R. ARTIUKH, V. KOSENKO, I. NEVLIUDOV

MODELS AND METHODS FOR MAKING DECISIONS ON PLANNING THE DEVELOPMENT OF A PRODUCTION ENTERPRISE

Monograph

ISMA University of Applied Science
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R. ARTIUKH, V. KOSENKO, I. NEVLIUDOV

LĒMUMU PIEŅEMŠANAS MODEĻI UN METODES RAŽOŠANAS UZŅĒMUMA ATTĪSTĪBAS PLĀNOŠANAI

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Reviewers:
Igor Chumachenko – Dr. Sc. (Engineering), Professor, Kharkiv Beketov National University of Urban Economy, Kharkiv, Ukraine,
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Authors: Roman Artiukh, Viktor Kosenko, Igor Nevliudov

The monograph contains a description of the models and methods for making decisions on the choice of the preferred option for the enterprise development plan to increase the validity and reliability of decisions taken at the pre-project planning stage. An analysis of the main concepts and directions in enterprise development management, an overview of the methods of supporting decision making in strategic planning was carried out. The methodological apparatus for making decisions consists of a method for assessing technological process variants, a method for choosing a preferred option for forming technological process variants using unified structural models and principles of a precedent approach, a queuing theory model for analyzing the production characteristics of technological processes.
Recommended for students, masters, aspirants and students of a wide range of specialties related to solving the problems of forming and evaluating plans for the innovative development of a production enterprise.

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CONTENT

INTRODUCTION

One of the characteristic features of the current stage of economic development is the intense competition in the product sales markets. An effective way to successfully compete is to continuously update the range of products, improve their quality, expand functional characteristics and take into account changes in consumer requirements. These circumstances determine the transition from mass and large-scale production to serial and small-scale production of products, as well as to the understanding of the need to modernize the organizational, design and production structures of enterprises.

A concept for the development of an enterprise in market conditions has been formed, in which the concept of development is associated with the constant updating of the range of products in accordance with fluctuations in the market environment. This concept for a purposefully developing enterprise is formed in the form of its development strategy. Planning a development strategy provides for the solution of such tasks as the formation of the composition of possible options for plans, criteria for their assessment and the choice of the preferred option.

The main requirement for planning and assessing the feasibility of a development strategy is efficiency. The solution to the problem of efficiency is largely determined by the use of modern information technologies to automate the processes of making managerial decisions, primarily in the field of production and its main part - the technological process.

The first chapter of the monograph analyzes the tasks in the field of decision-making for the development of an enterprise, taking into account the modern features of the economy in the context of the instability of the external environment. The structure of production is investigated with the allocation of its main part - the technological process. The necessity of assessing the feasibility of options for the development of an enterprise at the pre-project planning stage according to the main technical and economic indicators is substantiated. The resource component of the development plans feasibility is analyzed. Decision-making methods are reviewed.

The second chapter examines a generalized model for managing the innovative development of an enterprise, taking into account the assessment of the resource component of the feasibility of development plans. When forming options for plans for the development of an enterprise, a precedent approach is used. The issues of forming an archive of technological documentation of an enterprise on the basis of structural models of technological processes are considered. The parameters of production processes are estimated to select options for development plans.

In the third chapter, a generalized presentation of the set of information, functional and structural parameters of the technological process is formed as the basis of production. Methods for the formation and multi-criteria assessment of technological process options are based on the use of the experience of past developments. Models of making managerial decisions for the development of an enterprise are considered.

The fourth chapter describes the modified structure of the precedent decision-making system. Information support is formed in the form of a technological database of the enterprise and a corresponding archive of technological solutions.

1 ANALYSIS OF ENTERPRISE DEVELOPMENT PLANNING OBJECTIVES AND DECISION-MAKING METHODS

1.1 Tasks of industrial enterprise development management

The harsh conditions of competition in which an industrial enterprise operates, and the high dynamism of the external environment require the development of various kinds of strategies and means of adaptation to the disturbing influences of the external environment, the improvement of the structure and target strategy of the operation of the enterprise. A set of targeted strategies and management decisions creates the basis for the development of an enterprise [1-3].

An enterprise is understood as a design and production organization that has the structure and resources for socio-economic activities and interaction with the external environment.

There are several formulations of the concept of development for systems of different nature and properties of a developing object [4, 5]. The most general is the concept of "development" of an enterprise as a purposeful system in the form of a process of interrelated actions aimed at achieving the formed goal [6]. The paper [4] defines the concept of development for purposeful artificial systems. Here, development is viewed as a process of setting and achieving new goals that are dictated by the external environment, or are formed at the enterprise as a result of the analysis of its functioning.

The environment in which the production activities of industrial enterprises are carried out significantly affects the tactics and strategy of their behavior, and above all in matters of planning production processes in terms of volume and nomenclature.

Enterprises, trying to maintain their position in the market in conditions of competition and instability, are forced to continuously improve business processes, mastering new technologies and equipment. The issues of improving the methods of planning and managing the development process, the development of innovative products are of particular urgency and need [7-9].

The initial step in the entire management process is to define the management objectives. The goals of management differ in their content, for example, social, economic, environmental, etc.; this division should be understood as the definition of the predominant factor in the implementation of a certain goal [10, 11].

For industrial enterprises, priority is given to the technological goals of the enterprise development, taking into account a number of related aspects, such as, for example, and ecology. One of the characteristics of goals is their temporal aspect, since short-term tactical goals are a means of realizing long-term strategic goals, generating a hierarchical structure of the goal tree [12].

