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# What Future Contributions Can Or Offer to Improve the World Understanding of Global Problems

By

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# WHAT FUTURE CONTRIBUTIONS CAN OR OFFER TO IMPROVE THE WORLD UNDERSTANDING OF GLOBAL PROBLEMS

***Quelles sont les contributions futures que peuvent offrir les Recherches Opérationnelles (R.O.) pour bonifier la compréhension mondiale des problèmes globaux***

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**Abstract.** The process of studying global problems and building models to analyze them is an OR exercise. In this paper we conceptualize the OR approach to this type of problem and characterize some specific approaches which are available and are in operation. We also give the details of one of these approaches with which we have been directly involved. Based on the analysis of the difficulties the approach of global modelling faces, we anticipate the future contributions OR can offer towards the development of this approach and consequently to the understanding and solution of global problems.

**Résumé.** Le processus d'étudier des problèmes universels, et de construire des modèles pour les analyser, est une pratique des R.O. Nous concevons, dans cette étude, l'approche des R.O. pour ces modèles de problèmes, et nous caractérisons quelques approches spécifiques que sont dispenibles et que sont mises en vigueur. Nous donnons, aussi bien, les détails d'une de ces approches que nous nous en étions tout à fait occupée. Fondant sur l'analyse des difficultés que l'accès du modelage global confronte, nous prévoyons les contributions futures que les R.O. peuvent offrir au développement de cet accès, et par conséquent, à la compréhension des problèmes globaux et à leur solution.

## 1. Introduction

Over the last ten years or so, interest has risen in problems of a global nature. Problems like energy, raw materials and food shortage, population explosion, pollution and its effect on the environment, and low share of developing countries in the world's industrial output have been the subjects of interest of many international, regional and national organizations, development funds and governments. The issues considered include global policies of: efficient utilization of scarce raw materials, international division of labor for better utilization of resources (land, water, human, technology and raw materials), world policies for maintaining certain environmental standards... etc.

The awareness of these global problems began in the mid 1960's when people started wondering about the "Limits to Growth" for humanity and about the sufficiency of natural resources necessary for the continuation of human life. However, this has been happening only in limited circles until the study by Forrester and Meadows [1] came out, like an alarm, with its forecasts of serious problems facing and endangering humanity long before the end of the next century.

Since then, serious efforts started in order to investigate further the findings of the Forrester Meadows study and perhaps to investigate issues related to specific topics like energy, raw materials, and food shortage problems. By definition, these studies were of a long range nature as they were interested in the future when the resources of primary energy and of raw materials are exhausted, and also when the size of the world population becomes too large to be fed from the known sources of food. These efforts almost always materialized in some form of a model to study and analyze the situation concerned in the long run (long range).

In this paper we concentrate on these types of model. They are models intended for the analysis of a problem of a global nature. They also seek solutions of a global nature, i.e. solutions to be adopted (perhaps in different forms and to different degrees) by all (or some) nations of the globe. The models may alternatively be used to assess the impact of a group of national, or national and regional[1] policies on a certain problem of a regional or a global nature. Other uses of these models may include seeking optimum national policies which should be adopted in order to solve a problem or to stop a catastrophy from happening (even 50 years from now).

Several models, or studies to be more general, have appeared in the literature while others are still underway. In this paper, we conceptualize the OR approach to this type of problems, basing our analysis on most (but not all) of the studies that are existing. We then try to draw a general

[1] A region here refers to a region of the world, e.g. a continent.

consensus of the global modelling efforts and explain some of the serious difficulties which face them.

We believe that in as much as a good deal of OR work has been done in this field, but has seldom been documented under the OR umbrella, a good future exists for OR in this field. So we explain the most eminent areas in which OR techniques (currently available and to be developed) and practice are most needed. We also demonstrate that some of the basic tools of classical economics are not valid for this type of analysis and there is a need to develop new tools. This is another aspect in which OR could be of help.

## 2. OR approach to this type of problems

In this paper, we concentrate on global models of the Long Range Planning (LRP) type. We classify the OR approaches to these problems into two categories:

*Category 1: Approaches of a simulation nature*

In this category we find the Mesarovic–Pestel model [2] and the Leontief model [3]. In both studies, no attempt is made to optimize at any stage of the model.

*Category 2: Approaches of a hybrid nature*

Here we find the Bariloche model [4], the International Institute of Applied Systems Analysis (IIASA) energy strategies model [5], and the United Nations Industrial Development Organization (UNIDO) model [6]. These models are composed of modules (or sub-models, or components) of different natures. Some of these modules may be optimization models, others may be simulation models, while a third type includes models composed simply of a system of equations to be solved simultaneously.

In between the two categories, models vary in nature, structure complexity and solution effort. Also, models in the first category tend to be pushbotton models, while in the second category this is not usually the case.

In the following sections we explain briefly some of these models in an attempt to conceptualize the use of OR in this direction. Perhaps after going through these sections the reader will see clearly the similarities, although not intended in the first place, between the approaches in the same category. This will also lead us to a general consensus of the global modelling efforts and their future.

## 3. The Mesarovic–Pestel multi-level world models

As an outcome of a project launched by the Club of Rome, the Mesarovic–Pestel group developed global energy and global food models [2]. The models are aimed at developing policy analysis tools which help decision makers in assessing the results of some vital decisions related to to issues like:

(1) Planning for the production and transportation of foodstuffs necessary to guarantee at least the subsistence level for human beings in different parts of the world.

(2) Planning for efficient utilization of primary sources of energy with specific references to oil and to the studies of the conjoint price and production policies.

Here we concentrate on the efforts related to energy. The first generation of the energy model is available and was implemented in several parts of the world, e.g. Venezuela, West Germany, Iran and Egypt. The development of the second generation of models is currently in process.

In the model the world is divided into 10 regions: North America; Western Europe; Japan; Australia, South Africa, and the rest of market economy developed world; Eastern Europe including the USSR; Latin America; North Africa and the Middle East; Tropical Africa; South and South East Asia; and China. The time horizon of the model is 50 years from 1975–2025; past data used are based on the time period 1950–1965.

The energy model is of the discrete simulation type. It consists of three sub-models linked together: energy sub-model, economic sub-model, and population sub-model. The interlinkages betweek the energy sub-model and the two other sub-models are basically in the form of using the yearly estimate of Gross Regional Product (GRP) which is calculated in the economic sub-model, and the estimate of the total population (POP), which is calculated in the population sub-model, to estimate the yearly total energy demand by a functional relationship. The parameters of this functional relationship vary from one region to another.

Once the total energy demand is calculated, the proportion of oil demanded is calculated through the use of a curve which was developed by Linden and Parent [7] to calculate the anticipated percentage of oil based energy from total energy demanded [7]. The parameters of this curve also in general vary from region to region. As a result of this, one obtains the oil demanded for energy in each region of the world. From that point on the energy model becomes an oil model, i.e. it investigates only the issues related to oil as a primary source of energy and ignores the other sources of primary energy as well as the implications of oil policy in the use and development of other energy sources.

The oil sub-model consists of three parts: (a) oil demand, (b) oil production, (c) world oil trade. In the oil production part, the policies of oil production from oil fields or extraction from oil shale and tar sand together with the economies involved, are considered. Oil conservation policies and/or embargo policies also affect the rate of oil production and were left as exogenous policy parameters in the model. These policies can vary from region to region.

As a result of the oil quantities produced in each region and by comparison with the quantity of oil demanded in that region, we can decide whether it is an oil deficit or an oil surplus region. This information is fed into the world oil trade sub-model and either of the following situations appears:

(1) Oil production falls short of the actual demand: in this case the quantities received by various regions are reduced by quantities proportional to the quantities demanded, related to the total demand.

