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Japan's 10th Technology Foresight: Insights and Enlightenment

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Abstract: Technology foresight is a systemic national science and technology policy that is consistently and effectively implemented in Japan. To date, Japan has implemented technology foresight research for 10 times, thereby meaningfully promoting research and development in science and technology, technological innovation and management abilities of Japanese companies, and a deep understanding of the development laws of technology. This study introduces the methodology, modes, implementation system, and survey process of Japan's 10th technology foresight, analyzes its experiences and problems, and provides references and guidelines for technology foresight in China.
Keywords: Japan; technology foresight; problem–solution mode; scenario planning; Delphi method

1 Overview of technology foresight in Japan

As the pioneer of technology foresight, Japan conducted its first national technology foresight survey in 1971 and became the first country to enable its government to organize and implement large-scale technology foresight. The survey is conducted every five years, wherein each survey corresponds to a time span of 30 years. As of 2016, Japan has conducted 10 technology foresight surveys to determine the direction and goals for technological development over the next 15 to 30 years, making it the most influential country in terms of technology foresight and setting an example for countries participating in technology foresight programs around the world.

The 10 technology foresight surveys were characterized by constant progress in terms of sophistication and influence, and can be roughly divided into three phases: i) the 1st–4th surveys in the nascent stage that highlight the increasing numbers of participating sectors and projects and the improvements in the classification structure; ii) the 5th–7th surveys in the growing stage that highlight more reasonable and perfect procedures of implementation corresponding to a higher level of sophistication of questionnaire design and participant screening; and iii) the 8th–10th surveys in the ripening stage that highlight a greater diversity of prediction techniques [1]. With respect to the 8th survey, requirement analysis, bibliometric analysis, and scenario analysis techniques are used in addition to the Delphi survey. Furthermore, a cross-disciplinary approach is adopted to address the topics in three basic fields, namely industrial infrastructure, social infrastructure, and social science and technology, with social topics accounting for one-fourth of the total science and technology topics. With respect to the 9th survey, regional workshops are held to look into regional innovation capabilities in addition to the Delphi survey and scenario analysis with an increased focus placed on the impact and contribution of science and technology to social development. The 10th survey is based on the problem-solving scenario planning [2] approach that highlights the integration of science and technology and innovation policies and uses the future vision, Delphi survey, and scenario analysis techniques for the scientific and accurate prediction of technological development.

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2 Main methods and paradigms for Japan's 10th technology foresight survey

2.1 Problem-solving scenario planning

The 10th technology foresight survey in Japan was conducted by the National Institute of Science and Technology Policy (NISTEP). The NISTEP adopted the problem-solving scenario approach at the beginning of the 10th technology foresight survey. The approach reviews instances with multiple options available to solve a challenge and identifies effective policy options while considering potential trade-offs in terms of the economic impact, financial strain, technological feasibility, obstacles in adoption, and societal acceptance. The problem-solving scenario planning approach works as follows: first, science and technology topics that are expected to be achieved in the future are identified based on research on future visions. These science and technology topics are then evaluated. Next, a future scenario is developed, and policy options are identified by combining a technology scenario and a social scenario to achieve the integration of science and technology policies with innovation policies (Fig. 1).

For example, in a society that experiences a population decline caused by the effect of the aging population, diabetes is one of the major diseases affecting the productivity of the labor force population (between 15 and 65 years of age classified as economically active as per population statistics). The potential science and technology policy options to solve this problem include: ① early treatment intervention based on imaging technology that captures microscopic changes in pancreatic β-cells and precognition technology of the manufacturer; ② late-stage treatment intervention options through regenerative medicine, such as pancreatic β-cell injection for regeneration; ③ a drug cost reduction option by replacing insulin with low-molecular drugs that can be mass-manufactured; and ④ preventive intervention option by developing preventive treatment technology, such as lifestyle coaching, including kinesiotherapy and dietary therapy. Fig. 2 and Fig. 3 present the problem-solving scenario planning and policy options.

2.2 Overview of the survey implementation

2.2.1 Survey objectives

The key objectives of Japan's 10th technology foresight survey include studying the development of science and technology development toward a target society in the future to contribute to the formulation of science, technology, and innovation-related policies and strategies and enhance the possibility of developing academic and industry roadmaps. Accordingly, opinions from experts with respect to the direction of medium- and long-term development (over the next 30 years) in science and technology and social systems required to realize the future society are collected and analyzed to achieve these objectives. Science and technology topics with high potential and significance in the future are identified based on the analysis.

2.2.2 Implementation structure

Fig. 4 presents the implementation structure of Japan's 10th technology foresight survey.