In most cases, strategic objectives at the initial stage of planning are set in a qualitative form, determining the general direction of development, as well as the range of possible trajectories for the implementation of a given goal [13-15].

The object of management, in which technical, production, economic, determines the content of the management process and social components can be distinguished.

From a technical point of view, it deals with the processes of managing the design and transformation of the original product into products. In the production plan, management is the process of organizing production, i.e. interaction of elements of the structure of production. In economic terms, the management process is aimed at planning, monitoring and optimizing the economic parameters of the enterprise's business processes.

A managerial decision is a link in the management process that is made when there is a problem [16].

The process of solving the problem is reduced mainly to the following stages:

• identification, formulation and substantiation of the problem;

• analysis of information necessary for making a decision;

• selection and formulation of possible solutions;

• selection, justification and formulation of the best option.

The emergence of problems and their assessment can occur in two different situations: when the starting point is the problem itself and when the starting point is the possibility of a different solution to an already known problem. The situation of a "new problem" requires assessing the urgency of the problem and clearly formulating it. The situation of "new opportunity" means the emergence of new rational ways to solve a known problem and the need to assess and choose the preferred way.

The main difficulties that one has to face at the stage of forming and selecting possible solutions is to determine the number of alternatives and the criteria for their assessment. Additional difficulties arise for the reason that not all information lends itself to formalization, and both analytical approaches and various heuristic methods are used to select options [17].

At the pre-design stage of the analysis of the feasibility of development plans, the criterion of "effectiveness" can be considered quite acceptable. If this or that option contributes to the achievement of the set goals, it is called effective, regardless of the degree of this effectiveness. It is more difficult to determine the effectiveness of options if several goals are set or when one goal contains a number of criteria, which is quite common.

Models and methods of assessment and decision-making make it possible to choose from a formed list of possible alternatives. If the selection of possible options is carried out on the basis of a general performance criterion, then the assessment of solution options is made on the basis of the entire set of criteria that make it possible to obtain an assessment of each option. The works of this stage are the most responsible because of the high cost of mistakes in choosing the way to achieve the goal.

Considered in general terms, the target approach allows the most complete solution of the decision-making problem for the development of an enterprise development strategy [18].

Under the influence of the external environment, the business processes of an enterprise can be influenced by random disturbances, which lead to the need to forecast the development of an enterprise as a system with a high degree of uncertainty in the initial data. Analysis of the feasibility of development plans is an important element of forecasting the process over time [19-21].

Thus, *the development of an enterprise* is a process of purposeful change in its internal states under the influence of external management and self-organization processes of both individual subsystems and the enterprise as a whole [18].

There are several main sub-processes of management that determine the general process of enterprise development:

• financial - control and management of financial resources;

• logistic - movement of material and financial flows;

• production and technological - management of the technical and organizational subsystems of the enterprise;

• human resources - organization and management of human resources.

Each analyzed process (technological, financial, personnel, etc.) has its own discipline of development and, therefore, its own criteria for assessing feasibility. At the same time, these processes are closely related to each other as parts of the whole and, analyzing them separately, it is necessary to make a final assessment based on the analysis of their joint interaction and impact on the processes of the entire enterprise [22-24].

These processes are subsystems of the general system with their global development goal and its criteria. Perturbations of the external environment are perceived by subsystems in different ways, and the resource for compensating perturbations is formed either autonomously by the subsystem from its reserves, or with the involvement of centralized management [25].

When analyzing the options for achieving the goal, the issues of assessing the feasibility of the goals defined for the subsystem are considered, and it may turn out that the formed goals are unattainable under the given conditions and with the allocated resources. In this case, a problem arises associated with the need for system optimization, when targets and constraints are considered as variables. It becomes possible to vary the variables in a certain range and to solve the complex optimization problem by the criterion of generalized efficiency. This allows to get estimates of resources, timelines, etc. to predict the process of development of an enterprise as a system and its interaction with the external environment [26-28].

The decision maker (DM) regarding the enterprise development strategy is faced with the problem of analyzing the situation and assessing the way to implement the chosen strategy. First, the task of finding a set of acceptable actions is solved, and then the choice of the best strategy is made.

The procedure for finding possible solutions to a specific problem can be represented as a sequence of the following steps [29]:

- formulation of the problem (situation);
- forecast of the development of the situation;
- establishing diagnosis;
- collection of additional information;
- formation of a list of possible strategies;
- choosing the preferred strategy;
- forecast of the effectiveness of the chosen strategy;
- decision-making.

An enterprise is a complex organizational, technical and socio-economic open system associated with various objects, including the external environment, which is not fully manageable and controlled. The state of the external environment is determined by a large number of interrelated factors. The enterprise has a number of features that characterize it as a complex artificial, dynamic, purposeful system [30-32].

The main goal of the development of most industrial enterprises is the desire to improve the socio-economic situation. In a market economy, enterprises are faced with market instability, random fluctuations in competitors' strategies and risk factors when planning behavior strategies and forecasting development processes. Thus, the development of an industrial enterprise is mainly associated with the design, production and promotion of new competitive products on the market, according to the market demand [33-35].

The enterprise development management system is designed to ensure the integrity of the analysis and coordination of all processes and the optimization of options for business processes (production), organizational, financial and economic aspects of the enterprise [36, 37]. Planning and assessment of the feasibility of enterprise development plans is based on the formulated global strategic goal and the coordination of sub-goals of each of the incoming subsystems.

The transition from the conceptual stage of development management to the development of options for its practical implementation occurs on the basis of a pre-design study of various options and an assessment of the feasibility of achieving goals by individual subsystems and the global goal of the system in accordance with the strategic concept of development [38].