(2) Oil produced (or planned to be produced) is more than what is demanded. In this case the quantities produced by various regions are cut down by quantities proportional to the region's production related to the total production.

(3) Oil demanded equals oil produced (or planned to be produced), so there is no problem of adjustment in this case.

As a result of oil sales, at a predetermined oil price which is exogenously fed into the model, money is paid to the selling region either in the form of capital goods, consumption goods or credit in banks. It is possible that the oil producing region recycles the oil dollars back to the oil consuming regions in several forms of investment in these regions. Alternatively this money could be used for investment within the oil producing region itself for the purposes of economic and social development. The effects of raising oil price on the substitution of oil by other sources of energy and the cost of developing and implementing new energy sources are not considered in the first generation of the energy model. However the model caters for oil demand reduction with the increase in oil prices as well as the oil supply increase with price increase. These two effects are described by two exogenously determined factors and are fed into the model. The same applies for the oil conservation policies which are expressed in the model as a percentage of the annual demand. It is known that if the oil producing countries raise the price of oil, the oil consuming countries are likely to retaliate. One form of this retaliation could be by raising the cost of investment goods supplied by them to the oil producing countries, especially if the latter were in the developing stage. The model also takes care of this, but requires that this retaliation measure is determined exogenously, and that it should be expressed as a percentage of the prices of investment goods.

The inputs to the model are of two types: data base information and scenario information. Data base information include the non-policy data, various parameters, coefficients of various functional relationships, ... etc. Scenario input includes the policy and decision parameters, e.g. oil demand reduction with price increase, oil supply increase with price increase, annual increase in oil prices, relationships between oil prices and investment goods cost, desired economic growth rate, degree of oil dollar recycling efficiency, ... etc. There are two ways of feeding the values of the scenario input into the model: a qualitative way and a quantitative way. When the inputs are fed in the latter way, actual values are specified but when they are fed in the former way verbal descriptions are given (e.g. high, medium, or low). The input package translates, however, these qualitative descriptions into quantitative values to be used by the model.

As a result of running the model, considerable statistics are gathered. These summarize values of several economic, population as well as energy indicators. Amongst these statistics are the following:

(1) World oil deficiency and surplus,
(2) Gross regional product for various regions,
(3) Oil dollars accumulated.

## 4. The Bariloche world model

This model was built by the Bariloche Foundation in Argentina [4]. It was intended for further investigation of the third world countries future in response to the forecasts of doom which had appeared in the results of earlier world models such as the Limits to Growth by Forrester and

Meadows [1]. The idea of the model is to find out how to allocate, optimally, the capital and labor among the production sectors of the society so as to maximize the value of a humanitarian, rather than economic, indicator. This indicator was chosen to be life expectancy at birth. The philosophy behind this was that the prime objective of a society is to provide the individual with a good human life. This is accomplished through the satisfaction of some socially recognized basic human needs. Undoubtedly this is reflected on the life expectancy of the individual. Thus, according to this philosophy, it is logical to take the maximization of life expectancy at birth as an objective.

It should be borne in mind that the production sectors of the society depend primarily on some natural resources contained in the crust of the earth and in the sea bed. The production process results in some pollutants which are feared to destroy the quality of the environment. One of the objectives of the study was to investigate the scarcity of the resources and see how soon they will be exhausted (and thus endanger the continuation of human life); also to study the harmful effects of pollutants and how to reduce such effects or reduce the harm.

The model concentrates on the satisfaction of human needs in terms of: nutrition level, housing, and education as being the major objective of the production system of a society. The model also includes two major demographic parameters expressing the level of fertility and mortality, i.e. the crude birth rate and life expectancy at birth. These two parameters are expressed in the form of two coupled nonlinear functions of indicators of basic needs and other socioeconomic variables as follows:

(a) life expectancy at birth is expressed as a function of: the enrolment ratio in the first two stages of education, the crude birth rate, and the proportion of population engaged in agriculture.

(b) The crude birth rate is expressed as a function of: calorie consumption per capita, the enrolment ratio in the first two stages of education, life expectancy, adequate housing per family, and the proportion of population in the secondary economic sector.

The forms of these two functions were fitted from cross-sectional international data around 1970.

The model represents a production system consisting of five sectors: food production, housing services, education, other consumer goods and services, and capital goods. The first three sectors produce the goods for the satisfaction of basic needs (nutrition levels, houses and places in schools), the fourth sector produces goods and services which are over and above the basic needs level. The fifth sector provides for building up for future production.

Cobb–Douglas production functions are used for the five sectors under the following assumptions: constant returns to scale, substitution of labor and capital, and allowing the introduction of technological progress.

The optimization part of the model is of the multi-time period (but not dynamic) nonlinear programming type whose objective is to allocate capital and labor among the 5 production sectors so as to maximize life expectancy at birth during each year of the planning horizon.

The model has a complicated hierarchy of constraints, expressing:

• socio-economic limits that must be observed, e.g. capital and labor allocations to any production sector cannot change drastically from one year to the next.

• Characteristics of the proposed society or the policies required to bring it about, e.g. the satisfaction of basic needs is not allowed to decrease over time and the rate of economic growth of the developed countries is supposed to be within a certain limit.

• Limitations of available resources.

Elements of the set of constraints are given priorities according to a system of weights such that if some constraints had to be violated by the optimization scheme those having the smallest weights are sacrificed first.

The mechanism of the model is as follows: calculations for year $t$ start by the figures for capital and labor obtained as a result of the calculations for the year $t - 1$, capital and labor are then optimally allocated among the five sectors by the use of the optimization (NLP) part of the model. When sectoral capital and labor are known, they are fed to the corresponding production functions. As a result, GNP and physical production are known for each sector. Values of the levels of basic needs and other indicators are thus calculated and fed, as appropriate, to a component which calculates population and labor for year $t + 1$. On the other hand excess (or deficit) production is entered to an international trade component to redistribute it (or satisfy it) as appropriate, make the necessary adjustments of capital accumulated to be used for year $(t + 1)$. At this point, calculations for year $t + 1$ start. Fig. 1 shows a flow diagram for the model.

For this study the world was divided into four regions: developed countries, Latin America, Africa, and Asia.

The results of the model demonstrate how better qualities of life can be obtained for inhabitants of developing countries. It is also concluded that there is no foreseeable fear from the exhaustion of natural resources or from

