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1. Objectives

The National Institute of Science and Technology Policy (NISTEP) has to date conducted technology forecast surveys, generally every five years, since 1971 to ascertain the future direction of technology in Japan from a long-term viewpoint. This is the sixth survey conducted.

The promotion of science and technology is pivotal to the sound growth of Japan's business community, so it is crucial that we fully grasp the future direction of technological development from a long-term viewpoint.

In this light, we conducted a technology forecast survey that took in the next 30 years to ascertain the future of technology in Japan, and through this, contribute to the formulation of science and technology policy, and provide a basic reference point for technology strategies in the private sector.

2. Implementation structure

For the survey, NISTEP established a technology forecast committee to examine the overall survey plan and implementation guidelines, and IFTECH established 13 subcommittees(note 1) headed by members of the technology forecast committee to set the survey topics in each field, select the survey participants, and analyze the survey results. NISTEP conducted an analysis of all fields handled by the survey, and the technology forecast committee prepared a comprehensive report based on these analysis results.

3. Outline

(1) Survey fields

The survey covered the following 14 fields.

i) Materials and processing
ii) Electronics
iii) Information
iv) Life science
v) Space
vi) Marine science and earth science
vii) Resources and energy
viii) Environment
ix) Agriculture, forestry and fisheries
x) Production and machinery
xi) Urbanization and construction
xii) Communication
xiii) Transportation
xiv) Health, medical care and welfare

The fifth survey contained 16 fields (see Ref. 3), but the following changes were made for this survey.

- "Information and electronics" was divided into "Information" and "Electronics".
- "Mineral and water resources" and "Energy" were combined into "Resources and energy".
- "Particles" and "Lifestyle and culture" were removed as independent fields and incorporated into other fields.

(note 1) Of the 14 fields covered, "Resources and energy" and "Environment" are closely related, and were handled by a single subcommittee.

• “Production” and “Health and medical care” were changed to, respectively, “Production and machinery” and “Health, medical care and welfare”.

(2) Forecast period

The forecast period is 30 years from 1996 (the year the survey was conducted) to 2025.

(3) Survey method

Like the previous survey, this survey was conducted using the Delphi method, and responses were consolidated through two questionnaires.

Delphi method: The Delphi method is a method of consolidating respondents’ views by repeatedly giving the same questionnaire to a large number of people. In the second and subsequent questionnaires respondents receive a feedback of the results of the previous questionnaire so that they can reassess their answers to the questions in the light of the overall trend of views. This is the major characteristic that sets the Delphi method apart from ordinary survey methods. Respondents who are not confident in their answers will generally tend to support the majority view, so it is possible to consolidate their views. The Delphi method, developed by the U.S. Rand Corporation, was named after the site of the oracle of Apollo in ancient Greek mythology, and according to legend, many gods used to gather there to foretell future events.

(4) Setting the topics

The topics were set by the various subcommittees. The process began with the subcommittees determining the scope of the survey in each of the field, categorizing the future direction of technological development, and preparing a framework that would ensure important topics were not omitted. They then drew up a list of topics. This was done within the following parameters set by the technology forecast committee.

- Review the topic framework of the 5th survey in view of recent technological trends.
- The number of topics should generally be the same as the previous survey, with identical topics, revised topics and new topics each accounting for roughly 1/3 of the topics.
- Set the forecast topics with consideration given to an intersection of technological fields (four axes of aging countermeasures, safety, environmental preservation and recycling, and common base technologies, whose integration with technologies in a large number of fields is considered necessary when looking at future technological trends).
- In principle, topics that have no technological elements and are connected only to socioeconomic conditions should not be included in the survey.
- In principle, survey topics should be those thought to be realizable by 2025. Where necessary though, topics that are realizable after 2026 may also be included.
- In principle, the technological stage of each topic should be expressed by one of the four keywords of “elucidation”, “development”, “practical use” and “widespread use.”
- As for the place of realization, unless specifically mentioned the topic should assume realization anywhere in the world, that is the country or region where realization is earliest.
- Two or more forecast particulars should not be included in one topic.
- Topics should include specific objective values and champion data wherever possible, and should present an image of specific use and application.
- Where necessary, identical forecast topics should be surveyed in more than one survey field.

After the subcommittees evaluated previous topics, examined new topics and prioritized topics according to importance, they finally settled on 1,072 topics for the survey.

