Chapter 3

THE CONCEPT OF SCIENCE INDICATOR

3.0 Introduction

3.1 Meaning and Definition

3.2 Purpose and Functions

3.3 Historical Developments

3.4 Topologies and Types
Chapter 3

THE CONCEPT OF SCIENCE INDICATORS

3.0 Introduction

We are living in knowledge society, and the significance of knowledge society and the significance of knowledge in particular that is, scientific knowledge, is recognized like never before in the history of human society. Growing demands on S&T by society have led to a renewed interest in their measurement in particular: the progress of scientific and technological activities in a society or country. In order to fulfill the societal requirements, every country needs to step up investment in S&T research, higher education in S&T, medium and in basic needs area such as health, agriculture, primary and secondary education, defence, energy, etc. With the limited financial and human resources, there is a need to formulate the S&T plans and programs so as to maximize the social and economic return. For this purpose, sound methods /techniques and tools are needed based on reliable, up-to-date and comprehensive data on nation’s scientific and technological potential in order to assure the effects of S&T activities on nation’s social and economic development.

A major concern of research management, whether at the level of a research project, research institute or at the national level is how to improve
the performance of scientific activity. In the search for optimal configuration of human and material resources and management practices, the most important question is how to evaluate the performance of scientific activity?

Evaluation of scientific performance is as old as the history of science itself. It has been an integral part of the creative process of scientific research, and has greatly influenced its growth and development. Systematic evaluation of scientific performance began with the emergence of scientific journals which gave birth to the referee system. Until recently, the evaluation of science was the exclusive domain of the scientific community and the criteria employed for evaluation are primarily those which are concerned with the internal development of science. But now the scenario has changed, and this change has been brought out by the growing institutionalization of science and the government support to scientific research.

The rapid growth in financial investment by the government and the industry, and their capability to harness science for social, economic and political purposes have led to qualitative change in the concept of research performance and its evaluation. Such assessment needs the development of a variety of indicators or measures of different aspects of the S&T. In the words of Monta-Lou (1985), S&T indicators are needed for two purposes:
1. To describe and facilitate the analysis of specific historical situation, and hence the elaboration of diagnosis, and

2. To help identify inter-relations between different variables and phenomena whose scientific knowledge is applied through technology, and is to be used in policy formulation and planning. (IGNOU, 2004).

3.1 Meaning and Definition

In day to day life we find a few things easily measurable as the mass of a body, heart beats, speed of train, etc. But some phenomena like quality of life, happiness and innovations defy direct measurement. Indicators are tools used to assist in the measurement of such phenomena. The indicators display or highlight some facets of the object of evaluation. Literally, indicators are indicators of other things; usually each indicator emphasizes specific aspect as well. As such indicators are imperfect measurements, and, therefore, several of them need to be studied to discover some trends. By examining a set of indicators it is possible to understand the trends in the behavior of phenomena in hand. Monitoring the fluctuations and movements of a number of indicators over a time may reveal relationship between different elements on the aspect of the phenomenon.

Indicator research generally needs a clear and methodologically sound understanding of the basic process involved in science and
technology. The word ‘indicator’ has roots in the Latin word ‘indicare’ which means “to direct or to point out”. It is usually defined as “measurable variable sometimes hypothetically linked to another (latent) variable which cannot be observed directly”, (Bollen, 2001).

Indicators for S&T may be defined as “statistics which measure quantifiable aspects of the creation, dissemination and application of science and technology. These indicators should help to describe the science and technology system, enabling better understanding of its structure, of the impact policies and programmes on it, and of the impact of science and technology on society and the economy” (Martin B). Science and technology indicators are concerned with the systematic collection and interpretation of science and technology and its social impact for the purpose of assisting in policy formulation, science, management and organization. The following two types of S&T indicators are discernible:

- Indicators are intrinsic to science and technology system, which measure the efficiency of this system.
- Indicators are extrinsic to science and technology which measure the social, economic and environmental effectiveness of the system. These types of indicators are necessary for the purpose of planning, policy formulation, management and organization of science and technology in relation to development.
Science indicators are quantitative indicators of the many facets/characteristics of organized science and technology accompanied by trend analysis and interpretations. They are not intended to replace the judgment of policy makers and planners; rather they are presented to provide a broad information base to assist and stimulate the planning debate and negotiation which surrounds the issues faced by policy makers and planners. Indicators, when studied together in a group of phenomena, present a more comprehensive picture and encourage broader perspectives. And as indicators, they are an indirect reflection of performance, behaviours or status. (Pruthi and Nagpaul, 1985,x).

