Japanese and German Technology Forecast Survey (Mini-Delphi)

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1. Background of the survey

Science and Technology Agency has been conducting technology forecast surveys (Delphi method) every five years to see the directions of science and technology development in Japan since 1971 from a long-term viewpoint. In recent years, the interest in such technology forecast has grown mainly in Europe, and in Germany, German Federal Ministry for Research and Technology (BMFT) conducted a survey identical with the Japanese 5th Technology Forecast Survey as a collaborative project with Japan, and published the findings in August, 1993. As a result of the comparative analysis of the findings in both the countries (NISTEP Report No. 33, April, 1994), the differences between both the countries were found to be small in the forecast of technology realization years, but on the other hand, with regard to the evaluation on the importance of some technologies, large differences were observed. France also conducted a similar survey, and the results of the analysis will be published before long.

With a view to conduct an experimental survey for establishing a method for conducting international technology forecast surveys with an intention to internationally share future visions, Japan and Germany collaboratively commenced an international technology forecast survey (Mini-Delphi method) by jointly grappling with the survey from the stage of subject preparation for the first time in the world.

2. Survey method and features

(1) Survey areas and number of survey subjects

Both the countries collaboratively prepared subjects for the technological areas shown in Table 1. Concretely, the committees of both the countries prepared respective proposals, and exchanged them for coordination, to decide the final subjects. The number of subjects proposed by Japan and that by Germany in the current survey were almost equal.

When the first questionnaire was sent to Japanese and German answerers, the answerers were requested to propose any technologies to be surveyed other than the tens of technology subjects stated in the questionnaire, as well as problem solutions, etc. As a result, the number of subjects increased from 120 in the first questionnaire to 132 in the second questionnaire.

Table 1 Delphi survey areas and numbers of survey subjects

1. Materials and processes 1) Solar cells (18 subjects), 2) Superconductivity (12 subjects) 2. Information and electronics 1) Artificial intelligence (14 subjects), 2) Nanotechnology and micromachines (21 subjects) 3. Life science 1) Cancer (17 subjects), 2) Brain functions (18 subjects) 4. Environment 1)Refuse treatment technologies and recycling (17 subjects), 2) Global meteorological variations (15 subjects)

(2) Survey method and survey items

The survey method was Delphi method (questionnairing was conducted twice: the second questionnaire presented the categorically totalized results of the first questionnairing, and the answerers could re-evaluate the subjects, seeing the trends of general opinions, for converging their opinions). The answerers were experts of industrial, academic and governmental circles in both the countries; 405 Japanese experts and 459 German experts in total.

The survey items requested to be evaluated included the estimation of realization years, and the degrees of importance of respective subjects from the five viewpoints of science & technology, economy, environment, developing nations and society.

As "necessary conditions for subject realization", the degrees of necessity for subject realization were asked on the three conditions of the problem solution by science and technology, the increase of demand in the future market, and the improvement of price competitiveness in the future market. (In the German questionnaire, the degrees of prospect for these three conditions were asked.)

For the present situations of the technologies taken up in the survey ("Evaluation of factors concerning subject realization"), the answerers were asked to evaluate the present situations on the nine items of industrial efforts, public regulations, public aids, performance of international collaborative development, understanding by general society, availability of R&D funds, equipment, etc., availability and raising of competent persons, preparedness of technological innovation such as venture capital, and present R&D level.

Furthermore, the comments of answerers were fed back. That is, typical opinions for the respective technology

subjects proposed for the first questionnaire were stated in the second questionnaire. The comments for the stated opinions were also made for the second questionnaring.

3. General trends

(1) Importance

For development of science and technology

The averages of the values for all the subjects evaluated to contribute to the development of science and technology in a wide range (index: maximum 100 to minimum 0) were 81 in Japan and 87 in Germany. The development of science and technology was considered to be most important among the five viewpoints of importance in both the countries.

In reference to respective sub-areas, both the countries evaluated ″Brain functions″ most highly. The evaluation of ″artificial intelligence″, ″cancer″ and ″meteorological variations″ was relatively high in both the countries. On the contrary, the evaluation of ″solar cells″ and ″refuse treatment″ was very lower than the average in both the countries.

