THE MEASUREMENT OF NATIONAL SCIENTIFIC AND TECHNOLOGICAL POTENTIAL FOR POLICY-MAKING PURPOSES

Yvan DE HEMPTINNE, I.P.S.A.(*)
Jacques MBA-NZE, UNESCO

ABSTRACT

The concept of "national scientific and technological potential" originated within the Science and technology policy division of UNESCO in the early sixties. Il was gradually developed and made operational by actual surveys there of in a number of volunteer countries. The data collected through precoded questionnaires administered to the heads of Research and Scientific service units gave rise to computerized data bases whose processing and analysis made it possible to produce the most essential "indicators" needed by policy-makers in the field of science and technology. The paper discusses the main steps of this process, the listings that can be obtained from the survey data, the principal indicators to be derived there from as well as the major statistical analyses which may be carried out.

RESUME

Le concept de "potentiel scientifique et technique national" a été conçu au début des années soixante par la division des politiques scientifiques et technologiques de l'UNESCO. Il est devenu opérationnel à la suite d'enquêtes effectuées dans plusieurs pays volontaires. Les données collectées à partir de questionnaires précodés ont été stockées dans des bases de données informatisées à partir desquelles ont été produits les principaux indicateurs nécessaires aux décideurs politiques du domaine de la science et de la technologie. Cet article présente les principales étapes de ce processus, les listes de données que l'on peut obtenir de l'enquête, les principaux indicateurs et analyses statistiques qui en découlent.

(*) Research Commitee on Science and Politics, International Political Science Association.

I. ROLE OF THE NATIONAL SCIENTIFIC AND TECHNOLOGICAL POTENTIAL (STP) SURVEY (*)

The National Scientific and Technological Potential (STP) survey is primarily a policy-making and management tool in the area of Research (R&D) and Scientific and Technological Services (STS) at the national level. The data base generated and periodically updated by the survey includes : (i) numerical data (commonly known as science statistics and obtained by direct quantification) and (ii) descriptive or nominal (ie. administrative, functional, structural or qualificatory) data obtained by descriptive analysis.

These exclusively factual-numerical and descriptive-data cover all of the country's R&D and STS units and are deliberately restricted to the basic data characterizing the resources of national R&D and STS systems, namely their human, financial, physical (material base) and informational resources.

The Survey also includes data on the organization of the country's national R&D ans STS systems, and on scientific activities (R&D and STS) in progress in its component units.

II. UNESCO NATIONAL STP SURVEY METHODOLOGY AND DESCRIPTION OF THE SURVEY QUESTIONNAIRES

The STP Survey collects information from respondents at four levels of responsibility :

1. First level : the identification questionnaire (N°0)
is addressed to the controlling authorities of the Ministries and organizations (*) to which the S&T units to be surveyed belong.
2. Second level : the questionnaire on the S&T Units (N°1) Part I
is addressed to the Head of each Unit. The general section contains questions regarding the identity of and the place occupied by the S&T Unit in the body or institution of which it is a part, the year of foundation of the Unit, its legal status and the type of S&T activities it carries out.
Part II contains questions on the number and rotation of the personnel of the Unit : scientists and engineers, technicians and auxiliary personnel.
Part III concerns financial resources : it contains questions on the sources from which S&T activities are financed and the nature of the Unit's expenditure, intramural (current expenditure, including staff costs and capital expenditure), also extramural expenditure.

(*) This paper is based on the Unesco methodology for surveying the national scientific and technological potential (STP) which was developed, field-tested ans published by the Organization.

(*) Including public and private production enterprises.

Part IV concerns the physical resources (material base) of the Unit : buildings, land, equipment and computers.
Part V concerns informational resources and activities ; this includes books, periodicals ans microfiches and the Scientific and Technological Information and Documentation (STID) Services used by the personnel of the Unit.
3. Third level : Questionnaire N°2 is addressed to the principal person in charge of each R&D project or STS activity which is carried out in the S&T Unit.
The general section contains questions on the following aspects of each R&D project or STS activity : title, objectives, discipline concerned, target group, state of progress, geographical bearing, staff, budget, duration and evaluation dates.
The section reserved for projects concerns the type of research carried out and the likelihood of achieving the assigned objectives.
4. Fourth level : Questionnaire N°3 is completed by the scientific staff (scientists and engineers) of the S&T unit.
Part 1 contains questions on the individual scientists and engineers of the Unit : their training, age, field of competence, legal status of employment, level of responsability and an estimation of their time allotment.
Part II is devoted to scientific researchers and seeks more information on their qualifications, professional experience, function in the Unit and seniority in R&D activities. Information is also sollicited concerning R&D products, such as books, articles and other publications as well as Ph.D. thesis.

