
G	0.225	0.013
H	0.354	0.013
I	0.117	0.013

Table 10. Descriptive statistics

N	Min	Max	Sum	Average	SD	Distribution
9	0.117	0.528	2.764	0.307	0.138	0.019

item with a high connection strength, exceeding 4. Next, implications were derived using the eigenvector value for each evaluation item. Just like the results obtained by visualizing the network, the eigenvector values of A and I were very low, resulting in a relatively low influence on the evaluation model or independent items, with no linkage between the evaluation items. It is reasonable to exclude evaluation item A from the designated evaluation items, considering its linkage with the comprehensive evaluation. However, because necessity is an important criterion for evaluating the capacity of the applicant organization at the time of designation, it is appropriate to lower the score as an independent item, even if there is no linkage. However, in the case of I, it is judged that the necessity of evaluating the redesignation of the center is relatively low considering the promotion performance item of the final year. Furthermore, it is reasonable to exclude I because the promotion performance of the final year overlaps with the operational performance (entire period) of the evaluation item H. In the case of G, the value of 0.225 indicated a relatively low centrality. To analyze the cause of the low centrality of the evaluation item G, a second content review was conducted, targeting the respondents. Most respondents interpreted external cooperation as reduced to business agreements with overseas organizations. Therefore, it was considered necessary to change the name of the evaluation item G. The eigenvector variance value was calculated as 0.032 for the designated evaluation item and 0.013 for the comprehensive evaluation item, showing a difference of approximately 47% in the variance values of the two groups. Thus, it is necessary to adjust the evaluation items to improve them by using a balanced evaluation model. In addition, the maximum value of the eigenvector was derived as 0.528 for the designated evaluation item B. Through this, it was confirmed that the center of gravity of the specialized center designation evaluation was in the designated evaluation, and the necessity of changing the comprehensive evaluation items for redesignation as a specialized center was derived by improving the evaluation model.

C. Improvement Model Evaluation

The improved evaluation items are shown in Table 11. The comprehensive evaluation item I with a very low eigenvector value was excluded. Therefore, 20 points of I were assigned to E, F, G, and H according to the size of the centrality value. However, A was not excluded because it had an independent effect on the evaluation results. Next, an improved score was derived using the process shown in Fig. 7. First, the eigenvector value $E(i)$ for each evaluation item were derived. In the next step, $S(i)$ is calculated by standardizing the eigenvector value of each evaluation item. The sum of the $S(i)$ values for all items is 1. The points allocated to each existing evaluation item multiplied by $S(i)$, and $D(s)$ are then calculated. Again, the value of $D(s)$ is standardized and multiplied by the points allocated to each existing evaluation item to derive the final improved points allocated to each item.

The points allocated for improvement in each evaluation item are shown in Table 11. These are the results of the recalculation using the procedure in Fig. 7 based on the scores of each item in Table 5. The score for item A decreased from 20 points to 10 points, and that of B increased by 15 points to 55 points. The score for C decreased by 5

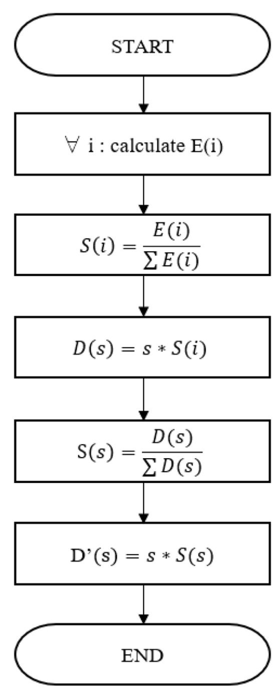

Fig. 7. Flowchart.