(5) Selecting survey respondents

For the most part, members in each of the subcommittees were asked to recommend experts in their respective fields as potential respondents. Our intention was to obtain as large a list as possible of experts with extensive knowledge in the relevant topics or technological fields, keeping in mind the need for a good cross-section of representatives from industry, the government and academia. In some cases however, rather than recommendations of individual names, the Secretariat chose respondents at random from a list put forward by the subcommittees.

The main people we were looking for as respondents were "people in research and development, research managers and others in corresponding positions who have expert knowledge in the relevant survey fields." We also considered people with the following attributes.

i) Sector (occupation)

The overall percentage breakdown of respondents across all fields in the fifth survey was company-related 37%, university-related 36%, public research institutions 15%, and others 12%, and for the sixth survey we aimed at a similar industry-academia-government mix.

ii) Age composition

For this survey we tried to increase the number of relatively younger respondents in their 30s and 40s (in the previous survey, most respondents were in their 50s, followed by those in their 40s, then 60s). We also tried to increase the proportion of female respondents (only 1% in the previous survey).

We asked potential respondents identified through the above process whether they would be prepared to cooperate in the survey, then chose those who were prepared to cooperate to take part in the first questionnaire. For the first part of the survey we sent questionnaires to 4,868 respondents, of whom 4,196 were sent questionnaires for the second part. We excluded those who decided to withdraw from the survey after the first questionnaire.

The breakdown of final respondents by sector for this survey is generally the same as it was for the fifth survey. By age, the number of respondents in their 30s and 40s increased over the previous survey, though only slightly. An increase was also recorded in female respondents, but here too, the increase was quite small (see Tables 3-1 and 3-2).

(6) Survey items

We drew up the questionnaires in question form covering the survey items listed below for each of the topics set at (4) above (for details see 4. Reading the survey results)

Degree of expertise

Degree of importance to Japan

Expected effect

Forecasted realization time

Current leading countries etc.

Effective measures the government should adopt in Japan

Potential problems in Japan

(7) Implementation of the questionnaires

The questionnaires were sent to respondents as follows.

First questionnaire: August 1996

Second questionnaire: December 1996

For the survey we asked the respondents to give their responses assuming that over the next 30 years there would be no wars of a global scale or natural calamities to cause socioeconomic upheaval. In the second

questionnaire we included the results of the first questionnaire for reference by the respondents.

The second questionnaire questioned respondents on the same topics as the first, though the wording of some topics was reviewed and revised in the light of comments by the respondents in the first questionnaire.

(8) Response assumptions

- In principle, this technology forecast covers what are considered to be key R&D topics over the roughly 30-year period from 1996 to 2025.
- There will be no wars of a global scale or natural calamities that would cause socioeconomic upheaval over the next 30 years.
- Unless expressly indicated in the topics with such terms as “in Japan,” topic realization means realization anywhere in the world.

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4. Reading the survey results

Questionnaire results are shown as follows.

Division	Topic serial no.	Topic	Questionnaire round	Number of respondents	Degree of expertise (%)			Importance (index, %)					Expected effect (%)			
					High	Medium	Low	Index	High	Medium	Low	Unnecessary	Socioeconomic development	Resolution of global problems	People's needs	Expansion of intellectual resources
	1	Development of technology capable of manipulating single atoms and single molecules.	1	290	12	38	50	71	48	42	10	0	62	6	7	75
			2	258	12	34	54	71	46	46	7	0	62	2	1	79
			X	30	100	0	0	91	83	13	3	0	67	3	0	93

i ii iii iv v vi

Forecasted realization time		Leading countries (%)						Measures the government should adopt (%)							Potential problems (%)			
Will not be realized (%)	Do not know (%)	USA	EU	Former Soviet Union and Eastern Europe	Japan	Other countries	Do not know	Foster human resources	Promote exchanges among industrial, academic and government sectors and different fields	Upgrade advanced facilities and equipment	Develop a research base	Increase government research funding	Adjust regulations (relax/toughen)	Others	Natural environment	Safety	Morals, culture or society	Others
1	4	85	26	0	63	0	9	60	40	45	5	53	1	1	8	2	8	2
1	3	92	22	0	69	0	3	64	36	47	2	55	0	0	5	2	6	2
0	3	100	37	0	77	0	0	80	47	47	0	63	0	0	0	0	0	0

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i) Topics

In some cases the two questionnaires differed slightly in the wording of the topic, but here we have used the wording contained in the second questionnaire. The definitions of the keywords used in the topics are as follows.

