MODELING OF LARGE-SCALE SYSTEMS DEVELOPMENT

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Summary

It would be very convenient to apply only one universal model while describing modeling of large-scale systems, and then to study this model thoroughly. Unfortunately, in reality, large-scale systems are so diversified and complex that they need various mathematical methods and models to be applied to for them to be described. Besides, progress in the fields of systems analysis like mathematical programming, operations research, mathematical economics and computing technique makes it possible to apply methods and approaches becoming much more complex, when modeling large-scale systems.

More than that, the notion proper of a “large-scale system” is far from being finally defined in science. The presence of such features of large-scale systems that cannot be deduced from known (observed) properties of their elements and methods of their conjugation is considered to be one of the indications of a large-scale system. Practically, any big airport, vertically integrated oil company, or a whole industry, etc. can be regarded as a large-scale system. Modeling of systems like that is generally reduced to solution of a number of large-scale optimization problems.

The results of modeling are further to be displayed visually in a comprehensive form because people responsible for decision making (they are usually politicians, top level managers and others) are in fact far from mathematics.

The above situation is especially valid for such complex problems like modeling sustainable development of whole countries or regions including various social, economic and ecological factors.

The purpose of this chapter is to present an approach to modeling the development of large-scale systems by an example of modeling sustainable development of whole regions, like some cities of Russia, to be specified.

1. Introduction

In spite of the fact that Sustainable Development (SD) movement is extremely popular across the world now, there is not, so far, any common definition of this notion. To be exact, there are over 50 definitions of SD at present. And what is more, the term "sustainable development" itself causes a lot of arguments as it is rather contradictory.

The most recognizable definition is considered to be the one given in the Brundtland Commission report (World Commission on Environment and Development, 1987), which describes SD as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

But sustainable development is a great deal wider than simple environment protection. This notion includes functioning of the three following components: nature, society and economy. Economically, development may be thought to be sustainable only if there exists a balance between human economic activity and the natural environment. As for social approach, it is focused on the fight against inequality of people's opportunities. From an ecological point of view, all efforts should be directed towards preservation of natural resources through various restrictions imposed on human activities because of their impacts on the environment and, therefore, efforts are to be directed towards providing people with proper comfortable life conditions both at present and rather the distant future.

In scientific literature in the world a lot of attention is paid to working out performance index of Sustainable Development at both regional and international levels.

It is the introduction of such a compound (integral) index that facilitates the transformation of Sustainable Development from the political sphere into the field of quantitative analysis and allows researchers to design specific tools of transition to Sustainable Development.

An index like that could be applied at the stage of development of strategic plans for Sustainable Development as well as at the stage of transition to Sustainable Development and adjustment of the trajectory of development of a particular system (a region or a country), as in Sustainable Development, of importance are not only the ultimate aim but also the process of development.

This approach agrees very well with the theory of optimal control. In accordance with the theory, at first an optimum trajectory of the system development is to be determined, in the present case it is a strategic plan for the development of a region (country or a city), and only after that, as the development progresses, the real trajectory is maintained close to the optimum one, while taking into account external factors, in the said case it means monitoring and adjustment of the development of the strategic plan in the course of its implementation (see also *Differential Equation Models*).

However, there do exist essential deviations from the theory of optimal control. Sustainable Development is not a rigid or peremptory command issued by the country's government or regional authorities but rather a guide to action, that makes it possible to reveal progress trends in the world, to determine the country's place among other countries of the world, to carry out comparative analysis of the behavior of other countries or regions similar in their characteristics.

Hence, the strategy of Sustainable Development is to be assessed and modeled. But any estimate can be made only when it can be measured because any science, and especially management science, will not begin unless there is measurability.

Nowadays, there are a lot of methods available in science literature for determining compound performance index of SD at different levels (regional, national and global ones). Prescott-Allen's Well-being Index (2001), the Ecological Footprint of Wackernagel et al (2002), the Environmental Sustainability Index of the World Economic Forum (WEF, 2002), and the Human Development Index of the United Nations Development Program (UNDP, 2001) are examples of global level ones. The International Institute for Sustainable Development, based in Canada, lists more than one hundred initiatives on ISD of national and regional levels.

