Report on Survey of China-Japan-Korea Technology Cooperation 2015

Advanced Manufacturing

China-Japan-Korea Technology Cooperation Survey Team,

Chinese Academy of Engineering

October 2015

Table of Contents

1. Overview of survey of technology cooperation

Engineering and technology are major forces promoting economic and social development. For China, Japan and Korea which act as major countries in East Asia, it is necessary to give play to the leading role of engineering and technology to create better cooperation opportunities to boost future development of the entire region and even the world.

For each of the three countries, the academy of engineering is a key representative organization of the national engineering and technology community, playing an important role in promoting local innovation and international exchanges and cooperation in technology. Since 2013, on the initiation of the National Academy of Engineering of Korea (NAEK),the three national academies Chinese Academy of Engineering (CAE), the Engineering Academy of Japan (EAJ) and the NAEK have carried out academician questionnaire surveys of technology cooperation under the East Asia Round Table Meeting (EA-RTM) framework, with the aim of studying the three countries' engineering and technology development status and cooperation needs and identifying potential fields of cooperation to promote technology cooperation in East Asia and provide suggestions for governments and industries. The 2013 and 2014 surveys, both led by NAEK, were respectively themed on "Green Technology (Clean Energy and Environmental Technology)" and "Relevant Technologies and Industries Supporting Aging Society".

The 2015 survey, led by CAE, is themed on "Advanced manufacturing", with the aim of studying the three countries' advanced manufacturing technology development status and cooperation needs and providing suggestions to further promote their advanced manufacturing technology cooperation. It covers assessment of key fields of advanced manufacturing, assessment of key technologies of advanced manufacturing, assessment of forecast of implementation time of key technologies of advanced manufacturing, assessment of urgency of advanced manufacturing technology cooperation, and assessment of potential for advanced manufacturing technology cooperation.

The survey questionnaire was handed out jointly by CAE, EAJ and NAEK in June 2015. The survey data was analyzed in August – October. They survey results will be submitted to the 18^{th} EA-RTM & International Symposium for discussion in November. For the questionnaire, 338 valid copies were collected, 160 (47.4%) from China, 86 (25.4%) from Japan and 92 (27.2%) from Korea.

2. Advanced manufacturing development status

Since the global financial crisis, the world has entered a new phase of vigorous innovation and industrial revitalization. Manufacturing is faced with unprecedented profound changes. On one hand, there are profound changes in the global manufacturing landscape as the developed countries has achieved economic recovery and solved the employment problem by means of "re-industrialization" while the developing countries are seizing opportunities to accelerate transformation and upgrading of manufacturing. On the other hand, as next-generation information technologies represented by mobile Internet, Internet of Things, big data and cloud computing are reshaping the manufacturing industry chain, intelligent manufacturing characterized by digitalization, connectivity and intelligence has become a commanding height of the new industrial revolution.

East Asia, with China, Japan and Korea as main representatives, is in a strategic high ground in global manufacturing. Statistics from the World Bank show that the three countries respectively accounted for 24.5%, 7.6% and 3.1% in global manufacturing value added (MVA) in 2013. The “2012-2013 World Manufacturing Competitiveness Index” report released by the United Nations Industrial Development Organization (UNIDO) shows that China, Japan and Korea respectively ranked first, fourth and seventh in manufacturing competitiveness. While Japan takes the leading position, China and Korea show an upward trend in the ranking.

In recent years, to address the negative impacts of market demand slowdown in the American and European countries and win in the next round of manufacturing development and competition opportunities, China, Japan and Korea have all launched appropriate strategic initiatives. The Korean government issued the *Manufacturing Innovation 3.0 Strategy* in June 2014 and announced the further improved *Manufacturing Innovation 3.0 Strategy Implementation Plan* in March 2015, stipulating that Korea shall vigorously develop13 emerging dynamic industries including unmanned aerial vehicles, intelligent vehicles, robotics, intelligent wearable devices and intelligent healthcare and strive to enter the top four in the global competitiveness ranking in 2025. In May 2015, the Chinese government released the *Made in China 2025*, prescribing that China shall take intelligent manufacturing as the roadmap and try to be a powerful manufacturing country by 2025. In June 2015, the Ministry of Economy, Trade and Industry (METI) of Japan announced the *2015 Edition Manufacturing White Paper*, suggesting that Japan should promote the transition to “next generation” manufacturing based on big data. As can be seen from the three countries’ manufacturing development strategies, accelerating in-depth integration of next-generation information technologies and manufacturing has become the pipeline of development of advanced manufacturing for the three countries and advanced manufacturing characterized by digitalization, connectivity and intelligence has become the focus of these countries.

This round of technology cooperation between the three countries is themed on “Advanced manufacturing”, which is just a choice made based on the overall consideration of the above situation. As can be seen from the questionnaire statistics,

Firstly, 92%, 87% and 98% of the Chinese, Japanese and Korean experts respectively believe that manufacturing will always hold a dominant position in a country’s national economy with the economic and social development (Figure 1).

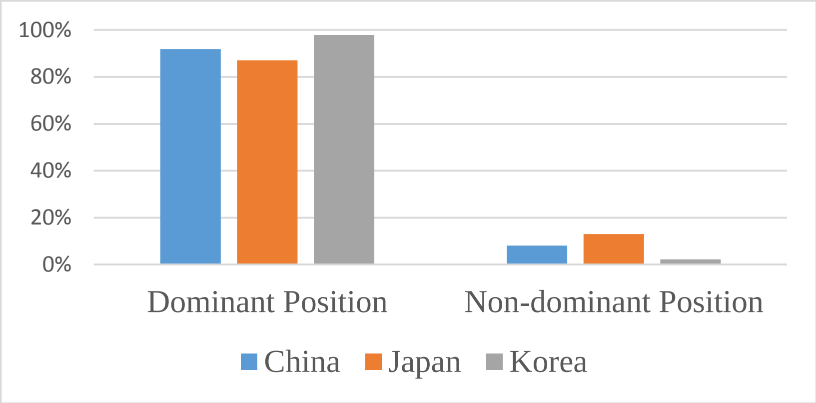

Figure 1 Survey of position of manufacturing in national economy

Secondly, more than 98% of the Chinese, Japanese and Korean experts respectively believe that a new industrial revolution has come or will come (Figure 2).

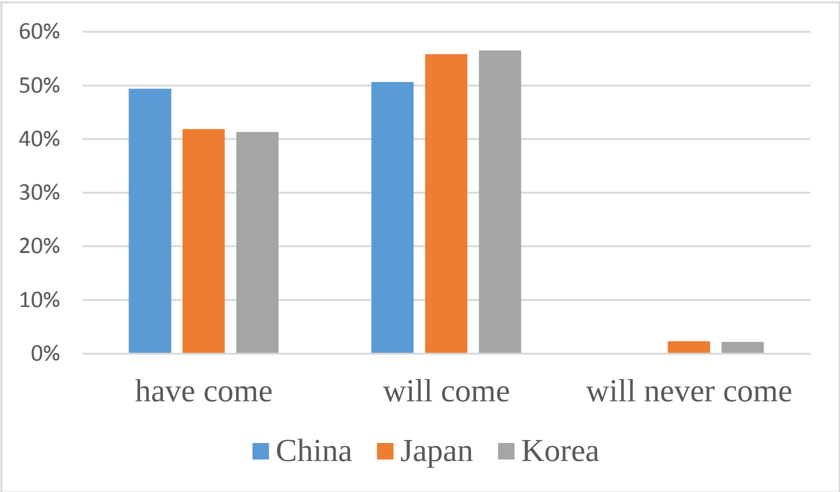

Figure 2 Survey of perception of approaching of a new industrial revolution

Thirdly, 74%, 25% and 45% of the Chinese, Japanese and Korean experts respectively believe that the new industrial revolution is characterized by digitalization, connectivity and intelligence. 28% and 32% of the Korean and Japanese experts respectively believe that the new industrial revolution is characterized by combination of artificial intelligence, robotics and digital manufacturing (Figure 3).

