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Structure Analysis of the Japanese Science Indicator System and Its Evaluation

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The purpose of this paper is to describe the structure of the developed Japanese Science Indicator System (JSIS) and to evaluate it based on two criteria : causality and balancing. In order to develop JSIS, first its purpose was considered, and we established a goal of constructing a reporting type indicator system. Because the indicators should be derived logically and systematically, basic guidelines were formulated as four statements.

Based on these statements, we selected the indicators and formed a structure from the chosen indicators. We came to the conclusion that a "cascade" structure is the most appropriate for describing a science indicator system (SIS) because it could solve two of the most difficult problems of SIS : relevancy and causality. In the end, we obtained a cascade structured JSIS comprised of 103 individual indicators, 6 major categories and two layers.

To confirm the extent to which the JSIS supports the guidelines, we analyzed it from the viewpoints of causality and balancing of indicators. It was determined that the JSIS satisfies these two criteria and four statements. Lastly, three existing science indicator systems were evaluated by balancing of indicators and compared to the JSIS.

1. Background

The "Council for Science and Technology", which is responsible in general for setting the guidelines for Japan's national science and technology policies for the coming decade, published the 11th Recommendation in November 1984[3]. The three focal issues of the Recommendation are ;

(1) promotion of creativeness in science and technology,

(2) harmonization of science and technology with man and society, and

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The Science and Technology Agency (STA) organized an informal investigation team in September 1984 to conduct a preliminary study on the development of a Japanese Science Indicator System. Based on the report of the team [1], the STA formed a committee in October 1985 to carry out further study on such a system. As members of the team and of the committee, the authors would like to summarize the main points of the committee's report [2]. The authors are grateful to Youichi Kaya, the chairman of the committee, for making the research possible, to Toshio Dokura for data collection, and to various reviewers for their constructive comments.

(3) strengthening international relationships.

We should understand these issues in the historical context of Japan's science and technology policies. In that context, it is clear that Japan has been making enormous efforts to promote science and technology, based on the recognition that science and technology must be the motive force for social and economic development and significant key to solving social problems.

However, the 11th Recommendation starts with an awareness of the following two new needs :

(1) the need to accumulate scientific and technological knowledge,

(2) the need to accomodate international expectations.

First, the awareness of the need to increase the scientific and technological knowledge is based on the fact that the country's potential to develop new technology is influenced greatly by the stock of technology and scientific knowledge that has been formed through the accumulation of past research and development (R & D) efforts. Therefore, we have to strengthen the intellectual stock —— the basic soil on which the technology of the next generation can grow.

The country's strength in R & D must overall include three aspects ; basic, applied research, and development. The need for accumulation of knowledge will require us to emphasize basic research with the purpose of deriving valuable seeds for future technology. It is no longer sufficient for us to continue improving and refining the existing technology. Rather, our efforts must be directed to strengthening basic research, developing creative researchers, and providing a better research environment.

Second, the awareness of the need to accomodate the international expectations is based on the fact that Japan's influence on the international community is becoming increasingly important, due to growth of the economy. Therefore, Japan is expected to contribute not only to worldwide economic activities, but also to various other fields including science and technology.

In order for Japan to play a more positive role internationally in the fields of science and technology, we must endeavor to,

(1) enhance the level of Japanese science and technology as a prerequisite for international cooperation and exchange, while seeking well-balanced development of basic and applied research,

(2) introduce an international dimension into our human resources, organizations and activities with the purpose of promoting cooperation and exchange with other nations.

Especially in the area of cooperation, Japanese activities should take more of a long-term and broader perspective. The framework and structure of cooperation and exchange programs will have to be improved so that the actual work being done can be accomplished more effectively.

It is for these reasons that the development of the Japanese Science Indicator System (JSIS) was initiated by the Science and Technology Agency (STA). Emphasis should be placed on how to measure scientific and technological stocks and how to measure the degree of international contribution.

2. Typology of Science Indicator System

In order to develop a science indicator system (SIS) which is organized from prudently selected indicators, we should think of its purpose and the ways of using it. First, a SIS would be used to grasp the status quo of the country's scientific and technological activities. Second, it would be used to set goals which will be attained within a certain time period. Third, it would be used to formulate and evaluate alternative policies which have been or will be implemented.