Elucidation	:	To scientifically and logically identify principles or phenomena.
Development	:	To attain a specific goal in the technological aspect (e.g. completion of a No.1. prototype).
Practical use	:	To be practically used after being proved economically viable (e.g. completion of the first object that can be actually presented for practical use).
Widespread use	:	To be widely and commonly used after an object is put to practical use.

ii) Questionnaire rounds

The terms 1, 2 and X are used to indicate the following.

1 : First round of the questionnaire (results from respondents indicating a “high,” “medium” or “low” degree of expertise)

2 : Second round of the questionnaire (results from respondents indicating a “high,” “medium” or “low” degree of expertise)

X : Aggregate results from respondents indicating a “high” degree of expertise in the second round of the questionnaire.

iii) Number of respondents

The number of respondents in rounds 1 and 2 of the questionnaire shows the total number of respondents indicating a “high,” “medium” or “low” degree of expertise (the number who indicated “none” is not shown).

The number in X shows the number who indicated a “high” degree of expertise in the second round of the questionnaire. Normally the number of respondents in the second round is lower than the number in the first (on average about 85% of the first round number), but there are a few cases where the number has increased because some who did not respond in the first round responded in the second.

iv) Degree of expertise

The degree of expertise shows a percentage breakdown of respondents in iii). above who indicated a “high,” “medium” or “low” degree of expertise. Respondents were asked to select one of the expertise degrees defined below.

High : Has considerable specialist knowledge about the topic through current research or work related to the topic (including research based on literature).

Medium : Was once engaged in research or work related to the topic; or has some specialist knowledge about the topic through research or work in an adjoining field.

Low : Has read technical books or literature about the topic or has listened to experts connected with the topic.

None : Has no expertise.

v) Degree of importance to Japan

The degree of importance to Japan shows a percentage breakdown of respondents who indicated “high,” “medium,” “low” or “unnecessary” for the topic’s importance. The index was worked out from the following equation; the index is 100 when all respondents indicate “high” and 0 when all indicate “unnecessary”.

Degree of importance index = (number of “high” responses × 100 + number of “medium” responses × 50 + number of “low” responses × 25 + number of “unnecessary” responses × 0) ÷ total number of degree of importance responses.

Respondents were asked to select one of the importance degrees defined below.

High : Extremely important

Medium : Important

Low : Somewhat important

Unnecessary : Not important

vi) Expected effect

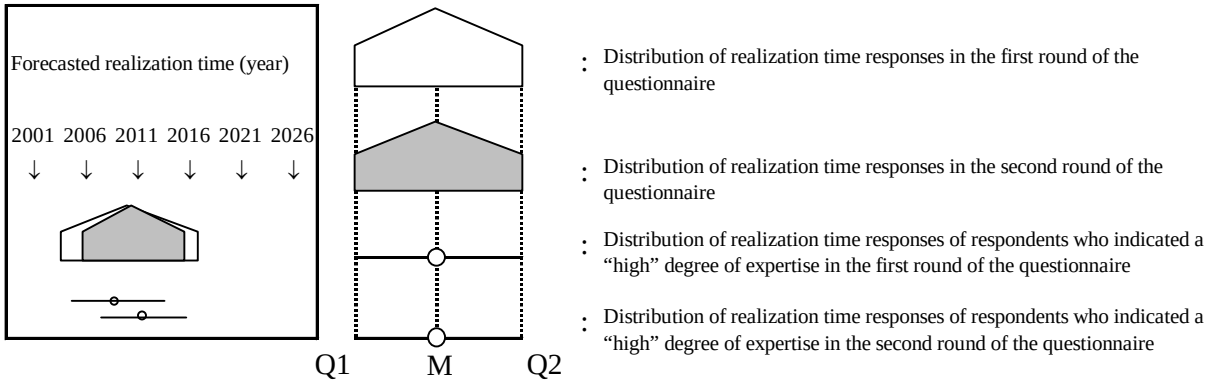
The figures here show the percentage of the respondents at iii) who selected each of the four expected effects of the topic's realization, listed below. For this, respondents were allowed to select more than one effect (or none if nothing was applicable).

Contribution to socioeconomic development	:	Development of innovative products, creation of new industries, expansion of economic frontiers, development of the socioeconomic base, etc.
Resolution of various problems of a global scale	:	Global environment, food, energy, resources, etc.
Response to people's needs	:	Prevention and cure of disease, improvement of the living environment, support for elderly people and people with disabilities, disaster prevention and safety, etc.
Expansion of human intellectual resources	:	Discovery of new laws and principles, construction of original theories, etc.

vii) Forecasted realization time

The forecasted realization time graph shows the distribution of responses of "1996–2000" through "2026-", and was calculated according to the method explained below. Responses of "will not be realized" or "do not know" were excluded.