1.2 Analysis of enterprise development processes

Purposeful management of enterprise development can be carried out in various ways, depending on the content of the formulated goals, the criteria for their assessment and the definition of the concept of enterprise development as a process [39]. An uncontrolled process of development of an artificial system increases its entropy and leads to an increase in the unpredictability of its behavior [40].

Industrial enterprises with a discrete cycle of multinomenclature serial production are characterized by the peculiarities of business processes, determined by the type of products manufactured, the volume of output, the type of technological process, serial production, etc.

The enterprise interacts with the external environment, which includes [20, 21]:

• suppliers of materials and components;

• consumers of finished products;

• the legislative framework;

• financial situation in the country;

• competitors, etc.

It is necessary to study the state of the external environment and to predict the occurrence of destabilizing effects on the planned operation of the enterprise.

Manufacturing as a system for converting raw materials into tangible products is a multi-level hierarchical object for both management and development planning. There are three levels of production planning and management:

• strategic,

• tactical,

• operational (fig. 1.1) [41].

At the strategic level, a long-term plan for the development of the enterprise is developed on the basis of studying the market situation and assessing the state of the enterprise [42]. At the tactical level, plans are developed for production work, equipment modernization, and delivery schedules for materials, components, etc.

In the process of managing the development of an enterprise, various areas of its activities are considered, that is, the business processes of production and the associated tasks of ensuring environmental requirements.

The results of the analysis of the feasibility performed in the relevant structures of the enterprise are concentrated in the organizational subsystem to generalize and form complex options for their consideration by experts and decision-making by DM.

At present, a fairly large number of information support systems for design, planning and control of the functioning of existing industrial production systems have been developed.

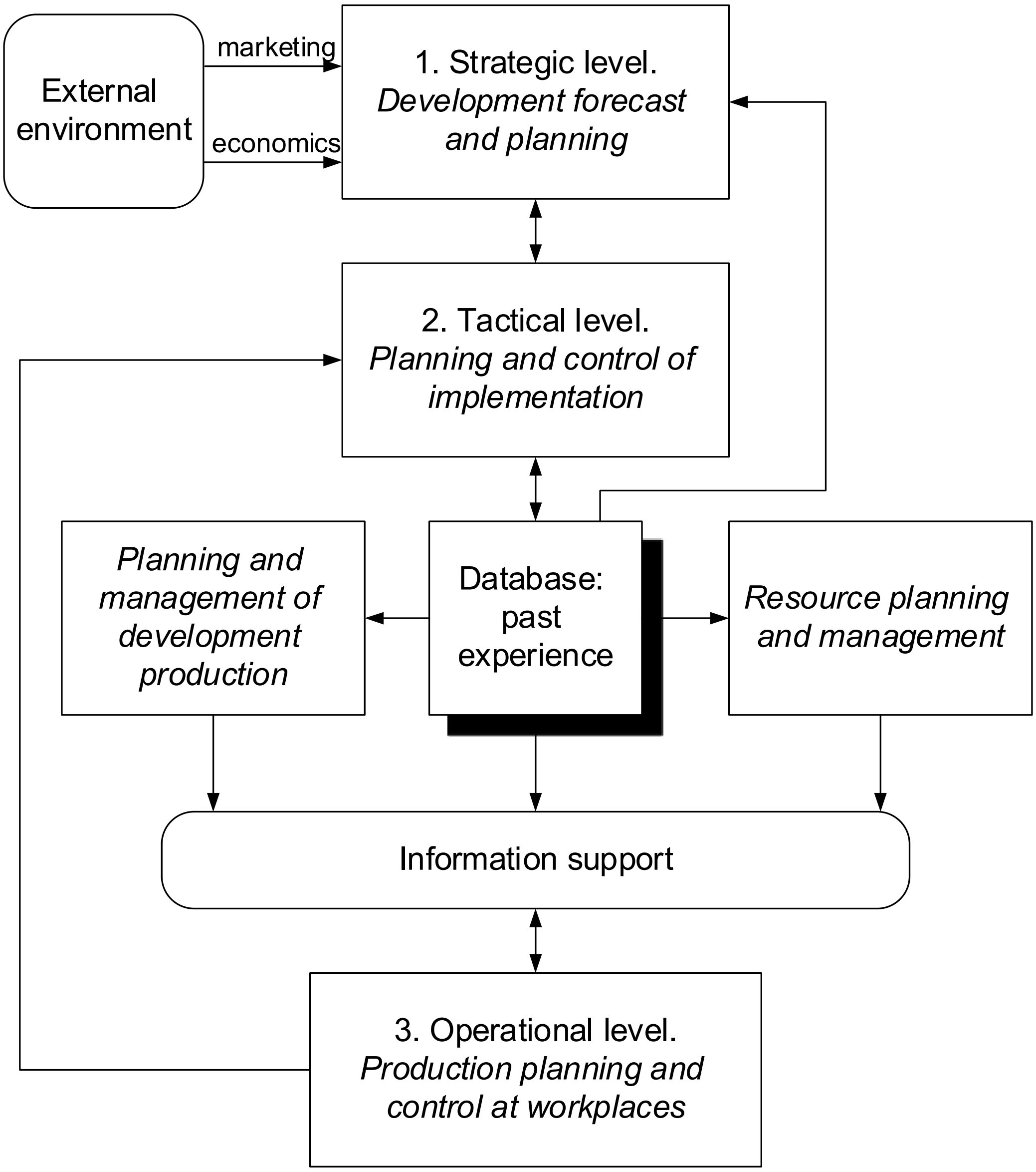

Fig. 1.1 Production planning and control levels

Planning for the development of an enterprise is an assessment of the possibilities of implementing each of the proposed options for each of the analyzed aspects and the development plan as a whole.