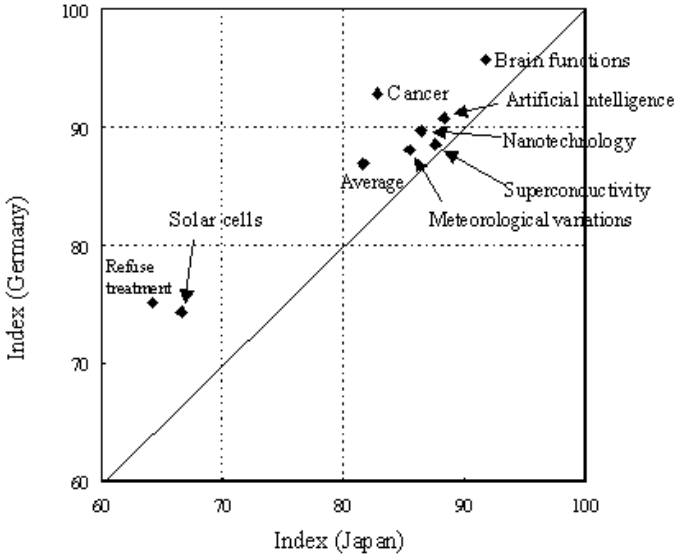

Fig. 1 For development of science and technology

For development of economy
The averages of all the subjects were 63 in Japan and 71 in Germany. Germany was higher.
In reference to respective sub-areas, ″artificial intelligence″ was evaluated most highly to contribute to the development of economy in both the countries. Among the other sub-areas, ″nanotechnology″, ″solar cells″ and ″superconductivity″ were evaluated relatively highly, and ″brain functions″ was evaluated low in both the countries. ″Cancer″ and ″meteorological variations″ were evaluated greatly differently between both the countries (Fig. 2).

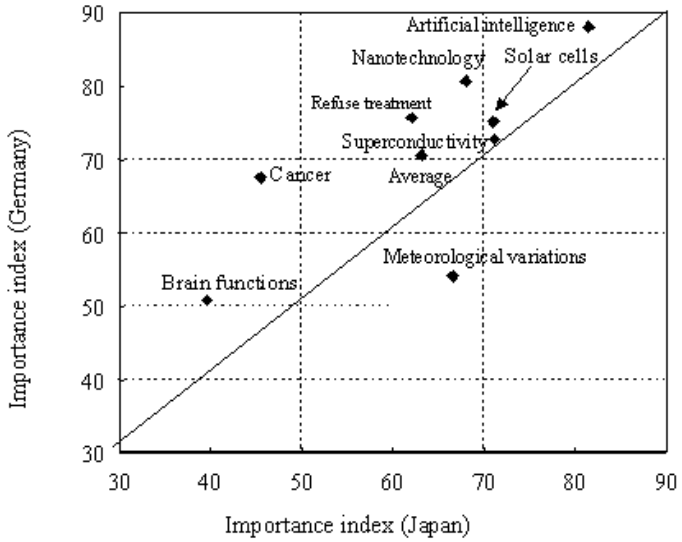

Fig. 2 For development of economy

Subjects evaluated to be especially highly economically important in ″artificial intelligence″ included subjects for grading up the information use environment such as ″212: Prevalent use of a system for retrieving data and knowledge within several minutes from throughout the world without specifying any data base″ and ″213: Prevalent use of an electronic library to allow access to necessary documents and literature from respective residences″, and subjects concerned with software such as ″203: Practical application of artificial intelligence for development of large-scale software, etc.″ and ″205: Practical application of an automatic program synthesizing method for synthesizing practical programs from specifications″.

(2) Comparison between Japan and Germany on the evaluation of present situations

″Performance of international collaborative development″ and ″R&D funds″ are introduced here.

(Performance of international collaborative development)

The averages of index values for all the subjects of ″performance of international collaborative development″ were 49 in Japan and 67 in Germany (100 if all the answerers thought the present situations were good, and 0 if poor), showing a relatively large difference between Japan and Germany. In Germany, the respective values of all the areas other than ″refuse treatment″ exceeded 50, and in relatively fundamental sub-areas such as ″brain functions″, ″cancer″ and ″meteorological variations″, international cooperation is carried out very actively. Large differences were observed between both the countries in the information and electronics area such as ″artificial intelligence″ and ″nanotechnology″ (Fig. 3).