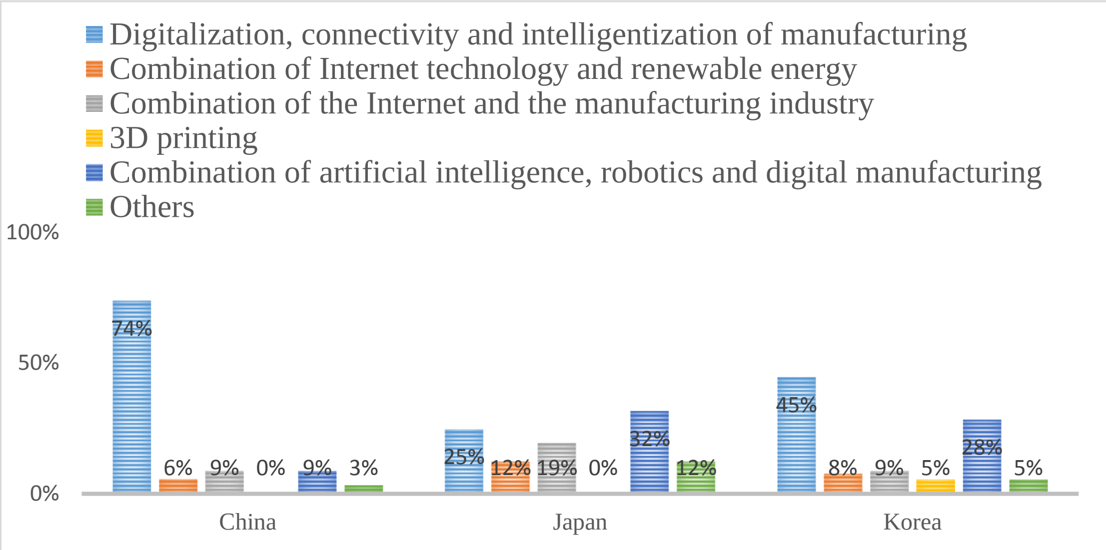

Figure 3 Survey of features of the new industrial revolution

Fourthly, 41%, 40% and 26% of the Japanese, Korean and Chinese experts respectively hold that main impact of next-generation information technologies on manufacturing is manufacturing industry chain optimization and reconstruction and service-oriented manufacturing gradually becoming a mainstream format. More than 46% of the Chinese experts believe that this impact is reflected in mass customization becoming a trend (Figure 4).

Figure 4 Survey of perception of impacts of next-generation information technologies on manufacturing[1]

Fifthly, 61%, 56% and 45% of the Chinese, Japanese and Korean experts respectively believe that main constraint on development of advanced manufacturing is human resources.52% and 48% of the Korean and Japanese experts respectively

[1]In Figure 4 / 5, "Grade" means the survey result expectation value obtained through conversion. "Most preferred" means 100, "second most preferred" means 50 and unselected 0.

hold that main constraint on development of advanced manufacturing is legislation. 36% of the Chinese experts identify funds as a major constraint (Figure 5).

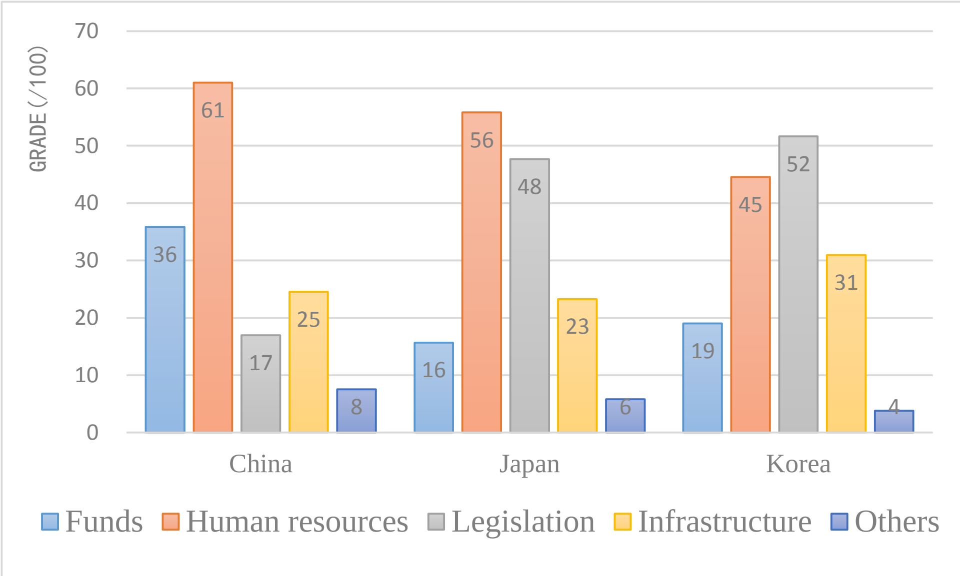

Figure 5 Survey of constraints on development of advanced manufacturing[1]

On the whole, all the experts all fully recognize the strategic position of manufacturing in local economic and social development and optimistically hold that a new industrial revolution has or will come and the new industrial revolution is characterized by digitalization, connectivity and intelligence. The Japanese and Korean experts emphasize that the new industrial revolution is characterized by combination of artificial intelligence, robotics and digital manufacturing. All the experts hold that in-depth integration of next-generation information technologies and manufacturing is driving manufacturing industry chain optimization and reconstruction and service-oriented manufacturing becoming a mainstream format. The Chinese experts emphasize that next-generation information technologies will make mass customization a manufacturing development trend. All the experts hold that the most important constrain on development of advanced manufacturing is human resources. The Japanese and Korean experts also take legislation as a main constraint. The Chinese experts regard funds as more important.

3. Analysis of key fields and technologies of advanced manufacturing

In recent years, with the fermentation of a new technological revolution and industrial revolution and acceleration of the in-depth integration of information technologies and industrialization, global manufacturing technology changes and innovation show new trends and characteristics. The extensive penetration and integration of new information technologies drives more active manufacturing technological transition and substitution and faster product and industry model upgrading and enables integration of manufacturing technologies and high-tech (high-technicalization), digital / intelligent manufacturing technologies(digitalization and intelligence), manufacturing technologies under extreme operating conditions (scaling-up, microminiaturization and nanocrystallization) and lightweight, precision and green manufacturing technologies to become major technological focuses.

The *Manufacturing Innovation 3.0 Strategy* by the Korean government stipulates that Korea shall capture eight core intelligent manufacturing technologies including 3D printing, big data and Internet of Things to narrow the gap between itself and the relevant technologically leading countries. The *Made in China 2025* by the Chinese government prescribes that China shall focus on ten fields: next-generation information technologies, high-end CNC machine tools and robots, aerospace equipment, marine engineering equipment and high-tech ships, advanced rail transportation equipment, power equipment, agricultural machinery equipment, energy-saving and new energy vehicles, new materials, bio-medicine and high-performance medical devices. The *2015 Edition Manufacturing White Paper* by Japan emphasizes high attention to robotics, big data, Internet of Things and software technology.

The questionnaire targets 63 technologies (Annex 2) in seven fields of advanced manufacturing (innovative design, robotics, 3D printing, sensing and detection, control and optimization, green manufacturing and service-oriented manufacturing). Key fields of advanced manufacturing primarily involve survey and analysis of two aspects: 1) the experts from the three countries identify key fields of advanced manufacturing for their own country; and 2) the experts identify key technologies in the key fields of advanced manufacturing and forecast breakthroughs in application of the key technologies.