2.2.3 Overview of technology foresight

The period covered by Japan's 10th technology foresight survey is up to the year 2050. However, the target years correspond

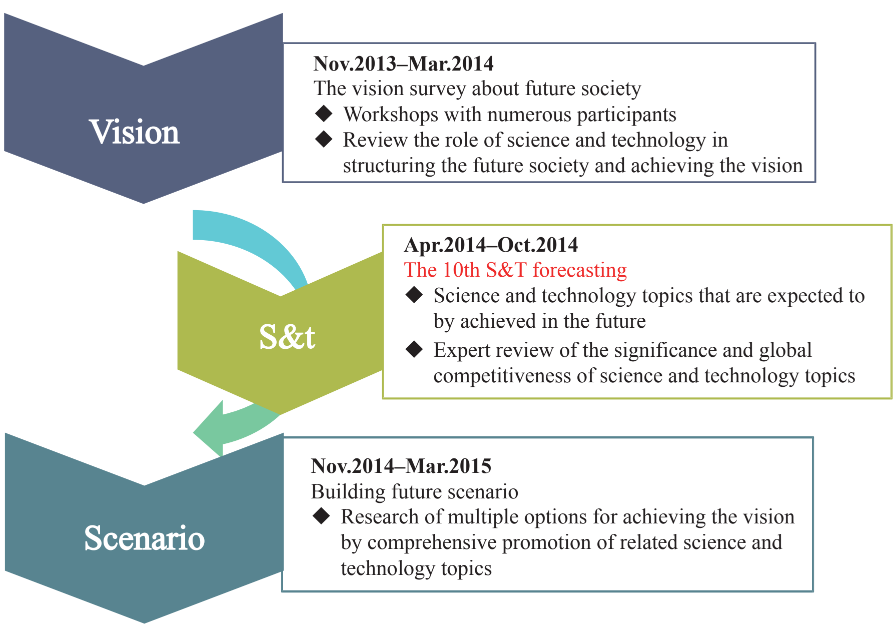

Fig. 1. Flowchart of the problem-solving scenario planning for Japan's 10th technology foresight survey.

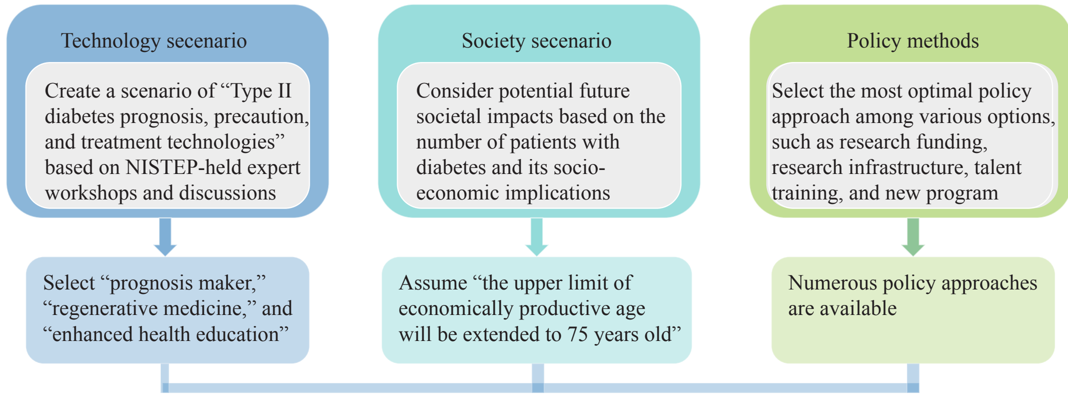

Fig. 2. Analysis of the problem-solving scenario.

Policy option 1	Investment in all technologicall development	30 billion Yen*1	The of realizing policy options 2–4	The of realizing policy options 2–4	Policy goal
Policy option 2	Targeted investment in the support of prognosis maker technology	10 billion Yen*1	Realized by 2020 or so	Adoption ratio 50 %*2	Policy goal
Policy option 3	Targeted investment in the support of regenerative treatment technology development	10 billion Yen*1	Realized by 2025 or so	Adoption ratio 15 %	Policy goal
Policy option 4	Targeted investment in helping eductation technology enhancement	10 billion Yen*1	Realized by 2020 or so	Adoption ratio 50 %	Policy goal
Policy option 5	No policy	-	-	-	

Fig. 3. Problem-solving policy options: *1total amount of investment based on an assumption (the annual investment amount remains the same from the assumption to the realization) and *2estimate (assuming that life-style improvement is observed among 50% of the maker users).