In reference to respective subjects, subjects evaluated to be sufficient in the performance of international cooperation in both the countries were ″308: Application of research of genome for developing new strategies for the diagnosis, prevention and treatment of cancer″, ″319: Revealing the entire molecule mechanism for long term potentiation and long term suppression of hippocampus″, ″331: [Additional subject] Revealing the mechanism of cancer metastasis at molecule level″, etc. in the life science area. Among the top 10 subjects highly evaluated in Japan, five subjects were concerned with ″meteorological variations″, but among the top 10 subjects of Germany, five subjects were concerned with ″cancer″, and 4 subjects, ″brain functions″, keeping the subjects of life science area at higher places.

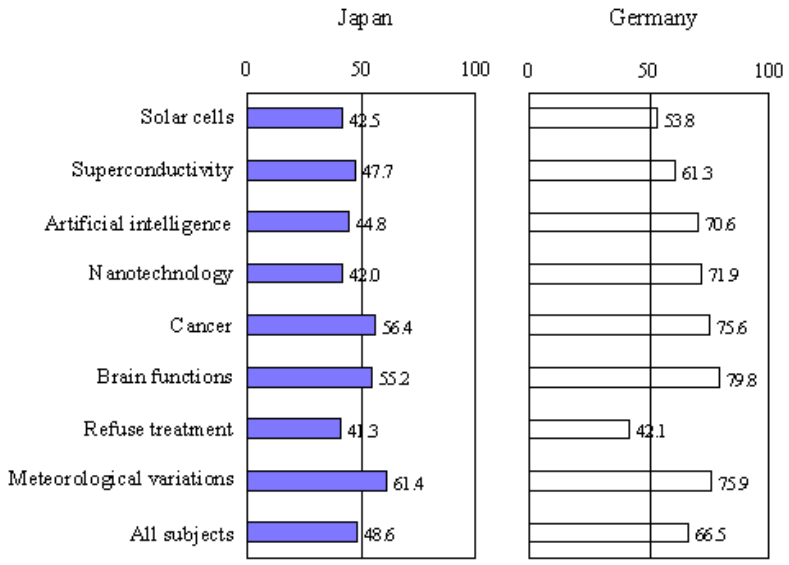

Fig. 3 Comparison of respective sub-areas between Japan and Germany

(performance of international collaborative development)

(Availability of R&D funds, equipment, etc.)
The averages of index values for all the subjects of "availability of R&D funds, equipment, etc." were 49 in Japan and 64 in Germany. In Japan, the present situation was evaluated to be of a medium degree, but in Germany, it was evaluated to be rather good. In respective sub-areas other than "cancer" and "brain functions", both the countries were greatly different (Fig. 4).
In reference to respective subjects, the present situations of few subjects were evaluated to be good in Japan, but in Germany, many subjects were evaluated to be relatively good in the present situation. The subject highest in index value in Japan was "102: Practical application of large area thin film solar cells with an efficiency of 20%", marking 65, and most subjects were evaluated to be neither good nor poor, rather unsatisfactory in the present situation. On the contrary, in Germany, subjects of 70 or more in index value accounted for about 30%, showing that German answerers were very satisfactory with the present situations. Among the respective top 10 subjects of both the countries, six subjects belonged to the life science area in Japan, while six subjects belonged to the material area in Germany, showing a clear difference in the areas highly placed between both the countries.