(Forecasted realization time graph)



Distribution of realization time responses in the first round of the questionnaire; Distribution of realization time responses in the second round of the questionnaire; Distribution of realization time responses of respondents who indicated a "high" degree of expertise in the first round of the questionnaire; Distribution of realization time responses of respondents who indicated a "high" degree of expertise in the second round of the questionnaire

Q1 : Realization time corresponding to the response at the 25th percentile of all responses after they were arranged in chronological order from the earliest to the latest realization time.

M : Realization time corresponding to the response at the 50th percentile.

Q2 : Realization time corresponding to the response at the 75th percentile.

The width of the pentagon (distance between Q1 and Q2) shows the range of realization time distribution for the half of all respondents who were positioned around the middle of the realization time responses.

A narrow width represents a strong consensus among respondents.

The M value is used in cases where the topic realization time in the chronological table is expressed as a numerical value. The number of respondents who selected “will not be realized” or “do not know” are shown as a percentage of respondents at iii). above.

viii) Current leading countries etc.

This shows the percentage of respondents at iii) who selected each of the six countries or regions below as a world leader in the topic in question. Respondents were allowed to select more than one country or region.

- USA
- EU
- Former Soviet Union and Eastern European countries
- Japan
- Other countries (enter specific country in the response column)
- Do not know

(As of May 1996 the EU comprises the 15 countries of Germany, UK, France, Spain, Netherlands, Greece, Belgium, Portugal, Sweden, Austria, Denmark, Finland, Ireland and Luxembourg.)

ix) Effective measures the government should adopt in Japan

This shows the percentage of respondents at iii). who selected each of the seven items below as effective measures that the government should adopt in Japan to promote R&D aimed at the realization of the topic in question. Respondents were allowed to select up to three separate measures. No selection was made where it was believed no measures were appropriate considering the nature of the topic; for example, realization was best left up to market forces.

- Foster researchers, engineers and research assistants
- Enhance systems to promote personnel exchanges among the industrial, academic and government sectors and cooperation among different fields of science and technology
- Upgrade advanced R&D facilities and equipment and make them available for more widespread use (covers facilities and equipment at national research institutions, universities and other public research institutions)
- Develop a research base comprising data bases, standard reference material, genetic resources and the like
- Increase the government’s funding for research (including research subsidies for private companies etc.)
- Adjust relevant regulations (relax/toughen/establish/abolish; including such tax measures as promoting the widespread use of electric cars by introducing a carbon tax)
- Others (enter specific measures in the response column)

x) Potential problems in Japan

This shows the percentage of respondents at iii) who selected each of the four items below as potential problems that realization of the topic in question could create in Japan. Respondents were allowed to select up to two items (none if nothing was applicable).

Adverse effect on the natural environment	:	Increased destruction of the natural environment, including air and water pollution, destruction of ecosystems, etc.
Adverse effect on safety	:	Adverse effect on disaster prevention, health, security, privacy etc. (occurrence of natural disasters, increase of crime, improper use of personal information etc.).
Adverse effect on morals, culture or society	:	Adverse effect on life ethics, human psychology, traditional culture, human relations, regional communities etc.
Other adverse effects	:	(enter specific effects in the response column)

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5. Presentation of information

The way this report presents the data and topics is described below.

- For questionnaire totals in each of the topics, forecasted realization times (year) are whole numbers with any decimals discarded, and degree of importance and other survey items with percentages or indices are rounded off to the nearest whole number.
- Average values for survey fields are, in principle, rounded off to the first decimal point, but where this is too cumbersome for graphs and the like, values are rounded off to the nearest whole number.
- For topic descriptions in tables etc., in principle we have used the wording used in the questionnaire (text of topics in the table of aggregate results for each field at Chapter 3), however where this may become too cumbersome, we have used a shortened form of the topic.

  (Example) Development of precision polymerization processes that can freely control stereoregularity, chain structure and molecular weight and distribution of polymer in supplementary polymerization reactions at the molecular level.

  ↓

  Development of precision supplementary polymerization processes for polymer controlled at the molecular level.

- In some cases, survey questions were preceded by two, three or six-digit numbers. Each number signifies the following:

  (Two or three-digit number) The topic number of the topic concerned within the field to which it belongs
  (Six-digit number) The first digit, which is 6, indicates that the topic concerned is a 6th Survey topic. The following two digits signify the field to which the topic concerned belongs (for field number assignment, see the table below). The last three digits signify the topic number of the topic concerned within its field.

