RR-76-6

# A SYSTEMS APPROACH TO DEVELOPMENT PLANNING OF THE FUEL POWER INDUSTRY OF A PLANNED-ECONOMY COUNTRY

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MARCH 1976

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# PREFACE

The aim of this paper is to characterize the main principles of a systems approach to development planning of the fuel power industry of a country with planned economy. The paper is based on the experience of the USSR; in particular, it reflects results of researches of the Siberian Power Institute of the Academy of Sciences of the USSR.

The paper forms part of the IIASA Energy Project investigation into the long-term (15-50 years) energy evolution of various countries (developed and developing, with planned and non-planned economy), taking into account global interfaces and constraints.

# SUMMARY

The fuel power industry (FPI) of a country obviously is a very large complex system; for countries with a planned economy, it must be considered as an entirely aggregate energy system. A special systems approach is needed for planning and forecasting its development. Such an approach has been developed in the Soviet Union since the creation of GOELRO Plan.[1] It includes the following main components:

- Creation of a systems hierarchy and a development task hierarchy;
- Elaboration and application of mathematical models;
- The use of special methods for taking into account uncertainties in input data;
- Consideration of the external interaction of energy systems, their environmental impacts, etc.;
- Improvement of organizational structure and practical management methodology.

As the second, fourth and fifth elements are sufficiently well known and widely accepted, attention in the paper is concentrated mainly on the first and third components.

Creation of a hierarchy of systems is necessary owing to the exceptional complexity of the fuel power industry. The system must somehow be decomposed into subsystems while at the same time its entirety is preserved. This paper describes the FPI systems hierarchy variant based on a combination of territorial and branch indicators. Different kinds of decisions on systems development are made at various hierarchical levels: they require various time periods to implement and must be made with corresponding degrees of planning (each decision at the appropriate time). A number of tasks must be solved to substantiate each decision; and for development planning of the entire system, the tasks at various hierarchical levels must be coordinated. With this aim, planning task hierarchies have been devised, together with the system hierarchy. Such a task hierarchy is described in the paper using the example of development planning for the generating capacity of electric power systems.

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[1] State Plan for the Electrification of the U.S.S.R.

Special methods must be used to take information uncertainty into account. These must be geared to complex problems, both static and dynamic, of large dimensions. Such methods have been developed in the USSR for the solution of energy problems, and their general features are described here.

Uncertain input data (i.e. whose distribution functions are not known) lead to uncertainty in decision-making. The aim of formal mathematical methods in this regard is the best possible identification of the consequences resulting from alternative decisions, and the definition of rational ("intelligent") decision variants from which the final choice may be made. But ultimately man himself--the specialists--must decide on the basis of experience and intuition. To decrease information uncertainty, final decisions should be made as late as possible, immediately before their implementation; thus the "freshest" information with the smallest possible degree of uncertainty is provided. In practice this means that final decisions should normally relate only to the nearest interval of time, to priority construction projects, etc.

The methods described in this paper take these factors into account. They are an expansion of well-known methods of decision-making under uncertainty as described in [5] to deal with complicated optimization problems. They are based on the use of a "payoff matrix" and application of special criteria (Wald, Laplace, Savage, Hurwicz, and others). The basic concepts consist of the "discretization" of continuous problems, and the distinguishing of the "first step" for dynamic problems. The sequence of operations for solving complicated optimization problems under uncertainty is given in this paper, with explanations for each operation.

# A Systems Approach to Development Planning of the Fuel Power Industry of a Planned-Economy Country

L.S. Belyaev

## 1. INTRODUCTION

For a country with a planned economy, the fuel power industry (FPI) can and must be treated as an entirely unified system. Basic decisions concerning its development are made centrally by the national planning authority. However, many planning and project organizations participate in preparing and substantiating both basic and lower-order decisions. On the whole, development planning of national and regional fuel power industry is a complex process that requires a special systems approach.

In the Soviet Union, a systems approach to energy development planning has in fact been applied for a long time. The widely known State Plan for the Electrification of the USSR (GOELRO), developed in the early 1920s under the direction of Academician G.M. Kržižanovskij, already contained the elements of a systems approach (at that time called the "multifaceted method"). Since then, the nature and methods of that approach have been developed and perfected.