III. INDICATORS DERIVED FROM THE NATIONAL STP SURVEY

One of the constant of Unesco is to bring the National Surveys of Scientific and Technological Potential of its Member States into line with the need of each Member State to make international statistical comparisons of scientific and technological development possible. There are two basic approaches to the derivation of indicators :
a) The static approach which involves the analysis of a situation at a specific point in time, and, a variant of this approach, the chronological or historical approach in which the analysis leads up to, and ends at a given out-off point ; this is the approach adopted in the present paper.
b) The dynamic approach which involves research and extrapolation on the basis of current trends and the projection of plans for the future. This approach is of special interest to planners.

The data obtained in the National STP Survey can be used to construct indicators to assess the status and the evolution of national scientific and technological development policy in a given country. These indicators measure both STP development level and STP structure.

A. Indicators of STP development level

These indicators measure the level of development of research (R&D) and scientific and technological services (STS) of a country in terms of the human, financial and informational resources and buildings assigned to them.

1. Indicators of human resources

a) The number of scientists and engineers and the number of technicians and auxiliary personnel engaged in S&T (R&D + STS) activities in a country. This indicator measures the actual capability of a country in terms of the scientific and technological staff who are engaged in these activites.

b) Number of scientific researchers (scientists and engineers and research technicians. This indicator measures the R&D potential of a country. It is usually expressed in Full-Time Equivalent (FTE) units, at least in the case of research scientist.

c) Number of research technicians per scientific researcher. This indicator measures how much assistance is provided to scientific researchers.

d) Number of scientific researchers (R&D) as a percentage of all scientists and engineers engaged in S&T (R&D + STS) activities. This indicator measures the relative weight of R&D and STS activities in a given country.

e) Number of teaching researchers as a percentage of the total number of scientific researchers in higher education and the overall number of scientific researchers in the country. These indicators measure the relative importance of R&D in higer education and the extent of the symbiosis between R&D activities and higher education in a country.

f) Number of scientific researchers per 10,000 inhabitants. Data on the ratio of scientific researchers to the population of a country are useful for making international comparisons. This indicator measures the R&D effort of a country in relation to its population. Ratios indicating the "density" of scientific and technological personnel in a country are widely considered to be among the most important indicators of the level of its development.

g) All scientific researchers : (i) by age group; (ii) by nationality; (iii) by sex.

- Age-group distribution is and indicator which may be used in trend forecast of the total number of scientific researchers of a country.
- Nationality distributions provide information on the foreign contribution to R&D in a country (proportion of foreign scientific researchers to all scientific researchers of a country).
- Sex distributions provide useful information on the access of women to scientific research careers.

2. Indicators of financial resources

These indicators are expressed in monetary units (national currencies and/or US dollars). The original figures are most often given in national currencies. For the purpose of international comparisons, the data have to be converted into a

standard unit, which is most often the United States dollar, using official rates of exchange.

a) Intramural R&D expenditure (national R&D expenditure). This indicator measures the financial support which a country gives to R&D activities. For the purposes of international comparison, intramural R&D expenditures are expressed : (i) as percentages of GNP; (ii) as percentages of GDP; (iii) as percentages of national income.

b) Intramural R&D expenditure per scientific researcher. This indicator measures the material conditions (expenditure on personne, supplies and equipment) in which research scientists carry out their R&D work. This indicator is more significant when expressed by groups of major disciplines. (*)

c) Intramural R&D expenditure per inhabitant. This indicator measures the effort devoted to R&D activities in relation to the population of a country.

d) Ration of capital to current expenditure on R&D. This indicator roughly measures the pace of modernization of the scientific and technological research plant of a country.

e) Ratio of expenditure of staff to total current expenditure on R&D. As this indicator approaches 100 per cent it signifies that scientific researchers do not have the means to carry out their work and that, accordingly, their work is likely to be quite ineffective.

f) Intramural R&D expenditure as a percentage of the total intramural expenditure on all S&T (R&D + STS) acitivities. This indicator measures the extent of the national financial outlay of a country on R&D in relation to its STS activities.