The diversity of efforts for developing compound index is a manifestation of the fact that science is still far from making a single perfect compound index of Sustainable Development.

This is due to the complexity of the system and the associated difficulties in the study of the functioning of a large-scale system like a country or a region, which is described by numerous interrelated parameters, including economic, ecological, and social ones. Hence, it results in a large number of definitions of Sustainable Development as each of them captures generally only some specific features of the large-scale system's functioning.

Most investigations determine compound index of SD from other, much simpler, indices or indicators characterizing the behavior of a large-scale system. Then, experts assign certain weights to these indicators and they are aggregated into one numerical value which is considered to be compound index of SD.

It is obvious that an approach like that is visual and simple for calculations. But it possesses one severe shortcoming.

To clarify this aspect, it is reasonable to consider some examples. Figure 1 shows a photo of the Cathedral in Palermo, one of the world’s masterpieces that accumulated various styles in its architecture: Byzantine, Arabic and Gothic. The Gothic tower in the photo appears tilted like the famous leaning tower in Pisa. Perhaps, the photographer was unskilled. However, a lot of booklets with photos of the world-known tourist cities reproduce the same defect.

Figure 1: The Cathedral in Palermo

Figure 2: Rembrandt. The Night Watch

And this is the principal drawback of the photo, since the three-dimensional world is projected onto a two-dimensional plane by taking photos. And some information is known to be lost while making this projection. It is interesting to note that artists attempt intuitively to overcome this drawback of the photo with the help of different devices, for example, by using another type of projections or by playing with colors.

Figure 2 presents one of masterpieces by Rembrandt the *Night Watch.* Rembrandt is a great master of colors. Looking at this canvas one has a complete illusion that a historical dramatic world is visualized. This is really a three-dimensional world, since the onlooker has got a deep impression that captain Frans Cocq and his lieutenant are moving several meters ahead of their company.

Figure 1 makes it possible to understand profoundly the difference between the art and the photo. The color bar on the right side of the photo is a projection of the photo onto a one-dimensional axis. Can the photo be reconstructed from this color bar? Certainly, it can’t.

Why does one need all these projections? The answer is very simple. Because operations like these are accomplished in business and economics every day.

Consider the process of thinking by decision-making officers on problems of Sustainable Development. For example, a manager calculates CO_2 emission per capita for his or her region and for other regions, see Figure 3. This is a well-known ratio of Carbon lifestyle efficiency in SD. Then the manager compares these ratios, makes some conclusions and … and forgets about these ratios. After that, the manager begins to analyze the ratio of CO_2 emissions per dollar GDP, see Figure 4. Again, he or she calculates these ratios for his/her region and for other regions, compares them and forgets them, and so on. However, to analyze all these ratios separately is like investigating the above mentioned color bar, see Figure 1, in order to reconstruct the original object.

