Emerging issues in the development and utilization of S&T indicators in developing countries of the ESCAP region[1]

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Abstract

Development of S&T indicators is expected to provide policy-makers and planners with a broad information base to assist national development planning. While much methodological work has been undertaken to develop S&T indicators, these indicators have often failed to create effective policies for scientific and technological development. The majority of the existing S&T indicators have little relationship with what they are attempting to measure, how those measurements might be carried out, how would these measures help to create intervention strategies into an existing system and how would the strategies so created influence the working of the economic system. This article outlines a conceptual framework for designing effective S&T policies. The design problem is sliced into four systems relating respectively to a) resource base and environment; b) management of production units; c) domestic macro-economic policy; and d) global economic relations. These four systems and the variety of technological patterns they subsume must be carefully understood for creating an effective policy design. System dynamics method is identified as a decision-support methodology which offering an opportunity to experiment with various strategic options proposed and implemented in the past and to understand the various scenarios created under laboratory conditions. Such experimentation helps to explain the variability of the patterns experienced in the past while also pointing toward the critical elements for a successful policy framework for the future. Policy guidelines are outlined for an effective technology-based intervention.

Key words: Science and Technology, Technology Transfer, Technological Development, Strategic Planning, System Dynamics

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Introduction

Technology has often been viewed as one of the strongest forces driving economic growth. This has been accompanied by a growing interest in the indicators for measurement of the progress and the status of technology and its integral counterpart science. S&T indicators are signals of the status of science and technology and what contribution they are likely to make to economic development. Such indicators are often used in two ways. The first is for purely descriptive purposes, where comparisons are made among countries and firms over time. The second is to discern the patterns of scientific and technological activities existing in a system, where technological indicators go beyond pure description and become an important aid to achieving a better understanding of the causal relationships in a system of science and technology development [Pavitt 1984]. The first category of use would only return temporal patterns, which without the second category of use would create direct policy interventions, often leading to unforeseen outcomes. Both categories of use implemented together, on the other hand, would identify pressure points for indirect intervention with a high degree of efficacy and a low potential for surprises.

Individual countries as well as international organizations, like OECD, World Bank, Asian Development Bank and the various organizations of the United Nations, have all attempted to formulate technological and industrial policies and plans to foster economic growth in the developing countries at the fastest possible rate. Meanwhile, considerable effort has also been made by the individual countries and international organizations to develop a useful set of S&T indicators. However, there have emerged many conceptual problems and methodological difficulties. The construction of these indicators implicitly embodies hypotheses concerning the characteristics of S&T and its interaction with the social-economic system. Presently, the construction of S&T indicators appears to be oriented towards international technology transfer, whether or not such a transfer may create sustainable economic development. Since an indicator may often represent narrowly just one facet of what is being measured [Hill 1986], it is likely that such narrowly focused indicators will lead to distorted policies that may not contribute to sustainable development in the long run.

Policy design has traditionally been driven by situational models rather than a comprehensive understanding of the complex relationships formed through the interaction of the concerned organizations. As a result of this, there invariably appear contradictions in the performance of policy. Policy design for the developing countries can especially not rely on situational models relevant to the developed countries in view of the differences in the economic structure and social set up which preclude the distribution of benefits to the majority of the people [Saeed 1996a]. Therefore, the role of technology and its consequences for sustainable development in developing countries must be carefully understood before a particular set of S&T indicators are delineated for wide application.

The methodology used to collect data and formulate indicators must also be evaluated very carefully. Expensive and time consuming data collection and formulation cannot in actual fact support policy design in the developing countries due to the lack of well trained personnel and organizational support. S&T indicators, like other social and economic indicators, are never ends in themselves. They are supposed to bring information feedback to the policy makers. The important consideration in selection and measurement of these indicators is understanding their role and interpreting their operational implications. Therefore, organizations concerned with S&T indicators should be involved in collating and interpreting data as well as creating a broad policy framework for its use rather than simply collecting data [Hill 1986].

This paper provides an appraisal of the existing S&T indicators and their use, and suggests also a framework for designing effective S&T policies. Section two presents a review of three main indicator systems currently in use: (i) OECD S&T indicators [OECD 1989], (ii) UNESCO S&T indicators [UNESCO 1970, 1977, 1984] and (iii) S&T Altas indicators [UN-ESCAP 1989]. Section three reviews selected country case studies on development and utilization of S&T indicators in the ESCAP region. These include studies on Indonesia, Malaysia, India and Thailand. Section four discusses the effectiveness of S&T indicators. Section five provides conceptual framework for improving S&T indicators for developing countries. Finally system dynamics is introduced as a methodological framework for designing S&T policy.

Review of scientific and technological indicators in ESCAP region

Technology began to draw academic and government attention in the 1950s. Since then, there has been a growing interest in the measurement of the status of technology. In the 1950s and 1960s, this interest led to establishment of many specialized quantitative S&T indicators. The use of such indicators became more wide-spread in the 1970s when international organizations also began to develop standard S&T indicators for international comparisons [Falk 1984]. The establishment of S&T indicators is, however, not merely a statistical endeavor. It embodies theoretical assumptions on the relationships between technology and social-economic structure. Any evaluation of S&T indicators should, therefore, necessarily examine the premises that development planners hold on the relationships between science and technology and social-economic structure, which is attempted in this section in our evaluation of OECD, UNESCO and Technology Atlas indicators.

OECD S&T indicators

The most widely used and influential S&T indicators are those of the OECD. These indicators have been developed primarily for application to developed countries. However, since the formulation of S&T indicators for the developing countries is influenced by OECD indicators, it is necessary to overview their conceptual and methodological characteristics.

a) Conceptual Framework of OECD S&T indicators

The original objective of the OECD S&T indicators was to provide an assessment of the current state of science and technology in the OECD member countries and to understand the determinants of technological change. They were also expected to facilitate the understanding of the consequences of technological change in terms of growth, productivity, competitiveness, employment, skills and international patterns of industrial production and international trade [Pavitt 1984]. With accurate information provided by relevant indicators, S&T priorities were expected to be set for achieving an optimal resource allocation among many possible research projects, which would yield the best possible results in terms of “progress,” in this case implying mainly the utility of the research conducted [Cooney 1984]. Therefore, S&T indicators were directed essentially to the concern for an effective allocation of resources to S&T research and data analysis so it is useful to a wide cross-section of public [OECD 1989].

b) Indicators used in OECD

OECD R&D indicators are placed into categories of *input indicators* and *output indicators*. The *input indicators* deal with resources that are required as inputs in the pursuit of S&T activities. Usually, this includes the financial resources and human resources in both public and private sectors that are devoted to R&D. Financial resources allocated to R&D will be used to estimate the general evolution of the resources devoted to R& D and production. Human resources in R&D activities are generally used to examine the performance of higher education in carrying out R&D work and its role in the R&D effort [OECD 1989].

The *output indicators* are of major interest to S&T developers. Output indicators try to measure the direct products of S&T activities [Fabian 1984]. Through *output indicators*, the efficacy of technological policies can be determined. The output indicators basically consist of the technological balance of payments, patent statistics and high-tech transfers. The technological balance of payments arises from technology transfer between countries, which measures the degree of a given country's dependence on foreign technology. Patent statistics measure invention activities. The state issues patents to encourage inventors to make public their inventions. Patents are granted for products, compositions, apparatuses and processes that are useful, new and inventive. They may be used, therefore, as indicators of the level and nature of inventive activities, the technical areas of inventive activities and the loci of inventive activities [Stead 1984]. The patents reflect scientific and technological activities which are 'leading edge'[Archibugi 1992]. The indicator of trade in high-tech intensity products is to demonstrate the impact of research and development on international trade. One may use this to help determine the trade pattern in a product group. It is expected that a carefully specified study would permit one to establish and analyze a link between trade specialization and technological indicators. Also, comparisons between international specialization and technological indicators permit researchers to situate each product in its innovation cycle for each period, which in turn can be used as new a indicator for innovation [Fabian 1984]

c) Limitations of OECD S&T indicators

OECD indicators have achieved some success in at least unifying terminology. The OECD has developed standard definitions for the terms used in its indicators. It provides technical notes to explain a wide range of terms such as "public funding" and "government R&D funding" etc., which have been used in S&T indicator system developed in other countries [Sharif 1986]. These indicators have, albeit, limitations for application to policy design.

1) OECD S&T indicators are based on inflow-outflow analysis. None of these indicators are able to represent technology as a stock, which is essential for discerning any potential for technological change, although it is expected that the technological trend can be

predicted through use of these indicators. Yang and Chung [1994] point out,

> “The expression that ‘a county's R&D expenditures rank in the nth position internationally’ is commonly used. The R&D expenditures used here indicate the expenditure, made every year in a certain country. With the volume of the R&D expenditures, the assertion of where in the ranking the R&D expenditures of a given country stand may be controversial. Even if two counties have the same amount of R&D expenditures, they may produce different outputs by their accumulated scientific knowledge. Therefore, there is a need for an R&D stock which reflects the accumulated scientific knowledge, rather than R&D expenditures.”

2) Another source of technological change not captured by aggregate R&D expenditure is innovation by small firms. Birch [1979, quoted in Huber 1985] found that in the United States, 80 percent of all new jobs are created in firms which employ less than 20 persons and which are less than five years old. In Great Britain, the number of plants with less than one hundred employees increased by more than 50 percent between 1968 and 1978. On the other hand, during the same time, the number of firms with more than one hundred employees decreased by 15 to 20 percent [Huber 1985]. Small specialized firms may not even have separate research and development departments reported in the R&D statistics, but they often have scientists and engineers working part time in the design office or production system, inventing and developing new products and processes. Yet, it is reported that no country has attempted to measure or estimate the R&D effort of these small enterprises [Pavitt 1984].

3) R&D expenditure captures only a part of the expenditure on innovation. It does not subsume the development effort of the production engineering departments of large firms. They are often not reported as undertaking R&D research but still play an important role in designing, modifying and developing particular instrumentation and production machinery. R&D expenditure as a measure of S&T activity, may therefore under-estimate its actual level [Pavitt 1984].

4) The impacts of R&D and innovation are only partly captured in the input-output balance sheet constructed with OECD S&T indicators. In reality, these impacts are exceedingly complex. If R&D planners are to succeed in harnessing technology for the benefit of overall human progress, they must be in a position to anticipate all the significant effects of R&D before they are realized in addition to being unable to assess

the potential for R&D [Cooney 1984]. Technology being a key policy instruments for achieving sustainable development, these limitations greatly reduce the usefulness of the indicators for policy design.