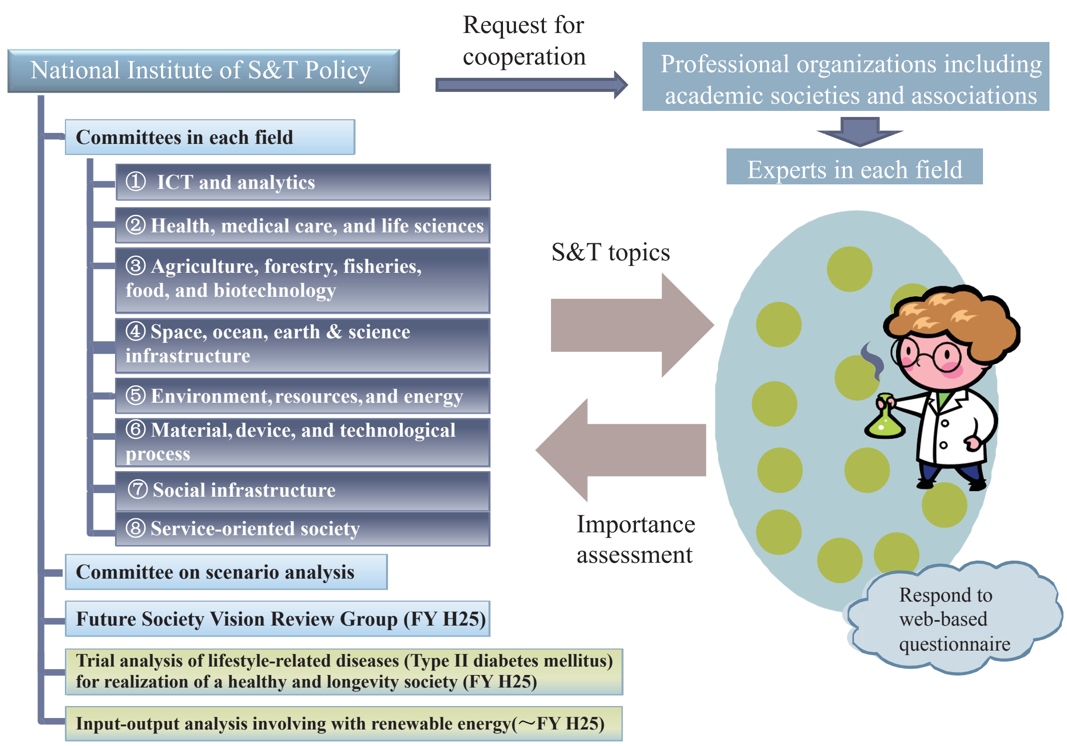

Fig. 4. Japan's 10th technological survey implementation structure.

to 2020, 2030, and 2050.

The eight covered fields are as follows: ① ICT and analytics; ② health, medical care, and life sciences; ③ agriculture, forestry, fisheries, food, and biotechnology; ④ space, ocean, earth, and science infrastructure; ⑤ environment, resources, and energy; ⑥ material, device, and technological process; ⑦ social infrastructure; and ⑧ service-oriented society. The committees discussed topics in each item, and a total of 932 topics were selected.

The technology foresight is centered on the Delphi survey. An online questionnaire survey was conducted from September 1 to September 30, 2014. The NISTEP asked approximately 2000 experts in the NISTEP expert network as well as members of related professional organizations to participate in the survey. Only 4 309 experts responded from a total of 5 237 registered experts. With respect to affiliation, 49.1% of the experts was from universities; 36.4% was from the business sector; and 14.5% was from the public sector. With respect to age, 30% of the experts was aged below 40 years; 26% was in the 40–49 year category; 22% was in the 50–59 year category; 12% was 60 years or above; and 10% was in the unknown age category.

2.3 Main questions in the questionnaire survey

The questionnaire considered R&D characteristics, predicted time of realization, and key measures (Tables 1–3).

3 Main results from Japan's 10th technology foresight survey

3.1 Analysis of R&D characteristics

Scores were computed based on the coded responses for each characteristic (Very high: 4; High: 3; Low: 2; Very low: 1). Figs. 5–9 represent the distributions of 310 topics of the top 1/3 main topics. The proportion of the main topics is shown based on the field.

3.2 Analysis of importance and global competitiveness

Science and technology topics are reviewed for their importance and global competitiveness based on the results of the questionnaire survey. For example, with respect to ICT and analytics (Fig. 10), items in "high-performance computing" (HPC) exhibit high importance and global competitiveness, while items in "cyber security" and "software" exhibit high importance albeit low global competitiveness.

For the field of health, medical care, and life sciences (Fig. 11), "regenerative medicine" shows high importance and global com-

Table 1. Design of the questionnaire on the R&D characteristics.

Project	Definition	Option
Importance	Comprehensively considering the importance from science, technology, and societal perspectives	Select one from Very high/High/Low/Very low Quantize response and calculate scores (Very high: 4; High: 3; Low: 2; Very low: 1)
Uncertainty	R&D process involves several stochastic elements that need to tolerate failures and consider multiple approaches	
Discontinuity	R&D results are not an extension of the current state, with market-destructive and innovative characteristics	
Morality	Morality and societal acceptance need to be considered during the R&D process	
Global competitiveness	Enabling Japan to exhibit global competitiveness over other countries	

Table 2. Design of the questionnaire on the predicted time of realization.

Project	Definition	Option
Technology realization	When a technology is expected to be realized (somewhere in the world, including Japan); when a technological environment is ready, such as the achievement of anticipated performance (e.g., when the prospect of technology development becomes clear during the R&D process in a laboratory); and when a theory or phenomenon becomes scientifically established in the case of fundamental science	Select one from Realized/To be realized/Not realized/Not sure
Social realization	When it is applied in Japanese society or internationally led by Japan; when the realized technology is available to be used as a product or service (or when it is widely available); and when a framework, ethical standard, value, or societal consensus is established in the case of non-science and technology topics	If "To be realized" is selected, then the additional question will involve asking the subject to identify the year between 2015 and 2050 when the technology will be realized.

Table 3. Design of the questionnaire of the pilot measures used by technological realization.

Project	Option
Measures that should be focused on for technological realization	Select one from Human resource strategy/Resource allocation/Internal and external collaboration and cooperation/Environment enhancement/Others
Measures that should be focused on for social realization	

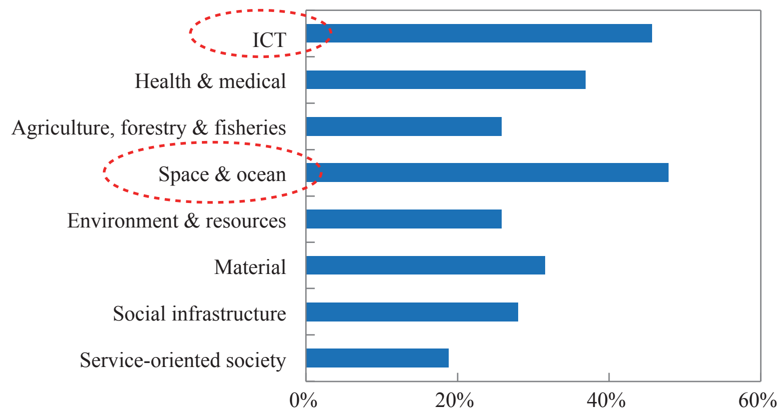

Fig. 5. Distribution of the top 1/3 topics in each field in importance.