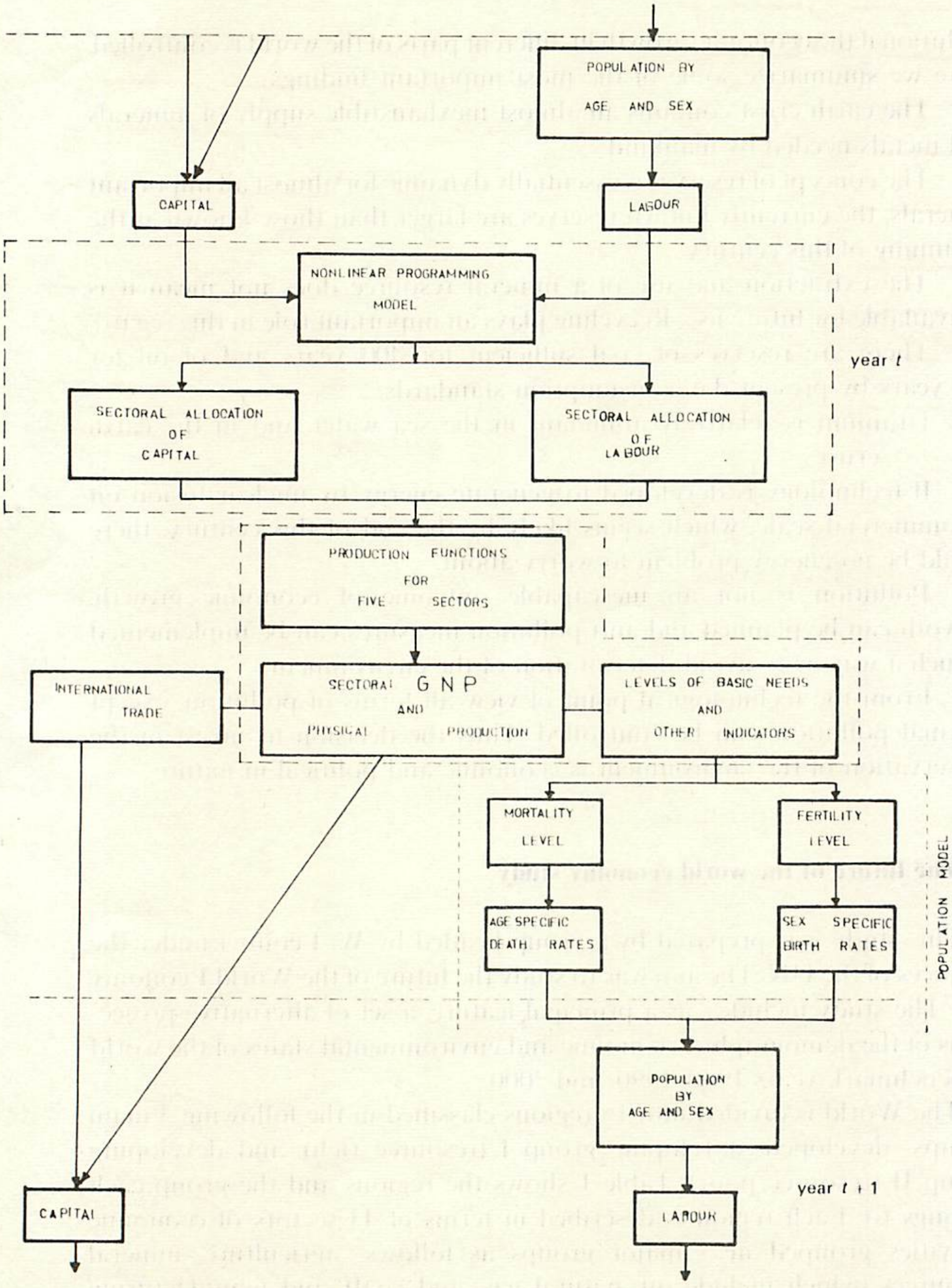


Fig. 1. Flow diagram of the Bariloche model.

pollution if the economic growth in different parts of the world is controlled. Here we summarize some of the most important findings:

The earth crust contains an almost inexhaustible supply of minerals and metals needed by mankind.

The concept of reserves is essentially dynamic for almost all important minerals, the currently known reserves are larger than those known at the beginning of this century.

The extraction and use of a mineral resource does not mean it is unavailable for future use. Recycling plays an important role in this regard.

There are reserves of coal sufficient for 400 years and of oil for 100 years by present day consumption standards.

Uranium is relatively abundant in the sea water and in the earth crust.

If technology is developed to generate energy by nuclear fusion on a commercial scale, which seems likely by the end of this century, there would be no energy problem to worry about.

Pollution is not an inescapable outcome of economic growth. Grwoth can be planned and anti pollution measures can be implemented in such a way as to avoid deterioration of the environment.

From the technological point of view all forms of pollution, except thermal pollution, can be controlled. Thus the decision to invest in the preservation of the environment is economic and political in nature.

## 5. The future of the world economy study

This study was prepared by a group headed by W. Leontief under the auspices of the UN. The aim was to study the future of the World Economy [3]. The study includes, as a principal feature, a set of alternative projections of the demographic, economic and environmental states of the world in benchmark years 1980, 1990, and 2000.

The World is divided into 15 regions classified in the following 3 main groups: developed, developing group I (resource rich), and developing group II (resource poor). Table 1 shows the regions and the group each belongs to. Each region is described in terms of 43 sectors of economic activities grouped in 3 major groups as follows: agriculture, mineral resources (which include oil, natural gas, and coal), and manufacturing activities. The model brings the regions of the world together through a complex linkage mechanism including exports and imports of some 40 classes of goods and services, capital flows, aid transfers, and foreign

Table 1
Regional grouping for Leontief's study

| Group | Region |
|---|---|
| I. Developed | North America |
| | Western Europe (high-income) |
| | Soviet Union |
| | Eastern Europe |
| | Western Europe (medium-income) |
| | Japan |
| | Oceania |
| | Africa (medium-income) |
| II. Developing group I (resource rich) | Latin America (low-income) |
| | Middle East |
| | Africa (tropical) |
| III. Developing group II (resource poor) | Africa (arid) |
| | Asia (low-income) |
| | Asia (centrally planned) |
| | Latin America (medium-income) |

interest payments. The model describes emissions of 8 types of major pollutants and 5 types of pollution abatement activities. The principal environmental policies considered are those concerning pollution, constraints on the extraction of mineral resources and constraints on food production. Based on results of model computations the study investigates, in a very broad framework, issues related to: food and agriculture, mineral resources (including oil, natural gas, coal), pollution and pollution abatement, structural changes in the economies, balance of payments and changes in international economic relations.

The model used for the study is a simulation model composed of input output (I O) models of various regions linked together. As a result, 15 regional sets are obtained each consisting of 175 equations, which are mostly but not exclusively linear, and 269 variables. 229 variables are region specific and 40 are export import variables. When the system is solved, 94 variables for each region are specified *a priori*, e.g.:

(1) Target variables: these are the variables which describe the future state of the economic system (such as: levels of per capita GDP, private and public per capita consumption and their respective rates of growth).

(2) A certain combination of some causal instrumental factors (such as: domestic savings, external balance, labour force participation, price of raw materials and so on).

This is done in such a way that the result is a number of linear equations in the same number of variables and the system can be solved.

The following remarks about the model structure are now in order:

(1) The economies of individual regions are linked with each other through flows of internationally, or rather interregionally traded goods.

(2) The consumption of internationally traded goods has to be balanced only for the world as a whole. The worldwide model system must contain a set of equations stating this in algebraic terms.

(3) The domestic output and the global input, or rather its separate regional components, are the variables that enter into the determination of the internal I/O balances of the trading regions.

(4) With sets of appropriate trade coefficients incorporated in the system of equations, any projected change in regional inputs and outputs of internationally traded goods will thus be accompanied by appropriate shifts in each region's pattern of exports and imports.

(5) The formulation does not involve any analysis of bilateral trade flows.

(6) The introduction of prices and income variables leads to the important question of the total value of the exported and imported goods and the problem of capital flows and of other types of international transfers.

(7) Outputs are treated as physical quantities only, export and import totals as well as trade balances are computed in current prices.

Several Scenarios were tested with the model. Scenarios are hypothetical pictures of the world economy at benchmark years 1980, 1990 and 2000. Scenarios embody assumptions about rates of growth of population and of gross product per capita. The basic issue investigated was the correction of the existing economic inequalities between the countries, and consequently the regions of the world; also the investigation of the conditions necessary for narrowing and eventually eliminating the income gap between developed and developing countries [3, p. 30]. It was found out as a result of the study that the gap in per capita gross product between the developed and the developing countries (which amounted to 12 to 1 on the average in 1970) is not likely to start diminishing by 2000 even if the growth rates in the developed countries were retained at their values observed during the last two decades while those of the developing countries were increased annually by about 3.5%. Thus in the basic scenarios used, growth rates of gross product per capita were set in such a way as to roughly halve the income gap between the developing and the developed countries by 2000, with a view towards closing it completely by the middle of next century. It was found out that the income gap is hardly reduced at all if the developing countries do not make provisions for (a) substantial increases in internal or external investment rates, (b) major increases in export shares and import substitution. This major finding helped in clarifying how the world can realize the aims stated in the Declaration on the Establishment of the New International Economic Order.