By examining the purposes, we derive the following SIS typology :

1. Reporting Type

The purpose of this type is to measure the various aspects of the present scientific and technological (S & T) activities as accurately as possible. Emphasis should be placed on investigating the right indicators which truly reflect the S & T activities to be measured. In other words, we do not have to be so concerned with inconsistency among individual indicators. The individual indicators could be selectively chosen without having to seriously consider the causal relationships among them.

However, by having these indicators at hand, we can understand the present levels of a country's S & T activities and forecast their future trends. From the policy maker's viewpoint, this type of SIS can be utilized as an early warning system for S & T activities.

2. Judgment Type

The purpose of this type is to formulate national goals of S & T. Some goals must be decided concerning a country's timetable of S & T activities during a specified time period.

In order to transform the reporting type into the judgment type, the selectively chosen individual indicators must be organized. Indicators which are more or less randomly chosen without assuming causality should be integrated into several comprehensive indicators. These indicators, which are selected to measure the current status of a specific country's S & T activities, should be consistently compared with the time series data of the country and with the corresponding data of other countries.

Through such transformation, policy makers can utilize SIS as the basis for formulating national goals of S & T activities.

3. Evaluation Type

The purpose of this type is to examine the causal relationships among indicators. The system must be further organized so that some statistical analysis could be made on the relationships among the indicators.

Almost all existing "Science Indicators" are the reporting type, although occasionally some attempts to construct a judgment type of "Science Indicators" are being made in various countries. However, such attempts have not yet been on a systemic and regular basis.

More importantly, this typology shows us that reporting type is the basis for two other types. In other words, the various types and purposes of SIS can be constructed based on the reporting type. Thus, effort was centered on the development of a reporting type SIS.

3. Basic Guidelines for Constructing a Science Indicator System

We have established a goal of constructing a reporting type SIS. The various indicators which reflect the current S & T activities are to be selected in terms of their relevancy to the assumed structure. The indicators should be derived logically and systematically, not arbitrarily and fragmentarily.

For these reasons, the basic guidelines to derive indicators and categories are expressed in the following statements. We will describe these statements and their meanings.

Statement I. **The system should be designed to grasp not only R & D activities but also S & T activities as a whole.**

Most of the existing "Science Indicators" are more or less centered around R & D activities. However, R & D activities are performed on the basis of a more general "scientific and technological infrastructure." Furthermore, S & T infrastructure is formed on the besis of a more general "societal infrastructure" which supports a country's S & T activities.

For example, R & D activities are performed by scientists who have been brought up through their country's educational system, consisting of the country's S & T infrastructure. The educational system of some countries, such as Japan, is financed from national tax, based on a national consensus that a part of the national tax should be used for education.

On the other hand, the impacts of R & D activities are explicitly recognized by society as contributing to the generation of technology that is useful to society, as well as the generation of information. Furthermore, many technological innovations induce changes in people's value systems and ways of life. Therefore, we need to examine two major categories, "S & T contribution" and "societal acceptance of S & T", as far as the impacts of R & D are concerned.

Statement II. **Classification scheme of objectives should be built into the scheme of activities.**

The unique nature of S & T activities is that they achieve various objectives. From this, S & T activities can only be described in relation to their objectives. Thus, it is indispensable for the classification scheme to be built into the scheme of activities.

Statement III. **R & D activities should be described not in terms of input/output relation, but in terms of infrastructure/impact.**

The input/output concept which is heavily used in economics, is not appropriate for describing R & D activities. R & D activities, by definition, deal with the unknown. Therefore, the activities never follow a standerd specific pattern. For this reason, it is impossible to identify an R & D activity in terms of a stable input/output relation. Furthermore, since R & D activities have a very dynamic nature in many aspects, they don't fit into the input/output concept, which is a very static one. Rather, they fit into a infrastructure/impact concept, because the causal relation between R & D activities is not so rigid as the input/output relation is. On this basis, R & D activities are divided into "R & D infrastructure" and "R & D results."

Statement IV. **Due consideration should be paid to stock indicators and subjective indicators as well as flow indicators and objective indicators.**

Most of the "Science Indicators" developed in the past have a bias toward objective, quantitative and flow indicators because they are easier to measure. They accordingly have a higher reliability and can be easily utilized. However, they are insufficient for grasping a country's S & T activities. Therefore, subjective, qualitative and stock indicators should be widely adopted to compensate for this insufficiency.

Although the size of R & D activities can be measured by means of flow indicators, their efficiency is dependent upon the availability of the supporting systems, such as the database and technicians. In addition to this, these supporting systems can only be established by accumulating the results of past activities. Moreover, the absolute size of "R & D results" can be measured by quantitative and objective indicators such as the number of the publications, but the contents can not be measured.