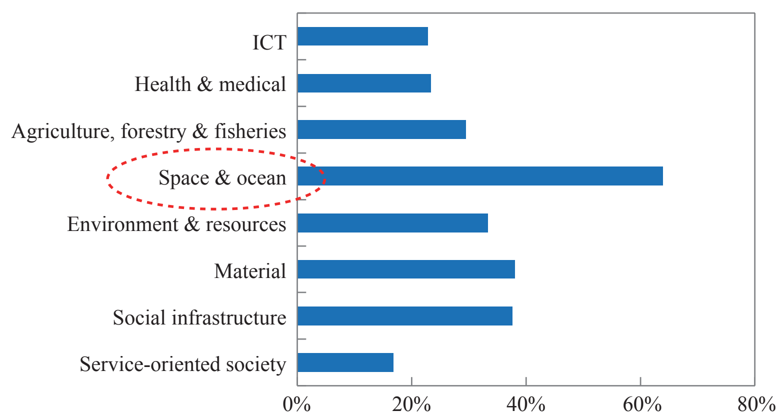

Fig. 6. Distribution of the top 1/3 topics in each field in global competitiveness.

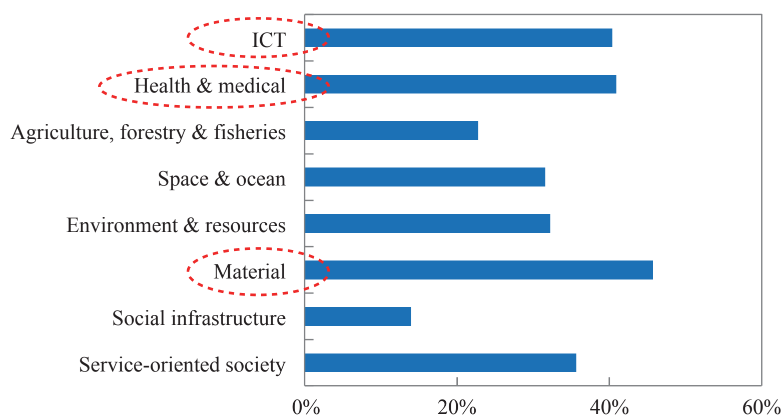

Fig. 7. Distribution of the top 1/3 topics in each field in uncertainty.

petitiveness, while "emerging and re-emerging infectious diseases" show high importance, but low global competitiveness.

Tables 4 and 5 present the top-rated topics identified in the survey.

3.3 Analysis of importance and discontinuity

The analysis of development trend and characteristics based on classification of science and technology items is an important purpose of technology foresight that is essential to science and technology policymaking. In this survey, the top 1/3 topics were compared and analyzed in terms of development potential, uncertainty, and discontinuity. Specifically, 312 topics with high importance (top 1/3 topics on the importance score) were examined with scores for uncertainty and discontinuity combined to extract topics within the primary 10% (30 topics) and secondary

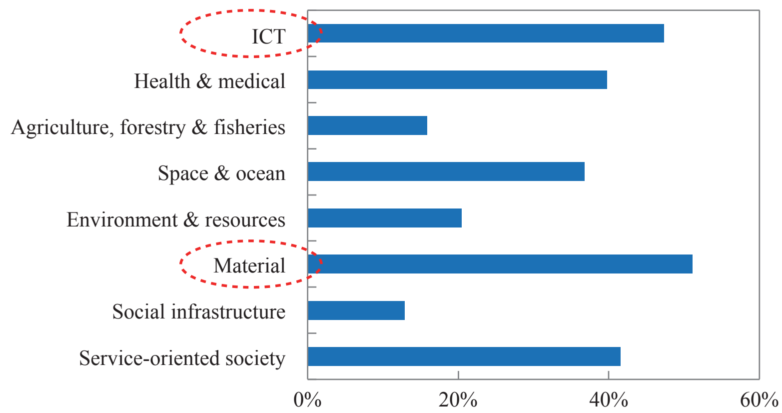

Fig. 8. Distribution of the top 1/3 topics in each field in discontinuity.

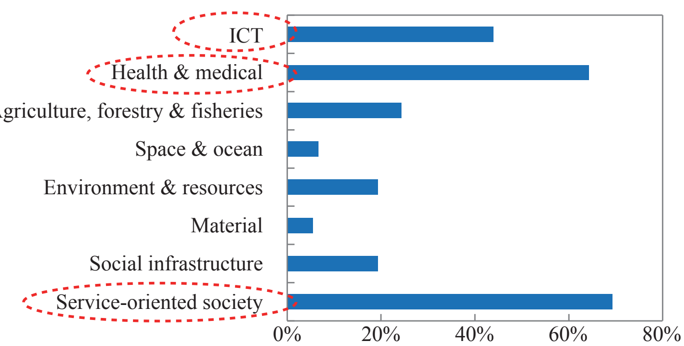

Fig. 9. Distribution of the top 1/3 topics in each field in morality.