It should be mentioned that the model also permits the use of data specific to individual industries in particular regions and consequently results in conclusions of relatively specific policy significance.

## 6. The IIASA energy model

This model is currently being developed by the energy group headed by Häfele at IIASA [5]. The model is a world model aimed at studying the strategies for energy transition and their impact on economies. This work is a culmination of many efforts aimed at studying the technical and economic feasibility of transition from fossil energy to nuclear, solar, and other sources of non-fossil energy.

The main philosophy behind this model is to develop a tool which assesses the impact of developing new energy generation sources on the economy and the environment. It is obvious that the development of an easy, safe and cheap source of nuclear or solar energy needs substantial financial resources for research. When and if such a source exists there is the need to manufacture it (an additional requirement on manufacturing industries) and also there is a need to modify the energy consuming machinery to accept this new form of energy. Obviously this requires financial resources as well as changes in technology; additional investments are necessary to sustain this and the economy may or may not be able to meet these requirements. These changes and/or additions may need some time to be implemented and there is a need to couple this with a model of the economy which takes into consideration the time factor. The resulting pollution from extensive use of new energy sources (e.g. nuclear parks containing fast breeder reactors), and their impact on the environment should be carefully assessed. The IIASA model is composed of several sub-models which are aimed at investigating some, if not all, of these issues.

There are six world regions in the IIASA model. In this context, however, a world region refers not so much to a geographic region as to operational similarities. The six regions are [5]:

(1) A region with a highly developed market economy and energy resources,

(2) A region with a highly developed market economy and without energy resources,

(3) A region with a highly developed centrally planned economy and energy resources,

(4) A region whose economy is developing and which has large energy resources,

(5) A region whose economy is only developing and which has some energy resources, and significant population growth,

(6) A region whose economy is only slowly developing and which has no energy resources but significant population growth.

Each regional module is composed of the following five models interlinked together as shown in Fig. 2: energy supply model, energy demand (end use) model, a macroeconomic model, a resource model, and a model to identify the requirements (from investment, labor, and land) for the optimal energy strategies identified by the supply model.

The macroeconomic model is an econometric model based on production and demand functions in aggregated forms. The model is built up in such a way as to incorporate a number of macroeconomic ratios (such as investment and consumption rates) which are expected to evolve slowly in the foreseeable decades in contrast to the fast changing variables (such as GNP, consumption, taxes, prices).

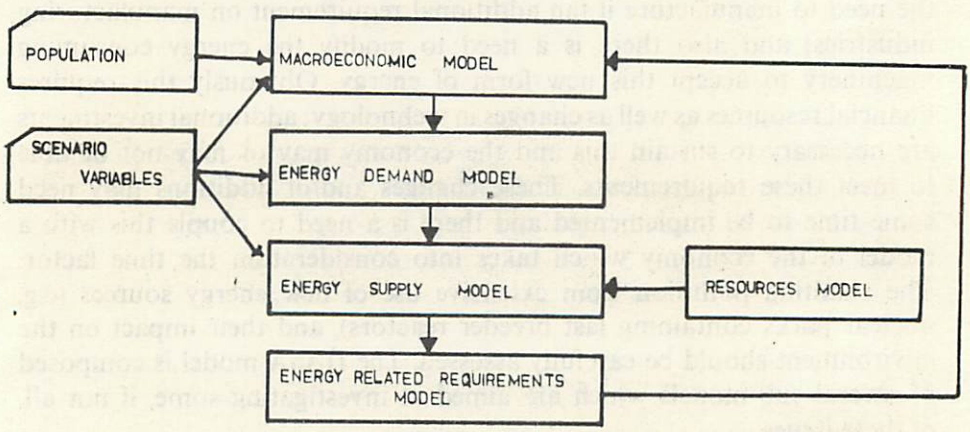


Fig. 2. Interlinkages between the models of a regional module.

The energy demand model distinguishes the demand for energy in five fundamental sectors, namely: industry, agriculture, services, transportation and household. It is composed of four sub-models: one for each sector with the exception of transportation and household where they are both represented in one sub-model. The sub-models are composed of demand functions where the independent variables are economic indicators of the sector concerned, e.g. the agricultural demand for energy is derived from the value added for agriculture in the case of developed countries and is derived from the level of irrigation and the number of tractors for the developing countries.

The energy supply model is a dynamic linear programming model which considers a number of primary energy sources and their associated conversion technologies; included also are resources and technologies which could permit an essentially unlimited supply of energy. The model optimizes the mix of energy supply technologies throughout a planning horizon of 70 years, and specifies the conjoint time phasing for the utilization of primary energy resources. The objective function is the sum of primary energy costs, costs of production and costs of investment over the planning horizon discounted as appropriate. The constraints include: resource constraints, capacity constraints, market penetration constraints, environmental constraints, and capital constraints.

The resources model is based on a simple computer program which incorporates tables of data on minimum and maximum availabilities with the corresponding minimum and maximum costs of the various resources. A more sophisticated model is being worked on currently at IIASA. This model is an optimization model which optimizes the cost of primary energy resources by allocating funds to activities of investigation, exploration, and research and development.

The requirements model investigates the direct and indirect requirements (from investments, land, and labor) resulting from the optimal energy strategy arrived at by the supply model. This is done by identifying input–output relations between sectors of the economy that are related for the energy supply system. A system of nonlinear equations results and is solved by an iterative procedure.

The investment requirements resulting from the requirements model must be consistent with those of the macroeconomic model. This is not necessarily true for all cases and, thus, an iteration of the whole procedure is required. As the convergence of this iterative procedure is not necessarily mathematically guaranteed, manual intervention should be introduced to check the output of each model, do the necessary changes in parameters and assumptions before proceeding to the next model and the loop continues until some reasonable results are obtained. Obviously the exercise here is not a pushbutton one but rather a learning exercise where the user gets more insight into the complex interactions between the components of the energy system. As a result, he takes into account new criteria and information, thus changes parameters and/or assumptions and continues.

The model is designed in a modular form. Each region has its own module with all interactions with other regions taken as exogenous variables. The modules for regions 1, 2, 5 and 6 have been completed with USA, West Germany, Egypt, and India as representative states. Modules for other regions are currently being built.

## 7. The UNIDO world industry cooperation model

This model is currently being built at UNIDO. A prime aim of this model is to investigate the industrialization, and related, strategies of the countries of the world on a long range basis [6]. For the developing countries, the model helps the user in understanding how the Lima target could be achieved [8], and if it could not be achieved what are the obstacles and/or bottlenecks. According to this target, at least 25% of the World industrial output by the year 2000 has to be contributed by developing countries. The model shows also the effect of achieving the Lima target on the economic growth of the developed countries, on the World trade policies, on the global and regional policies of movements of factors of production (e.g. capital, labor, technology, and raw materials) and primary sources of energy. The model tries to answer questions related to growth and skeletal changes of countries economies required to achieve the international consistency which is a prerequisite for any solution, of a global problem, to be realistic.

The model is composed of two layers: an inner layer and an outer layer as shown in Fig. 3, 4, and 5. The inner layer contains all the tools, in the form of models, necessary to either check the international consistency of national decisions, and plans, taken by individual national authorities or to take decisions on the international level, in such a way as to maintain some crucial physical balances. The outer layer feeds the inner layer with the national decisions, national data to be used as guides, elements of preference functions, elements of some constraints, and elements of scenarios for regional and international cooperation.