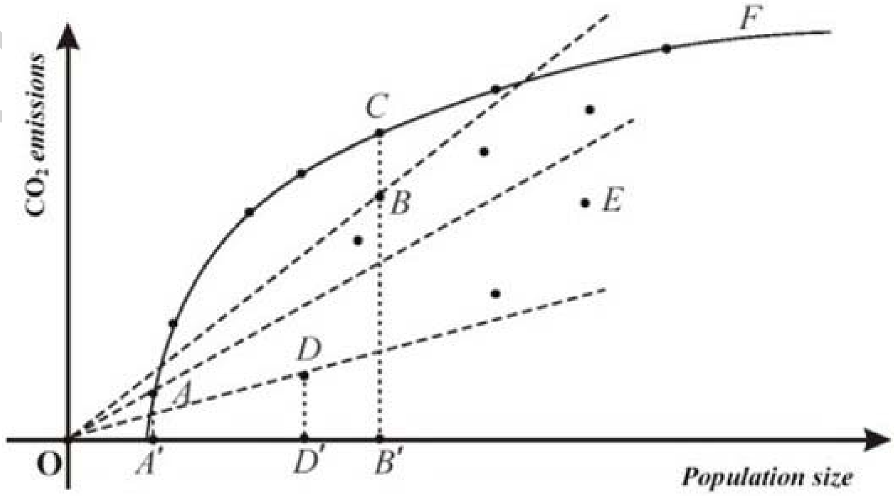

Figure 3: Calculations CO_2 emissions per capita for regions

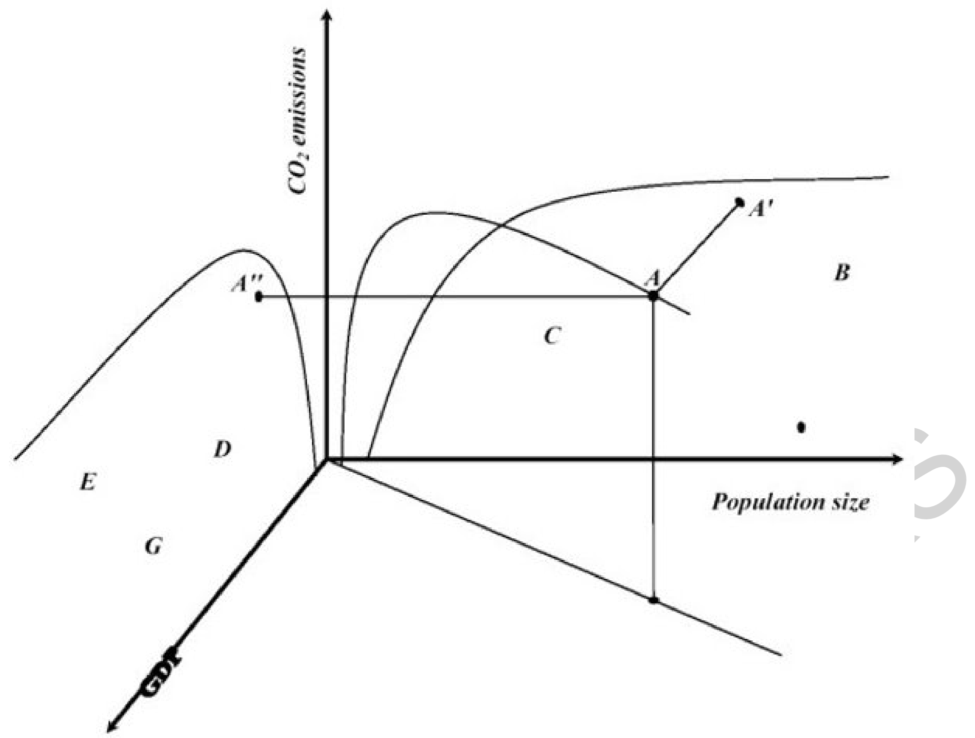

Figure 4: Calculations CO_2 emissions per dollar GDP for regions

DEA (Data Envelopment Analysis) approach allows a manager to analyze the efficiency of production units in a multidimensional space of inputs and outputs. In a sense, DEA is similar to the art that recovers to us our multidimensional and multicolored world.

Data Envelopment Analysis (DEA) enables a decision-making person to analyze the efficiency of large-scale systems such as production systems, banks, regions, cities and so on, in a multidimensional space of indicators (inputs and outputs). The division of them into inputs and outputs goes back to the production model by Leontiev (see *Input-Output Models*), inputs being generally connected with production costs, social expenditures, etc., while outputs characterizing the results of the system's activity, e.g. production output, incomings, various "quality-of-life" dimensions.

In business and economics there are simple measures of efficiency that are calculated as ratio of Output to Input. This is a commonly used measure of efficiency. DEA appeared as generalization of this ratio for the case of multi-input/multi-output models. A.Charnes and W.Cooper were founders of this approach.

DEA development showed that it is closely related with notions and methods of mathematical economics and operations research. At present there some thousands of publications on DEA in leading international journals and magazines are available. Data Envelopment Analysis, on the basis of empirical indicators observed, determines a frontier on which there are situated actual or hypothetical (it means capable to exist due to economic laws) efficient production units, that is, units whose efficiency cannot be improved by decrease of inputs and/or increase of outputs. The efficiency measure is calculated in terms of the distance along the given direction to this frontier. The distance is expressed in relative units of the vector given.