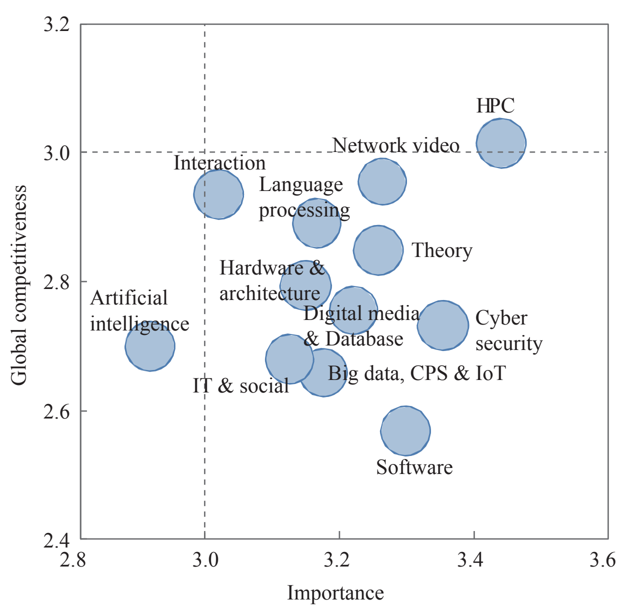

Fig. 10. ICT and analytics.

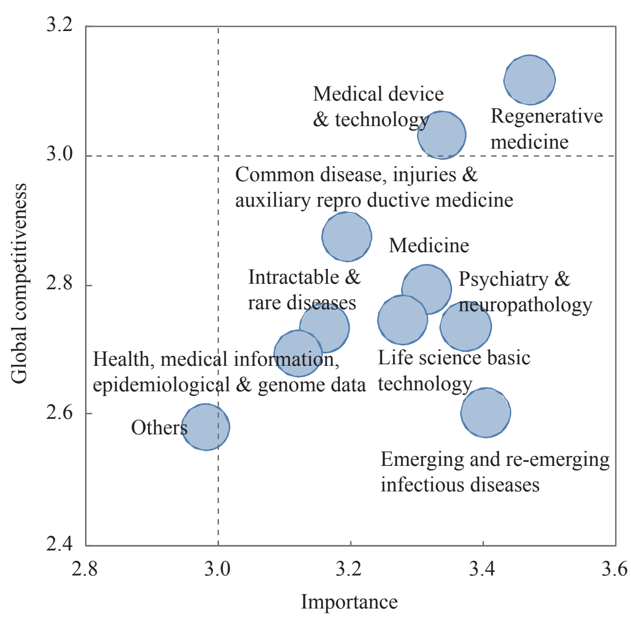

Fig. 11. Health, medical care, and life sciences.

10% (30 topics). Global competitiveness was considered to finalize the ranking of the above primary and secondary topics (Fig. 12).

Items with high importance were further divided into four categories:

Category I: relatively higher in uncertainty and discontinuity as well as in Japan's potential development (i.e., regenerative medicine, fuel cells and rechargeable battery for automobiles, and earthquake forecasting) (Table 6).

Category II: relatively higher in uncertainty and discontinuity

Table 4. Top 100 topics in importance–1

Field	Topic
ICT	Develop data utilization techniques with theoretically guaranteed preservation of privacy
ICT	Exclude the software development technologies, including the technology to remotely attack security holes
ICT	Technology to improve performance to the power ratio of super-large-scale supercomputers and big data IDC systems with more than 1 million nodes by a factor of 100 times when compared to the current systems
ICT	A low cost, easy-to-use, and secure personal authentication system that can be used with confidence even when many different websites are accessed over a long period
ICT	A health care system that monitors the condition of patients in real time to provide optimal nursing or medical care at a low cost
Health & medical care	A cheap and easy-to-introduce dementia care assistance system
Health & medical care	Medical technology to regenerate auditory and visual functions
Health & medical care	Preventative medicines that inhibit the development of carcinogenesis from a precancerous state
Agriculture, forestry & fisheries	Crops that are expected to produce a good harvest even in environments that are generally unsuitable for farming, such as deserts (arid regions)
Agriculture, forestry & fisheries	Technology to predict the variation in sardines, tuna, and other major fishery resources under different harvesting and long-term environmental conditions as well as technology for the proper management of fishery resources based on the prediction technology
Agriculture, forestry & fisheries	Technology to remove radioactive substances to revitalize fishing in coastal areas
Space & ocean	Urgency assessments for all active volcanoes to identify a volcano or volcanoes that are most likely to erupt in the near future

Table 5. Top 100 topics in importance–2.