4. Structuring of indicators

Based on these guidelines, we selected the indicators and formed a structure from the chosen indicators. We came to the conclusion that a "cascade" structure is the most appropriate one for describing the science indicator system.

"Cascade" is defined as a series of small waterfalls or as something arranged in a series or succession of stages so that each stage derives from or acts upon the product of the preceding stage. The major categories of JSIS take on characteristics of a series of waterfalls. R & D activities are located in the middle, and the infrastructure system moves from a more direct one to a less direct one, flowing in an upstream direction. In the other direction, the impact system, which is influenced by R & D activities, becomes less direct while moving in a downstream direction. The relation among the major categories is described in the cascade structure, as shown in Figure 1 (See Statement I, II and III).

The sub-structure of the major category "societal infrastructure," which is placed at the top of the upstream, is very simple, and it contains only few indicators because of its indirectness, i. e., this major category has no need for a

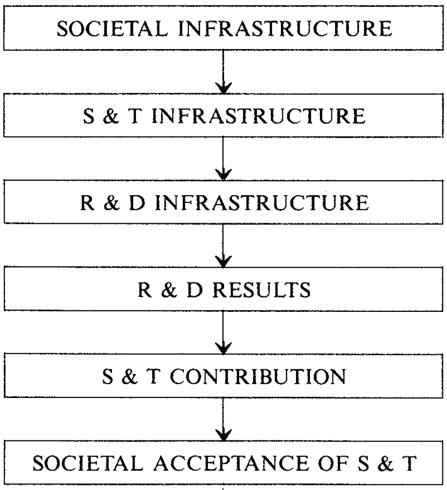

Figure 1. Flow of Major Categories

sub-structure. On the other hand, the major category of "R & D infrastructure" is placed in the middle of the cascade structure and needs a variety of indicators with a double-layer sub-structure because of its importance to JSIS. Because the "S & T infrastructure" is placed between the "societal infrastructure" and the "R & D infrastructure", it is appropriate to have only one layer. As far as the downstream part of the cascade structure is concerned, the sub-structure remains the same.

If we draw a picture of these categories along with subcategories and sub-subcategories, as depicted in Figure 2, we can easily come to imagine waterfalls with multi-stages, which is another key concept of the cascade structure. If you go from the ends in an upstream or down-stream motion to the middle, the number of indicators increases. The nature of indicators shifts from a representative one to a more concrete one, and the division becomes more detailed.

The subcategories of the major categories are as follows:

(1) Societal Infrastructure: The indicators which belong in this major category indirectly support the country's S & T activities.

(2) Scientific and technological infrastructure: The indicators in this category support indirectly the country's R & D activities.