The assessment of the possibility of ensuring sustainable development of the enterprise is determined by the availability of appropriate resources (own and borrowed) and their rational use. In particular, it can be a resource balance formula of the form [18]:

$$\Delta W = W_q - W_p - W_m - W_s \tag{1.1}$$

where ΔW – free resources; W_q - revenue side resources; W_p - – resources of the consumable part, given to the external environment; W_m - domestic consumption resources; W_s - resources of insurance funds (protection against risks, stabilization of external influences). If $\Delta W > 0$, then resources for development are available.

However, in various forms of economic analysis of innovative activity, the resource is considered in terms of all its components in value terms. This is a necessary, but not sufficient condition for the plans to be implemented. It is necessary to take into account the scientific and technical level of competitors and the existing intellectual and material base of the enterprise.

The steadily developing enterprise plans a promising strategy for further functioning based on research, design and testing of experimental samples of its own production. The resources allocated for these works, if necessary, can be used to stabilize the arising disturbances.

The development fund, embodied in a portfolio of modernization projects and the creation of new samples of competitive products, can be used as a stabilization resource.

The development fund must be used to organize a continuous process of updating production and manufactured products, transforming its monetary content into the development of the intellectual base of the enterprise and equipping with advanced equipment.

Thus, an enterprise will be considered as consisting of two functional subsystems with their own management methods - a subsystem for managing the main production activity and a subsystem for planning and managing development based on the organization of the innovative process of creating competitive products.

1.3 Generalized description of the production process and the main criteria for its evaluation

The main contribution to the formation of such properties of products as reliability, competitiveness, cost, etc. belongs to the production stage and its main component - the technological process [43]. Thus, the main characteristics of a product that provide its market advantages depend on the level of design projects and the perfection of the product manufacturing technology.

In modern market conditions, large-scale production is being replaced mainly by small-scale, constantly modernized and renewed production, which is able to quickly respond to fluctuations in the market situation. This circumstance forces us to quickly develop and implement new technological processes, equipment, materials, etc.

One of the ways to reduce the time for the development of technological processes, and, consequently, production as a whole, is to use the previous experience in project development [44].

Separate structures and functional components of production react with different degrees to operational change of external environment leading to change of production functioning. In addition, various types of production, type of products, serial production, etc. also affect the mobility of reactions to external influences. The situation considered to the greatest extent concerns enterprises working for the consumer market and, to a lesser extent, for manufacturers of standardized products, where mainly supplies are made under long-term contracts.

For the classification of industries, various characteristics can be selected, for example, the complexity and volume of production, the type of technological process, the level of automation, etc. Such characteristics as the complexity, volume, rhythm and serial production are most often used as initial information for making decisions at the initial stages, planning the release of new products or modernization of production [45].

The set of possible options for the structure of the technological process is determined, on the one hand, by the given characteristics of production, on the other hand, the options may differ in internal design-inherent properties, such as the level of typification, flexibility, level of automation, etc.

The second central research issue is the task of evaluating options and choosing the acceptable. As part of solving this problem, it is necessary to determine a list of characteristics for comparing options and how to measure them. For this purpose, below we consider the main issues of organizing TP, characteristics of their properties, equipment, TP typification, etc.

In general, the production system consists of two subsystems: an organizational subsystem and a technical one [38]. Fig. 1.2 shows a typical structure of a technical subsystem.