Firstly, as can be seen from the result of analysis of key fields of advanced manufacturing (Figure 6, Annex 1), the Korean experts identify sensing and detection, service-oriented manufacturing, control and optimization and innovative design as key fields of advanced manufacturing, the Japanese experts sensing and detection, robotics, innovative design and green manufacturing and the Chinese experts innovative design and green manufacturing. Innovative design is identified by all the experts, sensing and detection by the Korean and Japanese experts and green manufacturing by the Japanese and Chinese experts.

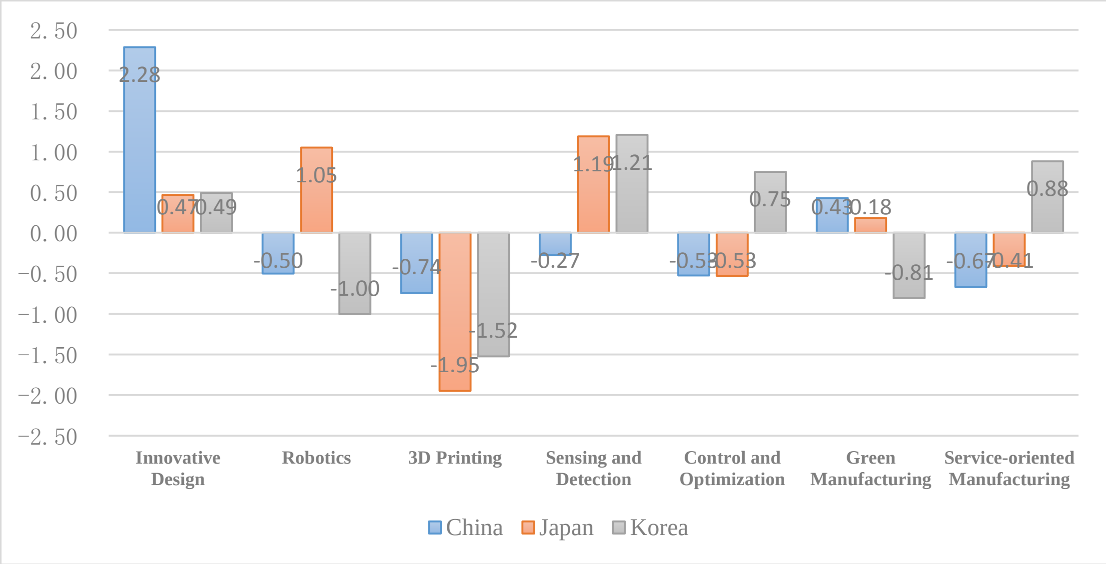

Figure 6 Assessment of importance of fields of advanced manufacturing

Secondly, as can be seen from the result of analysis of the 63 technologies of advanced manufacturing (Figure 7, Annex 2), in innovative design, the Korean experts identify two[2] technologies vital to local advanced manufacturing development, Japanese four[3] and Chinese one[4]. Amongst, multidisciplinary integrated design optimization (No. 2) is identified by all the experts. In robotics, the Korean experts identify three[5], Japanese two[6] and Chinese two[7]. Amongst, brain-like intelligence robots (No. 11) is recognized by all the experts. In 3D printing, the Korean experts identify three[8], Japanese two[9] and Chinese two[10]. Amongst, processes and equipment integrating 3D printing and precision machinery processing (No. 19) and 3D-printed living organs (No. 25) are given attention by all the experts. In sensing and detection, the Korean, Japanese and Chinese experts respectively identify two[11]key technologies. Amongst, the importance of micro- and nano-scale sensors (No. 34) is recognized by all the experts. In control and optimization, the Korean experts identify

[2]Multidisciplinary integrated design optimization (No. 2) and digital collaboration-based product development (No. 8)

[3]Multidisciplinary integrated design optimization (No. 2), ecologizing designing technology (No. 6), mathematical modeling methods and tools (No. 7) and digital collaboration-based product development (No. 8)

[4]Multidisciplinary integrated design optimization (No. 2)

[5]Public security robots (No. 9), brain-like intelligence robots (No. 11) and mechanisms, sensors and drives of intelligent industrial robots (No. 17)

[6]Brain-like intelligence robots (No. 11) and mechanisms, sensors and drives of intelligent industrial robots (No. 17)

[7]Public security robots (No. 9) and brain-like intelligence robots (No. 11)

[8]Processes and equipment integrating 3D printing and precision machinery processing (No. 19)、3D printing-based personalized modes of production (No. 22) and 3D-printed living organs(No. 25)

[9]Processes and equipment integrating 3D printing and precision machinery processing (No. 19) and 3D-printed living organs(No. 25)

[10]Processes and equipment integrating 3D printing and precision machinery processing (No. 19) and 3D-printed living organs(No. 25)

[11]Networked smart sensors in process industry (No. 31, Korea and China), high-speed and high-precision non-contact measurement in production lines and processing equipment (No. 33, Japan) and micro- and nano-scale sensors (No. 34, Korea, Japan and China)

two[12] key technologies and Japanese and Chinese respectively one[13]. Here, there is no technology on which all the experts reach a consensus. The importance of architectures of new control systems based on cloud computing, big data, and other information technologies (No. 39) is recognized by all the experts. In green manufacturing, the Korean, Japanese and Chinese experts respectively identify one[14] key technology. Amongst, the importance of equipment design technologies based on ecological materials (No. 52) is recognized by the Japanese and Korean experts. In service-oriented manufacturing the Korean, Japanese and Chinese experts respectively identify two[15]key technologies. Amongst, the importance of Internet of Things and intelligent logistics for manufacturing (No. 62) is recognized by all the experts.

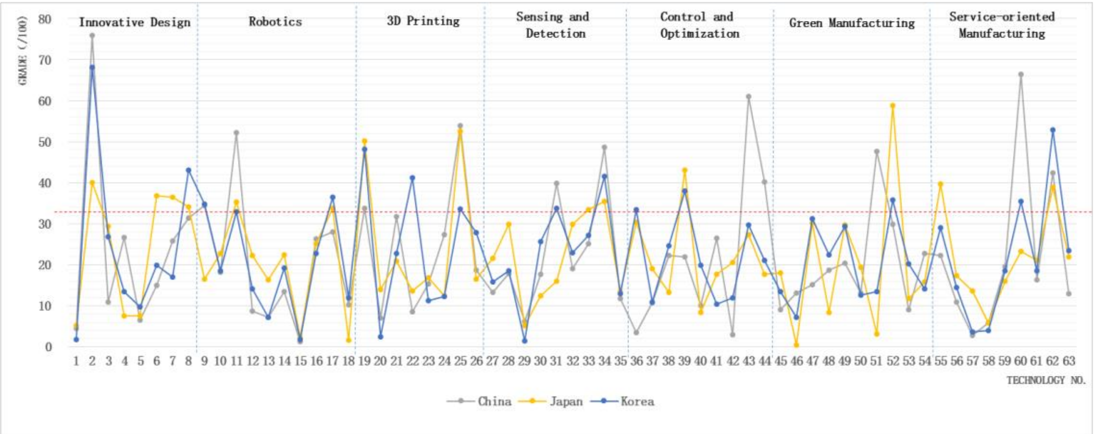

Figure 7 Assessment of importance of technologies of advanced manufacturing

Thirdly, as can be seen from the result of analysis of forecast of implementation time of some of the key technologies in the key fields of advanced manufacturing (Annex 3), in innovative design, the Korean and Japanese experts hold that multidisciplinary integrated design optimization in development of key products will be implemented by 2020 and Chinese 2023. In robotics, all the experts believe that brain-like intelligence robots will be implemented by 2027. In 3D printing, the Korean and Japanese experts hold that processes and equipment integrating 3D printing and precision machinery processing will be implemented by 2020 and Chinese 2022. The Korean experts believe that 3D-printed living organs will be implemented by 2023 and Japanese and Chinese 2024. The Korean experts believe that micro- and nano-scale sensors will be implemented by 2020, Japanese 2022 and Chinese 2023. In service-oriented manufacturing, the Japanese experts believe that Internet of Things and intelligent

[12]Automatic data mining, knowledge discovery and production optimization based on data at planning and control levels of workshops (No. 36) and architectures of new control systems based on cloud computing, big data, and other information technologies (No. 39)

[13]Architectures of new control systems based on cloud computing, big data, and other information technologies (No. 39, Japan) and intelligent open CNC systems (No. 43, China)

[14]Equipment design technologies based on ecological materials (No. 52, Korea and Japan) and directional solidification and single crystal casting of aircraft engine blades (No. 51, China)

[15]Industrial big data in product marketing (No. 55, Japan), cloud-based collaboration technology across multi industry chains (No. 60, Korea and China) and Internet of Things and intelligent logistics for manufacturing (No. 62, Korea, Japan and China)

logistics for manufacturing will be implemented by 2019, Korean 2020 and Chinese 2022.