3.2 Purpose and Functions

Science and technology indicators are a series of data designated to answer questions about the current state of, and/or changes in science and technology enterprise, its internal structure, its relationship with the outside world, and the degree to which it is meeting the goals set for it by those within and without(OECD, 1979 document).

In the words of Giorgio Sirilli of National Council of Research, Italy, the purpose and functions of science indicators are to follow changes in the scientific enterprise and its component over time and thereby to reveal strengths and weakness as they begin to develop. Such indicators, updated
regularly, can provide early warnings of trends, and, taken together, can make decision makers more aware of the interrelationships of the many variables that describe scientific system efforts. Hence, they can assist those who set priorities for the enterprise and allocate resources to it. Indicators are not simply statistics, and statistics are not ipso facto indicators, unless some theory or assumptions make them so by relating the indicator variables to a phenomenon that is not what it directly and fully measures" (Monta-Lou, 1985, p.188).

The primary purpose of S&T indicators, which are often used in conjunction with other economic indicators, is to guide the decision of S&T policy makers with an indication of the status of the national S&T system and the relationship between scientific and technological efforts and economic growth. They can serve as instruments of planning, evaluation and resource allocation.

❖ S&T indicators are useful in determining the nature and level of resources to be allocated to scientific and technological endeavors.

❖ They provide the necessary data for assuring past performance in capacity building and utilization.

❖ They are used to describe and map the national system of innovation so that national competitive advantage could be identified and promoted.
S&T indicators provide insights into the impact of S&T efforts on national socio-economic developments.

Help country's inventory to assure its S&T capabilities.

Identify the extent to which a country's S&T system is integrated into or dependent upon the world system.

Help in setting up priorities between different discipline, institutions or research groups competing for scarce funds, based on an assessment of their recent S&T performance.

Helps the research institutions and organization in better management of their research programmes (Monta Lou, 1985, p.25)(IGNOU, 2004).

In general, we can say that the S&T indicators have two basic purposes:

1. The scholarly study of structure and process in knowledge creation, and
2. The production of information for innovation policy. Hitherto, most S&T indicators have been based on R&D statistics patent at or bibliometric data and the literature model has dominated the quantitative study of scientific communication (Moed, et al. 2004).
3.3 Historical Developments

Since the 1960s there have been concentrated efforts by planners and scientists of the USA for developing the S&T indicators as they are not satisfied by the R&D statistics alone. They need some additional measures on science and technology which led in 1972 to the generation of S&T indicators reports. Now in the name of Science and Engineering indicators, this report is being published by National Science Foundation, USA Biennial.

Later on, on 1974 European Commission published European Reports on S&T indicators. Several European countries have set up different laboratories/observations of science and technology. OECD Reports on Science and Technology Indicators and OECD Science and Technology policy review and outlook series provide useful measures of the scale and direction of R&D in many countries, sectors, industries etc.

The science indicator’s movement was greatly helped by the publication by ISI in the early 1960s. The disciplinary database PASCAL published by INIST, France is also used, at least in Europe, for construction of indicators since the early 1980s. CHI Research Inc. an American Company founded by F Narin is developing literature based indicators. Many academic institutions such as ISRU of Hungarian Academy of Science, Budapest, science policy research unit at the University of Sussex
at abroad, In India NISTAD(NISCAIR) have stated working in this field to develop the indicators along with CSRI, INSA, Centre for Science and Environment, M-S Examination Research Foundation, Chennai, etc. (Pruthi and Nagpaul, 1985, IGNOU, 2004)

3.4 Topologies and Types

Science and technology indicators characterize particular characteristics of innovation process (Godin, 2004). They cover all aspects of research, technology and innovation. S&T indicators may be classified as input, output or process indicators. Expenditure on research and development and the number of employees in R&D sectors are examples of input indicators while the number of publication citations or patents is example of output indicators. While input and output indicators are among conventional indicators used in science and technology documents, process indicators are less clearly defined. To observe a process, static indicators need to be measured as different points in time. It is possible to construct time related indicators such as the relaxation time of process (Liang, 2000). For example, some authors propose the use of static co-citation maps as the basis for process indicator, indicating the formation of research fronts (Scharnhort & Wouters, 2006).