3. Indicators on buildings and informational resources

a) Usable laboratory floor space (in m2) per scientific worker (scientists and engineers). This indicator measures the work space assigned to scientific workers for the execution of their S&T (R&D + STS) activities.

b) Usable laboratory floor space (in m2) as a percentage of total usable floor space (laboratories and other premises). This indicator measures the importance which laboratories occupy in relation to the total building resources assigned to the S&T activities of a country.

c) Average number of books possessed and individual periodical subscriptions taken out per S&T unit. This indicator measures the volume of scientific and technological documentation placed at the disposal of the scientific workers of a country, and is major factor in the effectiveness of their work.

4. Other indicators

a) Average size of S&T Units. This indicator measures the average manpower strength of S&t units. It is usefully broken down into scientists and engineers, technicians and auxiliary personne.

(*) The two-digit level of Unesco's proposed international standard nomenclature for fields of science and technology (Document UNESCO/NS/ROU/257 rev. 1).

b) Average number of R&D projets per unit. This indicator measures the distribution of efforts and the extent of teamwork in research units.
c) Average annual number of meetings in the country and abroad attended by scientific researchers. This indicator measures the effort which a country devotes to the national and international exchange of experience between scientific researchers ; it measures the extent of the oral and firsthand scientific and technological information to which a country's scientific researchers have access.
d) Average seniority of scientific researchers in R&D. This indicator measures the average length of R&D experience of the scientific researchers of a country.
e) Average age of scientific researchers. This indicator can be used to monitor the ageing (or the rejuvenation) of the scientific researcher population of a country, and, through the construction of chronological series, to make trend forecasts in this connection.
f) Average number of patents registered per scientific researcher.

B. Indicators of STP structure

Because these indicators are both quantitative and qualitative in nature, they provide a better understanding of the orientation of the S&T policy of a country.

1. Human resources
a) Number of scientific researchers per discipline (fields of current employment). This indicator identifies the most highly developed disciplines that are in a given country, and can be used to compare the deployment distribution of research personnel with the priority distribution of the various disciplines with regard to the socio-economic development objectives of a country. (*)
b) Percentage of scientific researchers whose degree (highest and/or last degree) corresponds with their field of current employment. This indicator measures the extent to which training matches the deployment of scientific researchers in the major S&T fields or disciplines.
c) Distribution of scientific researchers by sector of performance. This indicator can be used to measure the distribution of the R&D work force according to the three sectors of performance (Higher education, General service and Production enterprises).
d) Distribution of scientific researchers by the type of activity in which they are engaged (in percentage of time). This indicator identifies the type of activity in which scientific researchers are engaged : R&D, STS, STET. (**)

(*) See on this subject n°40 in the Unesco series Sciences Policy Studies and Documents (SPDS) entitled "Method of priority determination in Science and Technology".
(**) STET = Sciences and Technology Education and Training.

2. Financial resources

a) Intramural R&D expenditure by sector of performance. This indicator measures the respective weight of the three performance sectors (Higher education, General service and Production enterprises) in the research effort of a given country.

b) Intramural R&D expenditure by type of research. This indicator measures the distribution of national effort by type of research (basic, applied, experimental development).

c) Intramural expenditure on R&D projects by source of funds. This indicator measures the extent to which the financing on R&D activities is dependent on each source of funds, the three principal sources of funds being the State, Production enterprises and Foreign Sources. This indicator is particulary important in the case of developing countries because it shows the extent to which these countries are dependent upon foreign aid.

d) Funds allocated to R&D activities by S&T discipline. This indicator can be used to identify the way the financial effort of a given country is allocated to various disciplines and to compare this distribution pattern with the performance of the same disciplines in support of national socio-economic development goals. (This is similar to the indicator of the number of research scientists per discipline - cf B/1/a above).

e) Funds allocated to R&D activities by socio-economic objectives. This indicator is used to determine the weight given to the promotion of each of the thirteen major R&D goals identified by Unesco (see Annex 1) and to determine to what extent the objectives receiving the most funds coincide with the priority socio-economic goals of national development plans.

In conclusion, the indicators thus defined serve to identify the structural imbalances and lack of coordination that can characterize the deployment of the research effort of a given country. For example, a given country may have a low indicator of R&D expenditure along with a high indicator of R&D manpower ; this is the case in countries where R&D is ineffective for lack of funds. In another example, certain indicators may identify the bottlenecks and the inadequacy of the national R&D effort in certain R&D disciplines or sectors of performance in relation to national socio-economic development needs.