The direction of operation within the inner layer is sequential in a

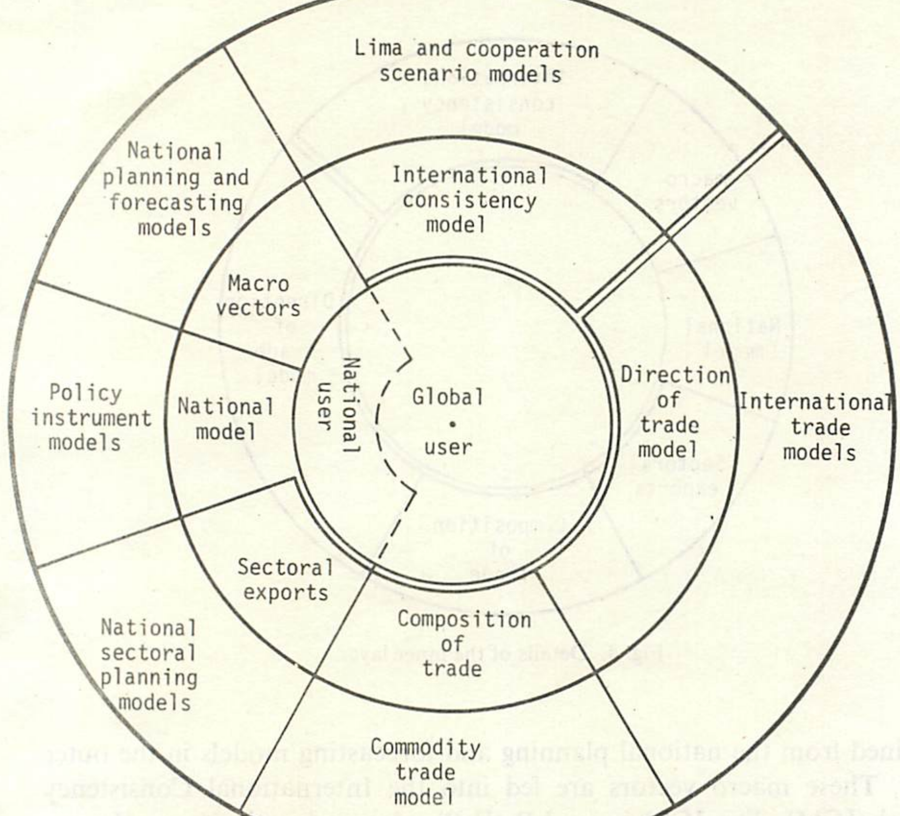


Fig. 3. Composition of UNIDO's world model.

clockwise direction. There is no sequential nature of operations in the outer layer as the elements in it are meant to feed data to the corresponding elements in the inner layer, thus the direction of operation is, in this case, radial and each element in the outer layer does not necessarily have relations with the adjacent ones in this layer.

The UNIDO model served as a starting framework for building a model for the study of the industrialization strategies for the arab states by 1985 and 2000. This latter model will be elaborately discussed later on in the paper. Thus, it may suffice here to discuss briefly the general functions of the elements in the two layers of the UNIDO model.

The operation of the inner layer can be triggered by the macro vectors

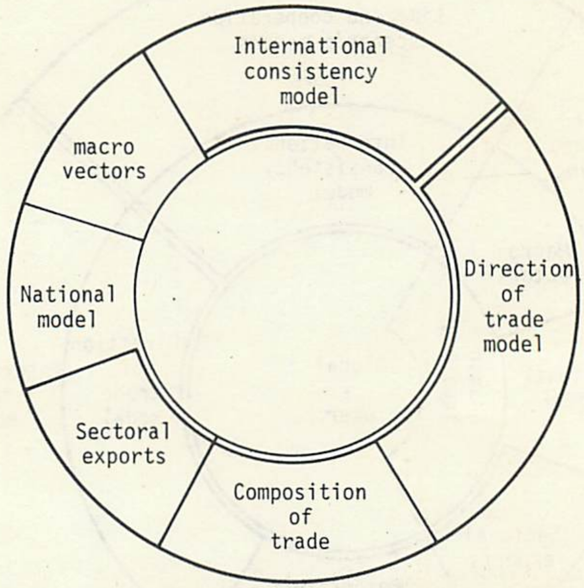


Fig. 4. Details of the inner layer.

obtained from the national planning and forecasting models in the outer layer. These macro vectors are fed into the International Consistency Model (ICM). The ICM is an LP (ILP) whose objective is to choose, for each country, a convex combination of these plans (only one plan) which is consistent with the ones chosen for other countries. The coefficients in the o.f. and the r.h.s.'s of the ICM are obtained from Lima and international co-operation scenario models, while the coefficients in the constraints are supplied by the national plans.

As an output of the ICM, we obtain, amongst other things, the total export and the total import activities of each country. These are fed into the Direction of Trade Model (DTM). The DTM breaks the total export and total import activities for the various countries into bilateral flows. The DTM turns out to be an LP with transportation-type constraints and the coefficients in the o.f. are supplied by the international trade models (and scenarios in the outer layer).

Once the bilateral flows are known, they are broken down into commodity flows by the Composition of Trade Model (CTM) which is the next block of the inner layer. The CTM performs the break-down guided by coefficients supplied by the commodity trade model (and scenarios) in the outer layer.

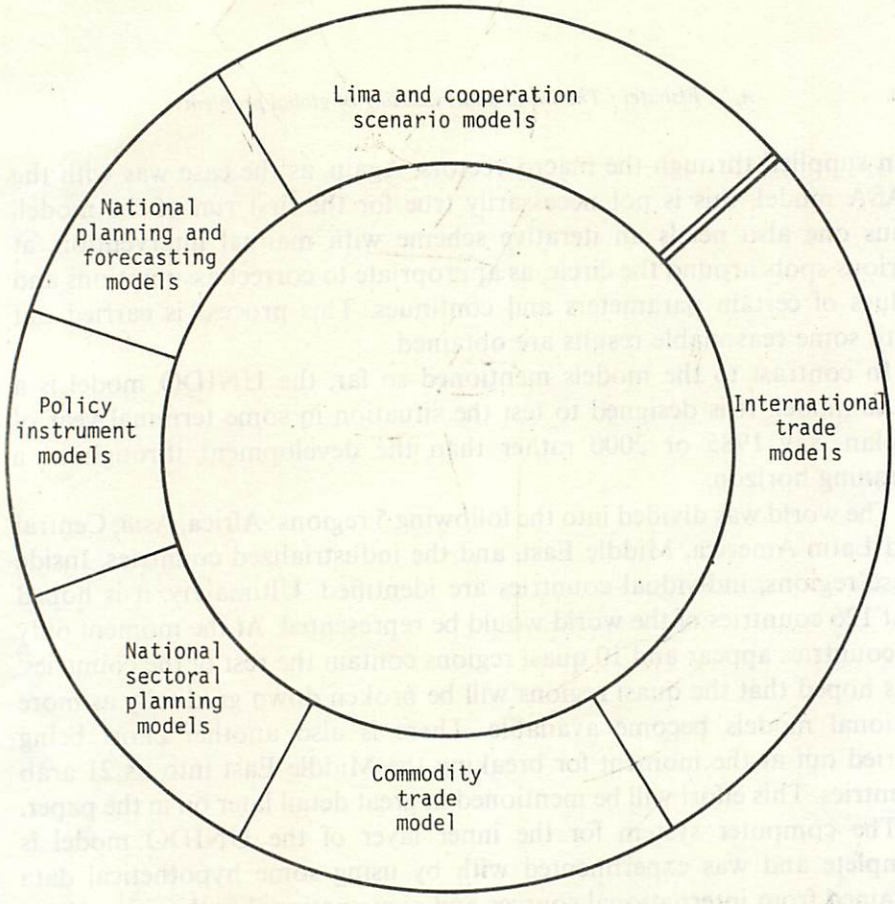


Fig. 5. Details of the outer layer.