Scientific research operates with information as input and produces information as output. Input information is, in part, already disclosed and, in
part, it originates from the researchers themselves who conduct the respective research work. Output information is, however, none and or recognized knowledge which is disclosed in the form of publication. The primary goal as well as innate need for any individual or team working in scientific research is to contribute to the scientific information production. Consequently, the evaluation of scientific activity should cover the evaluation of publication both qualitatively and quantitatively. The qualitative assessment may refer here to measuring the international impact of publications manifested in citations.

In practice, scientometric systems consist of several parts to be assessed. The main problem is caused by the difference in

- Scientometric features (publication and citation characteristics)
- Size (research capacity, number of staff)
- Fields and subfields and type of activity (Basic and applied research on development)(Vinkler, 2000).

A crucial problem in the evaluation of performance is the choice of appropriate criteria. For certain routine jobs, this is relatively simple: a count of the number of outputs, modified by some quality parameters. But in the case of scientific research, the criteria are perceived to be more complex and varied. Connolly (1972) has noted that the evaluation of research is essentially multi criteria, and the criteria/measures vary across
subjects and projects. Brinbaum (1980) has reported that in the decade 1956-65 there were only seven variables/indicators for performance measurement which has grown to 35 in the succeeding ten years related to both subjective and objective measurement (Nagpaul, 1985).

Indicators/measures used in the assessment of S&T can be of different types to be used by scientists for evaluation in different fields of study. Before discussing the types of science indicator, understanding the topologies of types of indicators is necessary. Some of the topology of types of S&T indicators are:

3.4.1 Indicator Topologies

a. Input Vs Output

Input and output analysis came to prominence with the work of the economist Vassilly Leontief. Being the tangible entity, it is easy to measure its input indicators by measuring the financial investment, counting the number of institutions established, the number of scientists working more in scientific field than measuring the output indicators as scientific knowledge produced inform products, articles, innovations hard to measure as it is intangible. Statistics on patents and data on bibliometrics are the two most used S&T output indicators. Quality and capabilities of scientists and standard of scientific activity in a country can be assessed with the help of
bibliometric indicators, while the level of innovation and inventiveness will be gauged with the help of patent based indicators.

While applying the input indicators like finance and human resource, it is difficult to assess the level of quality and the skills of the employees and scientists simply. Sometimes, the output in one system works as an input to the other system like the output of S&T education systems-Human Resources, is input to R&D activities.

b. Qualitative Vs. Quantitative

Science indicators may be either qualitative or quantitative. Hitherto, the main emphasis has been on the quantitative indicators in the studies. Quantitative indicators have a definite intellectual appeal, giving the impression of being more objective, more precise and more reliable than qualitative, which is being more subjective and cumbersome to identify peer review citation analysis and self citation. However, it may be argued that quality is more important than quantity since single innovation, or single paper, or high standard may be much more productive than a large amount of substandard work. Evaluation of scientific activity should be based on both quantitative and qualitative indicators.
c. Quality, Importance and Impact

While assessing the performance based on output indicators like project findings/results, one has to see how well the research has been done, whether it is elegant and applicable for societal benefit or not. Being relative in nature, it will be judged differently by different people. Importance denotes the influence on further research and its application, while impact means the effect of the result of this work for future scientific activity.

d. Macro Vs. Micro Indicators

Depending on the aggregation addressed by the indicators we can have macro and micro level indicators. The journal provides a macro level overview, i.e., predicts main research themes, topics and their linkage. It is extremely difficult to understand the linkage among concepts which is limited in scope, i.e., cognitive domain of knowledge requires one to link the concepts, together at the micro level. For the macro level analysis, two approaches have been adopted-economic and innovation chain. Economic analysis attempts to relate economic benefits gained from investments in scientific research with the help of cost benefit analysis, input-output analysis, net present value, etc., but it is difficult to measure the benefit of R&D outputs.
3.4.2 Financial Indicators

There is no known optimal level of R&D investment, since one would not expect each country to invest the same absolute amount in S&T activities. Expenditure in R&D activities can be measured by a). identifying the intramural expenditure on R&D performed by each statistical unit, b). identifying the sources of funds for these intramural R&D expenditures. Some well known financial indicators are.

i. **Gross Domestic Expenditure on R&D (GERD)**

One of the most commonly used financial indicators for R&D activities is the percentage of the Gross National Product (GNP) or GERD is the total intramural expenditure on R&D performed on the national territory during a given period. GERD and GERD matrix are fundamental to internal examination and international comparisons of R&D expenditures. GERD/GNP serves as a general indicator of S&T activity, and its estimates are sufficiently reliable for main use as an aggregate indicator for science.