5) Patents as output indicators might seem to provide reliable and detailed time series information on the impact. Their utility is, however, weakened by a number of factors: a) patent laws and procedures may differ from country to country, which creates a variability in the definition of the measure; b) different inventors do not make similar use of the patent systems, hence there is variability in reporting; c) patents are issued for inventions of unequal value which cannot be easily weighted in an aggregate measure; d) many patents are issued for inventions which are never used until long after the patent is issued, creating inter-temporal impacts unrelated to the measures; e) patent applications are governed by market pull as well as by technology push, so there will be a lower tendency to patent in small markets or small countries then in large markers and large countries; f) patent statistics are often incomplete and often not directly comparable, hence unreliable [Stead, 1984].

6) OECD S&T *output indicators* are not generally applicable in the developing countries. The technological balance of payments is relevant only to payments incurred in formal contracts of transfer of technology from one country to another forming a major part of technology transfer in the developed countries. In the developing countries, technology is transferred through many modes, including import-export of technology, import-export of machinery, the exchange of experts, the transfer of embodied skills, copying and imitating foreign technology and foreign direct investment [Pavitt 1984; Sharif 1986; Hill 1986].

7) Last but not least, both input and output indicators of OECD as well as the technology balance sheets they draw represent topological snapshots rather than patterns of change, which limits their use in the design of any policy endeavors for change.

UNESCO indicators

The international standardization of OECD S&T indicators is rooted in a relatively small but wealthy group of nations. These indicators may not necessarily be relevant to the developing countries. To partially tide over this problem UNESCO has developed a standardized set of indicators with a wider posited application. UNESCO at its 20th session in Paris in November 1978 adopted a "Recommendation Concerning the

International Standardization of Statistics on Science and Technology". This was followed by a series of "Guides" and "Manuals" to aid member countries in developing and improving their S&T statistics [Sharif 1986].

a) The conceptual framework of UNESCO indicators:

UNESCO indicators were first set of indicators developed specifically for the developing countries. The scientific and technological activities in the developing countries were quite underdeveloped and it was deemed necessary to promote science and technology in the planning agendas and focus policy attention on it. Since the contribution of science and technology was also not widely recognized by the governments of the developing countries, the early UNESCO S&T policies endeavored to impress upon governments the importance of S&T development. Since scientific and technological activities are for the most part carried out in the public sector, the S&T indicators also focused on government initiatives on scientific and technological activities [UNESCO 1970, 1977, 1984].

b) Indicators included in UNESCO Framework

In the case of the UNESCO S&T indicators the *input indicators* include:

1) The major R&D input indicators that have been developed by NSF (National Science Foundation) and OECD;

2) Science and Technology Education and Training at the third (higher) level (STET), which the OECD and NSF did not include: This incorporates statistics of educational background of staff in engineering and science which provide useful information on the scientific and technological profiles of firms, industries and nations [Jacobsson et al. 1996]. These indicators were expected to be more useful in the developing countries since engineers and scientists with higher educational background in these countries might be engaged in tasks directly related to their training. Secondary and basic educational levels are also included, although no specific explanation is given for this. Secondary education level can, however, represent the potential catchment for further technical education. The secondary educational level also facilitates to a certain degree the process of learning and innovation in the informal sector. The basic education level might influence the value system in developing countries since widespread illiteracy acquiesces into continuation of unprofessional attitudes [Saeed 1994];

3) Scientific and Technological Services [STS]: UNESCO recommended that the main

effort should be concentrated on “scientific and technical information and documentation”. STS mainly represents the scientific and technological atmosphere of a country as manifested in information institutions and their characteristics .

The UNESCO *Output Indicators* include: a) bibliometric indicators, such as S&T publication counts, citation counts, authorship counts, international authorship and international co-authorship counts; These indicators serve two purposes. First, they make research literature available to other researchers, second, the publications in literature serve as a principal means for establishing responsibility for advancement of science [STAID, 1993); b) Patent related indicators such as patent counts, patent citations, patents taken by residents, patents taken by foreigners, and patents taken out in foreign countries. Patent indicators are used to assess the volume of invention activities. The UNESCO output indicators might appear to be academically oriented, although they are expected to capture the expertise needed for the pursuit of S&T activity.

c) Limitations of UNESCO S&T indicators

The UNESCO S&T indicators are limited in the following ways in their ability to facilitate S&T policy in the developing countries

1) The output and input indicators may be used as a basis for determining overall national budget allocations and for designing incentives to regulate funds allocation within the private sector [Sharif 1986]. Since, they are not cognizant of the structure of the system in which allocations may be made or incentives implemented, they would issue interventionist rather than operational policy instruments . The indicators have not been an effective way to guarantee an effective allocation. Even when an effective allocation can be made, its impact in terms of technological improvements achieved is a question mark .

2) The UNESCO S&T policy aims to align economic sectors and social-economic objectives with scientific manpower and expenditures [UNESCO 1970, 1977]. However, the relationship between social-economic objectives and public funded scientific manpower and expenditures is not clear as there indeed is no direct relationship between the two.

3) The work on output indicators, according to some writings, appears to have been carried out independently of the work on input indicators. It is also seen to be primarily of academic orientation [Sharif 1986].

S&T Altas projects

Taking note of the limitations of the application of the OECD and UNESCO S&T indicators to developing countries, UNCTAD in 1989 initiated a S&T Altas project to develop a comprehensive set of S&T indic ators to guide the developing countries [UN-ESCAP 1989].

a) Conceptual Framework of the S&T Altas project:

The conceptual framework of the S&T Atlas project is stated in UN-ESCAP[1989]. The Altas Project does not clearly define its indicators in terms of inputs and outputs, instead it develops indicators to monitor the present technology level itself and assess technology capability. The Technology Atlas schema is at best mechanistic and subjective. It also incorporates use of information that is very difficult to assess accurately. Technology itself is the target of the Atlas project study, whose identification and measurement as an entity in the real world is difficult. The policy framework it issues attempts to achieve targets which should help to alleviate unequal terms of trade between the developed and the developing countries, although without substantiating the empirical and logical basis of this a priori or relating target achievement to the terms of trade.

b) Indicators used in Altas projects

The Atlas S&T indicators are measured at three levels. At enterprises level, these measures include technology components, technology capabilities, and technology strategies. At industry level, they include technology resources and technology infrastructure. At the national level, these measure are related to technology climate; and technology needs. The S&T indicators serve four major purposes: assessment of current standing against international bench marks, evaluation of strengths and weakness to focus investment effort, quantifying achievements for setting targets and for motivating growth in a set of postulated indicators of technological level [UN-ESCAP 1989; PAPIPTEK and LIPI 1993]. There are the following five categories of indicators:

1) Value added at the firm level

Value added is related to the sophistication level of four postulated components of technology, *technoware, humanware, infoware, and orgaware*, discerned through a combination of weighting of the inventory of facilities and expert opinion. It is claimed that such a schema facilitates assessment of the strengths and weaknesses of transformation elements, and enables the determination of priorities in resource allocation for upgrading the technology component. The generic criteria used in the assessment of the state of the technology is expected to help to improve capabilities for screening the technology selection for procurement by the enterprises [UN-ESCAP 1989].

2) Technology climate assessment

The technological climate of a country is the setting in which technology based activities are carried out. For the same technological level existing in the production units, their actual technological contribution will vary according to the technological climate they experience. The technology climate assessment analysis can indicate whether the situation in a country is conductive to effective utilization of its technology or not. This assessment is carried out by expert opinion [UN-ESCAP 1989].

3) The inter-country comparison of technology status

Technology status assessment of an industry helps in evaluating the technology gaps using the same postulated components as in case of a firm. Measurement of gaps in terms of the four components is posited to be useful for achieving a better understanding of the nature of the gap and for describing corrective action since this is seen to facilitates the preparation of plans in specific terms for strengthening technology in an industry.

4) Assessment of national technological capability

The assessment of national technological capability requires the measurement of the indigenous potential to improve technological capacity. It includes appraisal of independent technological learning capacity, independent technology creating capacity and independent technology reconnaissance capacity, which allow one to ascertain the speed of the technological change toward a desired level indicated by an international standard [UN-ESCAP 1989].

5) Technological needs assessment

The assessment of technological needs aims to formulate a strategy for sustainable development. The sustainable strategy is defined as “make some and buy some.” Therefore, it is necessary to forecast the international technology market and compare it with the national technological capacity to classify the technological areas and to assign priorities to them [UN-ESCAP 1989].

c) Problems of the Altas project indicators:

1) The criteria for the evaluation of technology are discretional and rather narrowly defined. The Atlas Project appears to propound that public policy concerning technology in the developing countries can be formulated in the same way as business strategy. Efficiency, defined as economy in the use of resources, is considered to be the chief criterion used in assessing development. Although the overall objective of the Altas Project is to offer a decision-support tool in the form of a set of methodologies for integrating technological considerations in the development planning process, the only way to realize a plan is to improve efficiency in resource use. Yet, the causal relation between technology and other social-economic factors is not considered. In reality, it is doubtful that an increase in efficiency alone can improve welfare for the majority of the population in the face of the economic structure and the institutions on ground in the developing countries.

2) The need for change in technological components is determined through a comparison of the present technology level in the developing countries with the developed countries. This method demands forecasting the international technology market and whether the technology polices are successful or not depends on the accuracy of forecasting. However, the discretional technology components forecast are based on extremely rough data. It is also unclear who is going to intervene into the system, private enterprises or government, and how.

3) The policies are formulated on the basis of experts' opinions and assessments. There is no rigorous model to test the experts' mental models and relate them with real world structure. Indeed, a large amount of information is stored in the human mental model. The driving force both for delineating the micro-structure of the system and in verifying its behavior is empirical experience. Quantitative information, qualitative data and the mental model are all information sources for formal model building. Yet, it is difficult to gain confidence in our understanding of the structure underlying the behavior pattern without rigorous testing [Forrester 1980; Forrester and Senge 1980]. Therefore, testable methodologies should be developed before policy suggestions are put into use.