The systems approach described in this paper has been formalized in the USSR in recent years. While it has not yet been fully implemented, it is increasingly gaining acceptance and is beginning to take root. We will first characterize the approach as a whole and then explain its components in more detail.

## 2. THE FPI AS A TOTALITY OF LARGE SYSTEMS

The fuel power industry of a country might be viewed as a totality of large artificial systems [1]. Some of the basic features distinguishing what we call "large" artificial systems from those that are merely complex are given below.

1) Hierarchical Structure of the System

   A large system consists of a number of subsystems of various hierarchical levels. Each subsystem fulfills defined functions and is relatively autonomous; in particular, it may have its own management organ. (Certain subsystems may themselves be large systems, in turn consisting of further subsystems.) Subsystems of a single large system, however, are strongly interconnected; their operations are subordinate to a common goal; and, for purposes of solving some of their development problems, they should be viewed jointly as a united system.

2) Organic Participation of Man in System Operation and Management

A large system is an organic "man-machine" entirety, which includes not only technical elements but also management organs. It may comprise several such organs, and these may form a hierarchy that corresponds more or less to a hierarchy of real subsystems.

3) External and Internal Random Factors Influencing System Development

Factors influencing the system arise from natural phenomena and peculiarities of technological processes, as well as from the actions of people (including those involved in system management). Consequently large systems are stochastic, a substantial element of uncertainty being introduced by the participation of men.

In addition to these basic features, large systems also have a number of other properties--multicriterion functions, adaptive and self-organizing capabilities, reliability, feedback capability--which will not be discussed in the paper.

This concept of large artificial systems corresponds better to reality. The fuel power industry and its individual branches may be viewed as a classic example of a large system. Obviously these are very complex objects for study; they cannot be described with exactitude mathematically, both because of their exceptional complexity and because of the part played by man), whose actions cannot be predicted. Moreover, random factors, data uncertainty, and the like must be taken into account.

The approach for development planning of such systems that has been developed in the Soviet Union will now be examined.

## 3. COMPONENTS OF THE SYSTEMS APPROACH

The methodology of a systems approach to development planning of the fuel power industry is based on the following principles.

1) Creation of a hierarchy of systems for the FPI, and identification of tasks for the development of each system;

2) Elaboration and application of mathematical models for solving the development tasks;

3) The use of special methods for taking account of uncertainties in input data;

4) Consideration of the external interactions of energy systems, their environmental impact, etc.;

5) Improvement of organizational structure and practical management methodology.

The need for creating a hierarchy of systems follows from the complexity of the fuel power industry. Decomposition into subsystems for which more precise mathematical models can be constructed provides the details required for solving various tasks.

For each subsystem of the FPI--that is, at each hierarchical level, a number of decisions must be made: for example, decisions on power plant design and construction, design of new types of equipment, production requirements, and so forth. Different decisions demand different time periods for their implementation and must be made with varying degrees of planning. To substantiate the decisions, specific tasks must be solved. Thus a number of development management tasks are solved for each subsystem, and a hierarchy of these tasks is defined along with the systems hierarchy.

Study and optimization of complex systems is unthinkable today without mathematical models. These models have been widely used in many countries for some time. We may make only the following observation. Models are constructed to carry out specific research or solve specific problems. For very complex systems, it is impossible, or senseless, to develop "all-inclusive" models reflecting in detail all the aspects of a real system that are of interest for solving various questions. This is particularly true of optimization models. Depending on the problems to be solved, the various properties of a system are reflected in the models with varying degrees of detail. Therefore several different models may be needed for the same system.

Even the best mathematical model cannot give correct results if supplied with insufficiently defined data; for the foreseeable future such uncertainty will continue to exist. That brings us to the third principle of our systems approach--the need for dealing with uncertain information. By uncertainty in input data we mean that neither the input data nor their distribution functions are known to us exactly. This can ultimately lead to uncertainty in decision-making, and mathematical models become powerless here. Ultimately man himself--the specialists--must decide on the basis of experience and intuition. The aim, therefore, of formal studies is the best possible identification of the consequences resulting from alternative decisions. They are also used to define rational variants from which the final choice may be made.