ii. **Gross National Expenditure on R&D (GNERD)**

GNERD is an optional supplementary aggregate which comprises total expenditure on R&D financed by institutions of a country during a given period. It includes R&D performed abroad but financed by national institutions or residents. It excludes R&D performed within a country but
funded from abroad. It is constructed by adding the domestically financed intramural expenditure of each performing sectors, and the R&D performed abroad but financed by domestic funding sectors (Frascati Manual, p.101).

iii. **Government R&D Applications (GRDA)**

GRDA denotes all appropriations by Central Government allocated to R&D in central government budget. It actually refers to the budget provisions only not the actual expenditures. The figure on actual expenditure will differ from the budget provisions. The ratio of total industrial investment for S&T to the domestic industrial production, the ratio of investment in R&D to the sales turnover, the ratio of investment in R&D to exports of technology-intensive products are some other financial indicators.

3.4.3 **Man Power Indicators**

One of the important classes of science indicators is S&T qualified personnel. The data on human resource indicator in the form of their level of education and training, the grade in which they are employed, their deployment in S&T, their mobility from one institution to other industries are useful for analyzing the stocks and the flow of highly skilled personnel like scientists, engineers, technicians, medical practitioners, consultants,
etc., but the qualitative assessment of the S&T work force as such is not an easy task.

3.4.4 Literature Based Indicators

i. **Publication Count.** Total number of publication output by a particular country in a specific field of study is covered under journals and conference papers. This indicator reflects scientific output of a country. Direct or fractional count methods are used for counting the multi-cultured publications. It is a cumbersome process, and relative in nature.

ii. **Science Production Index (SPI).** SPI is percentage share of world output, i.e., total number of articles published in a given country, in a given period of time, in a given specific field of science, identified by the total number of articles published in the world (WRD), in the same fields, over the same period of time.

\[
SPI = \frac{\text{Number of articles of a country (A)}}{\text{Number of articles of the World (WRD)}}
\]

iii. **Activity Index (AI).** The Activity Index (AI) was first proposed by Frame. It characterizes the relative research efforts of a country devoted to given field.

\[
AI = \frac{\text{the country's share in world's publication output in the given field}}{\text{The country's share in world's publication output in all science fields}}
\]

Or equivalently
iv. Relative Specialization Index (RSI). This indicates whether a country has a relatively higher or lower share in world publication in a particular field of science than its overall share in world total publications. RSI is closely related to the so called Activity Index (AI).

\[ RSI = \frac{AI - 1}{AI + 1} \]

v. Cooperative Efforts (COP). It measures the cooperative efforts made by a country through writing articles and the number of scientific links created between countries through common index. It measures the degree of scientific ties between countries and degree of participation of a country to scientific community. If there is n countries in the byline of a paper, there are n-1 links. As each country has a right to count its participation in internationally co authored papers, the total number of links will be nx(n-1), where n is the number of countries representing the paper.
vi. **International Cooperation Index (ICI)**. This is also known as Salton measure and defined as the number of joint publications divided by the square root of the product of the number of total publications of two nations/organization.

\[
R_{ab} = \frac{N_{ab}}{(N_a \times N_b)^{1/2}}
\]

Where \(R_{ab}\) is the cooperation index between countries \(a\) and \(b\), \(N_a\) and \(N_b\) are the total publications of two countries.

\(N_{ab}\) is the number of papers co-authored by those two countries.

Example: India has 11437 papers and China has 13878 papers and India and China have collaborated in 71 papers.

\[
ICI = \frac{71}{(11437 \times 13878)^{1/2}} = 0.005636
\]

vii. **Affinity Index (AFI)**. It is a measure of collaboration between a given country (A) and another (B), compared to the total collaboration of the given country (A) with the entire world in a given field of science, during the given period of time.

\[
AFI = \frac{\text{Number of COPs between A&B}}{\text{Total COPs of A with world}}
\]
For example: India has collaborated in 2015 papers in the year 2004 but only 88 papers collaborated with Canada. The AFI of India for Canada. Will be $\frac{88}{2015} = 0.04367$

viii. **Internationalization of Index (INI).** This index is the percentage of a total number of co-authors’ papers of a given country, in a given period of time, in a given field of study over the total number of articles published during that period in that given field.