4) The problem of low technology performance in developing countries is defined within the international market context. Technology of developing countries is valued at a low level in the international market. Hence, developing countries are forced to exploit their natural resources in exchange for high-tech imports. The Altas Project implies that

technology transfer can help to remove this disparity. The relationship between technology transfer and international socio-economic structure is, however, complex. There is no convincing evidence to demonstrate that there is a linear relationship between the adoption of modern technology and the removal of the postulated disparity. Studies show that technology transfer may result in an extreme case in moving all production to the developing countries while the majority of the resources are still controlled by the developed countries [Saeed 1996b], which will further strengthen income disparities.

5) The technology components and their magnitudes are measured relative to their counterparts in the developed countries. Given that technological developments of the past have strove to consume natural endowments and externalize environmental costs, technological development in the developing countries emulating the developed countries, which is posited as a solution to all problems, would be divorced from environmental agendas.

Country studies on S&T indicators development and application

This section examines attempts made at the national levels to develop and apply S&T indicators for national planning. Five cases, concerning four countries, respectively, Indonesia, Malaysia, India and Thailand are reviewed.

The Indonesian Science and Technology Management Information System under the methodology of the Altas Technology Project

In 1989, UNDP/UNESCO supported a 4-year project named Science and Technology Management Information System Project [STMIS] for Indonesia, which attempted to adopt the indicators suggested in Altas project for a specific country case. The project sought to collect S&T information at the micro level, using both qualitative and quantitative data. Later, the data was aggregated at the industry level. Nine categories of indicators were delineated as shown in Table 1 [PAPIDTEK and LIPI 1993]

The project staff reported several difficulties in constructing the indicators. The data required at the firm level was related to strategic information that the firm managers were reluctant to provide, hence, most of the data collected was descriptive and based on the judgment of the surveyors. Since, the survey teams could not obtain the data they sought, a recommendation of the project was that the industry bureaus organize their own survey teams [Ramanathan in (PAPIDTEK and LIPI 1993)]. Difficulties also arose when the information collected at the firm level were to be aggregated into industrial level indicators [PAPIDTEK and LIPI 1993]. Apparently, the problems involved with data identification, collection, processing, storage, maintenance and analysis could not be surmounted and the project generated only descriptive statements about how to attempt, hence the yield of the effort is uncertain.

Table 1 Indicators developed in STMIS [PAPIDTEK and LIPI 1993]

Indicators	**Purposes**
Company profile and activity indicators	assess transformation activities and outputs of firms
Technology component	assess technology used by the firm
Technology capability	assess the accumulation of technological capability by the firm
Technology infrastructure building	to assess firm level technology infrastructure for technology transfer and technology development
Technology productivity	to assess efficiency of transformation activities carried out by the firm
Owners and suppliers influence	to assess material and support inputs required by the firm but influenced by owners and suppliers
market rivalry	to assess influence of rivalry
Customer influence	to assess the influence of the customers
Industry climate and regulation	to assess national level development policy climate

Science and Technology for Industrial Development [STAID]: Macro-scale S&T indicators in Indonesia [STAID 1993]

This project was developed under the sponsorship of the World Bank and called Science and Technology for Industrial Development [STAID]. Unlike the STIMS project, the purpose of this project was to develop indicators of particular interest to policy makers concerned with S&T and the industrial development of the country. The head of the project reported that this project dealt mainly with resources - human and financial - and the output of the S&T process [Iman in (STAID 1993)]. The objective was to create and periodically publish S&T indicators to assess the national S&T *climate*. Indicators constructed and their respective purposes are listed in Table 2.

The indicators developed by STAID were expected to reflect the government effort to build an environment conducive to S&T development. No only these indicators might appear to be judgmental, it is also unclear how the relationships between government effort and industry motivation work to realize the development of S&T and its impact on the economy.

S&T Indicators in the Sixth Malaysian National Plan

Malaysia's Sixth National Plan postulated science and technology development to play a prominent role towards achieving a competitive, diversified and globally based economy which should yield a high standard of living for public. The role of S&T is aimed at widening and improving the S&T base and ensuring the development of comparative advantage in the production of goods and services. The impact of the technology on income distribution is, however, not mentioned [Six Malaysia Plan 1991-1995].

The S&T indicators used since the Fifth Plan cover a comprehensive orientation in terms of the size and management of research and development expenditures and the volume of R&D activities. These indicators are basically used for determining resource allocation to R&D. Technological importation is also used as an indicator to demonstrate the extent of reliance on foreign technology and to assess the rate of technological innovation. The technology import indicator is constructed by using the number of contractual agreements approved by the government [Six Malaysia Plan 1991-1995].

Table 2 S&T indicators developed by STAID (STAID 1993)

Indicators	Purpose
Input indicators	
General situation of R&D and production engineering expenditures	to determine the likelihood for the country to move toward knowledge-based industries and technology-intensive production
Human resources for science and technology	to guide national human resource planning
Government resources for science and technology	to provide the insight into the relationship between the country's stock of natural scientists and engineers and its ability to achieve national development goal.
Science and technology in industry	to assess the role played by science and technology in Indonesia's manufacturing sector in the training of Indonesian technical personnel
Science and technology in higher education	to assess the future demand and supply of higher education service
Output indicators	
Publication patterns	to measure the quality of the Indonesia higher education faculty, which serves a critical function
Patenting by Indonesian Inventors	to serve as indicators of economically oriented S& T activities in a country
Foreign and domestic investment in Indonesia	to be used as leading indicators of the growth of technology intensity in Indonesian manufacturing industries.
Foreign investment in Asia countries	to serve as a catalyst for technological development in newly industrializing economies.
Impact indicators	
Manufacturing output and value-added	to illuminate the economic impact of industrial S&T activities on manufacturing output and value-added
Imports and exports of manufactured products	to illuminate the economic impact of industrial S&T activities on export and import of technologic-intensive products

As in the earlier cases, not only the measurements are difficult, the constructed indicators are not easy to relate to their postulated impact. Hence, the efficacy of the process of indicator construction and their use in planning raises many doubts.

S&T indicators in Indian National Plan

India's recent Eight Year Plan calls for S&T to play a pivotal role in all important development tasks. Hence, the deployment of S&T as an effective instrument of growth and change becomes an essential strategy [Aggarwal 1993].

The main indicator used in the Indian case is, however, only the percentage of GNP spent in the past on S&T, which is a basis for new allocations. According to Aggarwal [1993]:

> "With the change in emphasis and direction enunciated in the Eight Plan, it has become essential to provide sufficient funds to the S&T agencies and to the socio-economic sectors to carry out crucial S&T projects and bring about a major change in our attitudes and performance. Many important programs and projects have been dropped in the past due to a lack of adequate financial support. Thus, it is customary to indicate the percentage of GNP spent on S&T as a measure of importance given by a country to the S&T sector.... In order to decide about the size of the total S&T outlay, the trends in S&T outlay as a percentage of total public outlay can be provided as a guide. "

Apparently, both the criteria for allocation and its postulated impact are arbitrary and little can be said about their efficacy [Aggarwal 1993].

S&T indicators in Thailand's Eighth National Plan

In Thailand's Eighth Five Year Plan, the role of the science and technology in the sustainable development is defined on the application of modern science and technology to raise productivity in the agricultural and industrial sectors and to gain competitiveness in the export market. The problems of the technologies are seen to be the inefficiency in the acquisition and transfer of technology and the limitations of scientific and technological manpower stock [Thailand Seventh National Economic and Social Development Plan].

The budget allocations are made on the basis of discrepancies between targets and actual conditions of two indicators reflecting, respectively, the S&T budget and the qualified manpower. Fiscal incentives are also provided to the private sector to encourage R&D in general [Thailand's Seventh National Economic and Social Development Plan].

Although intuitively sensible, this policy may neither guarantee the attainment of the target S&T levels nor the achievement of the expected welfare benefits since the relationship between the budget and performance is not known.

Effectiveness of S&T indicators

The various types of S&T indicators discussed in the last section and the expectations pinned to their use brings to our mind an interesting story.

The indigenous people of a small and remotely located Caribbean island suddenly realized their living standard was low when the US army decided to build a base there. The indigenous people lived in huts scatters haphazardly all over the west side of the island. They worked hard all day either on the farm or catching fish. They were poor, did not have modern amenities and very little money. On the other hand, the base which was established on the east side had housing organized in neat rows and its soldiers dressed well and seemed to have plenty of money and amenities. Unlike the indigenous people, however, the soldiers did not toil in the farms or catch fish. Instead, they marched all day in a square in the middle of their base, which perplexed the indigenous people. One day, the indigenous people found a solution to their enigma and surmised that the way the soldiers spent their day had some thing to do with their standard of living. This time the soldiers were perplexed when they saw that the huts on the west side were reorganized into neat rows and the indigenous people living there were marching up and down the block in the hope that their living standard would become similar to that of the soldiers.

Almost all ilkes of S&T indicators seem to have been constructed from conjecture and often have little relationship with what they attempt to measure, how those measurements might be carried out and used in policy design, and how the policy instruments they create would influence the working of the economic system. In particular, following problems are seen with the S&T indicator systems discussed in the last section:

Situational underlying models are unrelated to system performance

Since the relationship between science and technology performance and the social-economic system is very complex, there is no agreement on what the S&T policies should be. In different geographic areas, and at different times, different patterns between S&T performance and certain social-economic factors are observed. Therefore, theories guiding the formulation of S&T indicators are diverse.

OECD indicators assume that the presence of R&D activities is adequate to guarantee S&T development. The UNESCO system assumes that government effort would deliver S&T development. The Atlas indicator system assumes that collecting certain ingredients at the organizational and country levels would deliver the kind of S&T development that would help developing countries compete better in the global system. Not only are these models situational, their actual relationship with system performance is not understood and many contradictions exist their assumptions. There also appears a serious identification problem in cases when the indicators attempt to represent abstract entities, as in the case of the Atlas project system.

Indicators are unrelated to policy formulation process

None of the indicator systems discussed above attempts to understand the relationships that connect the indicators to policy intervention and policy intervention to economic performance. Hence they might only lead to creation of arbitrary targets for direct intervention.

Thus, OECD S&T indicators mainly create targets for R&D outlays, UNESCO indicators for public sector, S&T expenditure, and Altas indicators for technology transfer. None outlines how should these targets be met in a complex social-economic system which exists in reality.

Normative rather than positive perspectives

The exiting models prescribe change without understanding the S&T problem. These models give very little attention to the dynamic processes underlying the problems they address. The Altas Project claims that it forces the policy makers to use a dynamic approach to formulate a strategy, but refers only to dynamic forecasting of the international technology market rather than to understanding the information structure of the dynamic systems that determine their internal trends [UN-ESCAP 1989]. These models create normative policy that may interfere with the internal dynamics arising out of the systems actually existing.