Special methods are applied for the solution of complex optimization problems under uncertainty. Later we will briefly describe methods developed in the Soviet Union for application to energy problems. Note that the uncertainty factor in data and decision-making must be taken into account when constructing a hierarchy of development tasks for the FPI, in determining the structure and concerete statements of the tasks, compiling mathematical models, and delineating the functions of men and computers.

The fourth principle--consideration of the external interactions of energy systems with other branches of the national economy, their environmental impact, etc.--obviously requires no special explanation. Consideration of the various consequences of a given program is a widely accepted element of the systems approach. However, realization of this principle often encounters serious methodological and practical difficulties with respect to the compilation and comparison of criteria, numerical estimation of losses in other branches of the economy, changes in the biosphere, and so on. Specific methods for considering consequences will depend on the peculiarities of the tasks being solved and may differ for different subsystems of the FPI. As a rule, external interactions of the energy systems are taken into account by introducing corresponding restraints whose quantitative characteristics are determined by treating the national economy as a whole, or by standardizing biochemical, social and other indicators.

Finally, the fifth principle deals with the practical realization of the other principles of the systems approach. As the FPI develops and the methodology of the systems approach continues to be perfected with respect to theory, there is a need for continuous improvement of planning practices. It is necessary to refine, for example, the structure and functions of management organs and the flow of information, and to develop new mathematical models. Practical realization of the systems approach takes place more slowly than its theoretical development and is much more laborious. Experience, in turn, is a constant stimulus for the development of the theory and is the basic means for verifying the effectiveness of the methods proposed.

Some of the principles of the systems approach under examination will be illustrated later in more detail.

## 4. A HIERARCHY OF FPI SYSTEMS; THE TIME ASPECT

In the USSR at present, preference is given to a variant of the FPI hierarchy that is based on a combination of territorial and branch indicators [1, 2]. This variant is depicted in Figure 1 in a somewhat simplified form. On the territorial side, systems are divided into the levels: country, economic region, industrial center, plant. Features of the branches include: aggregate energy systems, electric power systems, gas supply systems, oil supply systems, and systems for the coal industry and atomic power industry. The "cross-cutting" of some territorial and branch levels forms systems; some of these are shown in the diagram. For other countries, some hierarchical levels--for example, the economic region in countries with smaller territory--or branches might be omitted.

| | | BRANCHES | | | | | |
|---|---|---|---|---|---|---|---|
| | | GENERAL ENERGY ECONOMY | ELECTRIC POWER | GAS | OIL | COAL | NUCLEAR |
| TERRITORY | COUNTRY | AGGREGATE ENERGY SYSTEM OF THE COUNTRY | INTERCONNECTED ELECTRIC POWER SYSTEM OF THE COUNTRY | | | | |
| | ECONOMIC REGION | | UNITED ELECTRIC POWER SYSTEMS | | | | |
| | INDUSTRIAL CENTER | | | | | | |
| | PLANT | | ELECTRIC POWER PLANTS | | | | |

Figure 1. The energy systems hierarchy.

As has been said, for each system--any territorial or branch level--the structure of management development tasks must be determined. The specific implications of these tasks depend not only on the peculiarities of the given system, but also on the period of time for which they are being solved. For nearer time periods, the tasks are connected with the construction of specific projects. Those for more distant periods concern system design tasks, development of new equipment, scheduling of scientific research, and so forth. The following time periods are defined in the Soviet Union for FPI development (see Figure 2):

- Long-term forecasting (20 to 30 years and more),
- 15-year planning,
- 5-year planning,
- Yearly planning.