• The following shortened forms have been used for field names.

Field	Shortened form	No. of field
Materials and processing	Materials	01
Electronics	Electronics	02
Information	Information	03
Life science	Life science	04
Space	Space	05
Marine science and earth science	Marine science	06
Resources and energy	Resources	07
Environment	Environment	08
Agriculture, forestry and fisheries	Agriculture etc.	09
Production and machinery	Production	10
Urbanization and construction	Urbanization	11
Communication	Communication	12
Transportation	Transportation	13
Health, medical care and welfare	Health	14

• The following shortened forms have been used for survey items.

Survey items	Shortened form
Degree of importance to Japan	Importance
Expected effect	Expected effect
Contribution to socioeconomic development	Socioeconomic development
Resolution of various problems of a global scale	Resolution of global problems
Response to people's needs	People's needs
Expansion of human intellectual resources	Expansion of intellectual resources
Current leading countries etc.	Leading countries
USA	USA
EU	EU
Former Soviet Union and Eastern European countries	Former Soviet Union and Eastern Europe
Japan	Japan
Other countries	Others
Do not know	Do not know
Effective measures the government should adopt in Japan	Measures the government should adopt
Foster researchers, engineers and research assistants	Foster human resources
Enhance systems to promote personnel exchanges among the industrial, academic and government sectors and cooperation among different fields of science and technology	Promote exchanges among industrial, academic and government sectors and different fields
Upgrade advanced R&D facilities and equipment and make them available for more widespread use	Upgrade advanced facilities and equipment
Develop a research base comprising data bases, standard reference material, genetic resources and the like	Develop a research base
Increase the government's funding for research	Increase government research funding
Adjust relevant regulations (relax/toughen/establish/abolish)	Adjust regulations (relax/toughen)
Others	Others
Potential problems in Japan	Potential problems
Adverse effect on the natural environment	Natural environment
Adverse effect on safety	Safety
Adverse effect on morals, culture or society	Morals, culture or society
Other adverse effects	Others

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Table 3-1 State of questionnaire responses and breakdown of respondent numbers

Unit ; persons

Field	No. of topics	Responses						Attributes (round 2 questionnaire)																		
		R1			R2			Gender			Age							Occupation						Occupational category		
		Sent	Returned	Response rate	Sent	Returned	Response rate	Male	Female	Did not indicate	20s	30s	40s	50s	60s	70s or above	Did not indicate	Company employee	University-related	Public servant	Other non-company employee	Other	Did not indicate	Research-related	Other	Did not indicate
01. Materials	109	441	366	83%	364	300	82%	299	1	0	1	14	71	156	53	5	0	99	158	27	10	6	0	264	36	0
02. Electronics	74	407	351	86%	350	312	89%	309	3	0	0	20	141	124	23	4	0	175	99	26	9	3	0	284	28	0
03. Information	79	295	242	82%	241	194	80%	188	6	0	0	29	92	60	12	0	1	118	59	7	8	1	1	167	26	1
04. Life science	94	380	337	89%	334	274	82%	268	6	0	0	21	99	110	40	4	0	38	185	33	15	3	0	259	15	0
05. Space	51	384	342	89%	339	305	90%	300	5	0	4	29	122	124	25	1	0	95	71	65	72	2	0	259	46	0
06. Marine science	74	335	294	88%	292	248	85%	242	6	0	1	21	93	89	37	5	2	36	131	52	24	3	2	210	36	2
07. Resources	88	495	433	87%	432	363	84%	358	5	0	0	22	106	177	51	6	1	138	115	39	58	12	1	275	88	1
08. Environment	39	411	351	85%	348	294	84%	283	11	0	11	35	108	90	42	7	1	82	107	60	32	12	1	239	53	2
09. Agriculture, etc.	84	384	355	92%	355	311	88%	300	11	0	1	13	90	131	70	6	0	49	111	120	26	5	0	280	30	1
10. Production	71	224	188	84%	186	154	83%	152	2	0	0	13	59	58	22	2	0	81	65	3	4	1	0	113	40	1
11. Urbanization	73	287	252	88%	251	219	87%	213	6	0	0	16	85	94	23	1	0	110	52	27	28	2	0	152	67	0
12. Communication	78	325	279	86%	278	242	87%	237	5	0	2	27	102	94	16	1	0	174	46	7	13	1	1	186	56	0
13. Transportation	60	276	255	92%	253	238	94%	238	0	0	1	17	81	106	33	0	0	99	57	35	44	3	0	154	84	0
14. Health	98	224	175	78%	173	132	76%	128	4	0	0	4	48	44	35	1	0	9	85	31	4	3	0	87	45	0
Sixth survey total	1072	4868	4220	87%	4196	3586	85%	3515	71	0	21	281	1297	1457	482	43	5	1303	1341	532	347	57	6	2929	650	8
Fifth survey	1149	3334	2781	83%	2781	2385	86%	2312	27	46	8	111	724	1054	410	32	46	879	864	349	203	42	48	1834	498	53