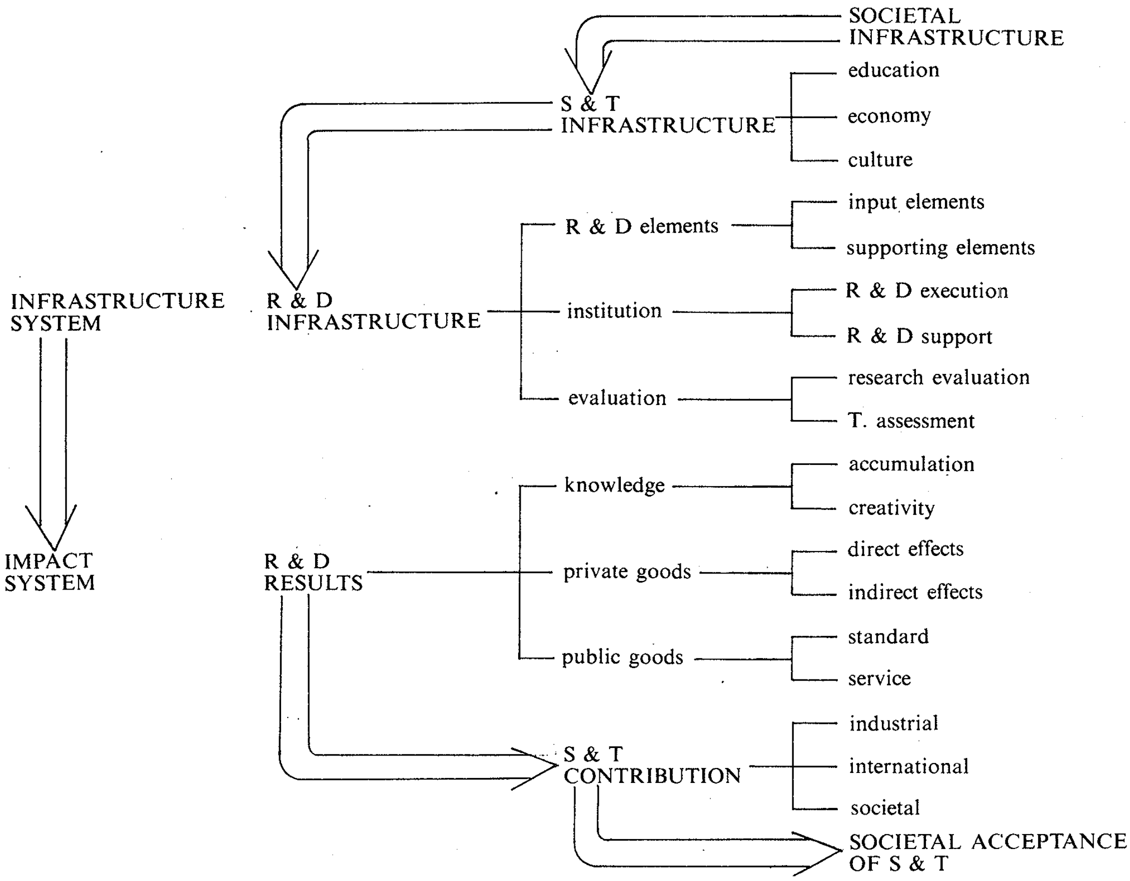

Figure 2. Cascade Structure of Science Indicators

Based on Statement II described above, this major category is classified into the following three sub-infrastructures: "educational," "economic" and "cultural" infrastructures. This is because, first, S & T is taught and researched as part of educational activities. Second, it is researched and utilized by economic organizations as an indispensable part of business activities. Third, it is an important part of cultural activities performed by society.

(3) Research and development infrastructure: The indicators in this category directly support the R & D activities. This major category is comprised of the following three subcategories: (a) system elements such as manpower, facility and money; (b) the institutional framework which organizes these system elements for a specific purpose; and (c) evaluation scheme which decides how well the R & D activities will be done. These subcategories are respectively named (a) "R & D elements," (b) "institutional framework" and (c) "evaluation scheme."
For example, the indicators that are related to the number of researchers, R & D expenditure and research facilities belong in the subcategory of "R & D elements." The indicators that are related to organizing principles, research funding methods, industry-university collaboration and mobility of researchers belong in the subcategory of "institutional framework." Those related to the promotion of researchers and allocation of research budgets belong in the subcategory of "evaluation scheme."
Furthermore, the subcategory of "R & D elements" is further divided into "R & D input elements" and "R & D supporting elements." The subcategory of "institutional framework" is divided into "institution for the execution of R & D" and "institution for the support of R & D."

(4) Research and development results: The indicators in this category are the direct results of R & D activities. As far as R & D results are concerned, the classification was made on the basis of the kind of values they produce. First of all, the case where the results produce a value as knowledge is discriminated from the case where results generate values by producing some form of goods. The production of goods is further divided into private goods and public goods. Therefore, this major category is classified into the following three subcategories: "knowledge value," "private goods value," and "public goods value."
For instance, if an R & D activity is published in a paper, it is recognized as having knowledge value. If it results directly in a patent right, it is recognized as having private goods value. If it results in legal information such as standardization, it is recognized as having public goods value.
Furthermore, these subcategories are further divided into two sub-subcategories. For example, the category of "knowledge value" consists of "accumulation in existing knowledge stock" and "creative contribution," and so on.

(5) Contribution of science and technology: The indicators in this category show the direct impacts of the results from R & D activities. This category is divided into three levels of contribution: "industrial," "international" and "societal." First, S & T contributes to the national economy through the utilization of industrial activities. Second, it can make an international contribution by transferring technology to the developing countries and by solving global problems, such as starvation. Third, it can contribute directly to society, for example, by preventing disasters and disease.

(6) Societal acceptance of science and technology: The indicators in this category are the indirect impacts of science and technology

on society and their acceptance by society.