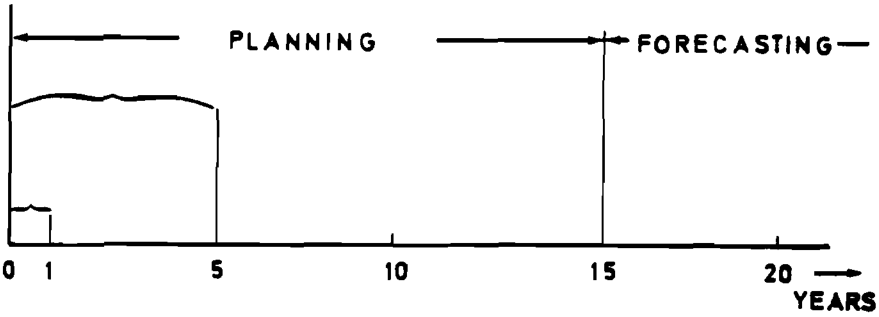


Figure 2. Time periods for fuel power industry development planning.

Long-term forecasting does not relate to planning in the sense of determining real control actions. Its aims are to identify long-term regularities and tendencies in the field of energy, and problems whose solutions take long periods to realize: new areas for future scientific research, possibilities for applying new methods in the production, distribution and utilization of energy, geological exploration for new resources, and the like. Also, long-term forecasts supply a reference point for more distant perspectives during the compiling of 15-year plans. In long-term forecasting, the country's fuel power industry is considered as a whole, with a rough view of economic regions and energy branches.

In 15-year planning, the time period considered is treated in 5-year segments. The following aspects are determined for the second and third segment: the rational proportions for the development of individual branches, the development scale for various fuel resource deposits, territorial siting of major plants and industrial complexes, distribution of fuel and energy, anticipated demands for power equipment, and other analogous large-scale problems. In this category only two high territorial levels are usually examined: the country as a whole and the economic region.

In 5-year planning, more concrete problems are treated: for example, those related to the design and construction of energy projects, including transport, and the determination of equipment and material demands. Here all the territorial levels are examined.

In yearly planning, start times for power installations and for the development of their output capacities are defined. Annual levels of investment and of production and consumption of equipment, fuel, and energy are also determined.

The tasks to be solved for development planning of each system are new defined in accordance with the appropriate time scale. At the same time, the tasks at various hierarchical levels must be coordinated with respect to timing and sequence for the effectiveness of the FPI as a whole. This implies construction of a task hierarchy.

As an example, Figure 3 shows a hierarchy of development tasks for the generating capacities of electric power systems. For the USSR, these tasks encompass three levels: the country's aggregate energy system, its interconnected electric power system, and the united regional electric power systems. The tasks are solved for various periods of time, depending on the nature of the decisions to be made. The arrows show the transmission of information about the decisions made ("direct" information). Of course there are back-and-forth flows of information from task to task.

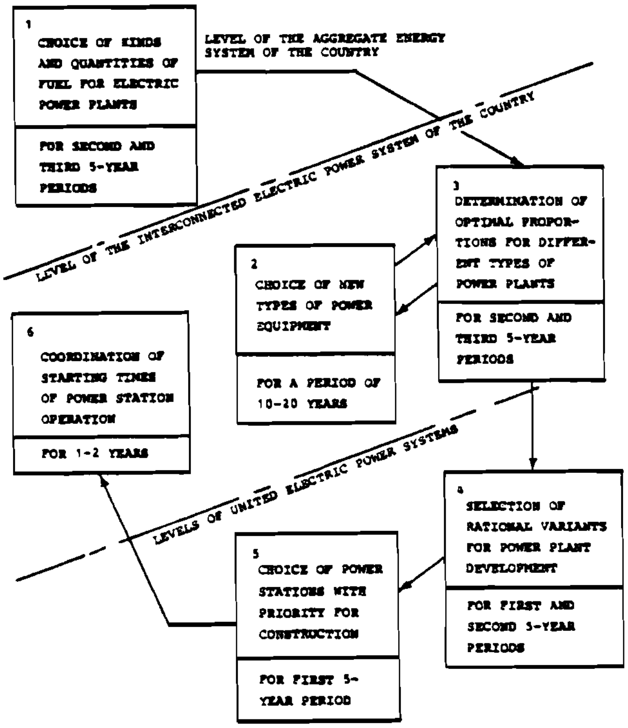


Figure 3. Task hierarchy for the planning of electric power system capacity.

For electric power systems, development tasks for electric power networks must also be solved; these too are divided by hierarchical level and should be coordinated with tasks already considered for generating capacities.