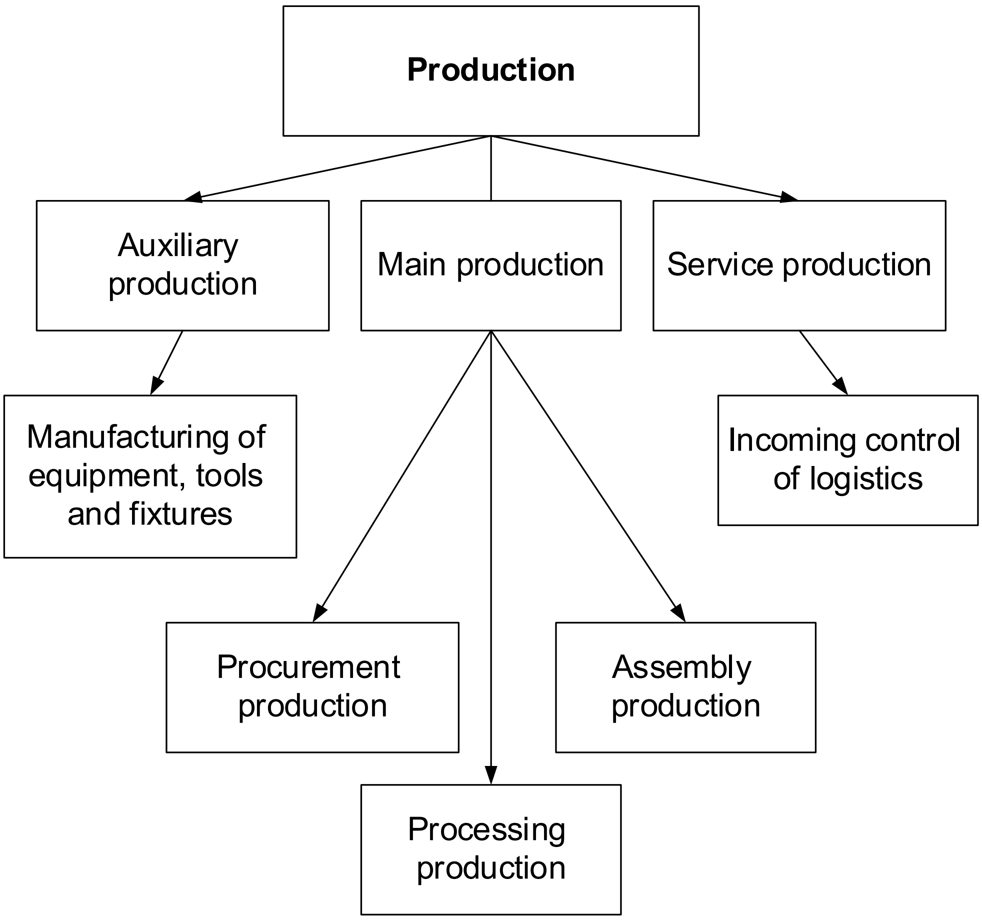

Fig. 1.2. The main elements of the technical subsystem of production

The basis of the technical subsystem is made up of technological production processes, which consist of separate operations [46, 47]. The set of operations located in a time sequence constitutes the operational technological process (OTP).

At the pre-project planning stage, when assessing the feasibility of possible TP options, the information obtained at the first stage of technological preparation of production (TPP) is of greatest interest, which consists in the development of requirements for planning material and technical supply, calculating the consumption rates of materials and components and determining the labor intensity by type of work. At the same time, an assessment of such production parameters as time, resource, personnel and environmental parameters is carried out. This information is used in assessing TP options and making decisions on the choice of long-term plans for the development of the enterprise.

Modern trends towards a reduction in the share of mass production towards an increase in small-scale production can lead to an increase in the cost and terms of production preparation and, as a consequence, to an increase in the price of manufactured products, and, accordingly, to a decrease in the profitability of production. The reduction of this negative impact can be regulated by such a criterion for assessing TP as flexibility, determined by the share of use of universal equipment and existing equipment. At the stage of pre-design analysis of the technological feasibility of development plans, it is necessary to take into account the possibility of increasing flexibility through design and technological design solutions.

The scientific, methodological and applied basis for the technological preparation of small-scale production, which increases its efficiency, is the typification of technological processes and group processing of parts. These characteristics of TP are criteria for assessing and choosing an acceptable option for organizing the production process.

The choice of the TP option is largely determined by such product design parameters as manufacturability [45].

The indicator of the coefficient of continuity is also involved in the assessment of TP options. It is most essential for such characteristics of business processes as timing, costs and quality.

Let's list the main features and tasks of work at the stage of pre-project analysis and management decision-making.

1. The modern market economic policy has moved away from the mass production of the same type of goods. The market situation forces to switch to expanding the range of products in small batches due to the modernization of existing samples and the release of new ones.

2. The implementation of this strategy largely depends on the mobility of the manufacturer's production base and its ability to quickly and cost-effectively rebuild, using the experience of past developments and available external borrowing.

3. The ability of production to adapt to the market situation in a mobile way is determined by the properties of the technological process of the main production.

4. Decision-making should involve a comparative selection of options, the assessment of which should be made promptly and without significant costs for a detailed study of each option.

5. Representation of TP in the form of a set of functionally completed in time independent blocks makes it possible to create on their basis a computer base of accumulated experience, which allows you to quickly consider various options for a possible construction of the production process.

1.4 Overview of decision-making methods

The widespread use of information technology in industry and the economy has now become a significant factor in improving the quality of planning and management of enterprises. The high level of instability of the external environment forces us to develop and use methods of prompt response to external disturbances, relying on the means of automating intelligent processes for managing the development of an enterprise. Therefore, an important task is to formalize decision-making processes as the basis for the procedure of purposeful activity to manage the development of an enterprise.

The founder of decision support methods is D.A. Pospelov [48]. The ideas of logical-linguistic management, developing the ideas of situational management, for the first time made it possible to create models that describe the knowledge of specialists in complex non-deterministic subject areas with fuzzy logic and vague definitions.

To date, the following methods are known in the theory of decision support.

Utility theory methods. D. Sedvizh developed an axiomatic theory that allows you to simultaneously measure utility and subjective probability [49]. This is reflected in the subjective expected utility (SEU) model, where probability is defined as the degree of confidence in the occurrence of an event. The advantage of the model is the ability to select the parameters of the SEU model. As a result, the main task is presented in the form of a decision tree (DT) [50]. In some of the vertices of the DT, the choice is made directly by the decision maker, in the other part - on the basis of the subjective probability of the occurrence of events. The decision tree ends with outcomes, each of which is assigned a certain utility. The probability of each outcome is calculated as the product of subjective probabilities on the path from the top of the DT. By "folding" the DT from end to beginning, the outcome with the highest subjective expected utility is selected. The decision tree method allows decision makers to determine the optimal sequence of actions, taking into account personal assessments and preferences. The main drawback of the axiomatic theory is the unverifiable nature of the axioms.

Prospect theory methods [51]. Prospect is a game with probabilistic outcomes. The methods take into account three behavioral effects: the certainty effect - the tendency to give more weight to deterministic outcomes; reflection effect - to the measurement of preferences in the transition from gains to losses; isolation effect - a tendency to simplify choices by eliminating common components of solution options. The disadvantage is that this method does not solve all the problems that arise when studying the behavior of people in the problems of choosing a solution.