Fourthly, as can be seen from the comparison of forecast of implementation time of key technologies, there are 2-3-year differences between the three countries in forecast of implementation time of key technologies. On the whole, the Chinese experts' forecast is 2-3 years lagging behind the Japanese and Korean experts'.

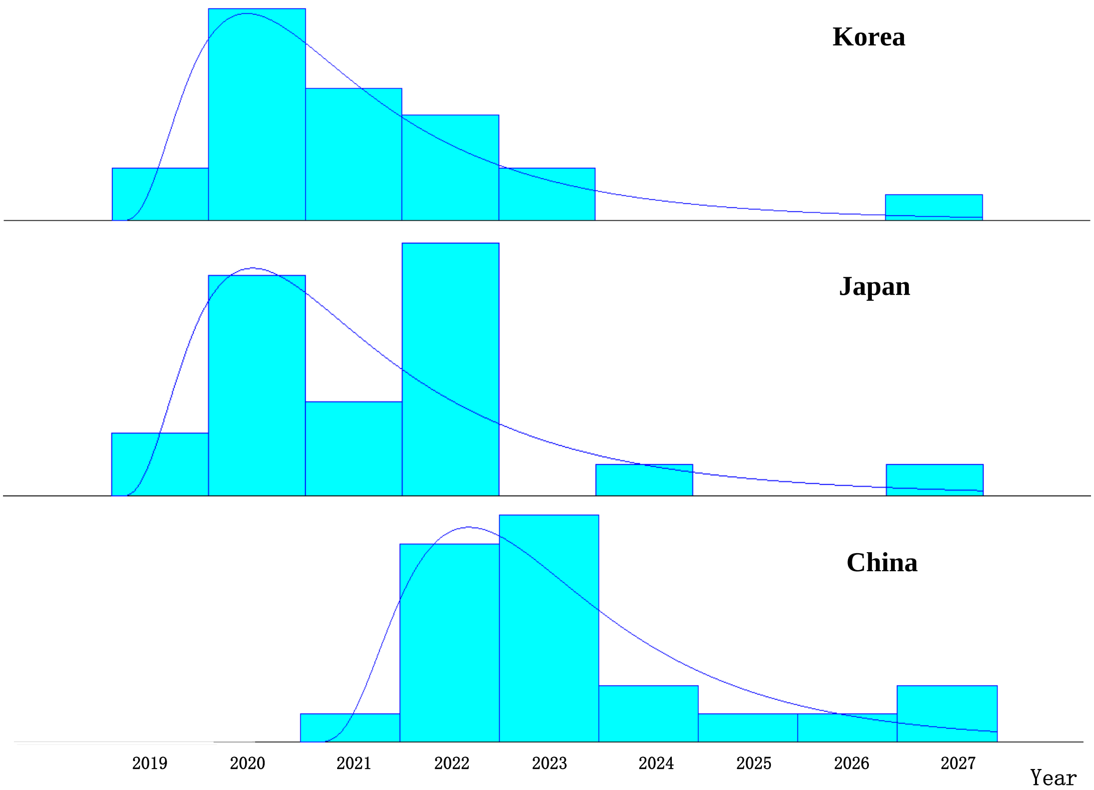

Figure 8 Trend of forecast of implementation time of key technologies

4. Analysis of advanced manufacturing technology cooperation

China, Japan and Korea are at different stages of development of manufacturing. In the process of development of advanced manufacturing, there is huge technological demand and room for technology cooperation. Strengthening China-Japan-Korea advanced manufacturing technology cooperation is of significance for promotion of advanced manufacturing and enhancement of overall competitiveness of manufacturing in East Asia.

The questionnaire focuses on basic assessment of the experts' cooperation expectation and cooperation potential for relevant technologies of advanced manufacturing. 1:1 weight of grade of cooperation expectation and cooperation potential will constitute cooperation expectation value.

Firstly, as can be seen from the comparative analysis, all the experts have cooperation expectation for processes and equipment integrating 3D printing and precision machinery processing, micro- and nano-scale sensors and equipment design technologies based on ecological materials. The Korean and Chinese experts, Korean and Japanese and Japanese and Chinese respectively have cooperation expectation for other technologies.

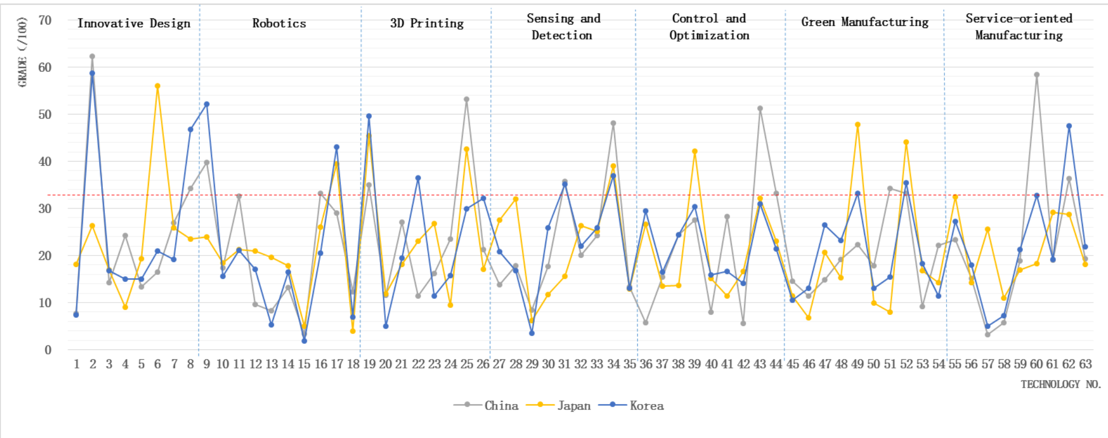

Figure 9 Assessment of cooperation expectation for technologies of advanced manufacturing

Secondly, as can be seen from the comparative analysis of cooperation promising – cooperation necessity (Annex 4), in the Korean experts' assessment result, one technology[16] falls in the second quadrant. For the technology (i.e., dismantling, recycling and remanufacturing of waste electric and electronic equipment), which is from the green manufacturing field, its cooperation promising is superior to its cooperation necessity. Three technologies[17] fall in the fourth quadrant, with their cooperation necessity superior to their cooperation promising. In the Japanese experts' assessment result, three technologies[18] see their cooperation promising superior to their cooperation necessity and three ones[19] just the reverse. In the Chinese experts' assessment result, three technologies[20] see their cooperation promising superior to their cooperation necessity and two ones[21] just the reverse. In the technologies in the first quadrant (i.e., both cooperation promising and collaboration necessity are higher than the reference value), six including two identified by the Korean experts[22], two by Japanese[23] and two by Chinese[24] are from

[16]Dismantling, recycling and remanufacturing of waste electric and electronic equipment
[17]Micro- and nano-scale sensors, intelligent open CNC systems and cloud-based collaboration technology across multi industry chains
[18]Communication protocol standardization of sensing and motion control systems, fault self-diagnosis and equipment self-healing and mass customization in manufacturing of apparel, footwear and headwear, building materials, and sanitary ware
[19]High-speed and high-precision non-contact measurement in production lines and processing equipment, intelligent open CNC systems and industrial big data in product marketing
[20]Brain-like intelligence robots, intelligent CNC technology and equipment design technologies based on ecological materials
[21]Telemedicine robots and networked smart sensors in process industry
[22]Processes and equipment integrating 3D printing and precision machinery processing and 3D printing-based personalized modes of production
[23]Processes and equipment integrating 3D printing and precision machinery processing and 3D-printed living organs
[24]Processes and equipment integrating 3D printing and precision machinery processing and 3D-printed living organs

the 3D printing field; five including two by the Korean experts[25], two by Chinese[26] and one by Japanese[27] from the innovative design field; and four including two identified by the Japanese experts[28], one by Korean and one by Chinese are from the green manufacturing field[29].