The situation is similar for other FPI systems.

Note that the need to assign systems development tasks to different hierarchical levels, instead of solving what seems to be a single optimization task, also stems from the uncertainty in input data. Different decisions require different time periods for their implementation. To reduce data uncertainty, decisions should be made as late as possible, immediately before being implemented, so that the "freshest" information with the smallest degree of uncertainty is provided. Each decision is thus made at the best possible time, the specific task substantiating it having first been solved. One is dealing with a number of interconnected development tasks rather than a single optimization task which, given the data uncertainty, would be unmanageable.

## 5. MATHEMATICAL MODELS FOR FPI DEVELOPMENT PLANNING

We have seen that many models must be used to optimize the fuel power industry complex. To clarify this, let us return to Figure 1, presenting the FPI systems hierarchy. For each system indicated here (each square in the table), several mathematical models have been or are being developed in various countries to carry out the corresponding systems development tasks. Of course, the many models cannot be discussed here. Some of them are described in [3, 4], and a review of USSR energy models is to be prepared at IIASA in the near future. The most important and interesting are models elaborated on a nationwide level. These are mainly optimization models, sometimes dynamic, utilizing linear programming methods. Some of them, particularly those for the country's aggregate energy system, may include several thousand equations and tens of thousands of variables. Usually they consist of several blocks representing territorial or branch subsystems.

Mathematical models for optimization of systems of lower territorial levels (economic regions, industrial centers, plants) are considerably more varied. Mainly nonlinear models are used here, which may also be dynamic, discrete, or stochastic, depending on the task to be carried out. The most complicated models are now realized on computers as program-information complexes, which include data banks and control and service programs along with the basic model programs. These complexes are usually comprised in an automated management system.

## 6. ACCOUNTING FOR UNCERTAINTY OF INPUT INFORMATION

To take adequate account of information uncertainty when solving development tasks of the FPI, special methods for solving complex tasks of large dimensions must be applied. Before the methods themselves are discussed, three important points should be stressed.

First, as I have already mentioned, uncertainty in initial information leads to uncertainty in decision-making. Consequently formal methods cannot offer single optimal solutions; they can only provide clearer and fuller analyses and elucidate rational decision variants.

Second, since input data are non-deterministic, their many possible combinations must be considered, and the variants offered must be compared for all these combinations. This makes these calculations very laborious and requires the simulated adaptation of each variant to different possible development conditions. In addition, procedures must be used that satisfy balance and technical constraints.

Finally, as noted earlier, decisions should be made immediately before their implementation in order to decrease information uncertainty. In practice this means that final decisions should relate only to the nearest interval of time, to priority construction projects, etc. When possible, decisions should be made in separate stages--for example, for the start of a design stage and the start of a project construction, or for the design of new equipment, production of prototypes, and commercial production. Thus, during realization of the first stages, technical-economic indicators for projects and equipment are made more precise, and other external conditions undergo refinement.

The methods described below take these three statements into account.

We have extended well-known methods of decision-making under uncertainty to cover complicated optimization problems. Those methods (see for example [5]) are based on the use of a "payoff matrix" and the application of special criteria (Wald, Laplace, Savage, Hurwicz, and others). They assume that decision-making takes place in one time or static situation with a finite number of actions and states of nature. But in the real-world development of energy systems, one usually encounters an infinite multitude of both decision parameters and non-deterministic input indicators; many tasks being dynamic in nature. This fact requires the development of special methods.

One basic idea consists in the "discretization" of continuous problems. Here one selects a finite number of "representative" points from the infinite domain of decision parameters or parameters characterizing states of nature. For these points the necessary calculations are made, the payoff matrix is compiled, and the analysis is carried out.

The scheme outlined here is based on research and on practical solutions of some energy tasks. It provides for the following operations:

1) Statement of the problem;

2) Selection of a representative set of states of nature, (i.e. of possible conditions for system development);

3) Search for and preliminary analysis of variants for problem solution;

4) Calculation of the payoff matrix;

5) Analysis of the payoff matrix and selection of rational actions;

6) Final choice of the action to be taken for realization.