Moral appeals rather than operational policy

Because the present S&T indicator models focus on policy design rather than on the understanding behavior patterns, effective policy entry points that can lead to changing existing patterns are difficult to determine. The majority of policy instruments call for more responsibility on the part of the government. Such policy agendas have in the past led to encouraging the enlargement of the scope of government in the developing countries. The empirical experience also demonstrates that the government may not necessarily commit to S&T plans as expected [Saeed 1990]. Jacobsson et. al. (1996) point out:

> "While a great deal of methodological work has already been undertaken with respect to technology indicators, it is fair to say that we are not in the position where a satisfactory set of valid and reliable indicators of technological activities are available to us, nor are we in a position where we can claim to have learned all there is to learn about the main indicators today."

Improving S&T indicators for developing countries

If S&T indicators are to be of assistance in developing countries for designing policies for change, they must at the outset be based on a valid theory of where technology fits into a particular social-economic structure [Hill 1986]. Before the indicators are constructed, it is necessary to review the basic social-economic structure and the emerging problems in the developing countries.

Social-economic structure in place in developing countries

There are four facets of the social-economicc structure to be considered. These include duality in domestic economic systems, duality in the global economic system, externalization of cost to environment and the functioning of the production units.

a) Duality in domestic economic systems:

There exist basic differences in the structure of the economies of the developed and the developing countries which makes it difficult to directly transfer strategic instruments or achieve comparable performance when turn-key transfers of technology are made. Policy instruments which work well in the developed countries may not be very effective when implemented in the developing countries.

The economic structure of the developing countries is characterized by the side by side existence of two equally significant subeconomies, a monopolistic and profit maximizing formal sector and a competitive and consumption maximizing informal sector [Saeed and

Prankprakma 1997]. This classification has been referred to variously in the literature, for example as capitalist and worker sectors [Pasinetti 1989, Dalziel 1991, Fazi and Salvadori 1985], oligopolist and peripheral firms [Gordon 1972, Riech, et al 1973], capitalist and subsistence sectors [Lewis 1954], modern and traditional subeconomies [Fie and Ranis 1966], and wage-paying and self-employed sectors [Saeed 1994]. Such a structure is predisposed to a value transfer from the traditional to the modern sector, thus excluding a large cross-section of households from the benefits of economic and technological development.

A dual economy structure is quite pervasive in the ESCAP countries. Table 3 gives a sampling of cases incorporating a dual economic system. Malaysia lies on one end of the spectrum in these cases with a predominantly wage employed workforce (62.7%) while Pakistan is on the other end where the majority of the workforce is self-employed (73.4%). For the remaining countries in the ESCAP region, the size of the two sectors seems to be comparable [ILO 1990]. It is also widely known that the level of sophistication of technology, discerned in terms of productivity and capital intensity, is much higher in large capitalist firms offering wage employment than in small entrepreneurial firms with self-employed workers, with the former firms also having a higher labor productivity [Lewis 1954, Boeke 1953].

Although the factor proportions as well as the productivity of labor and the capital worker ratio in the two production modes vary from country to country, there appear many similarities in the overall pattern. These similarities manifest in the side by side existence of both production modes with a relatively low productivity in the self-employed sector and a relatively high capital-worker ratio in the formal sector. The pervasive existence of a duality in the developing country economic systems renders all analysis implicitly or explicitly assuming the existence of a uniform economic environment quite invalid.

When, economic efficiency determines who should carry out production and financial efficiency who should control resources, while technology is homogeneous, the ownership of resources becomes concentrated in the formal sector in a dualist system while the informal sector carries out all production. When a technological differentiation is also created between the formal and informal sectors through international technology transfers, the former sector is able to employ a part of its resources in production because of the possibility of higher productivity and both formal and informal sectors carry out production, although ownership is still concentrated in the formal sector, which limits the dispersion of the benefit to a wide cross-section of households. The prevailing theories that guide the construction of S&T indicators only show the trend of the S&T activities and public policies in formal and big enterprises. The large cross-section of people engaged in informal or small enterprises are totally outside such policy considerations. This neglect, at the outset, overstates the effectiveness of any technology policy applied to the developing countries.

Table 3 The number of self-employed workers and wage workers in various countries

	Self-employed workers		Wage workers		Total
	(Million)	(%)	(Million)	(%)	(Million)
Bangladesh	17.3	56.7	13.2	43.3	30.5
Indonesia	53.3	73.5	19.2	26.5	72.5
Korea	7.2	42.6	9.7	57.4	16.9
Malaysia	2.2	37.3	3.7	62.7	5.9
Pakistan	19.9	73.4	7.2	26.6	27.1
Philippine	11.6	54.2	9.8	45.8	21.4
Sri Lanka	2.2	42.3	3.0	57.7	5.2

(Source: ILO Statistical Yearbook 1990)

b) Duality in the global economic system

At the outset, the global economy can be divided into the industrialized and the developing country blocks which are intrinsically different in terms of their markets, motivations, enablements and access to production resources and technology. The former block consists of profit maximizing coalitions operating in established niches and controlling a major part of the global production as well as its technology. The later constitutes fringe producers competing in small market segments often with the responsibility to maximize consumption rather than profit. The global economy, therefore, can also be viewed in the aggregate to have a dualist economic structure, with a formal sector consisting of the industrialized countries and an informal sector comprising the developing countries. With an increasing interaction occurring between the subeconomies of this dualist system, the resource base of one country often extends to other countries. Thus, trade pricing structure and the nature of trade flows cannot be divorced from a valuation system that transfers value from the developing to the developed countries and costs in the opposite direction when a trade exists between the two sectors, which in the long run would transfer control of resources to the developed countries. When technology transfer is allowed between the two country blocks, production would gradually shift to the developing countries, but not the control of the resources. When technology flows are restricted, production is carried out in both blocks, but with the control of resources still resting in the developed block [Saeed 1996b).

The world trade volume almost doubled over the decade 1980-1990 (figure 1). This increase is accompanied, however, by a worsening of the terms of trade for the developing countries [Todaro 1994]. Developing countries have long been compelled by the global market to rely heavily on their natural resource endowments to support their real income and earnings of foreign exchange. The industrialized countries, on the other hand, have undergone a change from raw material processing and heavy manufacturing towards knowledge intensive products and services. It should be noted that value added measurement is not independent of the criteria underlying the valuation process. The trade relations between the two understate the true economic worth of natural resources while overstating the value added through knowledge intensity. The overall trend is poised to create serious environmental damage in the developing countries [Saeed and Archaya 1995].

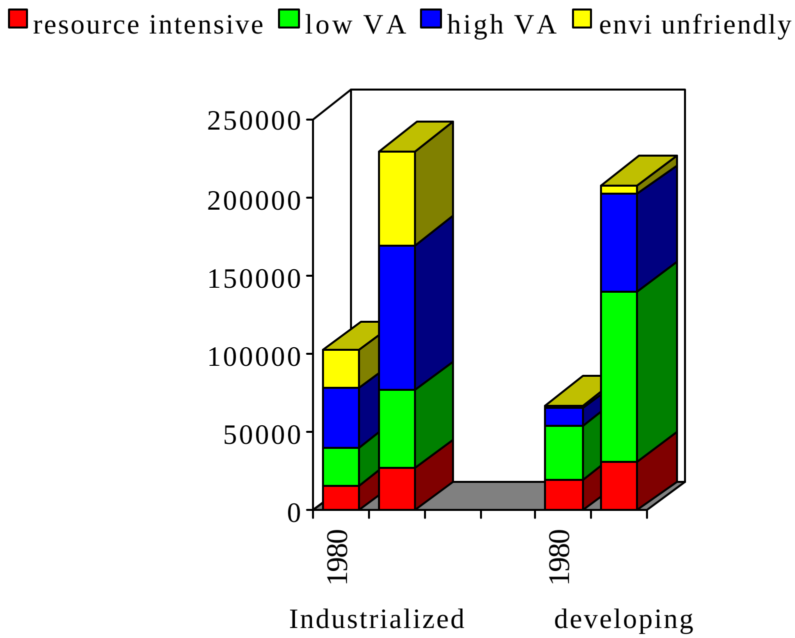

Figure 1 International trade patterns during 1980-1989

source: Saeed and Acharya (1995)

c) Externalization of Environmental Cost

Technological developments in the West have often been based on consuming the resource slack present either in the well-endowed territory from which the technology emerged or on resource availability through transfers from colonized lands. Application of technologies based on such criteria in the precariously balanced resource environment of a developing country possessing little slack can be quite disastrous since they would externalize cost on a precariously balanced environment with little slack in it. Ironically, history has generally seen the opposite situation take place. Thus, as consumption pressures have risen, technologies have been developed to tap richer geological resources. Control of technological progress thus appears to be an important entry point for implementing a sensible resource use policy. Resource use should apparently be based on geological information rather than on economic criteria. This implies a need to investigate ways and means of influencing technological progress that would help balance resource consumption and regeneration rates, which cannot be achieved when technology is obtained largely through a transfer process [Saeed 1985].

d) Learning disability in production units

Technology improvement is basically a learning process. Learning has been posited as a vehicle for economic development through its contribution to innovation and technological growth, which have been established as key sources of economic growth in the analyses concerning the developed countries [Abramovitz 1956, Solow 1957, Dennison 1962, Griliches 1963]. Seen as a prime mover of human ingenuity, innovation and entrepreneurship, the learning process indeed appears to be a powerful means for effecting economic development [Schultz 1979; Hirshman 1958, 1970]. Tapping these sources requires creation of innovative organization designs that not only allow knowledge acquisition, but also its imbedding in the societal context [Saeed 1998].

Experience shows, however, that the learning function of an organization itself is not easy to sustain. A very large number of attempts to create organizational learning are met with frustration, while, organizations in which knowledge acquisition and application is a key process often transform themselves into rigid bureaucracies that lack learning ability [Saeed 1998, Senge 1990]. A wide rage of formal and informal training processes involving information giving and skill practice are used for socializing members of an organization into their respective roles [Van Maanen 1976]. Even if created through such a training processes, individual learning cannot be imbedded into the organizational context unless an appropriate organizational culture converging individual and organizational interests is in place [Argyris 1964, Schein 1985].

