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

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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

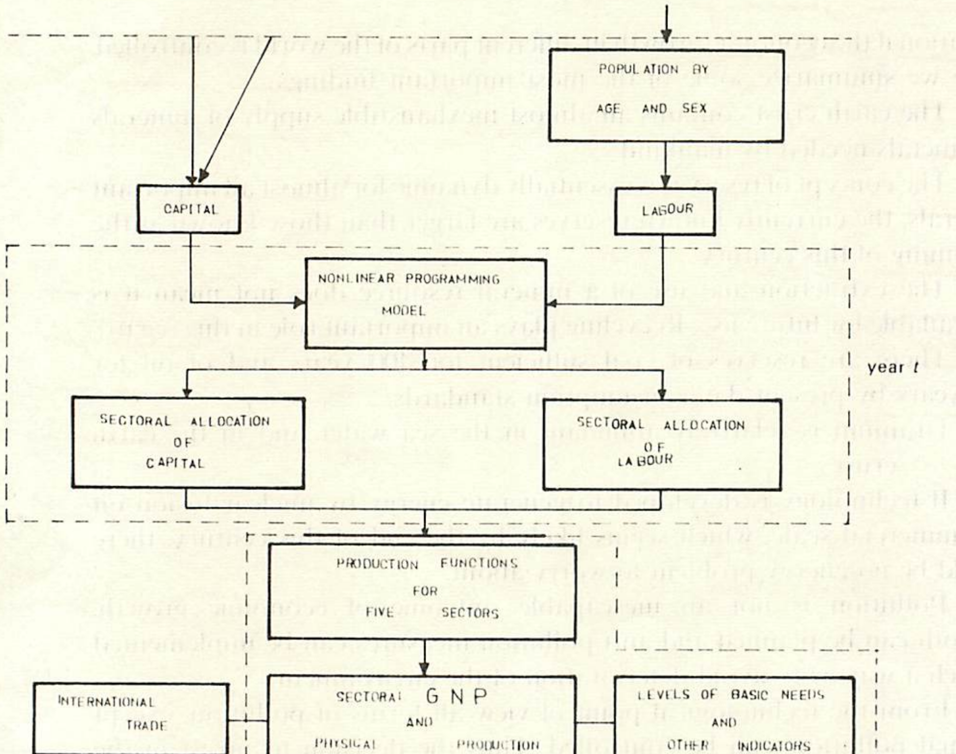

Fig. 1. Flow diagram of the Bariloche model.

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