What is interesting is that this cascade structure could solve two of the most difficult problems of SIS : relevancy and causality. There is no argument against the fact that the indicators related to R & D activities are most relevant to the policy makers. For long-term planning, condensed indicators placed at both ends of the cascade structure are relevant. Those indicators which are most relevant for policy makers for short-term planning are centered in the middle of the cascade structure, hence, they can be described in more detail.

In order to give some structure to selected indicators, we cannot avoid assuming some kind of causal relations among indicators. However, we have not yet come to agreement on the causal relationships in the fields of research on science policy. One of the ways to accomodate these kinds of uncertainties is to differentiate explicitness. In the middle of the cascade, causality is explicitly assumed, while it is assumed implicitly at both ends of the cascade structure.

5. Distribution of Selected Indicators

Based on the basic guidelines, we selected 103 indicators from about 200 candidates. These 103 indicators will not be described in detail here. Instead, we are concerned whether these indicators are selected according to the cascade structure or not. Therefore, we are interested in the distribution of the selected indicators.

The distribution along the categories of the cascade structure is shown in Table 1. In the cascade structure, it is assumed that the number of indicators should be larger in the middle and smaller at both ends. As far as the upstream part of the system is concerned, the frequency for the category of "R & D infrastructure" is 35, 14 for the "S & T infrastructure", and 3 for the "societal infrastructure." Therefore, the distribution of the upstream part accommodates the cascade structure.

On the other hand, the frequency for "R & D results" is 30, 18 for "S & T contribution," and 3 for "societal acceptance of S & T." Thus, as far as the downstream part is concerned, the

Table 1. Distributino of Selected Indicators

major category		subcategory		sub-subcategory	
SOCIETAL INFRASTRUCTURE	3				
S & T INFRASTRUCTURE	14	education	6		
		economy	4		
		culture	4		
R & D INFRASTRUCTURE	35	R & D elements	14	input elements	8
				support elements	6
		institution	12	R & D execution	8
				R & D support	4
		evaluation	9	R. evaluation	5
				T. assessment	4
R & D RESULTS	35	knowledge	9	accumulation	6
				creativity	3
		private goods	15	direct effects	7
				indirect effects	8
		public goods	6	standard	3
				service	3
S & T CONTRIBUTION	18	industrial	6		
		international	6		
		societal	6		
SOCIETAL ACCEPTANCE OF S & T	3				
TOTAL	103				

Table 2. Data Availability of Selected Indicators

	need to be collected	need to be processed	existing	TOTAL
SOCIETAL INFRASTRUCTURE	1	1	1	3
S & T INFRASTRUCTURE	9	0	5	14
R & D INFRASTRUCTURE	13	14	8	35
R & D RESULTS	12	12	6	30
S & T CONTRIBUTION	7	1	10	18
SOCIETAL ACCEPTANCE OF S & T	1	1	1	3
TOTAL	43	29	31	103
%	41.7	28.2	30.1	

distribution of the indicators could not sufficiently accommodate the cascade strcture. This is because the indicators are concentrated in the "private goods value" and the "industrial contribution," and we could not select as many indicators in "public goods value" and "international contribution" as would be desired.

We are also concerned whether the data collection is feasible or not. For this purpose, each indicator was investigated and classified into 3 types of data: (a) data already existing, (b) existing data needing to be further processed and (c) data that should be collected. The distribution is shown in Table 2. According to this table, the frequency for the "need to be collected" is 43, while it is 29 for the "need to be processed" and 31 for "existing." If we include the "need to be processed" in the feasible range, the degree of feasibility of this system is 58.3 percent at present.

6. Evaluation of the Science Indicator System

To confirm the extent to which JSIS supports the statements described above, we analyzed it from the following viewpoints: causality and balancing of indicators.

First, causality is one of the key concepts behind constructing the cascade structure. However, it is difficult to show the causality of SIS

Table 3. Examples of Causaiity*

major category	indicators
SOCIETAL INFRASTRUCTURE	Executives of scientists and engineers in government, municipal offices and companies. Journalists of S & T and researchers who observe S & T from the outside
S & T INFRASTRUCTURE	Expenditures for R & D by region Scientists and engineers engaged in R & D by region Organised research units by region Housed S & T books in libraries
R & D INFRASTRUCTURE	Expenditures for R & D by field Scientists and engineers by field Expenditures for R & D facilities by field Specimens
R & D RESULTS	Scientific and technical articles References S & T articles in core journals Fact-finding data
S & T CONTRIBUTION	Foreign scientists and engineers in Japan Japanese international journals of S & T International conferences of S & T in Japan
SOCIETAL ACCEPTANCE OF S & T	Publications in connection with S & T Trials in connection with S & T

* : It is indicated that all indicators of a certain major category are based on some indicators of the major category above it.

quantitatively. Therefore, we are only able to give some illustrations of causality which may be considered reasonable(See Table 3).