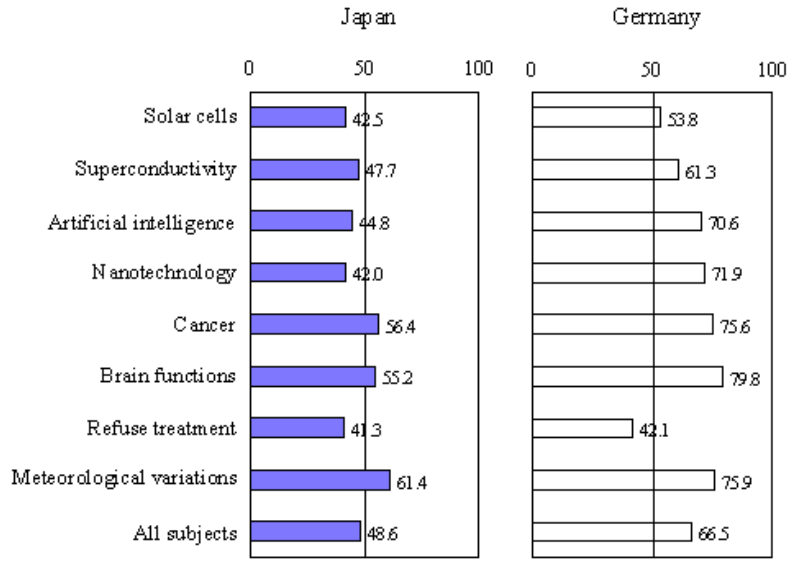

Fig. 4 Comparison of respective sub-areas between Japan and Germany (R&D funds)

4. Trends of realization by area

- Solar cells
  The practical application of solar cells of about 20% in conversion efficiency was considered to progress in about 10 years from now in Japan as can be seen in "101: Practical application of large area amorphous silicon solar cells with an efficiency of 20% or more" and "102: Practical application of large area thin film solar cells with an efficiency of 20%". The further improvement of conversion efficiency was estimated to be farther ahead, and it was considered to take further 15 years to 20 years from now for realizing a conversion efficiency of 30% or more, as can be seen in "106: Development of new materials with highly efficient photovoltaic power generation effects" (2013) and "103: Prevalent use of solar cells with an efficiency of 30%" (2017). The recognition of such technological difficulties can be seen also in answerers' comments, and there were many opinions that it is a realistic approach to pursue the development of technologies practical in view of cost even if the conversion efficiency is about 20%, rather than aiming at the technologically difficult improvement of conversion efficiency.
  Japanese experts thought that solar cells would be prevalently used in buildings and dwelling houses relatively early as can be seen in "107: Prevalent use of solar cell integrated building materials in the walls and roofs of buildings" (2005) and "113: Realization of electric power supply to dwelling houses and offer of excess electric power by prevalent use of solar cells for dwelling houses" (2009). Furthermore, it was estimated that electric motor vehicles using solar cells as the power source would also be prevalently used about 2010. On the other hand, it was estimated that the establishment of any international solar energy utilization system would be successful about 2020, even if it is successful, as can be seen in "116: Establishment of worldwide hydrogen economy by photovoltaic power generation" and "114: Establishment of photovoltaic power generation industry for supplying electric power worldwide by high temperature superconducting power transmission, etc."

- Superconductivity
  Subjects predicted to be realized relatively early are those concerned with the clarification of any theory and development of any apparatus such as "120: Development of a simple high temperature superconducting circuit using Josephson junction" (2002), "117: Revealing the mechanism of high temperature superconductivity" (2003) and "125: Fabrication of 1 GHz NMR apparatus by a 25T or more ultraprecise superconducting magnet" (2006). Subjects predicted to be realized after 2013 are those concerned with the development of room temperature superconductive materials and the development of large scale utilization technologies of superconductivity such as "119: Development of superconductors with a transition point at room temperature" (2014), "126: Realization of general use of power generation plants applying superconductors" (2016) and "122: Practical application of superconducting power transmission using high temperature superconductive materials" (2016).
  It was predicted that relatively small scale application technologies would be realized in more than 10 years from now, and that the mechanism of high temperature superconductivity would also be revealed within 10 years from now. However, for the development of room temperature superconductive materials, it was conservatively estimated that such development would take about 10 years after the mechanism of high temperature superconductivity is revealed.