It is indeed a challenge to create an appropriate set of S&T indicators and in the face of above realities and to create a fruitful set of policies in drawing on such indicators.

Notional framework for a technology policy

Given the structure on ground in the four domains discussed in the previous section, a notional framework should first be discerned for an appropriate technology policy. This framework should evidently have four parts relevant to each of the four domains identified, organized as shown in Figure 2.

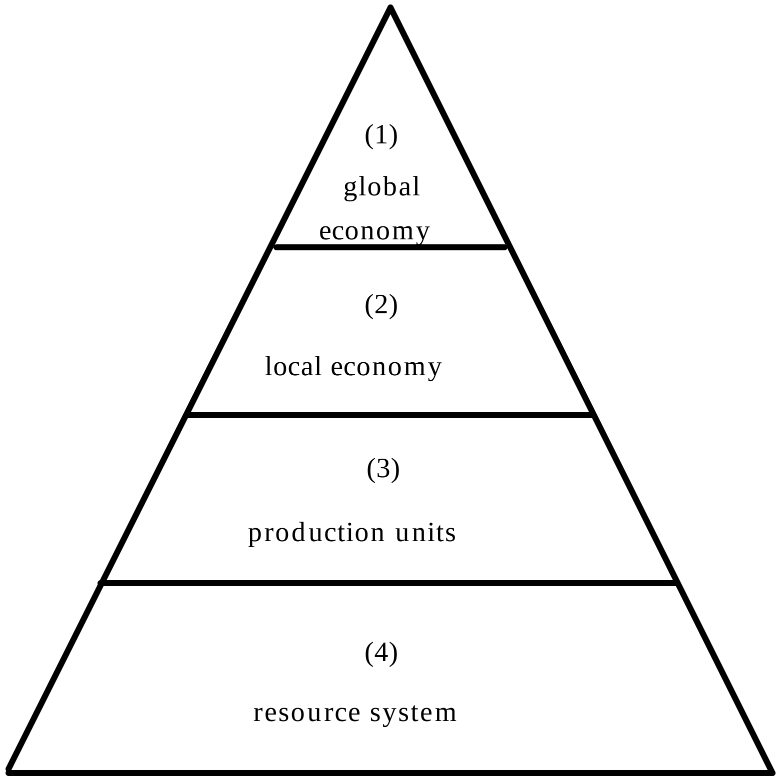

Figure 2 subsystems concerning technology in a national economic system

Considering all four domains together would unfortunately create a level of complexity not amenable to a penetrating analysis. Complex problems can, however, be partitioned into smaller systems and these systems analyzed separately, provided the partitioning process retains the symbiotic relationships existing in the larger system. Such a partitioning process is outlined in detail in Saeed (1992). Suffices here to say that the four domains discerned in the last section form four natural partitions of the complex economic system with important symbiotic relationships intact. The related systems organized into a hierarchy are shown in Figure 2. Technological considerations concerning each are discussed below:

a) Technological consideration in management of resource base and environment

The main consideration for managing the resource based outlined in the previous sections was to balance the consumption and regeneration rates of the aggregate resource basket in use. This is essentially a problem of directing technological progress in a way that the use of a resource is severed when it becomes scarce and increased when it is abundant. Given that nature will regenerate all resources given enough time, this policy practically amounts to influencing the aggregate regeneration time of the resource basket in use, which should increase the speed of circulation of materials through the regeneration cycle when consumption rises, so inter-temporal transfers are avoided. This can be attempted by a set of fiscal and institutional policies linked to the geological information as outlined by Daly (1974) and Page (1977) and operationalized using a system dynamics framework in Saeed (1985) and Acharya and Saeed (1996). The inputs needed to drive such policy instruments comprise of depletion patterns of existing stocks of resources and their consumption rates, which will indicate the degree of appropriateness or inappropriateness of the technology in use and the extent of correction needed.

b) Technological considerations in the management of production units

The ability of a technology to perform reliably is not necessarily only a function of its design, the use of a new technology must pass through a learning phase during which the user must become familiar with its idiosyncrasies and understand its managerial requirements. Many technologies may not successfully pass this phase thus limiting the performance of the production units. A variety of normative models have been proposed to explain the process of technology adoption. Unfortunately, the structure of these models is often highly abstract and difficult to utilize in real world applications. Hence, they may have had little significance from the point-of-view of policy design, although they are sometimes used for forecasting [Mahajan and Peterson 1985]. The most important organizational characteristic in fostering a constant search for an appropriate technology, guided of course by the fiscal instruments discussed in section 3.2.1, and successfully adopting it is the organizational learning function which should create an uninterrupted evolution of technology. Experience shows, however, that the learning function of an organization itself is not easy to sustain. A very large number of attempts to create organizational learning are met with frustration, while, organizations in which knowledge acquisition and application is a key process often transform themselves into rigid bureaucracies that lack learning ability [Saeed 1998, Senge 1990]. A wide rage of formal and informal training processes involving information giving and skill practice are used for socializing members of an organization into their respective roles [Van Maanen 1976]. Even if created through such training processes, individual learning cannot be imbedded into the organizational context unless an appropriate organizational culture converging individual and organizational interests is in place [Argyris 1964, Schein 1985]. It is, therefore, necessary to create and adopt innovative organizational designs for the production units, so they are able to live up to the technological challenges outlined above. A framework for creating such designs has been proposed in Saeed [19968]. The inputs into such design endeavors consist of patterns of organizational performance in terms of trends in resource allocation, productivity, and knowledge acquisition, performance attributes not available in any of the existing S&T indices.

c) Technological considerations for managing a dual domestic economy

Technology is an influential factor in the dual economy. Prior to the commencement of the economic development effort, the developing country economies were largely closed, with very little inflow of technological information from the developed countries. Production was carried out in an artisan mode in a feudalist environment in which the means of the production were largely controlled by the capitalist sector. These economies opened with respect to trade and capital flows as well as technological information when organized economic development effort was undertaken. Transfer of modern production methods from the industrialized countries allowed the owners of the capital to shift from renting to the artisans to a formal mode of production, which created large firms. The modern technology used in large firms also made their production more efficient than the small firms, thus allowing them to displace the later [Saeed and Prankprakma 1997]. This emergence of large firms is often seen as the expanding capitalist nucleus in the literature on economic development that has led to the creation of the dual economies now pervasive in the developing countries [Lewis 1954, Hunt 1989]. In such a system, any improvement in productivity due to the introduction of new technologies may not be passed on to workers in terms of increases in wage rates, which is widely supported by evidence [Morawetz 1977, Lipton 1977].

The pressure to invest in technology by a firm is determined by market competition. A firm must innovate to improve its productivity to function in a competitive market. However, when a firm has a monopoly, it does not have to innovate since its profitability is already high [Kamien and Schwartz 1982, Auerbach 1988]. The other factor which greatly affects the investment in technology is the production sector's financial muscle. A high liquidity makes a production enterprise capable of taking the risk involved in investment in technology [Dosi 1988]. The literature on diffusion of innovation also suggests that the size of investment for the adoption of innovations affects the rate at which it diffuses [Mansfield 1971].

Large firms often have no constraints on their liquidity while they also enjoy higher technological capability compared with the self-employed. However, their innovation rate remains low because there is little incentive for them to invest in technology improvement due to a lack of competition in a highly monopolistic market [Auerbach 1988, Hunt 1989]. Therefore instruments to foster indigenous technological growth are a promising alternative to the traditional development policies which have focused on growth of capital and importation of technologies. Promoting competition among the monopolistic formal firms simultaneously with providing positive assistance to the competitive informal firms is critical to the success of any technology development effort in terms of meeting both growth and equity goals effectively. The patterns driving this policy should incorporate information about the financial and performance attributes of both formal and informal sectors and, so a set of fiscal and institutional measures can be created to meet the objectives of the policies outlined above.

d) Technological considerations for dealing with a dual global economy

Likewise the duality in a national economy the main implication of the global duality is that unrestricted trade and factor movement between a monopolist industrialized block and a competitive developing block would transfer value from the later to the former gradually shifting the control of resources to the former. When a technological differentiation exists between the two blocks, production is carried out by both, when free technology transfer is allowed, production will shift to the developing block, but not the control of resources. This pattern extends also to the externalization of the environmental costs (also see figure 1) and the consumption of the resource base.

It has been widely argued that policies that help promote the technology level in developing countries can help reduce the reliance on natural resources based exports and slow down the depletion of natural resources. Albeit, since developing countries now are in a disadvantaged bargaining position, and if the biased international trade pattern can not be changed within a short period, it is possible that during the technology transfer process the natural resource slack will be totally depleted. There obviously is a need to create a valuation process in which the developing block may receive a better value for its production so any transfers of technology can work to its advantage. The patterns driving such policy initiatives must take into consideration the existing trends in value transfer.

Considerations for the design of S&T policy

A positive policy design framework cannot be divorced from a concerted effort to understand first the logic of the information relationships that have created the need for the policy. This is best achieved through creating a valid model of the social-economic system creating problematic patterns. The experimental procedure of system dynamics can be applied with advantage to support such a modeling effort.

Since models cannot be made overly complex if they are to remain understandable, complex problems must be sliced into smaller parts in a way that the parts meet the requirements of the intended policy design. This calls for separating the *multiple modes* contained in a complex historical pattern in a rather special way [Saeed 1992, 1996a].

The term *multiple modes* is not new to system dynamics, although it is used a bit loosely. Not all classes of behavior implied by *multiple modes* may be relevant to creating a model for an effective policy design. In fact, many intuitively sensible schemes of partitioning a system may create models that do not incorporate policy space for investigating the possibilities of change. The *multiple modes* relevant to a problem may refer to the simultaneously existing components of a complex pattern of behavior that is exhibited by a system over a given period; they may represent patterns experienced over different periods of time in a system of relationships; or even patterns experienced in similar organizations that are separated by geographic space. The conceptual space in which *multiple modes* can be found is, therefore, three dimensional as shown in Figure 3 [Saeed 1992, 1996a].