When the commodity exports and the commodity imports are known for each country, then the sectoral exports and the sectoral imports could be calculated via a simple model which takes into consideration the sectoral structure of the country economy as fed by a national planning model in the outer layer. Given the sectoral exports and imports, together with the national demand, a national model (based on the input–output technique) is used to calculate the levels of output required by each sector of the economy. The input–output structure is given as data and also given are various policy instruments required to drive this model. These data are supplied by national policy instrument models which are in the outer layer.

The output of the national model should be consistent with the information supplied through the macro vectors. Again, as the case was with the IIASA model, this is not necessarily true for the first run of the model. Thus one also needs an iterative scheme with manual intervention, at various spots around the circle, as appropriate to correct assumptions and values of certain parameters and continues. This process is carried out until some reasonable results are obtained.

In contrast to the models mentioned so far, the UNIDO model is a static model. It is designed to test the situation in some terminal year of a plan, say 1985 or 2000 rather than the development throughout a planning horizon.

The world was divided into the following 5 regions: Africa, Asia, Central and Latin America, Middle East, and the industrialized countries. Inside these regions, individual countries are identified. Ultimately, it is hoped that 126 countries of the world would be represented. At the moment only 12 countries appear and 10 quasi regions contain the rest of the countries. It is hoped that the quasi regions will be broken down gradually as more national models become available. There is also another effort being carried out at the moment for breaking the Middle East into its 21 arab countries. This effort will be mentioned in great detail later on in the paper.

The computer system for the inner layer of the UNIDO model is complete and was experimented with by using some hypothetical data obtained from international sources and some national authorities. However, the model will gain its potential as more national and regional authorities become interested in the exercise and so they supply models and scenarios for the outer layer and benefit from the results of the inner layer. Amongst the first of these authorities is the Industrial Development Centre for the Arab States (IDCAS) who comissioned the Institute of National Planning (INP) in Cairo to develop, in collaboration with the UNIDO, an "Arab Version" of this model.

## 8. The Arab regional industrialization strategies model

The fourth conference on Industrial Development of the Arab States was held in Baghdad during December 1976. As a result of the discussions during the conference, the delegates realized the importance of conducting a study to prepare a long range arab strategy for industrial development by 1985 and 2000. The study should conclude by arriving at a group of comprehensive and complete plans for the industrialization of all the arab countries. The strategy for industrial development should take into consideration the national plans and the development of other sectors of the economies of the arab countries involved in the study [9]. The study should be complete by the end of 1978 and to be tabled for consideration by the arab ministers of industry during their metting in Algiera in May 1979. IDCAS was delegated the task of conducting the study. IDCAS commissioned the INP to help in this study.

It was soon realized that the need exists for a detailed model, of the arab countries, to be used in preparing the plans refered to above. Needless to say, it is impossible to plan for the development of the arab countries in isolation from the outside world. Thus what needed is a global model, suited for investigating the industrialization and related, strategies. IDCAS and INP decided to take the UNIDO model as a starting point and do the necessary elaborations and changes necessary to render the model suitable for the study concerned.

The general structure of the UNIDO model (which was described before) remains more or less the same. The models of the inner layer were, sometimes, changed as appropriate. In the sequel, we give the details of these models as included in the arab model.

### *8.1. The international consistency model*

The model uses as a part of its input the national macro vectors produced by running national macroeconomic models in the outer layer. For such a national macroeconomic model we start by specifying structural policy variables (i.e. savings ratio, imports to various sectors of the economy, and investment allocation ratios). Then by solving the model we get values of the macro national indicators (e.g. GDP, investment, manufacturing activities, exports, imports, and foreign transfers). Several macro vectors could be generated by varying the structural policy variables in a manner reflecting alternative national plans. Thus, each macro vector contains the values of the macro indicators obtained from the national macroeconomic model as a result of a set of structural policy variables. Naturally, these indicators are nationally consistent[2] but they are not necessarily internationally consistent.

The ICM puts together the sets of vectors of the nationally consistent macro variables for all countries. Then it chooses, for each country, a convex combination of these vectors or a single vector if the user specifies

[2] Actually, in the inner layer model no attempt is made to check the national consistency of the items in macro vectors. This check is assumed to be provided in the outer layer.

this. The target is to choose the vectors which are internationally consistent and if more than one group exists, then the one which maximizes an objective function is used. This is done by solving a linear programme (LP) or an Integer Linear programme (ILP). As a result, we get an optimum vector of national macroaggregate indicators.

We explain the structure of the ICM as follows:

Assume there are $n$ countries ($i = 1, \ldots, n$) and each country has $k_i$ plan alternatives. A plan alternative consists of 11 macroaggregates. Then the $j$th plan alternative of country $i$ can be expressed as a vector of 11 elements as follows:

$$p_{ij} = [p_{ij}^{(1)}, p_{ij}^{(2)}, p_{ij}^{(3)}, \ldots, p_{ij}^{11}].$$

The eleven elements are defined as follows (for simplicity we refer to $p_{ij}^{(v)}$ as $p^{(v)}$):

$p^{(1)}$ = Gross Domestic Product.
$p^{(2)}$ = Manufacturing Activities (value added).
$p^{(3)}$ = Merchandize Exports (F.O.B.) excluding services.
$p^{(4)}$ = Merchandize Imports (F.O.B.) excluding services.
$p^{(5)}$ = Service Exports.
$p^{(6)}$ = Service Imports.
$p^{(7)}$ = Total Consumption.
$p^{(8)}$ = Domestic Savings.
$p^{(9)}$ = Gross Fixed Capital Formation.
$p^{(10)}$ = Deficit on Current Account.
$p^{(11)}$ = Labor Force.

The structure of the ICM is as follows:

*8.1.1. Constraints*

The aim of the ICM is to find the weight $w_{ij}$ attached to the $k_i$ vectors for country $i$ such that

$$\sum_{j=1}^{k_i} w_{ij} = 1$$

and in a manner which fulfills the following global and regional constraints:

(a) *Global Constraints.* (i) Lower bound on World total GDP constraint:

$$\sum_{i=1}^{n} \sum_{j=1}^{k_i} p_{ij}^{(1)} w_{ij} \geqslant WP_0$$

where $WP_0$ is the desired lower bound on World Total GDP.

(ii) Industrial production of the developing countries has to be $\geqslant \alpha\%$

of the world total industrial production

$$\sum_{i\in\mathcal{J}}^{n}\sum_{j=1}^{k_i} p_{ij}^{(2)}w_{ij} \geq \frac{\alpha}{100}\left(\sum_{i=1}^{n}\sum_{j=1}^{k_i} p_{ij}^{(2)}w_{ij}\right),$$

where $\mathcal{J}$ is the set of developing countries

(iii) World export/import situation.