Field	Topic
Space & ocean	Technology to observe local structure and electron state information essential to understanding the mechanisms for the functional expression of physical characteristics in functional materials and control of such properties at a nanometer-scale and femtosecond order
Space & ocean	Technology to predict the local occurrence of heavy rain, tornadoes, hail storms, lightning strikes, and snow that will occur for several hours in the future at a spatial resolution of less than 100 m using high-resolution simulation and data assimilation
Environment & resources	Mineral extraction and mining technology required to extract ocean mineral resources
Environment & resources	Predictive technology to assess the impact of global climate change on food production
Environment & resources	Technology of purification and recycling of contaminated water that is economical and generally available in developing countries
Material	A rechargeable automotive battery capable of a range of 500 km while maintaining the size and weight of the current batteries
Material	Integrated circuit technology to realize a performance level similar to that of the existing super computer with a single chip by improving the information processing capability without increasing the electricity consumption per unit area
Material	A simulation technology that can predict functions and physical property structures to hunt for. However, it instead predicts functions and properties after providing the structure itself
Social infrastructure	Low-emission and energy-efficient aircraft to realize noise reduction at takeoff and landing as well as gas emission reduction during the flight and achieve the goals of lowering the frictional resistance on the machine body and improving the combustion efficiency of the engine
Social infrastructure	Establishment of decommissioning and radioactive waste disposal technology for 1 million kW-class nuclear reactors
Service-oriented society	Generalization of robot inspection technology to inspect buildings or infrastructures that are more dangerous or costly for humans to inspect

while relatively lower in Japan's development potential (i.e., cyber security, mental disease, and infectious diseases) (Table 7).

Category III: relatively higher in certainty and continuity although relatively lower with respect to Japan's development potential (i.e., network technology, utilization of medical data, forestry, and surveillance) (Table 8).

Category IV: relatively higher in terms of certainty and continuity as well as Japan's development potential (i.e., electron beam application (material and treatment), high-efficiency power generation, and recycling of resources) (Table 9).

3.4 Analysis of key measures

Fig. 13 shows the statistical analysis results of the key

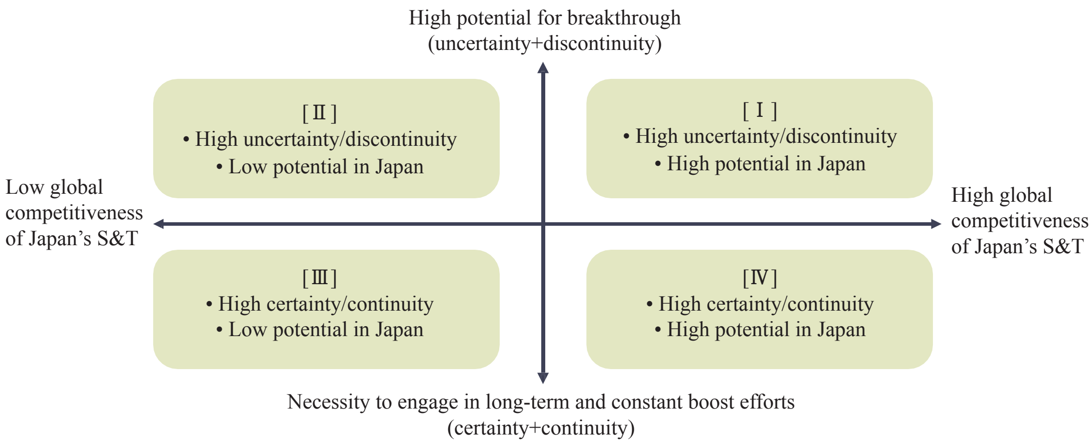

Fig. 12. Analysis of importance.

Table 6. Statistical results in Category I.

Field	Topic	Importance	Uncertainty	Discontinuity	Global competitiveness	Realization time (year)
ICT	A network node that uses the technology of nanophotonics to reduce the electricity consumed per unit of data transferred to 1/1000 of the current consumption level	3.5	3.0	2.9	3.2	2025–2030
Health & medical care	A comprehensive understanding of the reprogramming mechanism of differentiated cells	3.5	2.9	2.9	3.4	2023–2025
Health & medical care	Technology to create stem cells, such as an iPS cell, from differentiated cells irrespective of genetic transfer	3.5	3.0	2.9	3.2	2020–2025
Agriculture, forestry & fisheries	Technology to preserve perishable goods for approximately one week without refrigeration for use in logistics	3.6	3.0	2.8	3.3	2023–2025
Space & ocean	Prediction technologies for the timing (within a year), scale, affected regions, and damage of earthquakes exceeding magnitude 7 on the Richter scale	3.5	3.6	2.9	3.1	2030–2032
Space & ocean	Technology to predict the occurrence of large-scale earthquakes exceeding magnitude 8 on the Richter scale by analyzing the strain distribution on the Earth’s crust and the history of the past earthquakes	3.5	3.5	2.7	3.2	2030–2030
Material	Room-temperature superconducting materials that use strongly correlated electron systems	3.4	3.4	3.4	3.2	2030–2040
Materials	Solar cell with a conversion efficiency exceeding 50%	3.5	3.0	2.8	3.1	2025–2030
Materials	A rechargeable automotive battery capable of a range of 500 km (energy density exceeding 1 $kW{\cdot}h{\cdot}kg^{-1}$ and output density exceeding 1 $kW{\cdot}kg^{-1}$) while maintaining the size and weight of the current batteries	3.6	2.8	2.9	3.3	2025–2030
Materials	High-efficiency fuel cells for motor vehicles that do not use rare metals	3.6	3.0	3.0	3.3	2025–2030

measures identified in the technology foresight survey. As indicated, technology realization prioritizes human resource strategy and resource allocation. Fields that need to focus on human resource strategy for technology realization include ICT and analytics, materials, devices, and technological process. Social realization prioritizes collaboration/cooperation and environmental enhancement. The fields that must focus on environmental enhancement for social realization include social infrastructure and service-oriented societies.

Table 7. Statistical results in Category II.