Example: Total output of the country : 11437 coauthored papers are 2000

INI=$\frac{2000}{11437}$

ix. **The Attractivity Index (AAI).** The attractively index characterizes the relative impact of a country’s publication in a given field as reflected in the citations they attract.

\[
AAI = \frac{\text{The given field's share in citations attracted by the country's publication}}{\text{The given field's share in citations attracted by all publications of the world}}
\]

AAI = 1 indicates that the country’s citation impact in the given field corresponds precisely to the world average.

x. **Observed and Expected Citation Rate.** Observed citation is to the number of citation per paper, while expected citation rate is the average of the number of citations of all the papers published
in the same journal in the same year, which, in turn, depends on
the impact factor of the journal.

xi. Relative Citation Rate (RCR). Relative citation rate is the ratio
of observed citation rate.

\[ RCR = \frac{E \text{ observed citation rate}}{E \text{ Expected citation rate}} \]

RCR is a measure of whether the publication of a country attracts
more or less citations than expected on the basis of the average
citation rates of the journals (Schubert & Braun, 1986; Schubert et al.,

Some of the common problems with literature based indicators are

- Homonym
- First author problem
- Journal quality
- Citation log
- Institutional address
- Abstract/Index coverage
- Journal/organisation’s abbreviations
- Technical limitations of the citation database
- Sociological characteristics of citation practices (Pruthi and Garg,
  1988).
3.4.5 Indicators for Inventive Activity

Patent data can be used as an indicator for the inventive activity. Scientists, inventors and co-operations protect their inventions or innovation by patenting their research product. Two major indicators used for measuring the patenting activity are auto-sufficiently and dependency ratio. Auto sufficiency is the ratio of patent applications by residents to total applications, while dependency ratio is the ratio of foreign applications to the applications of the individual country. Patent per GDP, patent per value export and patent for total R&D expenditure are some useful inventive indicators.

3.4.6 Indicators for Competitiveness (National Science Foundation, 1995).

Every nation makes investments in R&D activity to improve its socio-economic conditions. The socio-economic developments come by increase in productivity. Some of the measures/indicators used for measuring the competitiveness of a country are:

(i) Current Impact Index (CII)

This attempts to find the impact of a country’s patents on the technological community and its significance by calculating how frequently
a country’s recent patents are being cited by all the current year’s patents. This normalized indicator has an expected value of 1.

(ii) **Technology Cycle Time**

This indicator identifies those countries which are inventing (patenting) in rapidly changing technology fields. By measuring the median age of the patents cited as prior art, it identifies fast developments in the field of technology.

(iii). **Socio-economic Infrastructure**

It assesses the underlying physical, financial and human resources needed to support modern technologies. This indicator can be constructed based on secondary school and higher education population.

(iv). **Productive Capacity Indicator**

This indicator is used for evaluating the nation’s current, in place of manufacturing infrastructure. So that the future growth in the field of advanced technologies can be assessed. This indicator basically depends on the availability of skilled labour, number of indigenous hi-tech companies, management capabilities, combined with published data on current electronic production in each country.
3.4.7 Self Indicators

Everything in S&T domain is not measurable or quantifiable. The societal factors are affecting the scientific activities and scientific inventions are changing social and cultural environment which is not possible to measure with the above mentioned indicators. For measuring such non-quantifiable S&T activity soft indicators are used based on the perception of experts, scientists and engineers. The productivity of scientific research is immensely influenced by the environment of the institutions where the research is being carried out. As S&T research is funded by public, it is imperative to incorporate the feelings of the masses in public policy. This helps in getting valuable feedback from the performer to S&T policy planners and decision makers.

The complexities of the facilities and structure of science and technology make it challenging and difficult to assess the scientific and technological development easily in country which is again very important for the future policy and programmes of S&T. Different countries are adopting different criteria for assessing S&T activities, and their impact on socio-economic developments. In assessing the performance and the utility of science towards society, assessing measures/tools like indicators play a very vital role. With the help of indicators or a set of indicators, one can measure the S&T performance of a nation qualitatively as well as
quantitatively, which, in turn, helps S&T policy planner and decision maker to plan the future S&T activities of the country in advanced technological as well as sound sociological base. With the help of literature based indicator, qualitative as well as quantitative evaluation, can be done while indicators for competitiveness and soft indicators help assessing the quality of national life.
References