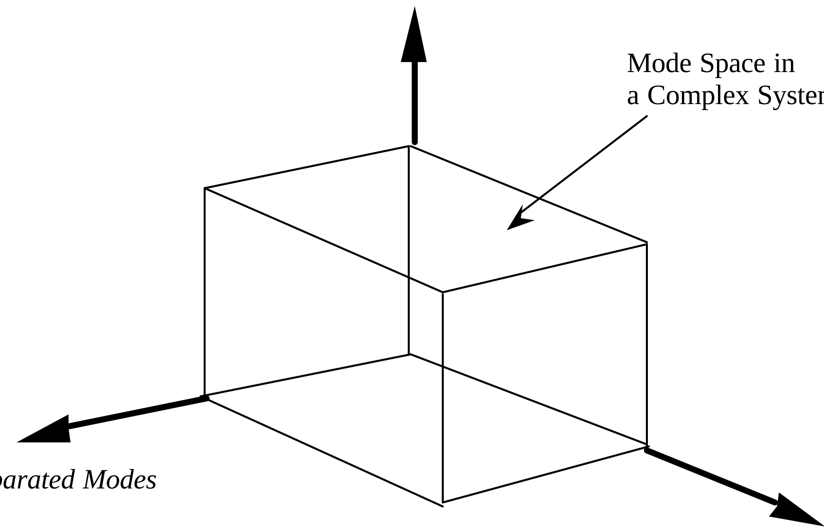

Figure 3 Multiple mode space
source: Saeed 1992

When multiple modes contained in a complex historical series are the focus of a modeling effort, the complex modal space will be sliced as shown in Figure 4. The simultaneous modes constituting the complex historical pattern will be subsumed in a selected partition while the variety of patterns in the temporal and geographic dimensions is ignored. Such a problem slicing process will create situational theories and forecasting models that may explain a unique and complex pattern, and also extrapolate it into the future, but without shedding any light on the possibility to change it[Saeed 1992,1996a].

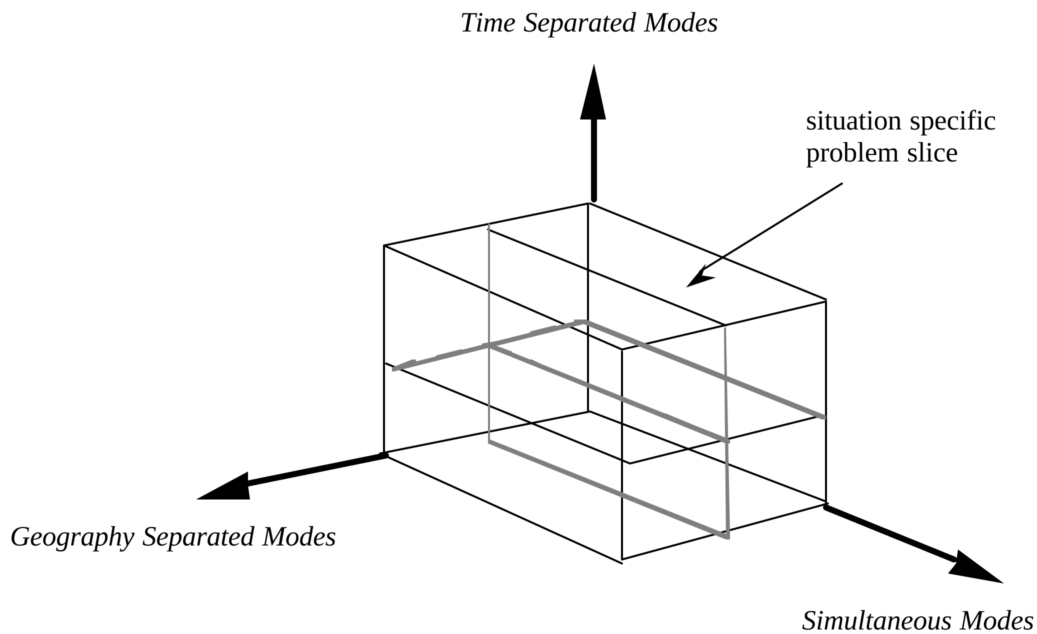

Figure 4: Problem slices for developing forecasting models and situational theories
source: Saeed 1996a

On the other hand, when a model is intended for exploring policy options for system change, the complex modal space must be sliced as shown in Figure 5. The partition selected for modeling will subsume multiple modes that are separated by time and geography since only then its underlying structure would contain the mechanisms of modal change. It may not necessarily incorporate multiple modes that exist simultaneously in system behavior since interaction between the mechanisms creating these may not provide any additional policy space, although this may enhance a model's ability to track history accurately. When policy exploration rather than tracking history is the primary purpose of modeling effort, simultaneously existing multiple modes and their underlying structure can be separated and addressed in different models for limiting complexity contained in a single model [Saeed 1992,1996a].

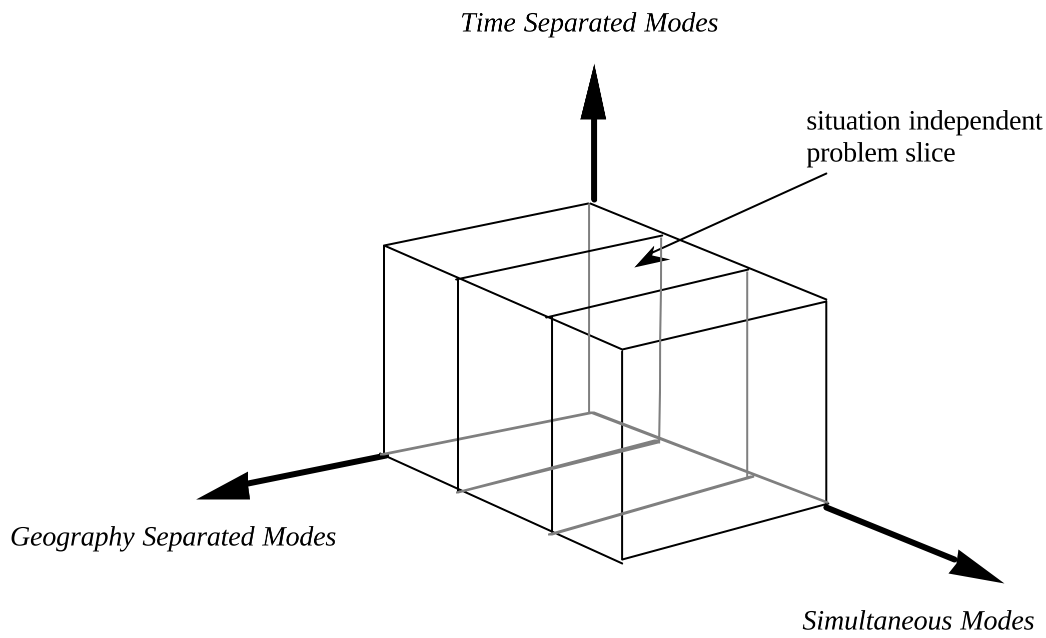

Figure 5 Problem slices for exploring policy design
source: Saeed 1996a

Representing a complex system as a number of submodels that produce behavior different from what appears in the historical data require defining reference mode differently from historical behavior. For example, each of the two complex time histories shown in Figure 6 contains a trend simultaneously existing with a cyclical tendency. To be able to address the two issues concerning the cycles and the trends, this problem may be represented by two models: One subsuming the multiple modes existing in the two trends, the other subsuming the cyclical mode existing in both of them. The two models so created will keep together the symbiotic processes underlying the potential multiple patterns thus providing the policy space to attempt a design for change. Also, the two components of the design so created can be pursued quite independently [Saeed 1992,1996a].

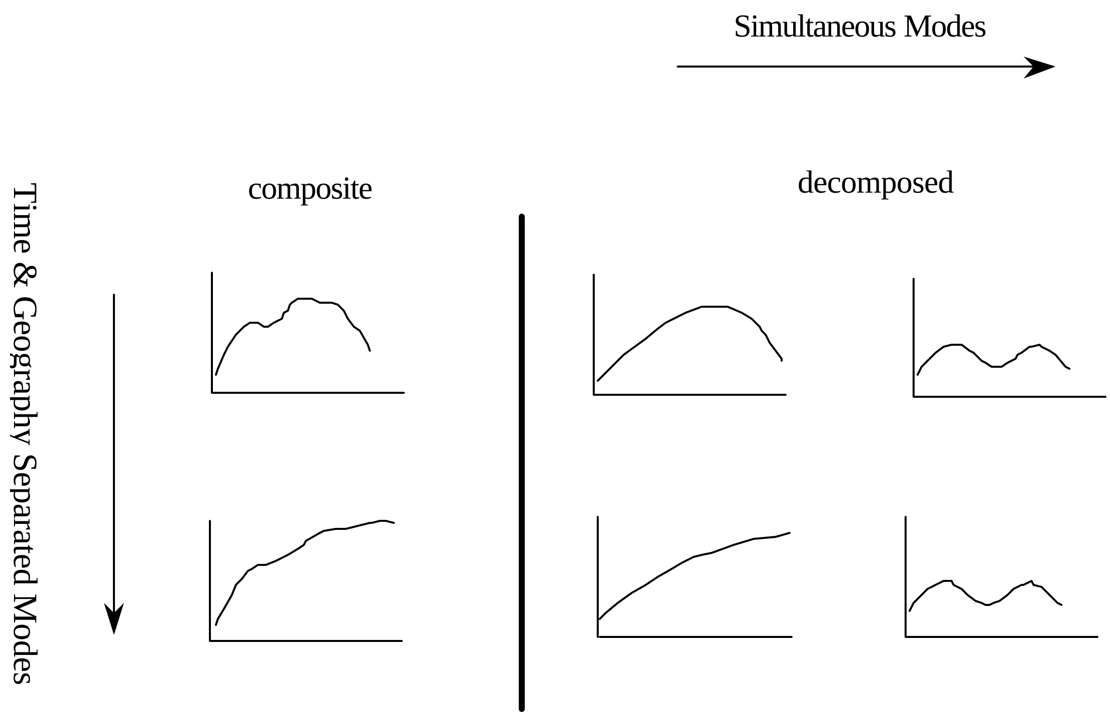

Figure 6 Decomposing multiple modes for slicing a complex problem
source: Saeed 1992

The problem slices concerning technology policy were described in section 5.2 and consist of four systems relating respectively to a) resource base and environment; b) management of production units; c) domestic macro-economic policy; and d) global economic relations. At the outset, these four systems and the variety of technological patterns they subsume must be carefully understood. It is, however, not possible in this brief paper to actually propose an alternative system for S&T policy design, which should rightly claim a more substantive effort. It is, however, possible to outline the frame work within which such an effort can be undertaken, which is attempted in the next section.