Field	Topic	Importance	Uncertainty	Discontinuity	Global competitiveness	Realization time (year)
ICT	Develop a new computation model to understand calculation difficulties: a theoretically solvable model for computationally difficult problems as the foundation to construct a realistic and marginal problem-solving platform	3.5	3.0	3.0	2.9	2027–2035
ICT	Defense technology that recognizes dynamic changes in the pattern of an attacker's attacks and automatically implements the most effective defense	3.6	3.0	2.9	2.7	2020–2022
ICT	Technology to prevent illegal activities by individuals who are authorized to access a specific system	3.6	3.1	2.8	2.7	2020–2024
Health & medical care	Pharmaceuticals based on new functional molecules to follow pharmaceuticals based on low-molecular weight compounds, antibodies, and nucleic acids	3.5	3.0	3.0	2.8	2024–2025
Health & medical care	A new antipsychotic drug based on the pathogenesis of schizophrenia in the brain that has fewer side effects when compared to those of current drugs and leads to the social reintegration of patients	3.5	3.0	2.8	2.7	2027–2031
Health & medical care	A new antidepressant therapy that is fast-acting and prevents the recurrence of depression based on the diagnostic classification of subtypes of depression according to the pathology of depression in the brain	3.5	3.0	3.0	2.7	2025–2029
Health & medical care	A new mood stabilizer based on the pathogenesis of bipolar disorder in the brain with fewer side effects when compared with those of current drugs and the possibility of preventing the recurrence of symptoms	3.5	3.0	2.8	2.8	2028–2030
Health & medical care	Therapies and intervention methods based on the pathogenesis of autistic spectrum disorders in the brain that enable an independent social life	3.4	3.1	2.9	2.6	2025–2030
Health & medical care	Flu vaccines that do not cause antigenic variations in the virus and provide lifelong protection against infection only through a few vaccinations	3.4	3.3	3.0	2.5	2025–2030
Material	Simulation technology that can predict functions and physical properties of the structure itself, but instead provides it with a structure and predicts its functions	3.5	3.0	2.9	2.9	2025–2030

Table 8. Statistical results in Category III.

Field	Topic	Importance	Uncertainty	Discontinuity	Global competitiveness	Realization time (year)
ICT	Automatic configuration technology for integrated wired/wireless networks that provides uninterrupted access to a network without the need for users' awareness of configuration changes relative to the changes in the status of the network over time	3.4	2.3	2.3	2.9	2020–2022
ICT	A highly reliable network that provides services without disruption by using network virtualization technology that dynamically adjusts based on operating conditions that are internal and external to the system	3.4	2.3	2.4	2.9	2020–2020

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Table 8 (Continued from preceding page)

Field	Topic	Importance	Uncertainty	Discontinuity	Global competitiveness	Realization time (year)
Health & medical care	Disease-prevention methods based on the utilization of big data methods to analyze lifestyle data	3.4	2.3	2.3	2.7	2020–2025
Health & medical care	A prediction and alert system for infectious disease epidemics based on a comprehensive infectious disease surveillance system that utilizes medical data, such as electronic medical records (EMR), system data, test results, and prescription records, along with various types of web data	3.5	2.3	2.2	2.5	2020–2022
Health & medical care	Technology for the separation and identification of unknown pathogens by utilizing a pathogen database	3.5	2.4	2.3	2.7	2022–2025
Agriculture, forestry & fisheries	Establishment of security assessment methods for genetically modified crops and animals	3.6	2.3	2.3	2.7	2024–2025
Agriculture, forestry & fisheries	Woodland creation technology corresponding to the period from forest thinning to final clear cutting to ensure the reproduction of the forest following a harvest	3.5	2.3	2.0	2.3	2021–2025
Agriculture, forestry & fisheries	Development of high-strength wood components and fire-resistant wood structures for the construction of low- and high-rise wooden buildings, such as office buildings	3.4	2.2	2.3	2.6	2020–2025
Space & ocean	A high-precision land monitoring system based on satellites to ensure public safety and security and provide data for industrial use	3.5	2.2	2.2	2.9	2025–2025
Social infrastructure	Unmanned aircrafts for a low-altitude autonomous flight, to be used for the surveillance of territorial waters, disaster monitoring, and rescue support	3.4	2.3	2.3	2.9	2020–2025

Table 9. Statistical results in Category IV.

Field	Topic	Importance	Uncertainty	Discontinuity	Global competitiveness	Realization time (year)
Health & medical care	Radiation therapies to enable cancer treatment within a short period without disturbing daily life by using a small system for the irradiation of an intensity-modulated particle beam	3.5	2.2	2.2	3.3	2025–2030
Space & ocean	Buoy-type technology to observe crustal deformation and tsunami formation in the sea without laying submarine cables	3.5	2.2	2.3	3.4	2025–2030
Space & ocean	A medium-sized high-intensity synchrotron radiation facility exceeding Spring-8 in the soft X-ray area (electron energy of 3 GeV, horizontal emittance of 1.2 nmrad or less, and brilliance equal to or exceeding 1020 phs/s/mm^2/mrad^2/0.1% BW)	3.6	2.0	2.6	3.4	2020–2020
Space & ocean	Technology for the field observation of functional materials and structural materials by using neutrons and X-rays to visualize the three-dimensional stress and strain distribution of the two materials during the actual operation	3.5	2.2	2.4	3.2	2020–2022