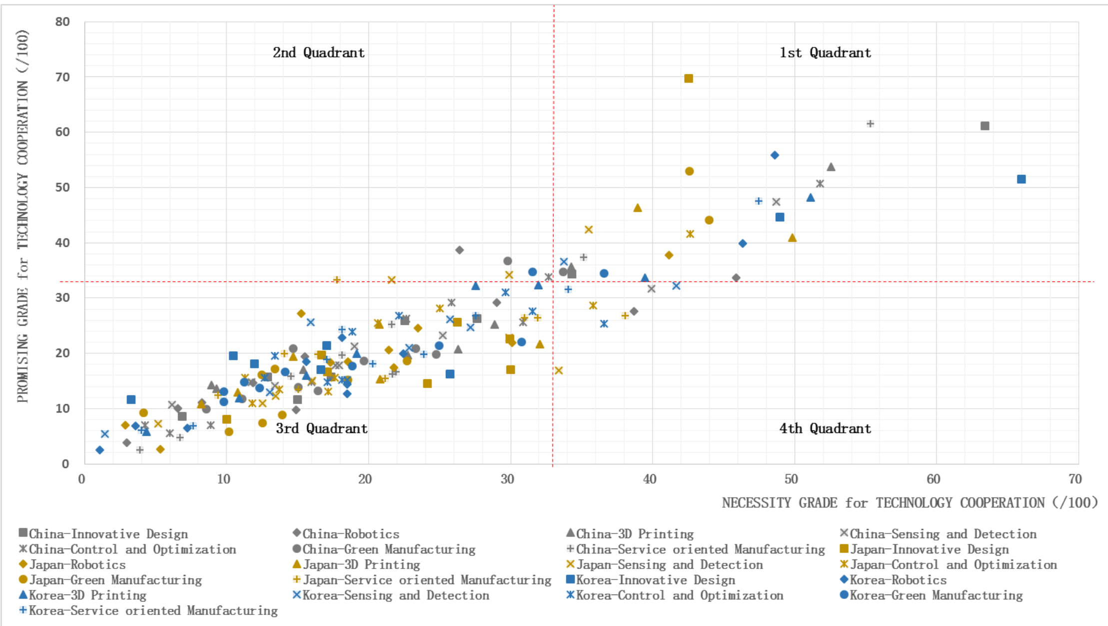

Figure 10 Comparative assessment of cooperation promising – cooperation necessity

Thirdly, as can be seen from the comparative analysis of cooperation expectation – technology importance, two technologies including dismantling, recycling and remanufacturing of waste electric and electronic equipment identified by the Japanese experts (placed on the border of the second and third quadrant by Korean and in the third quadrant by Chinese) and digital collaboration-based product development by Chinese (placed in the first quadrant by Korean and in the fourth quadrant by Japanese) fall in the second quadrant (the experts thinks that technology importance is neutral but their cooperation expectation is high). Seven technologies including architectures of new control systems based on cloud computing, big data, and other information technologies identified by the Korean experts (placed in the first quadrant by Japanese and in the third quadrant by Chinese) and six technologies identified by the Japanese experts (three from the innovative design field, two from the service-oriented manufacturing field and one from the robotics field)fall in the fourth quadrant (the experts think that technology importance is extremely high but their cooperation expectation is not high). A total of 26 technologies fall in the first quadrant (the experts think that technology importance is high and their cooperation

[25]Multidisciplinary integrated design optimization and digital collaboration-based product development
[26]Multidisciplinary integrated design optimization and digital collaboration-based product development
[27]Ecologizing designing technology
[28]Dismantling, recycling and remanufacturing of waste electric and electronic equipment and equipment design technologies based on ecological materials
[29]Equipment design technologies based on ecological materials (Korea) and directional solidification and single crystal casting of aircraft engine blades (China)

expectation is high). Amongst, 10 are identified by the Korean experts, nine by Chinese and seven by Japanese. Six are from the 3D printing field[30], five from sensing and detection field[31], four from the innovative design field[32], four from the robotics field[33], three from the green manufacturing field[34], three from the service-oriented manufacturing field[35] and one from the control and optimization field[36].

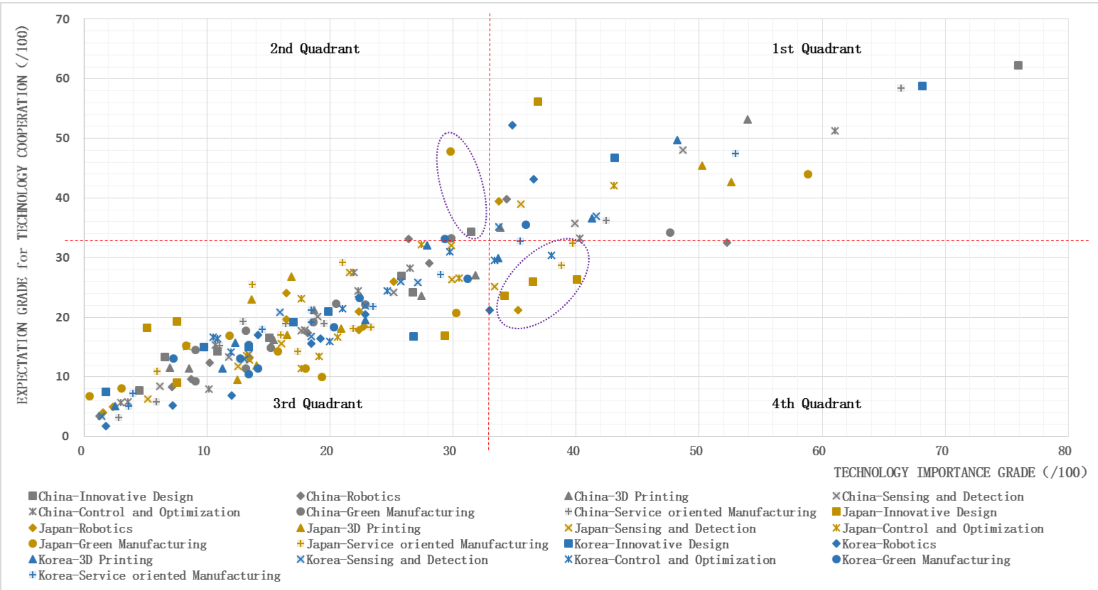

Figure 11 Comparative assessment of cooperation expectation – technology importance

5. Overall assessment of technology cooperation

With the acceleration of globalization, global and regional technology cooperation and exchanges are becoming increasingly frequent. With the increase in size and volume of modern sci-tech projects and enhancement of technological complexity and mutual penetration, cross-border sci-tech innovation cooperation is becoming more and more necessary. China, Japan and Korea respectively as developing, developed and emerging industrialized country are in possession of their own traditional comparative advantage in the process of development of advanced manufacturing and highly

[30] Processes and equipment integrating 3D printing and precision machinery processing (Korea, Japan and China), 3D printing-based personalized modes of production (Korea) and 3D-printed living organs (Japan and China)

[31] Networked smart sensors in process industry (Korea and China) and micro- and nano-scale sensors (Korea, Japan and China)

[32] Multidisciplinary integrated design optimization (Korea and China), ecologizing designing technology (Japan) and digital collaboration-based product development (Korea)

[33] Public security robots (Korea and China) and mechanisms, sensors and drives of intelligent industrial robots (Korea and Japan)

[34] Directional solidification and single crystal casting of aircraft engine blades (China) and equipment design technologies based on ecological materials (Korea and Japan)

[35] Cloud-based collaboration technology across multi industry chains (China) and Internet of Things and intelligent logistics for manufacturing (Korea and China)

[36] Architectures of new control systems based on cloud computing, big data, and other information technologies (Japan)

complementary, embracing huge room for technology cooperation and exchanges.