ELECTRE method. B. Roy proposed a constructive approach to the development of solutions, in which methods, models and concepts are considered as auxiliary means of practical analysis of the situation [52]. These tools make it possible to understand the goals of decision making and better understand the preferences of the decision maker [53]. The disadvantage of ELECTRE methods is that they are auxiliary tools and not a way to come up with a better solution [54].

Hierarchy analysis method [55-57]. This is a decision-making method based on a multi-criteria description of the problem. The method uses a criteria tree, in which general criteria are divided into criteria of a particular nature. For each group of criteria, importance coefficients are determined. Alternatives are also compared with each other according to separate criteria in order to determine each of them. Pairwise comparison is a means of determining the coefficients of the importance of criteria or the criterion value of alternatives. The comparison result is assessed on a point scale. On the basis of such comparisons, the coefficients of the importance of the criteria are calculated, the assessment of alternatives, and the overall assessment is found as a weighted sum of the assessments of the criteria. In the course of a detailed study, the following shortcomings were identified: mismatch of estimates associated with difficulties in assessing the relations of complex elements; the recalculation of the ratios of the significance of elements into their importance is carried out by an approximate method.

Heuristic methods. Heuristic methods are described in the works of J. Jones [58], I. Muller [59], and A.I. Polovinkin [60]. An example of a heuristic method is the compensation (or interference) method. This method is used for pairwise comparison of alternatives. The advantage of heuristic methods is simplicity and convenience, and the main disadvantage is that they all have no scientific basis.

Methods and models of knowledge and artificial intelligence [61-64]. These models are conventionally divided into declarative and procedural. In declarative models, knowledge is presented in the form of descriptions of objects and relations between objects without explicitly specifying how to process this knowledge. Such models imply the separation of descriptions of information structures from the inference mechanism operating with these structures. In procedural models, knowledge is represented by algorithms (procedures) that contain the necessary descriptions of information elements and at the same time determine how to process them. The concrete models used in practice are a combination of declarative and procedural representations. The most common are logical, production, network and frame models of knowledge representation.

The analysis showed that the considered methods, which form the basis of the theory of decision-making, are often axiomatic and heuristic in nature, i.e. do not have a rigorous scientific proof (they are presented in the works of L. Aleksandrov [65], N. Vvedensky [66] and Yu. Vermishev [67]).

The content of the decision-making procedure can be defined in four stages:

• goal formation;

• determination of the set of possible ways to achieve it;

• development of a method for evaluating options;

• choosing the best solution.

Thus, the problem of evaluating and choosing an option is part of a more general decision-making problem, which in turn is part of systems analysis and systems theory [68, 69]. A *system* is understood as a set of elements on which a certain set of relations is implemented, which order the elements into a structure that has a set of properties that ensure the achievement of the set goal.

The implementation of the stage of evaluating options is associated with the need to move from qualitative linguistic variables to a certain metric of a given set of particular criteria of options [70, 71]. The complexity of solving the problem of multivariate estimation is due to the multidimensionality of the factor space and the heterogeneity of its dimensions, intervals of possible values, etc. Thus, the problem arises of constructing a multivariate estimation model that corresponds to a certain decision-making situation.

From a formal point of view, the choice of the best version of the system from the admissible set is the main task of decision-making, and the main stage of assessment is the determination of the best solution.

Difficulties in deciding on the choice of the best option in multicriteria problems arise in situations where one particular criterion cannot be improved without deteriorating at least one other criterion. This situation is identified with the so-called area of compromise (Pareto area). In the general case, the solution of compromise problems can be carried out by introducing some additional rule, the principle of optimality, which makes it possible to decide on the choice of the only best option [72].

Basically, a decision on the choice of an option can be carried out on the basis of one of two approaches [73]:

• heuristic (informal), when the ranked series is formed by the decision maker on the basis of intuitive considerations;

• constructive (formal), when a certain principle of optimality (compromise) is formed on a set of contradictory particular criteria [74].

The problem of making a multicriteria decision can be formulated as follows. A set of possible solutions X and a set of particular criteria $K=\{K_i\}$, $i=\overline{1,n}$, characterizing each of these solutions are given, and there is information about the mutual importance of particular criteria $I(a_i)$. It is necessary to find (accept) the best solution x° from the given:

$$x^\circ = \arg \underset{x \in X}{extr}\, P(x), \tag{1.2}$$

where $P(x)$ is a utility function.

The theoretical basis for the formation of multicriteria scalar estimates is the utility theory, which assumes the existence of a quantitative assessment of the preference of solutions in the sense that if the solutions $x_1, x_2 \in X$ and $x_1 \succ x_2$ (x_1 is preferable than x_2), then the utility function

$$P(x_1) > P(x_2).$$

The construction of a mathematical model, including the utility function, provides for the need to solve two problems - structural and parametric, i.e. identification of factors influencing the output and definition of structure, i.e. the kind of operator that establishes the connection between the input and output data of the model. The second task is related to the determination of quantitative values of the model parameters. The form of the decision utility function *x* is determined by the particular characteristics $K_i(x)$, which have different weights for the decision maker. Then the utility function is defined as:

$$P(x) = F\left[\lambda_i, K_i(x)\right], \quad i = \overline{1,n}, \tag{1.3}$$

where λ_i is an isomorphism coefficient of the *i*-th particular criterion $K_i(x)$, F – operator that determines the type of dependency.