IV. STATISTICAL ANALYSES BASED ON THE STP SURVEY DATA 2 (COMPOSITE INDICATORS)

Statistical analyses of the STP data involve the transformation of the primary data contained in the STP date base grouped together according to the type of resources which characterize a national R&D and STS system : human, financial, physical and informational resources

The primary data used for these statistical analyses are identified by references to the running numbers of the questions in the survey questionnaires (Q1, Q2,

Q3). Each section contains the following headings : the aim of the analysis, the table(s) corresponding to the analysis and how to draw up this/these table(s).

A. Utilization of data relating to human resources

These data are collected at the level of the S&T Unit, at the level of the R&D project or the STS activity and at the level of the scientific worker.

1. Number of personnel in the R&D and STS System (Scientits and Engineers) (SE), technicians and auxiliary personnel by type of institution to which the units belong, by sector of performance and by economic sector.

By means of this analysis it is possible (i) to determine the distribution of scientific workers and technicians (total number and full-time equivalent) engaged on R&D and STS by type of institution and by sector of performance in the national R&D and STS system ; and to determine the total number of auxiliary personnel in the system; and (ii) to determine the trends in the development of these various groups, the scale of which may be assessed on the basis of the statistical series covering several years.

The data required for the completion of these tables are obtained by aggregating the data collected from Questionnaire n°1 only.

2. Number of S&T units and average number of scientific workers and technicians by unit, by type of institution and by sector of performance. The aim of the analysis is to obtain the average size of the S&T unit by type of institution and by sector of performance.

The date required for the completion of this table are obtained from Questionnaire n°1.

3. The number of R&D projects and the average number of scientific researchers and technicians by R&D project on a full-time basis in full-time equivalent by type of institution and by sector of performance. This analysis provides the distribution of personnel assigned solely to R&D projects in absolute numbers and in full-time equivalents, as well as their average number by research project. It also reveals the technical support supplied to researchers participating in R&D Projects and the auxiliary personnel allocated to them.

4. Distribution of scientists and engineers by type of activities on which they are engaged. R&D : for scientific researchers; STS : for STS personnel; STET : for teacher researchers, by type of institution and by sector of performance on the one hand, and economic sector on the other. The analysis provides the exact number (total in FTE) of scientist and engineers engaged on the three types of activities; R&D, STS and STET. It can also be used to establish significant ratios. These various ratios provide the basis for a sensible policy of symbiosis

and cross-fertilization between R&D on the one hand and STS and STET on the other.

The data required for the completion of these tables are obtained from Questionnaire n°3.

5. Total number of scientific workers (R&D and STS) by major discipline (2-digits level) of their initial training and current employment. The analysis establishes the correspondence between the training and employment of R&D and STS personnel by major S&T field or discipline. It is required by science and technology policy-makers to ensure the sound planning of training for the personnel required for R&D and STS.

The data required for the completion of these tables are obtained from Questionnaire n°3.

6. Distribution of scientific researchers by percentage of time spent on R&D, STS, STET activities, purely administrative tasks and other activities. This analysis identifies the type of activity which takes up most of the time of scientific researchers. It shows up those cases in which scientific researchers spend more time on purely administratve tasks than on R&D, STS or STET activities. An analysis by type of institution provides a factual basis for forecasting the efficiency of R&D in the various sectors of performance.

The data required for the completion of these tables are obtained from Questionnaire 3 and 1.

7. Distribution of scientific researchers by age-group, nationality and sex. The analysis is used to construct an age-pyramid for scientific researchers and provides a significant indicator for estimating future personnel in the field of science and technology (R&D and STS). The distribution by sex provides information about women's access to scientific and technological careers. The distribution by nationality (foreigners and nationals) provides information about international mobility and indicates the proportion of foreigners in the total number of scientific researchers.

The data required for completion of these tables are obtained from Questionnaire n°3.

8. Utilization of data relating to financial resources. These date are collected at the level of the S&T Unit and at the level of the R&D project or STS activity.

B. Utilization of data relating to financial resources

1. Intramural expenditure on scientific and technological activities (R&D and STS) by source of funds, by type of institution, by sector of performance and percentage of total spent on R&D. This analysis provides as assessment of the relative importance of the main sources of funds scientific and technological

activities and it measures : (i) the proportion represented by productive enterprises in total national scientific and technological activities; (ii) the foreign contribution to this effort.

This analysis also provides an estimate of the national R&D obtained from Questionnaire n°1.