The table shows that from the middle to both ends of the cascade, causality varies from explicit to implicit, from exclusive to inclusive, and from short-term to long-term relation. In a similar way, relationships among the indicators of different major categories vary from direct to indirect along the distance. For example, the causality between the number of "scientists and engineers engaged in R & D by field" and the number of "scientific and technical articles" is not only direct but also obvious. On the other hand, the causality between "expenditures for R & D by field" and "publications in connection with S & T" is not so direct or obvious.

By observing this table, it is understandable that JSIS is designed to grasp S & T activities as a whole (Statement I), and that R & D activities are described in terms of infrastructure/impact (Statement III).

Second, balancing of the indicators is one of the most important criteria in constructing SIS as a whole, because the relationships between all S & T activities are extremely complicated. In the case of JSIS, the distribution of science indicators in the major categories is quite similar to the cascade form because the frequency in the middle is high, while those at the ends are low. Furthermore, the shape of the distribution is nearly symmetrical. This suggests also that JSIS satisfies Statement I.

The distribution by classification type is shown in Table 4. The statistics on "R & D infrastructure" are collected by field, consequently the corresponding statistics of "R & D results" should be collected by field. Therefore, the frequency of the classification by field is high, but the distribution by classification type, which is the result of selection from the viewpoint of Statement III, is generally well-balanced.

Furthermore, JSIS has three subjective indicators. Although it appears relatively small in comparison with the emphasis of Statement IV, they can actually represent various aspects of S & T activities, because the questionnaire of each indicator includes many questions.

7. Comparison with other Science Indicator Systems

The comparison of the Japanese Science Indicator System with others is most effective for inspecting the validity of JSIS. At present, we have three SIS: SIS of the United States of America[4, 5], SIS of the Organization for Economic Cooperation and Development (OECD) [6, 7], and SIS of the United Nations (UN) [8].

SIS of The United States of America

Table 4. Distribution of Indicators along the types of Classification

	by field	by industry	by social[1] sector	the others
SOCIETAL INFRASTRUCTURE	2	0	1	0
S & T INFRASTRUCTURE	7	3	38	14
R & D INFRASTRUCTURE	25	8	15	14
R & D RESULTS	14	15	4	12
S & T CONTRIBUTION	4	5	2	14
SOCIETAL ACCEPTANCE OF S & T	0	1	0	2
TOTAL	52	32	25	56[2]
%	50.5	31.1	24.3	54.4

1) The social sectors consist of indusry, government and academia.
2) Because some indicators are classified by more than 2 criteria, the grand total exceeds 103.

Table 5. Number of Indicators in "Science Indicators" by NSF

year	1972	1976	1980	1985
number	69	113	127	130

The National Science Foundation (NSF) has developed science indicators since 1972 and publishes "Science Indicators" every two years. As Table 5 shows, the indicators compiled in "Science Indicators" have increased in number, and now are about 130. Furthermore, we classified those indicators by major and sub-category of JSIS (See Figure 3). These figures show the following:

(1) The ratio of infrastructure system (up-stream)and impact system (downstream) varies from about 4 : 1 in 1972 to about 1 : 1 in 1980.
However, the indicators of "R & D infrastructure" have increased, and the balance of the two systems has been lost to a certain degree (Figure 3).

(2) The majority of the indicators in "R & D infrastructure" are related to personnel and expenditures which belong to "R & D elements," but recently those of "institution" have increased.

(3) The ratio of "R & D elements" to the total continued to decrease until 1980, but it increased in 1985.