Table 11. Evaluation items

	Designated evaluation			Comprehensive evaluation	
	Item	Points		Item	Points
A	Related performance	10	E	Goal achievement (mid)	25
B	Validity of operation purpose and plan	55	F	Operational performance (mid)	20
C	Suitability of center manpower	15	G	Internal and external collaboration performance (mid)	45
D	Facility and equipment securing plan	20	H	Operational performance (comprehensive)	10

	A	B	C	D	E	F	G	H
A		2	2	1.5	1.5	1	0.5	4
B			4	10.5	6	4	1	8
C				1.5	7.5	5	1.5	8
D					6	4	1.5	8
E						5	2.5	14
F							2	12
G								6
H								

Fig. 8. Network of evaluation items.

points, whereas that of D remained unchanged. The score for E increased by 5 points from 20 to 25 points, whereas that of F increased by 4 points. G demonstrated the biggest change from 4 points to 45 points. This trend is consistent with the government's policy to strengthen international cooperation. In contrast, the score for H decreased significantly from 40 points to 10 points, which is believed to have occurred because of the evaluation index for intermediate performance.

To verify the effect of the improved evaluation items and point allocation, a network centrality analysis was conducted under the same conditions. The standard deviation and variance values were derived through a statistical analysis of the centrality values, and a quantitative value comparison was performed. The matrix that considers the improved evaluation items and the score distribution is shown in Fig. 8. W_N is the same as that listed in Table 12.

The eigenvector values of the evaluation items are listed in Table 13. These results are obtained using Eq. (4).

The eigenvector values of A, B, C, F, and G were lower than the previous values, whereas those of D, E, and H increased. H showed the largest increase, whereas G showed the largest decrease. A qualitative analysis of this confirmed that in the case of G, the evaluation range of E, F, and H as “internal and external collaboration performance (mid)” was relatively low, and it was improved to an appropriate level. H is the “operational performance” of the entire operating period and is the key evaluation item with the highest score in the comprehensive evaluation. From the analysis, the allotment of the peripheral evaluation items, which are related to most of the evaluation items, such as E, F, and G, and have a high linkage, indicating a high centrality. In addition, it was confirmed that the evaluation model improved as it expanded to a more comprehensive evaluation instead of focusing on the existing designated evaluation.

The descriptive statistics are presented in Table 14. It was confirmed that the network balance of the evaluation items improved to 5%–10% of the evaluation items when compared with the existing evaluation model, as both the standard deviation and variance values were reduced when compared with those of the previous evaluation model. The standard deviation and variance of centrality were lower than before, resulting in a more balanced model.

Table 12. W_N data

N	W_N
A	0.1
B	0.4
C	0.2
D	0.3
E	0.3
F	0.2
G	0.1
H	0.4

Table 13. Eigenvector centrality value

Item	Value
A	0.135
B	0.362
C	0.314
D	0.346
E	0.437
F	0.357
G	0.170
H	0.534

VIII. CONCLUSION

This study prepared a plan to improve the performance evaluation system for the redesignation of specialized centers related to the Korean supercomputer joint utilization system. Network analysis was performed on the evaluation items related to the redesignation evaluation, and the evaluation items and points were adjusted using the suggested algorithm. This analysis confirmed that the standard deviation and variance of the centrality values

Table 14. Descriptive statistics

	N	Min	Max	Sum	Average	SD	Distribution
Existing	9	0.117	0.528	2.764	0.307	0.138	0.019
Improvement	8	0.135	0.534	2.655	0.332	0.130	0.017

were reduced, resulting in a more balanced model. The improved evaluation model is expected to contribute to the establishment of a joint utilization system for supercomputers in Korea by enabling the redesignation of specialized centers fairly and effectively. In the future, we plan to promote follow-up verification and improvement of this evaluation model using the redesignation evaluation results and establish an evaluation system for the designation and redesignation of unit centers as a benchmark evaluation system for specialized centers.

Conflict of Interest(COI)

The authors have declared that no competing interests exist.

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Hyungwook Shim https://orcid.org/0000-000-8688-0309

Hyungwook Shim received a Ph.D. degree from Seoul National University, Republic of Korea, in 2021. He is a senior researcher at the Korea Institute of Science and Technology Information.

Jaegyoon Hahm

Jaegyoon Hahm received an M.S. degree in computer science from Korea Advanced Institute of Science and Technology, Republic of Korea, in 2002. He is a principal researcher at the Korea Institute of Science and Technology Information.