The frontier envelopes the production possibility set, it means that it includes all those production units that could exist owing to the given economic conditions.

Thus, if the production unit in question is situated inside the production possibility set, then its efficiency measure can be increased by shifting it onto the frontier.

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Biographical Sketches

Arkady Dvorkovich was born on the 26th of the March, 1972. In 1989 he was admitted to and in 1994 he graduated from Moscow State University (Department of Economics). In 1993 he worked as Research Associate at the Institute of Economic Forecasting (consumer markets research and macro modeling) and in the Macroeconomic and Finance Unit (J. Sachs group in Moscow (fiscal federalism project)). At he same time he studied at the New Economics School in Moscow (1992-1994) and worked as a Teaching Assistant in macroeconomics, financial economics and public finance at the New economic School (1993–1994). In 1994 he took the master's degree in economics at this school. Then, from 1994 to 1995 he worked as expert of economics, fiscal and monetary policies with the Economic Expert Group of the Ministry of Finance of the Russian Federation. From 1995 to 1997 he studied at the Duke University (Department of economics), USA. In 1997 he took MA degree in economics at this University. From 1997 to 1999 he worked as supervisor of research projects on the Russian financial crisis at the New Economic School. From 1997 to 2000 he filled a position of Head of Group of the Economic Expert Group of the Ministry of Finance of the Russian Federation. From 2000 to 2001 was Advisor to the Minister in the Ministry of economic development and trade of Russian Federation. Now he is a Deputy Minister of the Ministry of Economic Development and Trade of the Russian Federation.

Prof. Vladimir Krivonozhko is an author of more than 100 publications written in Russian and English, published in Russian and international scientific and business journals. He was born in Moscow in 1948. In 1972 he graduated from the Moscow Institute of Physics and Technology. In 1979 he did his Ph.D. degree in the field of mathematical programming and its applications to economics. Prof. Vladimir Krivonozko has been working with the Institute for Systems Analysis of the Russian Academy of Sciences since the moment of the foundation of this Institute, for more than 25 years. His doctor thesis was entitled "The Development of Decomposition Methods". Prof. Krivonozhko is a supervisor for students and post-graduates at the Moscow Institute of Physics and Technology. He is a permanent participant of various scientific international conferences and congresses on mathematical programming and operational research. In 2002 he was an organizer of the International 2002 DEA Symposium in Moscow, Russia. He proposed and substantiated an approach for construction of a set of parametric optimization algorithms for analysis and visualization of complex systems behavior. He validated the use of a set of parametric algorithms for constructing and generalizing major functions in mathematical economics such as: production function, isoquant, isocost, isoprofit etc. He made an adaptation of parametric methods for calculation of the most important qualitative and quantitative indicators of complex systems behavior like *returns to scale*, *scale elasticity*, *marginal rates*, etc. The approach developed is applied to modeling of economic systems activities. Prof. V. Krivonozhko is a scientific advisor to the Smart Technology Center in the *Global S. Consulting* company where high-tech computer-based elaborations are being developed for economics and business.

Oleg Utkin was born in 1946 in Russia. In 1964 he entered the department of Biophysics of the 2nd Moscow Medical Institute. In six years he graduated from this Institute. In 1970 Oleg Utkin worked as an employee in the Ministry of Public Health of the USSR. From 1971 to 1972 he was an employee in the Ministry of Foreign affairs of the USSR. Since 1973 till 1993 Utkin worked as an employee in various divisions in the Ministry of defense (USSR, Russia). In 1978 he received the candidate's degree. His Ph.D thesis was titled "US federal legislation on new drugs evaluation". His monograph "Main statements of new drugs approvement system in USSR and foreign countries" was published in 1982. Since 1994 Utkin is a businessman, founder and president of Russian consulting company "Global S. Consulting". The company has been consulting many big commercial companies as its client's (energetical, financial, transport ect.). During this period of time he has been actively doing his scientific works in the economic and business spheres. He published more than 50 scientific papers (himself and with his co-authors), including the monograph: "Economical and mathematical methods of making optimal decisions by oil companies".