For each operation, methods of implementation have been investigated and recommended, [1, 6, 7, 8, 9], which I shall not discuss here in detail. Related work will be done at IIASA. Below I shall briefly explain these operations.

Statement of the problem is the first step, and a very important one. Here one must establish:

- Identification of parameters (components of vector x) characterizing the decision to be made,

$$x \in X;$$

- Identification of the probabilistic input data characterizing the states of nature,

$$y \in Y$$

  (X and Y are domains of possible values for vectors x and y);

- An evaluating function for estimating the effect of actions (or expenditures) under different states of nature;

$$E\ (x,y)$$

- Existing constraints and procedures to satisfy them.

Function $E(x,y)$ is not an objective function in the usual sense. We cannot talk about minimizing it (if it represents expenditures), since each value of vector x may attain its minimum under a different state of nature. We can try, however, to make the values of function $E(x,y)$ as small as possible.

If we are dealing with a dynamic problem, formulation of the evaluation function $E(x,y)$ becomes more complicated. This will be discussed at the end of the paper.

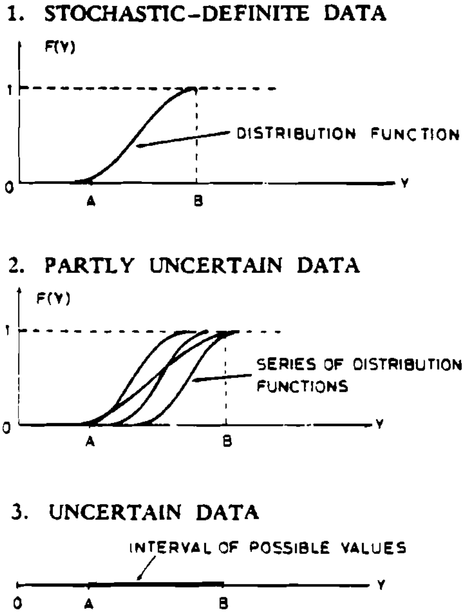
The second and third operations are in fact the "discretization" of the problem I mentioned earlier. In the discontinuous sets Y and X, a finite number of points must be chosen that characterize the set as a whole sufficiently well. As an example, let us consider the set of possible states of nature Y.

The following methods of formal description (see Figure 4) may be used for non-deterministic input data (components of vector y) that are of a continuous nature:

1) For stochastic data with a known date-generating process, a distribution function;

2) For partly uncertain data, a series of possible distribution functions;

3) For uncertain data, an interval of possible values.


1. STOCHASTIC-DEFINITE DATA

2. PARTLY UNCERTAIN DATA

3. UNCERTAIN DATA

Figure 4. Quantitative description of non-deterministic data.

For each of these methods of description we can, or must, show a range (from A to B) of practically possible values of the data considered. For vector y with all its components we should obtain a continuous field Y (n-dimensional parallelepiped or some other space), and in that space choose a definite number of points as its representatives.

Several selection methods have been proposed, generally based on the (in some sense) regular distribution of a given number of points in an n-dimensional parallelepiped or single cube. In particular, linear code theory is used for choosing points evenly or uniformly distributed on a grid or in the centers of spheres having equal and maximum possible diameters. Figure 5 illustrates such selection within a two-dimenasional single cube. Figure 5a shows the selection of seven points on a regular grid, and Figure 5b that of three points in the centers of spheres.