As can be seen from this survey, all the experts agree that technology cooperation between the three countries is necessary and will bring benefits for technology development. 94% of the experts believe that cooperation necessity is “very high” or “somewhat high” and 90% recognize that benefit of technology cooperation is “very high” or “somewhat high”. In the eyes of the experts, technology cooperation quantity / quality grade is slightly lower than cooperation importance / necessity grade. 88% and 87% of the experts respectively believe that quantitative / qualitative level of cooperation is “somewhat high” or “neutral”. In terms of future technology cooperation, all the experts are optimistic about potential for technology cooperation between CAE, EAJ and NAEK. 73% of the experts believe that potential for technology cooperation between the three countries is “somewhat high”. As can be seen from this, all the experts have high consensus on awareness of technology cooperation between the three countries but their practical actions need to be further strengthened.

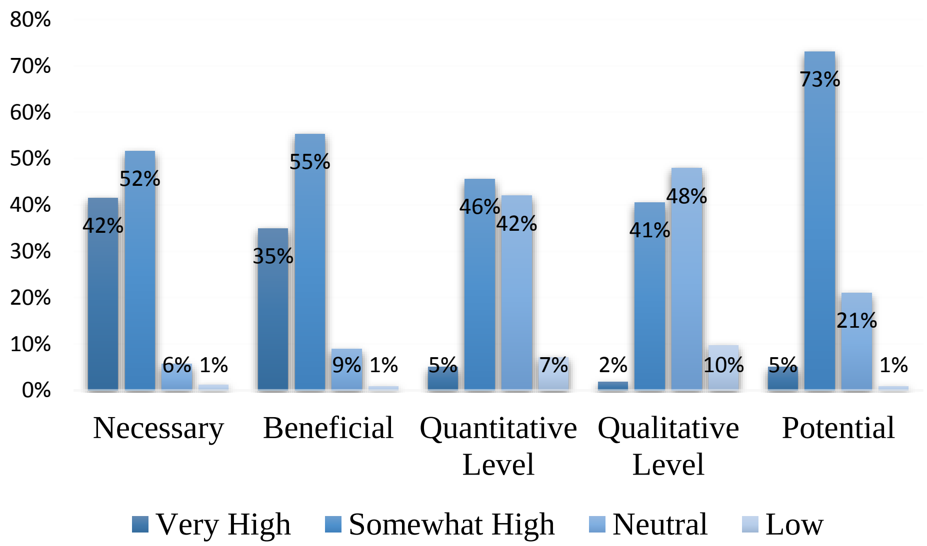

Figure 12 2015 survey of China-Japan-Korea technology cooperation indices

The indices of technical cooperation were obtained from 5 sub-surveys, which were respectively necessity of technical cooperation (Factor 1), benefits of technical cooperation (Factor 2), quantity level of technical cooperation (Factor 3), quality level of technical cooperation (Factor 4), and potential of technical cooperation (Factor 5). By calculating the means of scores on these 5 sub-items, the expected values of technical cooperation indices are obtained (the calculation formula is as shown below):

Expected value of technical cooperation index = $\frac{\text{Factor1} + \text{Factor2} + \text{Factor3} + \text{Factor4} + \text{Factor5}}{5}$

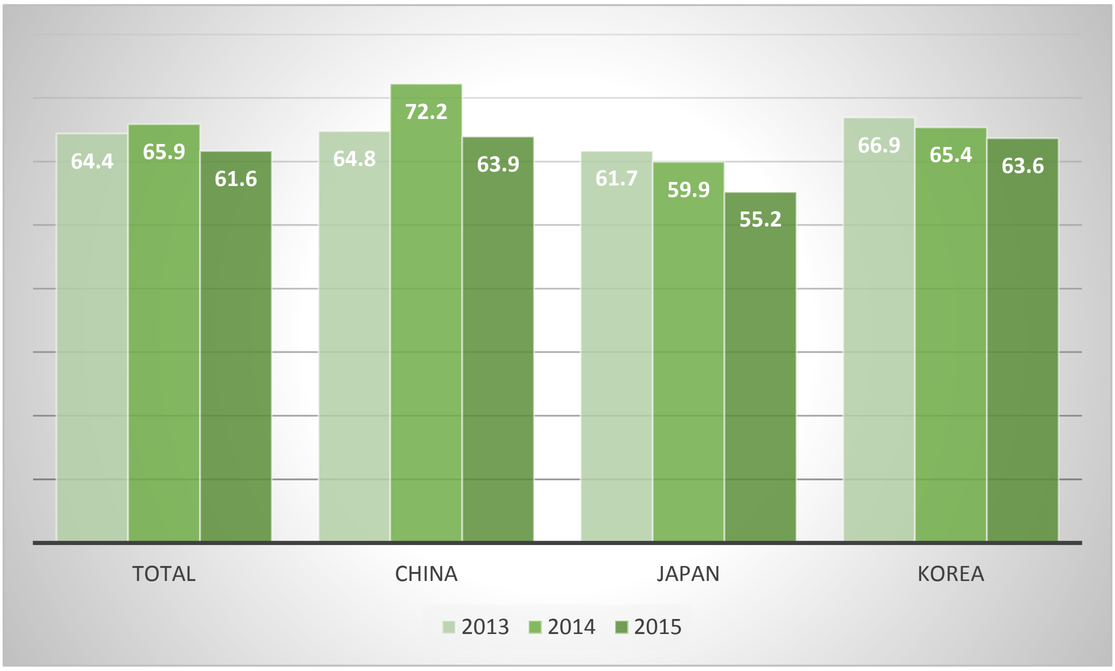

Figure 13 2015 survey of China-Japan-Korea Technology Cooperation Index

The survey results of 2015 show that the expected value of technical cooperation indices was 61.6 points (out of a total score of 100 points), lower than the value of 64.4 points in 2013 and 65.9 points in 2014. For all three countries, the expected value of technical cooperation indices in 2015 was lower than what was obtained in the survey results of 2013 and 2014. Moreover, there was a fall in the expected value of technical cooperation indices in both China and Japan.