World total exports have to be $\geq$ world total imports

$$\sum_{i=1}^{n}\sum_{j=1}^{k_i} p_{ij}^{(3)}w_{ij} \geq \sum_{i=1}^{n}\sum_{j=1}^{k_i} p_{ij}^{(4)}w_{ij}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{k_i} p_{ij}^{(5)}w_{ij} \geq \sum_{i=1}^{n}\sum_{j=1}^{k_i} p_{ij}^{(6)}w_{ij}.$$

Any surplus of world total exports over world total imports[3] should be $\leq \gamma\%$ of the world total imports:

$$\sum_{i=1}^{n}\sum_{j=1}^{k_i} p_{ij}^{(3)}w_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{k_i} p_{ij}^{(4)}w_{ij} \leq \frac{\gamma}{100}\sum_{i=1}^{n}\sum_{j=1}^{k_i} p_{ij}^{(4)}w_{ij}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{k_i} p_{ij}^{(5)}w_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{k_i} p_{ij}^{(6)}w_{ij} \leq \frac{\gamma}{100}\sum_{i=1}^{n}\sum_{j=1}^{k_i} p_{ij}^{(6)}w_{ij}$$

(iv) World balance of current account.

$$\sum_{i\in\mathcal{J}}\sum_{j=1}^{k_i} p_{ij}^{(10)}w_{ij} + \sum_{i\in J^c}\sum_{j=1}^{k_i} p_{ij}^{(10)}w_{ij} \geq 0,$$

where $J^c$ is the set of developed countries.

(b) *Regional Constraints.* (i) Minimum Regional Share of Industrial production

$$\sum_{i\in R_l}\sum_{j=1}^{k_i} p_{ij}^{(2)}w_{ij} \geq r_l\left(\sum_{i=1}^{n}\sum_{j=1}^{k_i} p_{ij}^{(2)}w_{ij}\right) \qquad \forall l \in L,$$

where $r_l$ is the minimum share of region $l$; $R_l$ is the set of countries in region $l$; $L$ is the set of all regions in the model.

[3] Such a discrepancy is, in fact, due to the following: (a) Insufficient information about the origin of imports brought in specific regions. The same applies to exports. (b) Commodities in bonded warehouses or on board ships. (c) Transportation time lag and inflation. There may be some goods leaving one country but not arriving at another one for some time.

(ii) Lower limits on consumption in different regions

$$\sum_{i\in R_l} \sum_{j=1}^{k_i} p_{ij}^{(7)} w_{ij} \geqslant C_{0_l} \qquad \forall l \in L,$$

where $C_{0_l}$ is the lower limit for region $l$.

(iii) Upper limit on the labour available for region $l$

$$\sum_{i\in R_l} \sum_{j=1}^{k_i} p_{ij}^{(11)} w_{ij} \leqslant B_l \qquad \forall l \in L,$$

where $B_l$ is the upper limit for region $l$.

*8.1.2. Objective function of the ICM*

Under the constraints mentioned in Section 8.1.1, a solution which maximizes a certain objective function is sought. At the moment, two forms of this function are suggested:

(a) Maximize the total world GDP, given by

$$\sum_{i=1}^{n} \sum_{j=1}^{k_i} p_{ij}^{(1)} w_{ij}.$$

(b) Maximize the developing nations industrial production, given by

$$\sum_{i\in \mathcal{F}} \sum_{j=1}^{k_i} p_{ij}^{(2)} w_{ij}.$$

*8.2. The trade model*

The trade model used here is somewhat different from the one referred to in Section 7 above. Here we use the export (import) element $E_i(I_i)$ in the optimum vector for each country $i$, together with some preference factors, to determine the commodity exports and imports for each country. We proceed in two steps:

*Step* 1 find $x_{ik}$ ($m_{ik}$), total exports (imports) of country $i$ from commodity $k$.
*Step* 2 find $y_{ijk}$, exports of country $i$ to country $j$ from commodity $k$.

For Step 1 we formulate the following LP problem

Max $\sum_i \sum_k (a_{ik} x_{ik} + b_{ik} m_{ik})$

Subject to:

$$\begin{array}{llll} \sum_k & x_{ik} & = E_i & \\ \sum_k & m_{ik} & = I_i & \end{array} \Bigg\} \forall_i$$

$$\sum_i \quad x_{ik} - \sum_i m_{ik} = 0 \quad \forall k$$

$$x_{ik'}, \quad m_{ik} \geqslant 0 \quad \forall i, k$$

where $a_{ik}(b_{ik})$ is a weight given by country $i$ for its exports (imports) from commodity $k$. $a_{ik}$ and $b_{ik} \forall i, k$ are policy parameters in the model and they can be used to express the degree of willingness of the country to export (import) a certain commodity.

For Step 2 we formulate the following $k$ LP problems:

$$\text{Max} \sum_i \sum_j \sum_k c_{ijk} y_{ijk}$$

Subject to:

$$\left.\begin{array}{ll} \sum_i \quad y_{ijk} = m_{ik} & \forall_j \\ \sum_j \quad y_{ijk} = x_{ik} & \forall i \\ \left.\begin{array}{r} l_{ijk} \leqslant y_{ijk} \leqslant u_{ijk} \\ y_{ijk} \geqslant 0 \end{array}\right\} & \forall i, j \end{array}\right\} \forall k$$

where $c_{ijk}$ are the weights given as preference factors for the flow from country $i$ to country $j$ of commodity $k$. $c_{ijk} \forall i, j, k$ are policy parameters in the model and they are naturally related to $a_{ik}, b_{ik}$. $l_{ijk}, u_{ijk}$ are policy parameters also expressing physical, or otherwise, upper and lower bounds on the flows.

The formulation for step 1 is a general LP, while that for step 2 results in $k$ LP problems which can be solved by a general network code which caters for upper and lower bounds on the flows in the arcs of the network.

### *8.3. The sectoral exports and imports model*

This model reflects the commodity exports and imports for each country into outputs and inputs of the appropriate sectors in the input–output table representing the country's economic structure; this table is given by the national sectoral planning models in the outer layer. Thus this model needs a conversion table, for each country, to convert the traded commodities into sectoral outputs and inputs. This table differs, in general, from country to country.

Once the sectoral external inputs and outputs are known, they are fed into the national model which is the next block in the inner layer.

### *8.4. The national input–output model*

This model is aimed at calculating the levels of output required by each sector of the economy in order to sustain external (foreign) and domestic demand. Given these demand elements, which are nationally as well as internationally consistent, what are the levels of output from the various economic sectors. Obviously, there might be more than one possible set of outputs and one may like to choose the *best*. If so, a criterion (objective) function has to be chosen and the model can be solved as a LP.

Several forms of the objective function were suggested and experimented with, e.g. maximization of the total output, maximization of some social measure as the number of workers employed or their wages, and maximization of the total value added.

The model constraints are: input–output relationships for intermediate products and for imports, definitional equations of domestic financial sources for government expenditure and of domestic financial sources for gross capital formation and the government deficit. There are also simple equations to define taxes, subsidies, gross capital, wages, consumption, revenues, and depreciation in terms of sectoral levels of output. Additional constraints (upper bounds) on factors of production available and constraints (lower bounds) on the sectoral levels of output were generated according to the nature of the economy of the arab country concerned. The input–output structure is given to the inner layer as data and so are all the policy instruments in the moderl which are generated by the policy instrument models in the outer layer.

The input–output structures for most of the arab countries were not known to us at the stage of building the model. Input–output tables were known to exist for at most 7 arab countries. These tables were constructed at different dates with some of them dating back to the early 1960's while others were completed as late as 1975. Also, in a study like this, one aims at a visualization of the input–output structure by 1985 and by 2000 rather than an existing or an old one. Building input–output tables for 21 arab countries by 1985 and by 2000 was well beyond the scope of this study. It was decided, thus, to seek some analogy between the structure of each arab country by 1985 and by 2000 on the one hand and the present day known structure of another country in the world on the other. If this analogy is realistic, then it may suffice to take the input–output table of the latter country as a representative of the future input–output structure of the former (arab) country. Thus it was necessary to form a team which was delegated the task of analyzing the present structure (for each arab country) and of studying future plans in order to be able to anticipate the future structure to a reasonable degree of realism. Once this anticipation is available, analogy is sought with other countries present day structure. In carrying out its task, the team should consult the available references on country plans, should contact intellectuals and institutions with good knowledge of the country concerned and its most probable directions for future development. Obviously more than one anticipated future could be arrived at, in which case one should test each of them and state the assumptions and justifications behind each one and the results obtained. Clearly, this is by no means a trivial task, but it has already been started with some startling results.