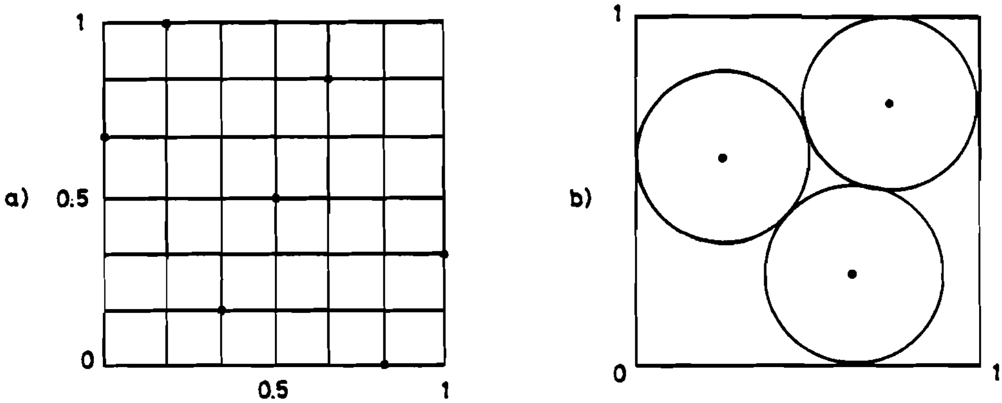


Figure 5. Selection of uniformly situated points.

To select possible actions for subsequent examination, i.e. to complete the third operation, another method may also be used. It involves making deterministic optimization calculations for several states of nature selected during the second operation. The "local" optimal variants so obtained can be included among the actions considered.

As a result of these two operations we obtain a finite number (S) of considered states of nature $y_s (s = 1,2,...,S)$ and a finite number (I) of possible actions $x_i (i = 1,2,...,I)$.

Calculation of the payoff matrix means estimating the values of function E(x,y) for all possible actions $x_i$ and all states of nature $y_s$. A payoff matrix is represented in Figure 6. On the right side of the figure, characteristic values of function E(x,y) are shown which may be obtained from the payoff matrix.

Because of the uncertainty of future system development conditions we cannot obtain a single (deterministic) estimate for each possible action $x_i$; the series or vector of estimates obtained depends on the states of nature. Since the probabilities of different states of nature are not known either, we also cannot determine the mathematical expectation of expenditures. Only certain characteristic values can therefore be determined: the maximum expenditure $E_i^{max}$, the minimum expenditure $E_i^{min}$, and the arithmetic mean $\bar{E}_i$. In addition, we can determine the maximum risk (regret) value ($R_i^{max}$).

The selection of rational actions can be made using the above-mentioned criteria for uncertain conditions. The most logical and interesting criteria are shown below.

Wald's criterion (of minimax expenditures):

$$\min_i E_i^{max} = \min_i \max_s E_{is} \longrightarrow \overset{0}{x}_W$$

Savage's criterion (of minimax risk):

$$\min_i R_i^{max} = \min_i \max_s R_{is} \longrightarrow \overset{0}{x}_S$$

Laplace's criterion:

$$\min_i \bar{E}_i = \min_i \frac{1}{S} \sum_{s=1}^{S} E_{is} \longrightarrow \overset{0}{x}_L$$

Hurwicz's criterion (of pessimism-optimism)

$$\min_i \left[\alpha E_i^{max} + (1-\alpha) E_i^{min}\right] \longrightarrow \overset{0}{x}_H$$

$$0 \leq \alpha \leq 1$$

Wald's and Savage's criteria are minimax, the remaining two use a certain average estimation of expenditures. A certain generalized criterion (K) can also be constructed on the basis of characteristic values of the payoff matrix:

$$\min_i K_i = \min_i \left[\alpha_1 E_i^{\max} + \alpha_2 E_i^{\min} + \alpha_3 \bar{E}_i + \alpha_4 R_i^{\max}\right] \longrightarrow \overset{0}{x}_K$$

$$\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 = 1; \qquad 0 \leq \alpha_1, \alpha_2, \alpha_3, \alpha_4 \leq 1 \quad .$$