System dynamics as a methodological framework for designing S&T policy

The term *system* is used extensively in the context of both science and mathematics. In the context of science it implies natural and societal organisms which exist independently from how we view them. In mathematics, however, a system necessarily implies an abstraction visualized through perceptual and methodological filters. Although, it is impossible to see the natural and societal systems in their true natural form, the various methodologies following the principles of science attempt to define criteria to create a consensus on how natural systems should be viewed, albeit only in terms of transcendental models.

The transcendental models of systems are also divided into two classes. The first one, often termed concrete systems, concentrates on the common characteristics of natural and societal organisms, viewing them as living systems. The second focuses on specific functions or problems and is often referred to as abstract systems [Rappoport 1980]. The open system defined by Ludwig von Bertalanffy belongs to the former category [Bertalanffy 1968], whereas the closed system referred to by Jay W. Forrester belongs to the later [Forrester 1968]. Thus, a system dynamics model is an abstract system, conceptualized around a pattern of behavior and it may not represent any concrete system *per se*.

The classical system dynamics practice is aimed at arriving at a clear understanding of how information relationships in an abstract system create a problem behavior, so policies for system improvement may be conceived. The procedure followed in the classical system dynamics practice creates a cyclical learning process which calls for the development of a number of rather abstract concepts in a sequence requiring use of both cognitive and physical skills, which are not clearly defined. A widely recognized view of this process is illustrated in Figure 7.

Empirical evidence is the driving force both for delineating micro-structure of the model and verifying its macro-behavior, although the information concerning the macro-behavior may reside in the historical data and that concerning the micro-structure in the experience of the people. Thus, the modeling process draws on both historical and experiential data.

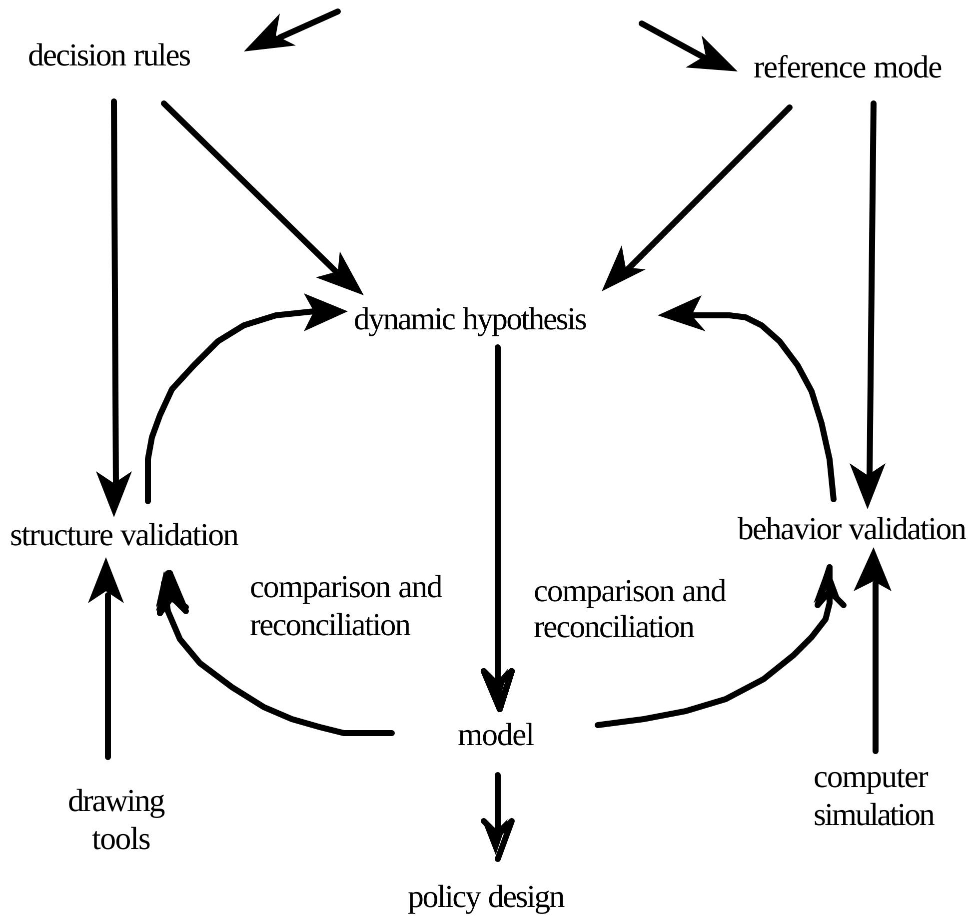

Figure 7 A widely recognized view of classical system dynamics practice

Source: Saeed 1997

The first requirement of the method is to organize historical information into what is known in the jargon as "reference mode." The reference mode leads to formulation of a "dynamic hypothesis" expressed in terms of the important feedback loops existing between the decision elements in the system that create the particular time variant patterns contained in the reference mode. The dynamic hypothesis must incorporate causal relations based on information about the decision rules used by the actors of the system, and not on correlation between variables observed in the historical data.

A formal model is then constructed using the given rules of information structure and incorporating the dynamic hypothesis along with the other essential detail of the system relating to the problem being addressed. The model structure must be "robust" to extreme conditions and be "identifiable" in the "real world" for it to have credibility, where real world consists both of theoretical expositions and experiential information. A model might undergo several iterations in a cyclical process to arrive at an acceptable structure, and this process creates a basic "understanding" of the information relationships in the system underlying the problem being addressed through an iterative learning mode it embodies.

Once a satisfactory correspondence between the model and the real world structure has been reached, the model is subjected to behavior tests. Computer simulation is used to deduce time paths of the variables of the model, which are reconciled with the reference mode. If a discrepancy is observed between the model behavior and the reference mode, the model structure is re-examined and modified if necessary, and this leads into to another cycle of behavior tests. This iterative process creates additional learning that further enhances "understanding" of the information relationships in the system and how they yield the problem behavior. In rare cases, such testing might also unearth missing detail concerning the reference mode, leading to a restatement of the reference mode, although for most cases, the reference mode delineated at the start of the modeling exercise must be held sacred.

When a close correspondence is simultaneously reached between the structure of the model and the theoretical and experiential information about the system, and also between the behavior of the model and the empirical evidence about the behavior of the system, the model is accepted as a valid representation of the system [Bell & Senge 1980, Forrester & Senge 1980, Richardson & Pugh 1981, Saeed 1992].

Since there exists large variability in the outcome of the modeling procedure described in Figure 7, in terms of the learning and new knowledge it creates, its accuracy in representing the actual process carried out by an experienced modeler is in question. It is instructive to look at a generic model of learning proposed by Kolb [1979, 1984] to identify the missing links in the prescribed procedure for system dynamics practice so it becomes possible to represent it more accurately.

While there exist many views of the experiential learning process, a model developed by David Kolb appears most relevant to the system dynamics modeling practice [Kolb 1984, Hunsacker and Alessandra 1980, Kolb, et. al. 1979, Kolb 1974]. Kolb perceives experiential learning in his model as a four stage cycle illustrated in Figure 8.

Kolb's learning cycle is driven by four basic faculties - watching, thinking, doing and feeling. For the learning process to be effective, watching must result in careful observation of facts, leading to discerning organized patterns. These patterns then must drive thinking, which should create a concrete experience of reality. The implications of the concrete experience must be tested through experimentation conducted mentally or with physical and mathematical apparatuses. Finally, this experimentation must be translated into abstract concepts and generalizations through a cognitive process driven at the outset by feeling, which would, in turn, create further organization for careful observation thus invoking another learning cycle.

The learning faculties, according to Kolb’s model, reside in two basic human functions, physical and cognitive, each integrated along two primary dimensions, which are also illustrated in Figure 8. The first dimension concerning the physical functions is passive – active. The second concerning the cognitive functions is concrete – abstract. Thus, the faculty of watching is a passive physical function, thinking a concrete cognitive function, doing an active physical function and feeling an abstract cognitive function. Since the mental construction of reality and its interpretation must filter unwanted information, each faculty must be guided by certain organizing principles to effect learning. Additionally, the learner is required to shift constantly between dissimilar abilities to create opportunities for refuting the anomalies which would appear among the constructs of each ability.

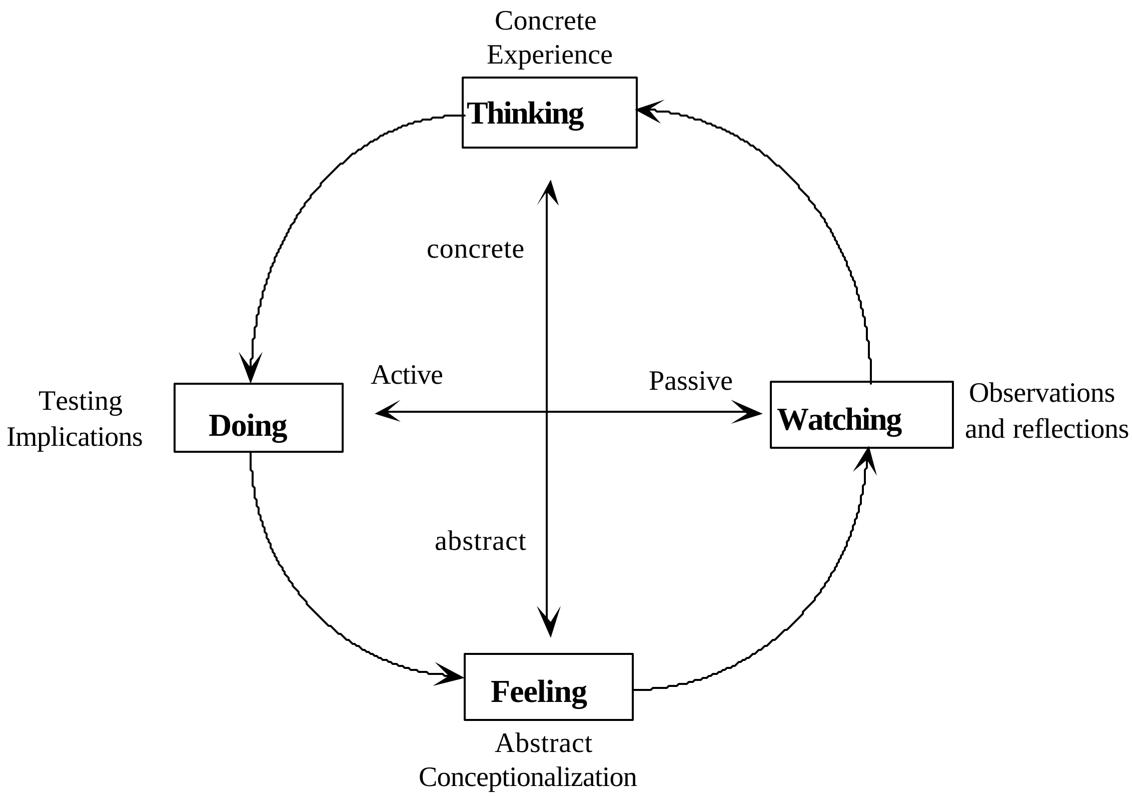

Figure 8 Kolb's model of experiential learning

Source: Saeed 1997

Even though the practice of system dynamics on the simplistic lines illustrated in Figure 7 may not appear to conform to Kolb's model of the learning cycle, it is known to have created learning and new knowledge, in cases when it has been carried out skillfully, by an experienced modeler. Clearly, Figure 7 does not fully describe the process actually implemented when learning is created through system dynamics practice. Evidently, the skillful modeler implicitly goes through the steps of a learning process which is not explicitly known. I have attempted to draw on Kolb's model of experiential learning to help me describe those implicit steps.