Table 1 Item-by-Item Expected Values of Indices of Technical Cooperation among China, Japan and South Korea

	Necessity of Technical Cooperation			Benefits of Technical Cooperation t			Quantitative Level of Technical Cooperation			Quality Level of Technical Cooperation			Potential of Technical Cooperation		
	2013	2014	2015	2013	2014	2015	2013	2014	2015	2013	2014	2015	2013	2014	2015
China	79.3	82.5	76.5	69.4	81.1	73.1	56.7	62.3	54.2	56.0	61.5	51.7	62.4	73.6	64.0
Japan	81.8	78.2	68.0	79.9	76.3	64.8	42.9	43.5	47.9	41.3	43.0	38.7	62.4	58.6	56.7
South Korea	96.3	93.8	90.0	92.6	89.8	87.4	44.8	43.9	43.0	38.3	39.4	38.3	62.6	59.9	59.5

In 2015, most expected values on the sub-items of technical cooperation indices were lower than their respective values in 2013 and 2014. However, similar to the survey results of the previous two years, the expected value of technical cooperation indices in 2015 remained at a rather high level in terms of necessity of technical cooperation and benefits of technical cooperation, but lower in both quantity level of technical cooperation and quality level of technical cooperation. Compared with the survey results of 2014, there was a fall in China in the expected value of technical cooperation indices in all sub-items, while Japan saw a drop in its expected values in necessity of technical cooperation, benefits of technical cooperation and quality level of technical cooperation. For South Korea, there was a fall in the expected value of technical cooperation indices over all sub-items. But, the fall was not apparent.

6. Conclusions and suggestions

As can be seen from the results of this survey, firstly, all the experts make positive comments on the important role of advanced manufacturing in economic and social development. They agree that digitalization, connectivity and intelligence of manufacturing, which will be the next stop in the roadmap of advanced manufacturing amid the new industrial revolution, will have tremendous impacts on manufacturing. All the experts show high expectation for advanced manufacturing technology cooperation between the three countries and believe that there is huge room for that.

Secondly, in terms of key fields of advanced manufacturing identified by the experts, the Chinese experts pay more attention to innovative design and green manufacturing, Japanese sensing and detection, robotics, innovative design and green manufacturing and Korean sensing and detection, service-oriented manufacturing, control and optimization and innovative design. The experts' identification is related to the stage of development of manufacturing the country is in but also intrinsically connected with the country's traditional advantage in manufacturing.

Thirdly, in terms of key fields of advanced manufacturing technology cooperation, all the experts pay more attention to 3D printing. Amongst, they are all optimistic about cooperation on processes and equipment integrating 3D printing and precision machinery processing. Also, they are optimistic about cooperation on micro- and nano-scale sensors from the sensing and detection field and equipment design technologies based on ecological materials from the green manufacturing field.

Based on the above conclusions, the research group has come up with the following suggestions: Firstly, a technology cooperation list should be formed on the basis of this survey to provide a reference for relevant enterprises that conduct practical advanced manufacturing technology cooperation and offer suggestions to relevant government authorities. Secondly, a sound China-Japan-Korea technology cooperation questionnaire survey mechanism should be further established. In particular, predictive study on key technologies of concern for all the three countries should be conducted and research results jointly released to provide research support for each country's sci-tech decisions.

Annex 1 Result of survey of importance of fields of advanced manufacturing

Manufacturing Field	Importance Grade[37]		
	China	Japan	Korea
Innovative design	96	79	76
Robotics	72	82	70
3D Printing	70	67	68
Sensing and detection	74	83	79
Control and optimization	71	74	77
Green manufacturing	80	78	71
Service-oriented manufacturing	70	75	78

[37]To increase discrimination of the statistical result, this report converts the original 5-point scale into 100-point scale. 100 = 5 (very important), 75 = 4 (important), 50 = 3 (neutral), 25 = 2 (unimportant), 0 = 1 (very unimportant)

Annex 2 Grade of importance of technologies[38]

Field	NO.	Technology	Grade		
			China	Japan	Korea
Innovative Design	1	reduction design of typical mechanical equipment	4	5	2
	2	multidisciplinary integrated design optimization in development of key products	76	40	68
	3	integrated bionic design and manufacturing systems	11	29	27
	4	product design based on appearance perception	27	8	13
	5	enterprise-level product data management systems	7	8	10
	6	ecologizing designing technology	15	37	20
	7	mathematical modeling methods and tools	26	37	17
	8	digital collaboration-based product development	31	34	43
Robotics	9	public security robots	34	16	35
	10	robots with cognitive and bionic capabilities	18	23	18
	11	brain-like intelligence robots	52	35	33
	12	human-machine harmonized manufacturing	9	22	14
	13	artificial human body structures and tissues	7	16	7
	14	micro- and nano-scale robots	13	22	19
	15	RV reducers with new mechanisms and tooth profiles	1	2	2
	16	telemedicine robots	26	25	23
	17	mechanisms, sensors and drives of intelligent industrial robots	28	34	37
	18	autonomous underwater vehicles	10	2	12
3D Printing	19	processes and equipment integrating 3D printing and precision machinery processing	34	50	48
	20	4D printing	7	14	3
	21	high-energy laser beam additive manufacturing	32	21	23
	22	3D printing-based personalized modes of production	9	14	41
	23	selective laser sintering	15	17	11
	24	high-energy electron beam 3D printing in aeronautics and astronautics	27	12	12
	25	3D-printed living organs	54	53	34
	26	high-energy metal powder preparation for	19	16	28

[38]To increase discrimination of the statistical result, "Grade" in this report converts the score in the original questionnaire into the survey result. "Most preferred" = 100 points, "Second most preferred" = 67 points, "Third most preferred" = 33 points, unselected = 0. In comparative assessment / analysis, this report uses 33 points (assignment of "Third most preferred") as the baseline.

		additive manufacturing			
Sensing and Detection	27	communication protocol standardization of sensing and motion control systems	13	22	16
	28	fault self-diagnosis and equipment self-healing	18	30	18
	29	nano characterization and testing based on single atoms and molecules	6	5	1
	30	networked remote monitoring systems in process industry	18	13	26
	31	networked smart sensors in process industry	40	16	34
	32	radio frequency identification technology in process industrial automation	19	30	23
	33	high-speed and high-precision non-contact measurement in production lines and processing equipment	25	33	27
	34	micro- and nano-scale sensors	49	35	42
	35	motion and visual perception and intelligent identification of multiple working conditions	12	13	13
Control and Optimization	36	automatic data mining, knowledge discovery and production optimization based on data at planning and control levels of workshops	4	30	33
	37	multimodal intelligent modeling and complex control theory	11	19	11
	38	methods of hybrid system-based decision-making and intelligent optimization computing	22	13	25
	39	architectures of new control systems based on cloud computing, big data, and other information technologies	22	43	38
	40	plug-and-play and system-reconfigurable implementation network OS technology	10	8	20
	41	full-process cluster collaborative optimization and self-adaption optimization technology	27	18	11
	42	knowledge discovery from distributed and heterogeneous knowledge sources and knowledge management	3	21	12
	43	intelligent open CNC systems	61	27	30
	44	intelligent CNC technology	40	18	21
Green Manufacturing	45	ultra-precision and 16/14-nm machining processes and equipment	9	18	13
	46	net shape forming in gear manufacturing	13	0	7
	47	micro/nano-scale sensor manufacturing	15	30	31
	48	remanufacturing of engines, engineering machinery and machine tools	19	8	22

	49	dismantling, recycling and remanufacturing of waste electric and electronic equipment	20	30	29
	50	high-energy beam and hybrid high-energy beam welding	13	19	13
	51	directional solidification and single crystal casting of aircraft engine blades	48	3	13
	52	equipment design technologies based on ecological materials	30	59	36
	53	pressure die casting of aluminum and magnesium alloys (low-pressure, semi-solid, and high vacuum)	9	12	20
	54	near-dry/dry machining technology	23	16	14
Service-oriented Manufacturing	55	industrial big data in product marketing	22	40	29
	56	connectivity technology with service status/environment sensing and control capabilities	11	17	15
	57	mass customization in manufacturing of apparel, footwear and headwear, building materials, and sanitary ware	3	14	4
	58	Online sales exceeding physical-store sales	6	6	4
	59	cloud manufacturing service platforms for machine tools and machining processes	20	16	19
	60	cloud-based collaboration technology across multi industry chains	66	23	35
	61	integrated supply chain and logistics management	16	21	18
	62	Internet of Things and intelligent logistics for manufacturing	42	39	53
	63	integrated sharing and collaboration for manufacturing and services	13	22	23