The operator *F* can be specified in the form of the two most well-known ways of representing the utility function [89] - additive

$$P_k(x) = \sum_{i=1}^{n} \lambda_i K_i(x),$$

and multiplicative

$$P_k(x) = \prod_{i=1}^{n} \lambda_i K_i(x).$$

Particular criteria describe different properties of variants and therefore have different dimensions and ranges of values. Thus, a form of representation of the utility function is needed, which makes it possible to take into account the importance of particular criteria, and at the same time bring dissimilar $K_i(x)$ to the same measurements. Such requirements are implemented by representing the utility function in the form:

$$P(x) = \sum_{i=1}^{n} a_i K_i^H(x), \tag{1.4}$$

where a_i – relative weights coefficients $0 \le a_i \le 1$, $\sum_{i=1}^{n} a_i = 1$, $K_i^H(x)$ – normalized partial criteria.

The construction of such a model is made in several stages:

- reduction of all particular criteria $K_i(x)$ to isomorphic form;
- determination of methods for obtaining information from the decision maker about the values of the coefficients a_i;
- definition of the operator F in the utility function.

A constructive approach to decision making is focused on defining formal rules for choosing a single solution from the area of compromises [76]. Two cases are possible.

1. Decisions are ranked in the order of decreasing or increasing quality on the plural of compromise X^c or on the entire admissible plural X, that is, strict $x_1 \succ x_2 \succ \ldots \succ x_n$ or non-strict $x_1 \succ x_2 \sim x_3 \succ x_4 \succ \ldots \succ x_n$ order is determined, where $\succ$ and $\sim$ are signs of advantage and equivalence, respectively; then find the extreme element of the series.

2. Directly determine the extreme solution $x^{\circ} \succ \forall x \in X$.

The general approach to solving this problem is to transform a multicriteria problem into a one-criterion problem with a scalar criterion. There are several ways to transform multi-criteria optimization problems into single-criteria.

The *principle of the main criterion* is based on the selection of the main criterion and the translation of all other criteria into a limitation [77]. For this, an analysis of the features of a multicriteria problem is carried out; the most important one is selected from a set of criteria, which is taken as the only optimization criterion. For each of the other criteria, a limit value is assigned, below which it cannot fall. The choice of the main criterion and levels of restrictions $k_{iH\Gamma}(x)$ for all other criteria is a subjective operation carried out by experts or decision makers.

Functional cost analysis [78]. The initial number of particular criteria $K=\{\kappa_i(x)\}$, $i=\overline{1,n-1}$, is divided into two subsets:

$$K_F = \{k_j(x)\},\ j=\overline{1,m} \text{ and } K_V = \{k_l(x)\},\ l=\overline{1,L};\ m + L = n.$$

The first group of criteria K_F characterizes the functional quality of the solution, that is, the degree of achievement of the goals of the system. The second group K_V - costs required to implement the solution *x*. One main criterion is distinguished from each subset; denote them respectively K_F^* and K_V^*, and other particular criteria are transferred into limitation. We get an optimization problem with two scalar criteria. Therefore, there is a need to bring the constructed problem to a single-criterion by one of the following methods.

1. If both criteria K_F^* and K_V^* have the same measurability or they can be transferred to the same measurability, then a generalized optimization criterion is used

$$K_1(x) = K_F^*(x) - K_V^*(x), \tag{1.5}$$

and the optimal solution is determined according to the scheme

$$x_1^0 = \max_{x \in X}\left[K_F^*(x) - K_V^*(x)\right], \tag{1.6}$$

where X^* - the area of feasible solutions narrowed by additional restrictions.

Criterion $K_1(x)$ can be interpreted as system profit.

2. If the criteria K_F^* and have different measurability, the form of the generalized criterion is used

$$K_2(x)=\frac{K_F^*(x)}{K_V^*(x)}, \tag{1.7}$$

and the optimal solution has the form

$$x_2^0=\max_{x\in X}\left[\frac{K_F^*(x)}{K_V^*(x)}\right]. \tag{1.8}$$

Criterion $K_2(x)$ is the effect of the system normalized per unit of expenditure.

3. To reduce a two-criterion problem to a one-criterion problem, the principle of the main criterion can be used.

The principle of sequential optimization (lexicographic ordering). The idea of this method is to transform a multicriterial optimization problem into an ordered sequence of one-criterion. To do this, all private criteria are ordered in a sequence of decreasing importance: k_1 f k_2 f ... f k_n.

In accordance with the principle of sequential optimization of solutions $u \in X$, $v \in X$ the first is more important, that is u f v, if the conditions are met

$$k_j(u)=k_j(v),\quad k_j(u)>k_j(v),\quad j=\overline{0,i},\quad i=\overline{1,n}. \tag{1.9}$$

Hence, the best solution is determined according to the following scheme. At the first step, from the initial set of feasible solutions *X,* a subset x_1^0 of solutions is selected that are equivalent according to the first (most important) criterion. For this, the one-criterion optimization problem is solved:

$$x_1^0=\arg\max_{x\in X}k_1(x). \tag{1.10}$$

If the set x_1^0 contains more than one solution, go to the next stage, that is, we solve the problem of choosing equivalent solutions according to the second most important criterion, but already from the set x_1^0:

$$x_2^0 = \arg\max_{\substack{x \in X \\ x \in x_1^0}} k_2(x). \tag{1.11}$$

Optimization continues until we get a single solution at the *i*-th step or all the criteria are exhausted. If all the private criteria are exhausted, but the only solution is not received, additional criteria are formed.

Formation of a generalized scalar criterion that takes into account all private criteria. In this case, the only criterion $\overline{K}$ is formed as a functional of particular criteria

$$\overline{K} = F\left[k_i(x)\right], \quad i = \overline{1,n}. \tag{1.12}$$

This is the most general and universal approach to solving the multicriteria optimization problem, known as the multivariate estimation problem. The central task of this problem is the synthesis (identification) of the model for the formation of a generalized assessment.