2. Intramural expenditure for S&T activities by source of funds and by nature of expenditure for the various types of institutions. This analysis highlights indicators of considerable importance at the national level - by types of institution and sectors of performance - in respect of intramural expenditure on scientific and technological activities : (i) the relative percentage of capital expenditure and current expenditure; (ii) the percentage of expenditure on personnel in current expenditure.

The data required for the completion of these tables are obtained from Questionnaire n°1.

3. Total intramural expenditure on R&D activities by type of institution and by sector of performance as a percentage of GNP, GDP and national income. This analysis identifies the types of institution and sectors of performance which are the largest spenders of the financial resources allocated to R&D. It enables the authorities responsible for national scientific technological policy to orient support for R&D programmes in the light of these data with due regard to national development policy.

The data required for the completion of these tables are obtained from Questionnaire n°1. The figures for GNP, GDP and national income are taken from the annual reports of the World Bank.

4. Total expenditure on R&D projects by type of institution, by sector of performance and by type of research. This analysis provides the basis for an assessment of the distribution of national R&D effort by type of research (basic, applied and experimental development).

The data required for the completion of these tables are obtained from questionnaire Nos Q2 and Q1.

5. Total funds allocated to R&D projects (or STS activities) by main field (discipline) of S&T reduced to two-digit codes. By means of this analysis it is possible to compare the funds allocated (or STS activities) by main fields of S&T and to calculate the ratios for the average cost of a scientific researcher by type of discipline. It can also be used to assess the probability of the achievement of the aims defined in 6 below.

The data required for the completion of this table are obtained from Questionnaires n°2.

6. Total funds allocated to R&D projects and STS activities by socio-economic aims grouped in accordance with Unesco's thirteen aims. By means of this analysis it is possible to determine the importance attached to the advancement of a clearly defined aim. The intented purpose of the national R&D effort may be assessed from the apportionment of public funds.

The data required for the completion of these tables are obtained from Questionnaire n°2.

C. Utilization of date relating to buildings and land

1. The surface areas in sq. metres of the premises and the area in ha. of the experimental stations by type of institution and by sector of performance. This analysis provides indicators for the usable laboratory space per scientific worker (scientists and engineers) according to the types of institutions. A second series of useful indicators is obtained by calculating for the type of institution the relationship between usable laboratory space (laboratories and other premises) for each type of institution and by sector of performance.

The data required for the completion of these tables are obtained from questionnaire n°1.

D. Utilization of data relating to informational resources

1. Distribution of Scientific and Technological Information and Documentation (STID) Centre and average number of their informational resources by type of institution and by sector of performance. The aim of this analysis is to locate the sectors of performance and types of institutions where STID Centers are situated and to determine their size.

The data required for the completion of these tables are obtained from questionnaire n°1.

2. Distribution of libraries and their average number of informational resources by type of institution and by sector of performance. The aim of this analysis is to locate the sectors of performance and types of institutions where libraries are situated and to determine their size.

The data required for the completion of these tables are obtained from questionnaire n°1.

References

1. National Scientific and Technological Potential (STP) Survey, n°67 in the UNESCO Series. "Science Policy Studies and Documents" Paris. 1990 (Exists also in French). Second enlarged and fully computerized edition of the methodology first published in 1965 under n°15 in the same UNESCO series.

2. A field-test application of the statistical analyses described in this paper relates to the countries of the member States of the Community of West African States (C.E.A.O.) which was published jointly by UNESCO and UNDP (1986) in "Le potentiel scientifique et technologique de la Communauté des Etats de l'Afrique de l'Ouest".

Annex

Objectives of aims ot the S&T activities (*)

National activities in R&D and STS should be classified by major socio-economic aims objectives as listed below, on the basis of funding (ex-ante) or expenditure (ex-post) financed from public funds and, if possible, from all other sources of funds.

i) Exploration and assessment of the earth, sea and atmosphere
ii) Outer-space (civil)
iii) Development of agriculture, forestry and fishing
(iv) Promotion of industrial development
(v) Production, conservation and distribution of energy
vi) Development of transport and communication
vii) Development of education services
viii) Development of health services
ix) Social development and other socio-economic services
x) Protection of the environment
xi) General advancement of knowledge
xii) Other aims
xiii) Defence.

(*) Source : Recommendation concerning the International Standardization of Statistics on Science and Technology. Twentieth session of the General Conference of Unesco, Paris, 27 November 1978.