As stated earlier, all components of the cyclical process described in Figure 7 indeed fall in the category of conceptualizations lying in the abstract cognitive domain and moving directly from one to another will be unproductive from the standpoint of learning. To create any learning, moving from one abstract conceptualization to another must involve a learning cycle calling on all learning abilities as described in Kolb's model.

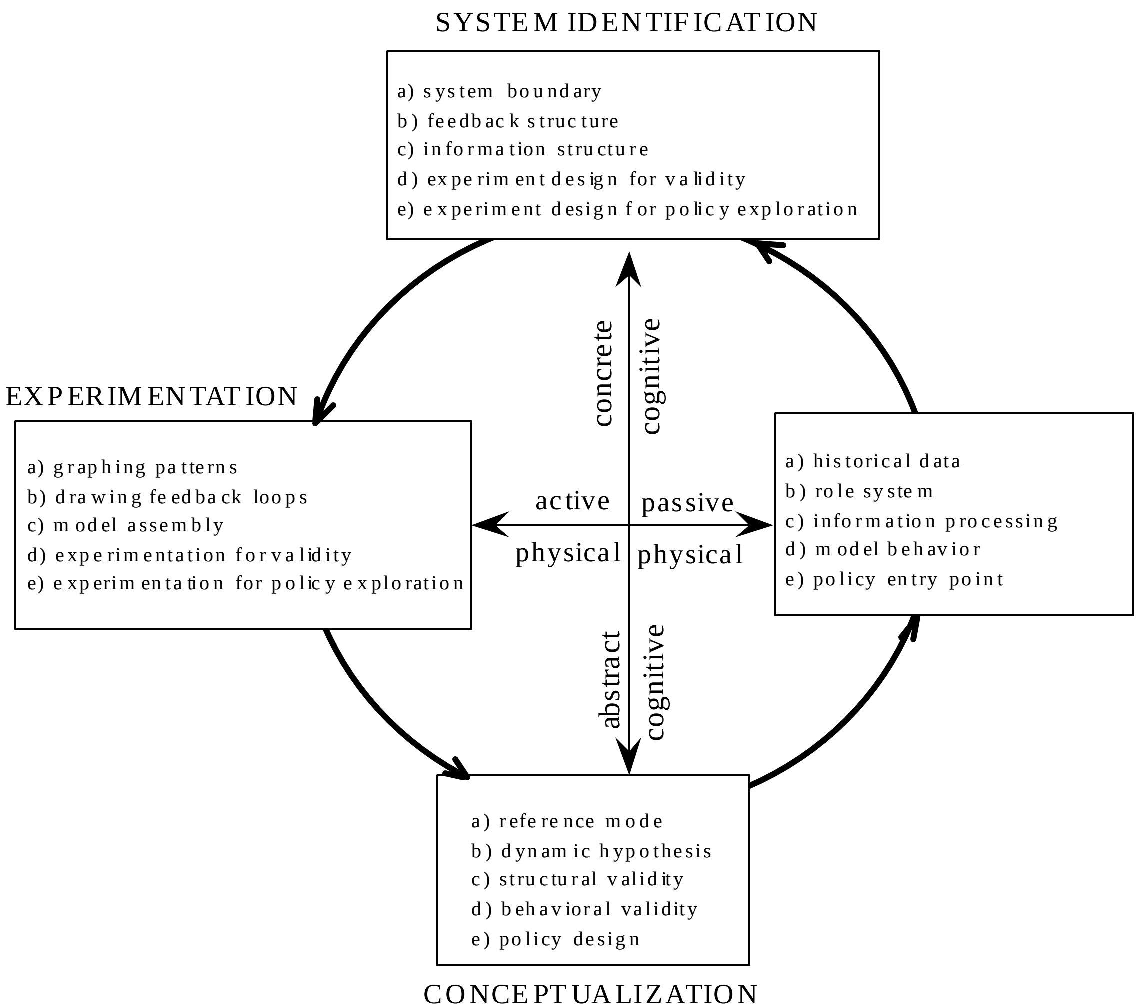

Figure 9 Learning cycles implicit in good system dynamics practice

Source: Saeed 1997

Thus, reference mode must be viewed as an abstract concept created by first drawing upon the observation ability in the passive physical domain to examine historical evidence, which at the outset becomes a basis for delineating system boundary when processed through drawing on the thinking ability in the concrete cognitive domain. An effort is made then to graph patterns to represent the reference mode, which is an experimental process in the active physical domain. Finally, reference mode is conceptualized as a mental picture of a fabric representing a multi-dimensional pattern in the abstract cognitive domain. The graphed time profiles drawn in two dimension space rather poorly describe the multidimensional mental image constituting reference mode - like the straight lines representing all two-dimensional objects in Abbot's flatland, whose real shape can only be imagined [Abbot 1987]. The graphs we create are nonetheless important for constructing a mental image of the multidimensional fabric the reference mode actually is.

The dynamic hypothesis represents an aggregate visceral appreciation of the system lying also clearly in the abstract cognitive domain. Its formulation originates, however, in the passive physical domain where role systems are carefully observed. This observation is followed by the delineation of the feedback structure in the concrete cognitive domain which creates the basis for drawing the feedback loops in the active physical domain. Conceptual images of how those feedback loops translate into an archetypal explanation of the reference mode constitutes the dynamic hypothesis.

The structural validity of the model formulated is, likewise, an abstract concept creating the confidence that the model structure indeed represents equivalent information processing norms in the real world. Its appreciation originates in the passive physical domain through recognition of the information processing patterns discerned through experience, and literature descriptions. The information processing patterns recognized lead to the formulation of the mental image of the information structure in the concrete cognitive domain. This image is translated through an experimental assembly process into an explicit model, which is carried out in the active physical domain and this provides the basis for the abstract concept of structural validity.

The behavioral validity of the model is also an abstract concept bridging the gulf between the system decision relationships and its behavior through use of deductive logic. It originates in the passive physical domain through recognition of patterns in the model behavior. This leads to the creation of the experiment designs in the concrete cognitive domain to test the sensitivity of the model behavior to various assumptions and to refute anomalies observed. The results of this experimentation deliver a visceral appreciation of the behavioral validity of the model, which resides in the abstract cognitive domain.

Finally, the conceptualization of system improvement is an abstract cognitive process, which likewise the processes described earlier, originates in the passive physical domain through the observation of possible entry points into the system. Experimentation to investigate these entry points is conceived in the concrete cognitive domain. Experimental exploration occurs in the active physical domain and the results of this exploration are translated into system improvement concepts in the abstract cognitive domain.

The modeling practice represented in Figure 9 involves five successive learning cycles described above. The shift from one cycle to the next occurs after the preceding cycle has yielded learning in its own niche. The shift actually takes place when moving from the abstract cognitive domain to the passive physical domain. The five cycles, thus, lie on a spiral converging into system improvement.

In performing above tasks over the conduct of the five learning cycles, the modelers draws upon both physical and cognitive functions as in the case of Kolb's generic model of learning. Also, the physical and cognitive tasks carried out in these cycles seem to appear alternately while they also lie at the opposite extremes of the continuums representing the physical and cognitive functions similar to Kolb's model of experiential learning. It is not surprising that system dynamics practice conducted in this way should create learning. Learning gets inhibited when above process is severely truncated from literally following the simplistic procedure for system dynamics modeling reported in the literature which seems to require moving between abstract concepts within the cognitive abstract domain of human functions.

Conclusion

Since the relationship between science and technology performance and the social-economic system is very complex, there is no theoretical agreement on what the S&T policies should be. In different geographic areas, and at different times, different patterns depicting S&T performance as well as certain social-economic factors are observed. Theories, based on such situational patterns, which can be quite diverse, have guided the formulation of S&T indicators. The conceptual models and the methodologies followed to construct S&T indicators are in general discretional and leaning towards dogmatism rather than science. There is often little relationship between an indicator, the policy it issues and the system the policy is expected to change. It is not surprising that S&T policy has often been associated with uncertain performance.

This paper has attempted to provide a conceptual and methodological framework to help the policy makers to understand the nature of the S&T indicators currently in use and their relevance to S&T development agenda. A theoretical framework is outlined for achieving a better understanding of the causal relationship existing between science and technology and other variables in the social-economic system in developing countries. This framework divides the S&T policy-related agenda in to four parts: a) resource base and environment; b) management of production units; c) domestic macro-economic policy; and d) global economic relations. More work should be done to identify the variety of temporal patterns in these domains and understanding their underlying decision relationships. These patterns can then be organized into categories leading to the archetypical relationships in the complex social-economic systems affected by S&T policy. These categories of patterns and their underlying archetypical relationships should perhaps substitute the discretional systems of indicators in place.

System dynamics method is posited both as a learning process and a policy design tool discern pattern, identify archetypical relationships underlying this patterns, and building apparatuses for experimental policy exploration. Following this methodology, the policy designers have to undergo several iterations in a cyclical process to get confidence on their understanding of the information relations in the system underlying the problem being addressed. With the simulation tool, policy makers can experiment with the suggested policies and identify pressure points for indirect intervention with a high degree of efficacy and a low potential for surprises. a concerted effort stretching over an extended period of time should be dedicated to this task.

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