Annex 3 Implementation time of some of the key technologies

Field	Technology	Implementation Time (Year)		
		Korea	Japan	China
Innovative Design	Wide application of multidisciplinary integrated design optimization in development of key products	2020	2020	2023
	Wide application of digital collaboration-based product development	2019	2020	2023
	Wide application of ecologizing designing technology	2022	2021	2026
Robotics	Clarification of brain-like intelligence robots	2027	2027	2027
	Wide application of public security robots	2020	2022	2022
	Development of mechanisms, sensors and drives of intelligent industrial robots	2020	2020	2021
3D Printing	Clinical application of 3D-printed living organs	2023	2024	2024
	Wide application of processes and equipment integrating 3D printing and precision machinery processing	2020	2020	2022
	Wide application of 3D printing-based personalized modes of production	2022	2020	2027
Sensing and Detection	Wide application of micro- and nano-scale sensors	2020	2022	2023
	Wide application of networked smart sensors in process industry	2021	2020	2022
	Wide application of high-speed and high-precision non-contact measurement in production lines and processing equipment	2022	2021	2023
Control and Optimization	Wide application of intelligent open CNC systems	2019	2022	2023
	Comprehensive promotion of intelligent CNC technology	2021	2022	2023
	Promotion of automatic data mining, knowledge discovery and production optimization based on data at planning and control levels of workshops	2022	2022	2023
	Research on architectures of new control systems based on cloud computing, big data, and other information technologies	2021	2021	2025
Green Manufacturing	Practical application of directional solidification and single crystal casting of aircraft engine blades	2021	2022	2022

	Wide application of equipment design technologies based on ecological materials	2023	2022	2024
	Wide application of micro/nano-scale sensor manufacturing	2021	2022	2023
Service--oriented Manufacturing	Application of cloud-based collaboration technology across multi industry chains	2020	2019	2022
	Wide application of Internet of Things and intelligent logistics for manufacturing	2020	2019	2022
	Wide application of industrial big data in product marketing	2020	2020	2022

Annex 4 Grade of necessity / promising of technology cooperation[39]

Field	NO.	Technology	Necessity Grade			Promising Grade		
			Chin	Japa	Kore	Chin	Japa	Kore
Innovative Design	1	reduction design of typical mechanical equipment	7	17	3	9	20	12
	2	multidisciplinary integrated design optimization in development of key products	63	30	66	61	23	51
	3	integrated bionic design and manufacturing systems	13	17	17	16	17	17
	4	product design based on appearance perception	23	10	12	26	8	18
	5	enterprise-level product data management systems	15	24	10	12	15	20
	6	ecologizing designing technology	17	43	26	16	70	16
	7	mathematical modeling methods and tools	28	26	17	26	26	21
	8	digital collaboration-based product development	34	30	49	34	17	45
Robotics	9	public security robots	46	23	49	34	25	56
	10	robots with cognitive and bionic capabilities	16	19	19	19	18	13
	11	brain-like intelligence robots	26	15	22	39	27	20
	12	human-machine harmonized manufacturing	8	21	16	11	21	18
	13	artificial human body structures and tissues	7	22	4	10	17	7
	14	micro- and nano-scale robots	12	17	18	15	18	14
	15	RV reducers with new mechanisms and tooth profiles	3	3	1	4	7	3
	16	telemedicine robots	39	30	18	28	22	23
	17	mechanisms, sensors and drives of intelligent industrial robots	29	41	46	29	38	40
	18	autonomous underwater vehicles	15	5	7	10	3	7
3D Printing	19	processes and equipment integrating 3D printing and precision machinery processing	34	50	51	36	41	48
	20	4D printing	9	11	4	14	13	6
	21	high-energy laser beam additive manufacturing	29	21	19	25	15	20
	22	3D printing-based personalized modes of production	9	21	39	14	25	34
	23	selective laser sintering	15	32	11	17	22	12

[39] To increase discrimination of the statistical result, "Grade" in this report converts the score in the original questionnaire into the survey result. "Most preferred" = 100 points, "Second most preferred" = 67 points, "Third most preferred" = 33 points, unselected = 0. In comparative assessment / analysis, this report uses 33 points (assignment of "Third most preferred") as the baseline.

	24	high-energy electron beam 3D printing in aeronautics and astronautics	26	8	16	21	11	16
	25	3D-printed living organs	53	39	28	54	46	32
	26	high-energy metal powder preparation for additive manufacturing	23	15	32	20	19	32
Sensing and Detection	27	communication protocol standardization of sensing and motion control systems	13	22	16	14	33	26
	28	fault self-diagnosis and equipment self-healing	18	30	18	18	34	15
	29	nano characterization and testing based on single atoms and molecules	6	5	1	11	7	5
	30	networked remote monitoring systems in process industry	18	13	26	18	11	26
	31	networked smart sensors in process industry	40	16	34	32	15	37
	32	radio frequency identification technology in process industrial automation	19	30	23	21	23	21
	33	high-speed and high-precision non-contact measurement in production lines and processing equipment	25	33	27	23	17	25
	34	micro- and nano-scale sensors	49	35	42	47	42	32
	35	motion and visual perception and intelligent identification of multiple working conditions	12	13	13	15	12	13
Control and Optimization	36	automatic data mining, knowledge discovery and production optimization based on data at planning and control levels of workshops	6	25	32	6	28	28
	37	multimodal intelligent modeling and complex control theory	16	11	13	15	16	20
	38	methods of hybrid system-based decision-making and intelligent optimization computing	23	14	22	26	14	27
	39	architectures of new control systems based on cloud computing, big data, and other information technologies	26	43	30	29	42	31
	40	plug-and-play and system-reconfigurable implementation network OS technology	9	17	17	7	13	15
	41	full-process cluster collaborative optimization and self-adaption optimization technology	31	12	18	26	11	15
	42	knowledge discovery from distributed and heterogeneous knowledge sources and knowledge management	4	18	13	7	16	16
	43	intelligent open CNC systems	52	36	37	51	29	25

	44	intelligent CNC technology	33	21	19	34	26	24
Green Manufacturing	45	ultra-precision and 16/14-nm machining processes and equipment	15	14	10	14	9	11
	46	net shape forming in gear manufacturing	11	4	12	12	9	14
	47	micro/nano-scale sensor manufacturing	16	23	31	13	19	22
	48	remanufacturing of engines, engineering machinery and machine tools	20	13	25	19	17	21
	49	dismantling, recycling and remanufacturing of waste electric and electronic equipment	25	43	32	20	53	35
	50	high-energy beam and hybrid high-energy beam welding	15	13	11	21	7	15
	51	directional solidification and single crystal casting of aircraft engine blades	34	10	14	35	6	17
	52	equipment design technologies based on ecological materials	30	44	37	37	44	34
	53	pressure die casting of aluminum and magnesium alloys (low-pressure, semi-solid, and high vacuum)	9	19	19	10	15	18
	54	near-dry/dry machining technology	23	12	10	21	16	13
Service-oriented Manufacturing	55	industrial big data in product marketing	22	38	28	25	27	27
	56	connectivity technology with service status/environment sensing and control capabilities	15	15	17	16	13	19
	57	mass customization in manufacturing of apparel, footwear and headwear, building materials, and sanitary ware	4	18	4	3	33	6
	58	Online sales exceeding physical-store sales	7	9	8	5	12	7
	59	cloud manufacturing service platforms for machine tools and machining processes	18	14	18	20	20	24
	60	cloud-based collaboration technology across multi industry chains	55	21	34	61	15	32
	61	integrated supply chain and logistics management	22	32	20	16	26	18
	62	Internet of Things and intelligent logistics for manufacturing	35	31	47	37	26	48
	63	integrated sharing and collaboration for manufacturing and services	22	16	24	17	20	20