Table 3-2 State of questionnaire responses and percentage breakdown of respondents

Field	No. of topics	Responses						Attributes (round 2 questionnaire)																		Unit : %
		R1			R2			Gender			Age							Occupation					Occupational category				
		Sent	Returned	Response rate	Sent	Returned	Response rate	Male	Female	Did not indicate	20s	30s	40s	50s	60s	70s or above	Did not indicate	Company employee	University-related	Public servant	Other non-company employee	Other	Did not indicate	Research-related	Other	Did not indicate
01. Materials	109	441	366	83%	364	300	82%	100%	0%	0%	0%	5%	24%	52%	18%	2%	0%	33%	53%	9%	3%	2%	0%	88%	12%	0%
02. Electronics	74	407	351	86%	350	312	89%	99%	1%	0%	0%	6%	45%	40%	7%	1%	0%	56%	32%	8%	3%	1%	0%	91%	9%	0%
03. Information	79	295	242	82%	241	194	80%	97%	3%	0%	0%	15%	47%	31%	6%	0%	1%	61%	30%	4%	4%	1%	1%	86%	13%	1%
04. Life science	94	380	337	89%	334	274	82%	98%	2%	0%	0%	8%	36%	40%	15%	1%	0%	14%	68%	12%	5%	1%	0%	95%	5%	0%
05. Space	51	384	342	89%	339	305	90%	98%	2%	0%	1%	10%	40%	41%	8%	0%	0%	31%	23%	21%	24%	1%	0%	85%	15%	0%
06. Marine science	74	335	294	88%	292	248	85%	98%	2%	0%	0%	8%	38%	36%	15%	2%	1%	15%	53%	21%	10%	1%	1%	85%	15%	1%
07. Resources	88	495	433	87%	432	363	84%	99%	1%	0%	0%	6%	29%	49%	14%	2%	0%	38%	32%	11%	16%	3%	0%	76%	24%	0%
08. Environment	39	411	351	85%	348	294	84%	96%	4%	0%	4%	12%	37%	31%	14%	2%	0%	28%	36%	20%	11%	4%	0%	81%	18%	1%
09. Agriculture, etc.	84	384	355	92%	355	311	88%	96%	4%	0%	0%	4%	29%	42%	23%	2%	0%	16%	36%	39%	8%	2%	0%	90%	10%	0%
10. Production	71	224	188	84%	186	154	83%	99%	1%	0%	0%	8%	38%	38%	14%	1%	0%	53%	42%	2%	3%	1%	0%	73%	26%	1%
11. Urbanization	73	287	252	88%	251	219	87%	97%	3%	0%	0%	7%	39%	43%	11%	0%	0%	50%	24%	12%	13%	1%	0%	69%	31%	0%
12. Communication	78	325	279	86%	278	242	87%	98%	2%	0%	1%	11%	42%	39%	7%	0%	0%	72%	19%	3%	5%	0%	0%	77%	23%	0%
13. Transportation	60	276	255	92%	253	238	94%	100%	0%	0%	0%	7%	34%	45%	14%	0%	0%	42%	24%	15%	18%	1%	0%	65%	35%	0%
14. Health	98	224	175	78%	173	132	76%	97%	3%	0%	0%	3%	36%	33%	27%	1%	0%	7%	64%	23%	3%	2%	0%	66%	34%	0%
Sixth survey total	1072	4868	4220	87%	4196	3586	85%	98%	2%	0%	1%	8%	36%	41%	13%	1%	0%	36%	37%	15%	10%	2%	0%	82%	18%	0%
Fifth survey	1149	3334	2781	83%	2781	2385	86%	97%	1%	2%	0%	5%	30%	44%	17%	1%	2%	37%	36%	15%	9%	2%	2%	77%	21%	2%

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