- Artificial intelligence
  It was predicted that about 85% of subjects concerning artificial intelligence would be realized in a period from 2003 to 2010, and that in the beginning of the 21st century, various applications would be practiced and prevalently effected one after another in a short period of time.
  It was predicted that technologies relatively close to our daily life such as "213: Prevalent use of an electronic library to allow access to necessary documents and literature from respective residences" and "212: Prevalent use of a system for retrieving data and knowledge within several minutes from throughout the world without specifying any data base" would be realized about 2003. For these subjects, answerers made many comments to indicate economic and social problems such as the reduction of communication cost, copyright, and disclosure of data. It was considered that "202: Development of a large scale coordinately dispersed AI system" and "211: Development of a general purpose expert system in a shorter period of time" expected to be a foundation for various applications would be realized relatively early in both the countries.
  On the other hand, for the subjects for realizing functions close to those of human beings such as "209: Development of a voice conversation system with a vocabulary of tens of thousands of words", "204: Practical application of a system capable of recognizing two-dimensional patterns like photographs at a speed as high as that of human beings" and "206: Development of a language capable of depicting problems in words and drawings", the realization years estimated in Japan tended to be later. With regard to this matter, for example in the case of pattern recognition, many studies have been conducted for the needs of recognizing handwritten characters in Japan, and on the contrary, the difficulties of the technological development are also sufficiently recognized, to affect the answers.

- Nanotechnology
  Generally in this area, both the countries agreed well, and it was predicted that more than 80% of subjects would be realized in a period from 2003 to 2010.
  It was considered that such technologies as "Practical application of a technology for identifying kinds of individual atoms by high resolution surface analysis" and "225: Development of a technology for repairing and controlling the surface defects of silicon" expected to be foundations for various applications would progress by 2006, and that "217: Production of materials with surface structures decided on the nano order", "222: Practical application of a reaction and synthesis technology for atoms and molecules by use of STM related technology", "223: Practical application of a technology for producing patterns of atom sizes by any other method than the proximity method", etc. would progress by 2010.
  A subject predicted to be realized in different years is "229: Diagnosis and treatment with a micro system

embedded in the human body will be practiced", and Japan predicted the year at 2013, while Germany, at 2007. For this subject, some answerers indicated the feeling of resistance against embedding in the human body. The subject considered to be most difficult to realize was "224: Development of microprocessors using living cells", and the realization year was predicted to be 2019 in both the countries. There were also many experts who thought this subject would not be able to be realized (any other method would be developed) (25% in Japan and 14% in Germany).

- Cancer
  Both the countries agreed in predicting that about 70 to 80% of subjects would be realized in a period from 2003 to about 2010. The respective subjects were predicted to be realized earlier by German than by Japanese, or in the same years.
  It was thought that research of such subjects as "309: Practical application of cancer clinical diagnostic technologies such as three-dimensional imaging technology" and "314: Prevalent use of a data base concerning cancer therapy" would progress at first, and that genetic research such as "308: Application of research of genome for developing new strategies for the diagnosis, prevention and treatment of cancer" and "311: Development of gene therapy for specific cancer" and research on the canceration process as molecule science such as "301: Revealing the mechanisms of signal transmission, etc. in cell canceration at molecule level" and "332: [Additional subject] Prevalent use of DNA diagnosis for cancer" would progress concurrently till 2010.
  The applications for cancer therapy as can be seen in "308: Application of research of genome for developing new strategies for the diagnosis, prevention and treatment of cancer", "312: Clinical application of effective means for preventing cancer metastasis" and "311: Development of gene therapy for specific cancer" were predicted to be realized by two to four years earlier in Germany than in Japan. The subject considered to take the longest time for realization was "313: Practical application of an artificial organ containing normalized patient's own cancer cells", and it was predicted to be realized in 2018 in Japan and 2014 in Germany.