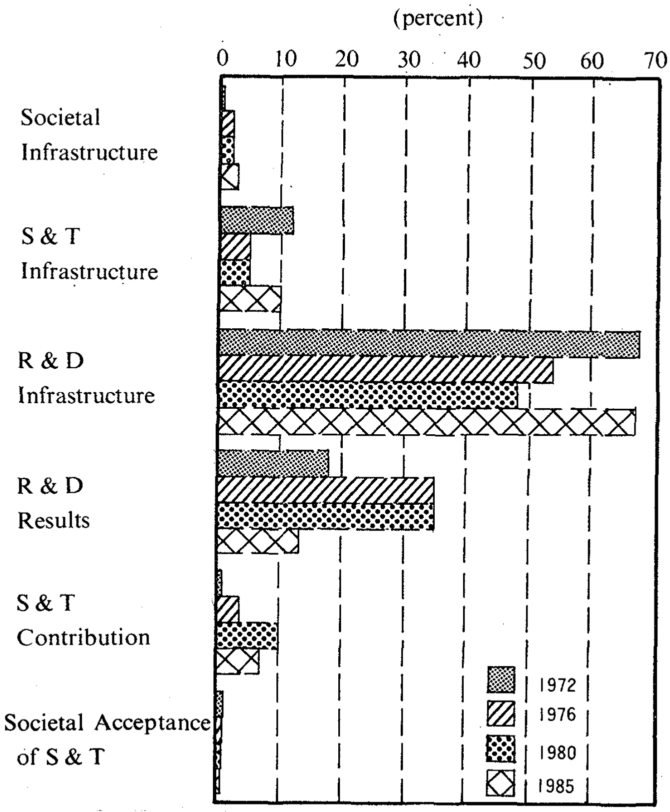

Figure 3. Distribution of Indicators of NSF

These are the chracteristics of NSF's SIS. In addition, "Science Indicators" has several points of value:

(1) The "Science Indicators" includes not only core indicators, which are collected periodically by NSF itself and other organizations including Department of Commerce, but also many other indicators which are collected or developed by NSF in each "Science Indicators". These indicators are selected so that they reflect appropriately the current R & D activities. That is, NSF's SIS are very broad and flexible.

(2) NSF has a unit for the purpose of collecting, compiling and publishing indicators. Although it is one of the sub-subbranchs of NSF, it has about 50 researchers who analyze and develop the indicators, and its budget was about 4 million dollars (excluding personnel expenditures) in 1986.

(3) Because the "Science Indicators" of NSF is very easy to read, it is used effectively in various fields. It is understood that the U.S. Congress uses it most frequently. It is so widely used that NSF has not complete information on where and how it was used.

SIS of OECD and the UN

The Organization for Economic Cooperation and Development and the United Nations proposed science indicator systems, but they did not collect the statistics themselves. The SIS of OECD is called Science and Technology Indicators. They are classified in the major categories of JSIS. In the case of the UN, Science indicators, which were proposed by the United Nations Center for Science and Technology for Development, adopted a similar classification. The distributions of these indicator systems are shown in Figure 4.

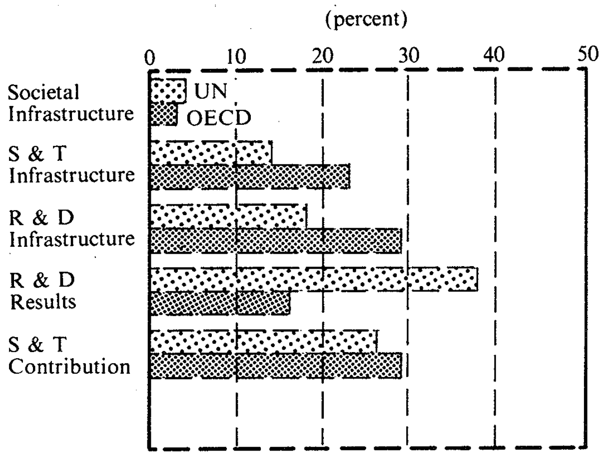

Figure 4. Distribution of Indicators of UN and OECD

This shows that:

(1) In the case of OECD, indicators of the "S & T infrastructure" and those of the "contribution of S & T" exceed those of the "R & D infrastructure" and the "R & D results." Especially, the "contribution of S & T" is over evaluated. This indicator system seems to stress the indirect infrastructures and the indirect impacts of R & D.

(2) The "infrastructure system" and the "impact system" according to the UN's indicator system are well-balanced, but the indicators of the "R & D infrastructure" are relatively few in number.

Concluding Remarks

Through our investigation, we came to the conclusion that a Science Indicator System can be best described with a cascade structure. We also found that the cascade structure could solve two of the most difficult problems of science indicators: relevancy and causality.

Through trial and effort of forming the Japanese Science Indicator System, we concluded that the heart of the problem of constructing such a system was how to select the individual indicators in a balanced manner. Therefore, it is very effective for us to examine the distribution of selected indicators.

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