With the results of the national input–output model coming out, we come to the end of the loop around the inner layer. At this point, the results obtained here should be consistent with the elements of the macro vector generated by the national macroeconomic model at the start of the loop. Again, as in the cases of the IIASA and the UNIDO models, this is not necessarily true in all cases. One could reduce the inconsistencies by designing the macroeconomic and the input–output model in such a way that the same policy instruments are used as appropriate in the two models. However, manual intervention is also needed here in order to change parameters and assumptions before starting another cycle. Another technical difficulty faced was for the cases of using an input–output table, of another country, chosen by the method of analogy described earlier. In these cases, there is no guaranteed compatibility between the structure represented by the macroeconomic model and that one represented by input–output table. This difficulty was overcome by fitting a macroeconomic model of the latter country and using it instead of the original one.

### *8.5. Status of the work*

At the time this paper was written, all the components of the inner layer were completely programmed in an integrated computer package. Parts of the outer layer were also programmed and integrated in the package. The package was run with data from international sources together with the data base for the UNIDO world model. However, national data was being collected and the input–output structures were still being sought. Trial runs of the model with national data is scheduled for May 1978 and production runs are scheduled for September–December 1978 when the model will be ready for use by the Arab Ministers of Industry during their meeting in Algeria in 1979.

## 9. A general consensus of the global modelling efforts

As the concept of global modelling is entering its second decade, we find that the models are showing the strong tendency towards the concept of building models of hybrid natures. Also, there is less and less effort being done to develop pushbutton models. Most of the models favor the interactive mode where the user is allowed to intervene, at certain points in the model, to investigate the results, to make the necessary changes in assumptions and parameters and then continues.

We also notice that the models are paying increasing attention to the national components, together with regional and global components. More emphasis is being put on the data and the scenarios supplied by the national user as well as on scrutinized representative structures of the national economies supplied also by the national users. This stems, perhaps, from the fact that unless the information on the national level are correct, the conclusions on the national, regioned and global levels would be meaningless.

So far, the models have concentrated on economic indicators as an objective or a yardstick. Very little attention has been given to humanitarian, rather than economic, indicators.

All but two of the global models referred to earlier in the paper are of dynamic nature. Some of them move in one year intervals while the length of the intervals in the other ranges from 3 to 7 years. Dynamic models seem to be at an advantage of offering the time path for the process of development, and perhaps of ensuring the feasibility of the path at each time step. On the other hand, dynamic models are usually more core and CPU time consuming on the computer.

We notice that the methods used for modelling the global systems are in almost all cases OR methods. Heavy use is being made of linear programming and its extensions, and of the simulation technique. Nonlinear programming was used and quadratic programming could have been used for the trade part of the UNIDO model except for the inavailability of an efficient commercial code of this type. Most of the models built, and their components, are models of large scale systems and they require good knowledge of large scale systems optimization techniques, which have been developed by OR people.

## 10. Difficulties in global modelling

Based on the analysis in the previous sections, we list here the difficulties commonly faced in the efforts related to global modelling of a long range nature:

1. Lack of data, as the models generally require massive data which are seldom available; if available they are from more than one source and if so they might be riddled with inconsistencies due to differences in definitions.

2. The models deal with the world 25–75 years from now. It is impossible to forecast the exact values of the different parameters for this length of time. Available forecasts are, thus, expected to be of uncertain nature and they are always obtained under numerous provisos.

3. The models depend a lot on data provided by national governments or official sources. Frequently these national sources are either not interested or do not know enough about the model. However, if interested, they might not have the required data in their statistics. Also, for political reasons they might raise, or reduce, the values of certain parameters and statistics to give a certain impression.

4. The models require massive data processing equipment, usually of a modern type which may not be available for a number of developing countries. The process of adapting them to more moderate machines poses, oftentimes, some insurmountable barriers.

5. The models, sometimes, lead to conflicting results: while some of them predict doom to come sometime next century, others assure that there are no foreseeable problems to worry about in that concern. This might lead the general user to loose interest in the entire philosophy and approach of global modelling.

6. In this approach, the process of development, especially in developing countries, necessitates that the future should not reproduce the past. On the contrary, it should be more prosperous and different. This might necessitate that some major changes in the economic structure of the country must take place. Thus, one is not able to use a classical economic tool, i.e. the macroeconomic model which is fitted on the basis of the current economic structure. Consequently, there is definitely a need for

tools to substitute such classical economic tools. How to obtain such tools is a problem still open for investigation.

## 11. Anticipation of future OR work in the area of global modelling

### *11.1. Work on methodology*

(a) Develop a methodology to guarantee consistency when finishing the loop in case of hybrid models like IIASA and UNIDO models. If consistency cannot be guaranteed perhaps a convergant iterative scheme, around the loop, can be designed.

(b) Develop a methodology to cater for the fact of the existence of uncertainties in the values of a number of highly interacting parameters or variables.

(c) Develop tools to replace classical economic tools based on extrapolation in case the process of development necessitates changes in the economic structure in a manner which rejects the principle that the future reproduces, or is an extension, of the past.

### *11.2. Work on the concept of scenarios*

A *scenario* means of a group of values for parameters which translate a future policy in terms of numbers to be fed in the model. As a result, the implications of this policy are tested and they are measured in terms of some economic or humanitarian indicators. Several scenarios are formed, expressing alternative policies, and tested. By examining the resulting values of the indicators, one could choose the "best" scenario and hence the "best" policy to adopt.

So far in this field, scenario development took place on *ad hoc* bases. This has been facilitated by the fact that in earlier models (e.g. Mesarovic–Pestel and Bariloche), macroaggregates were used for regions of the globe and the number of policy parameters were limited. However, in more recent models, e.g. UNIDO model, sectoral policy parameters are needed and the regions are broken down to countries. Intra regional relationships appear now together with interregional relationships. Also, these relationships are concerned with a great number of issues and policies since these models are working on sectoral bases. Over and above, scenarios should include values for these policies throughout the planning horizon (25–75 years). On the one hand, not all the possible combinations of the specified values for parameters are feasible, and on the other hand restricting the choice to one or two feasible combinations might not be desirable.

Thus the process of developing feasible and consistent scenarios needs a formal approach. A method of checking the internal consistency between the parameters forming a scenario should be developed. This consistency should be checked between the different parameters at various points in time and also checked for the values of the same parameter along the time path of the plan. A multi-dimensional tree search approach is needed here. Levels of the tree represent time periods and cross sections at these levels pass through nodes which are feasible (representing consistent parameters at this point in time) and through other nodes which are infeasible. An efficient method for tracing feasible paths through these trees should be sought. Feasible paths really represent a consistent strategy for development, with parameters value specified throughout the planning horizon. This is by no means an easy task. However it was partially undertaken while conducting the Arab Industrialization study.

*11.3. Work on data management*

Massive data are needed for these models, with some of them needing entries in excess of 10,000. Thus, an efficient method of data filing and retrieval is necessary. Perhaps some of the techniques of search theory could be used to reduce the access time wasted in data retrieval.

## 12. Conclusions

It is noticed that OR methods have been heavily used in the studies of global problems. The approach of global modelling is still in its infancy and faces some difficulties. However, it is noticed that there is a good future for OR methodology and practice in this direction and we expect the OR scientists to pay it a formal attention in the future; thus contributing to the understanding and solution of global problems.

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