- Brain functions
  Both the countries predicted that no large progress would be made till about 2008, and that more than 70% of subjects would be realized stepwise taking about 10 years since then. Subjects considered to be realized relatively early are experiment and observation technologies useful as research tools such as "317: Development of a technology for simultaneously recording the activities of numerous neurons for a long time", "316: Development of anon-stress high resolution observation technology for higher human brain function activities" and "315: Development of a non-stress observation technology for molecule level changes caused by human brain activities", and they were considered to be realized by 2008.
  Subjects directly concerned with the revealing of brain functions were predicted to be mostly realized after 2010 in both the countries, and the realization years were almost the same in both the countries or earlier in Germany. Such subjects include "318: Revealing the relation between synaptic plasticity and memory" (2008 in Japan and 2009 in Germany) and "323: Revealing a neurophysiological foundation of human language activities" (2018 in Japan and 2014 in Germany), etc. The subject predicted to be realized latest in both the countries was "324: Revealing the relation between the neuron activities of the brain and ideation", and it was predicted to be realized in 2020 in both the countries.
  A subject predicted to be realized later in Germany than in Japan was "327: Revealing the information processing functions of the cerebral nerve systems of model animals" (2013 in Japan and 2018 in Germany). For this subject, it is very likely that German answerers did not think animal experiments would progress smoothly because of the animal protection. This is suggested in the comments made by German answerers. Also for other subjects, German comments were made to the effect that Animal Protection Law would hinder research.

- Refuse treatment technologies
  Both the countries generally relatively well agreed in the prediction of realization years, and the subjects greatly different between both the countries were "415: Successful purification of mass-polluted soils by use of microbes" (2010 in Japan and 2003 in Germany) and "401: Prevalent use of small household refuse boxes capable of automatically classifying all kinds of refuse" (2013 in Japan and 2005 in Germany).
  In the development of technologies in this area, both the countries thought that recycle related technologies such as "404: Introduction of industrial standard for environmental preservation and recycling concerning valuable materials", "403: Practical application of any economical method capable of sorting or separating valuable materials from urban refuse for recycling" and "405: General practice of composing plastics to allow diverse recycling also as mixtures" would be realized till about 2006. Both the countries thought systematization such as "414: Prevalent use of a regional information management system for controlling all wastes from their generation to final disposal" would progress in succession, and that "406: Almost all materials will be recycled under established resource recycling economy" by 2011.
  Subjects considered to be realized late in both the countries include "402: Prevalent use of any pipeline collection system for the refuse discharged from dwelling houses and office buildings (2014 in Japan and 2013 in Germany) and "Useful lives of products (consumable goods) will be extended to 5 times" (2015 in Japan and 2017 in Germany). For subject No. 402, answerers' comments included the opinions that the method is very promising as a method for collecting the refuse discharged from large office buildings and large dwelling houses, to substitute garbage wagons, and on the other hand, opinions that the method is not so preferable in view of difficult recycling and economic inefficiency in equipment investment and maintenance. So, the realization years were considered to be very later in both the countries.

- Global meteorological variations
  It was considered that about 70% of subjects would be realized in a relatively short period from 2005 to 2010. The remaining 30% of subjects include many long-term subjects, and were considered to be realized

gradually one after another till about 2020. Also for individual subjects, both the countries agreed fairly well in prediction, and there was no problem showing any large difference in realization year.
Both the countries thought that R&D concerning global warming and the ozone layer such as ″429: Practical application of perfect substitutes for chlorofluorocarbons and halons″, ″421: Economic impacts of global warming effects will be approximately evaluated″ and ″432: [Additional subject] Quantitatively and qualitatively revealing the influence of methane gas on global warming″ would be realized relatively early till about 2007. Both the countries predicted that subjects concerning global air and ocean such as ″417: Quantitatively revealing the influence of the activities of volcanoes and the sun on meteorological phenomena″, ″419: Quantitatively revealing the roles of clouds by meteorological model computation″ and ″424: Prevalent use of a technology to forecast the advent of water masses caused by the Japanese current and the Gulf of Mexico current″ would be realized in succession till 2010.
With regard to the increase of carbonic acid gas by use of fossil fuels, it was thought that ″418: Quantitatively revealing the influence of human beings on the carbon dioxide circulation in the atmosphere, ocean and biosphere″ would be realized till about 2010 (2011 in Japan and 2010 in Germany), and that ″428: Emission of carbon dioxide in the world will decline to 80% of the present level″ in 2020. The subject predicted to be latest in realization year by both the countries was ″427: Inhibition of exponential increase of carbon dioxide by substituting fossil energy by regeneration systems″, and both the countries predicted it would not be realized by 2020.