$E_{is} = E(x_i, y_s) \qquad i = 1,\ldots,I; \qquad S = 1,\ldots,S.$

| $x \quad Y$ | $Y_1$ | $Y_2$ | $\ldots$ | $Y_s$ | $\ldots$ | $Y_S$ | $E_i^{\max}$ | $E_i^{\min}$ | $\bar{E}_i$ | $R_i^{\max}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $x_1$ | $E_{11}$ | $E_{12}$ |  | $E_{1s}$ |  | $E_{1S}$ | $E_1^{\max}$ | $E_1^{\min}$ | $\bar{E}_1$ | $R_1^{\max}$ |
| $x_2$ | $E_{21}$ | $E_{22}$ |  | $E_{2s}$ |  | $E_{2S}$ | $E_2^{\max}$ | $E_2^{\min}$ | $\bar{E}_2$ | $R_2^{\max}$ |
| $\vdots$ |  |  |  |  |  |  |  |  |  |  |
| $x_i$ | $E_{i1}$ | $E_{i2}$ |  | $E_{is}$ |  | $E_{iS}$ | $E_i^{\max}$ | $E_i^{\min}$ | $\bar{E}_i$ | $R_i^{\max}$ |
| $\vdots$ |  |  |  |  |  |  |  |  |  |  |
| $x_I$ | $E_{I1}$ | $E_{I2}$ |  | $E_{Is}$ |  | $E_{IS}$ | $E_I^{\max}$ | $E_I^{\min}$ | $\bar{E}_I$ | $R_I^{\max}$ |

$$E_i^{\max} = \max_s E_{is}; \qquad E_i^{\min} = \min_s E_{is}; \qquad \bar{E}_i = \frac{1}{S} \sum_{s=1}^{S} E_{is};$$

$$R_i^{\max} = \max_s R_{is}, \qquad \text{where } R_{is} = E_{is} - \frac{\min E_{js}}{j \in 1,I}$$

Figure 6. The payoff matrix and its characteristic values.

Depending on the accepted values of coefficients $\alpha$, one may pass from this criterion to each of the four preceding ones or obtain various combinations of criteria.

Note that each of the criteria has definite drawbacks. None inspires complete confidence, and no decision based on a single one is allowed. These criteria merely provide the possibility to identify rational actions that are desirable in some respect.

As stated before, the final choice of a decision from among a number of rational variants must be made by man himself. Here additional objectives, not considered during the earlier examination of the problem, may be taken into account, use may be made of estimations by experts, and the like. Without dwelling on these, I will merely note that despite a "subjective" choice at the final stage, the preceding analysis guarantees only rational variants and insures us against gross errors.

This, in brief, is the general scheme for solving problems under conditions of uncertainty. We have not covered here many difficulties that occur during the various steps, nor how to deal with them. The scheme we have outlined has been verified by application to practical problems and continues to be developed and refined.

Now let us consider briefly the statement of dynamic problems, to which the majority of power systems development tasks are related. On formulating dynamic problems, it is important that the principle of taking only priority decisions be reflected--that is, decisions concering the nearest time interval (the "first step"). For a correct evaluation of the consequences of priority decisions, an additional time period ("after-action" period) must be examined. Different statements for dynamic problems are possible, depending on the ways chosen to account for system development during the "ater-action" period [9]. The most logical and flexible statement is the following [8, 9].

The given period is divided into T time intervals ($t = 1,\ldots,T$). It is assumed that the final decision is made only for values of decision parameters in the first interval $x_1$. These alone characterize alternative courses of action, and for them the possible variants are outlined (during the third operation):

$$x_i = x_{1i} \quad (i = 1,\ldots,I) \quad .$$

The states of nature are characterized by the specific realizations of vector $y$ for the whole period T examined:

$$y_s = (y_{1s}, y_{2s}, \ldots y_{ts} \ldots, y_{Ts}) \qquad s = 1,\ldots,S \quad .$$

The economic impact of some variant $x_i$ for a certain state of nature $y_s$ is determined by the following calculation of the payoff matrix:

$$E_{is} = E_1(x_i, y_{1s}) + \min_{xt} \sum_{t=2}^{T} E_t(x_t, y_{ts}) \quad ,$$

where $E_1$ and $E_t$ are expenditure functions for the $1^{st}$ and $t^{th}$ intervals respectively, and $x_t$ is the value of the decision parameters in the $2^{nd}$ and subsequent time intervals. The first term of the relationship estimates the effect in the first time interval for which a final decision is sought. The second term takes into account the effect in the "after-action" period. Here it is assumed that in the "after-action" period the system would develop optimally depending on the action selected in the first step, and on the conditions $y_s$ that in fact occur.

All subsequent decision-making, after one obtains the payoff matrix, will be as considered above. This statement is a very time-consuming one since it demands the completion of IxS deterministic optimization calculations. Note, however, that dynamic problems are always more complex than static ones.

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