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Table 9 (Continued from preceding page)

Field	Topic	Importance	Uncertainty	Discontinuity	Global competitiveness	Realization time (year)
Space & ocean	According to the frequency link technology based on fiberoptic network technologies, including high-precision standards, reference signals and location information can also be used remotely (i.e., high stability and ultra-high-precision technology based on optical fiber link technology, optical comb transmission technology, and GPS technology through the timely synchronization of optical carrier frequency)	3.4	2.2	2.4	3.2	2021–2025
Environment & resources	720 °C level supercritical pressure thermal power generation technology that achieves 46 % efficiency (HHV standard)	3.4	2.4	2.2	3.3	2022–2025
Environment & resources	Large-scale combined cycle power generation with high efficiency and large-scale gas turbines (inlet temperature exceeding 1 700 °C)	3.4	2.3	2.2	3.2	2021–2025
Environment & resources	Technology for the reasonable recovery and utilization of rare metals from sewage, sludge, incinerator fly ash, waste, and small electronic devices	3.4	2.4	2.2	3.2	2022–2026
Environment & resources	Technology for purification and recycling of contaminated water that is economical and generally available in developing countries	3.6	2.3	2.1	3.2	2020–2025
Service-oriented society	Popularization of supervision terminal technology that can be naturally mastered by general consumers to monitor individuals, such as those who suffer from dementia who may wander off	3.5	2.2	2.3	3.2	2020–2022

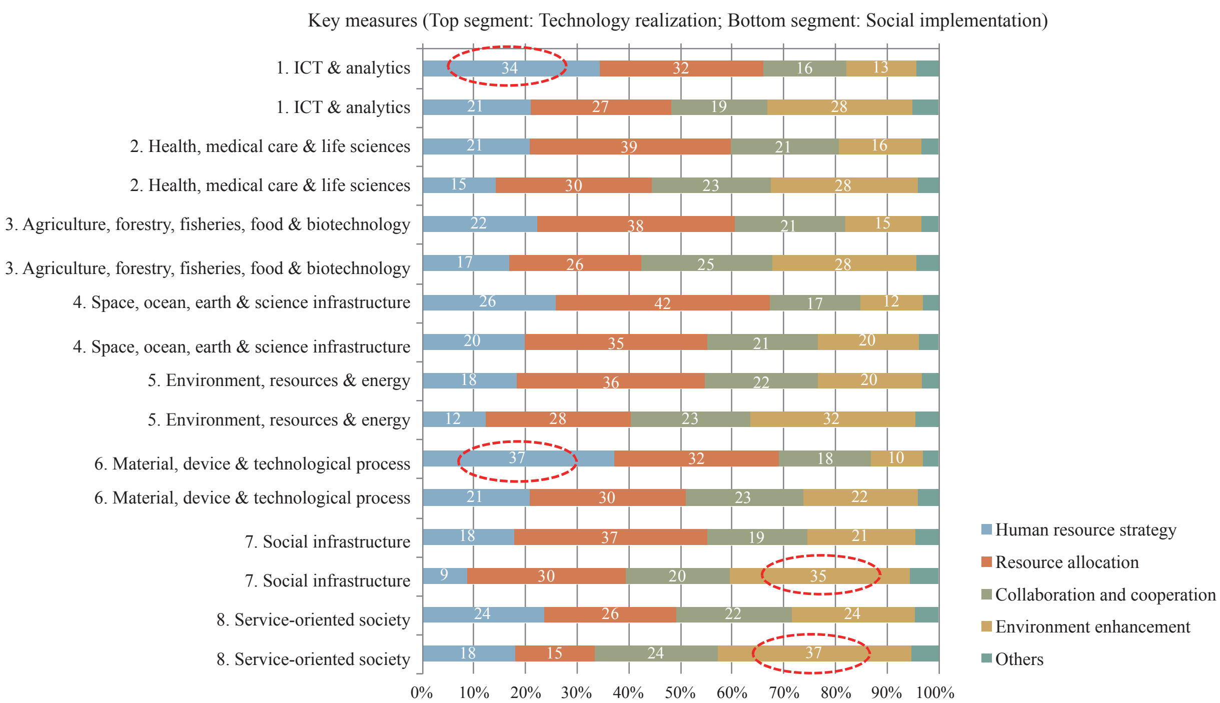

Fig. 13. Analysis of the contributory factors.

4 Lessons from Japan's technology foresight

The concept of technology foresight emerged in Japan in the 1960s, and the practice of technology foresight began in the 1970s because of the economic transformation that occurred in Japan. Japan's economy rapidly developed through the introduction of advanced foreign technologies, and Japan emerged as a world leader in several fields after the country's gross domestic product (GDP) exceeded that of the Federal Republic of Germany to correspond to the second largest GDP in the world. In light of role changes, a major concern for the Japanese government involved formulating the right science and technology policies to bolster sustainable economic development, which naturally requires foresight and prediction in the policymaking process [3]. China is currently in a critical period of innovation-driven development and economic transformation. Learning from the success story of Japan, seriously considering uncertainty and discontinuity in technological progress, and fully appreciating the impact of social demands and policy on technological achievement are important in achieving the strategic goal of becoming a leading power in science and technology. Given the moderately prosperous vision of society in China, a systematic approach should be developed to explore the path of technological development, planning, and shaping to forge ahead in technology trends.

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