2 STRUCTURAL AND PARAMETRIC MODELS OF TECHNOLOGICAL PRODUCTION PROCESSES

2.1 Generalized model of resource provision for development plans of enterprises

For enterprises producing consumer goods or products under contracts, the main incentive for the formation of an innovation program is the results of market monitoring and analysis of competitors' behavior strategies. On the basis of this, a development strategy plan is formed in the organizational system of the enterprise, which is based on a program for the modernization of products or the development of new product samples.

The implementation of these programs is mainly carried out in the field of production, and success is determined by the level of business processes, technical and personnel security. The innovative component of the development plan is less concerned with changing the functional purpose of the planned modernization and is mainly associated with the finalization of the design, the use of new materials, technological processing processes and the corresponding technological equipment and specialists of the required qualifications.

Thus, the development of a development strategy associated with the development of new types of products is mainly based on assessing the technological feasibility of plans in the required time frame.

The production system fulfills the set development goals due to its inherent properties of a different nature and, above all, properties of a systemic nature [17]. A goal-oriented system can be represented as

$$S = \langle E(t), R(t), P_z(t) \rangle \tag{2.1}$$

where $E(t)$ – a set of system elements and properties; $R(t)$ – a set of quantitative characteristics; $R_z(t)$ - a subset of properties that allow the system to achieve a given goal.

In the process of functioning, the system spends a certain amount of the planned resource $W_p^н(t)$, part of it $W_p^x(t)$ is allocated for the development resource.

The analysis of the state of the external environment provides information for predicting and taking into account random perturbations on the system from the worst $B^х(t)$ to the best $B^н(t)$. Then the resources are distributed as follows: $W_p^x(t)$ - to compensate for perturbations $B^х(t)$ and $W_p^н(t)$ - to compensate for perturbations $B^н(t)$.

Then if $W_p^н(t) \geq W_p^x(t)$, the value of $W_p(t)$ should be considered as a means of stabilizing the functioning of the enterprise and as a means of forming new strategies.

Internal disturbances are associated either with a violation of the production schedule of work due to technological reasons or errors in the documentation, or due to emergencies of various natures. In the first case, the situation is restored without significant material losses. In the second case - emergency situations - material costs are compensated by insurance organizations, and disruptions in delivery terms under contractual obligations are provided in force majeure terms of contracts.

The most characteristic external disturbances can be considered the deterioration of market conditions, leading to falling demand and changes in monetary policy by the state in the worst direction for the company.

The success of competitors in the market must be contrasted with their achievements in the field of modernization of products or the creation of new product models. Given the high inertia of socio-economic systems, compensatory management should be carried out with anticipation of the most effective means of stabilizing market conditions.

Efficiency of entering the market with new products can be ensured if there are options for new products with varying degrees of completion. To implement this requirement requires a management system of innovation in the enterprise as a means of ensuring sustainable development.

At present, such an approach to the analysis of development processes has not been sufficiently applied due to the lack of scientifically sound methodology and tools for information support for decision-making in the field of development strategy, selection of possible development options and evaluation of their feasibility at the pre-project development planning stage.

The analysis of the process of enterprise development can be represented by some stages, reflecting the composition and interaction of the elements of the considered subsystems and the system as a whole.

At the stage of formation of goals and strategies of their achievement, displays are performed:

$$M_s^* \times W_0 \times P_k \times C \xrightarrow{\tilde{R}\,(n)} S_p,$$

$$S_p \times J \times C \xrightarrow{\tilde{R}\,(n)} P_{\text{тэ}}, \qquad (2.2)$$

$$Z \times P_{\text{тэ}} \xrightarrow{\tilde{R}\,(n)} K,$$

where M_s^* - strategic plans for enterprise development; W_0 - the amount of resources for enterprise development; P_k - structure of competitiveness indicators; C - options of subjects of external environment behavior; J - set and characteristics of economic relations of the enterprise with the external environment; S_p - a general list of possible development strategies; $P_{\text{тэ}}$ - the composition of the technical and economic indicators strategies used to assess the options; Z - many goals achieved by the company through strategies; K - a set of decision evaluation criteria.

The symbol $\tilde{R}\,(n)$ indicates that the mapping is the result of heuristic procedures for the formation of variants and criteria for their evaluation.

Following the mapping (2.1), a set of possible innovations, their characteristics and implementation technologies is formed:

$$Q_0 \times S_p \times Z \times M_{\text{T}} \xrightarrow{\tilde{R}\,(n)} Q, \tag{2.3}$$

where Q_0- possible (initial) set of innovations; M_{T}- set of production technologies.

Next, the allocation of W_0 resources to various innovation plans W_1 is carried out.

$$Q \times W_0 \xrightarrow{\tilde{R}\,(n)} W_1 \tag{2.4}$$

and evaluation of results L_1 for each innovation

$$Q \times M_0 \times C \xrightarrow{\tilde{R}\,(n)} L_1. \tag{2.5}$$

At the final stage of the development strategy, innovative resources are allocated to the stages of the innovation life cycle.

$$Q \times W_1 \times \mu \xrightarrow{\tilde{R}\,(n)} W_2$$

$$Q \times L_2 \times \mu \xrightarrow{\tilde{R}\,(n)} L_1, \tag{2.6}$$

where W_2- a set of resource allocation plans for life cycle phases; μ - stages of the innovation life cycle.

Thus, a generalized model of enterprise development management is proposed in the form:

$$V_p = V_p\big(W_0, S_p, Q, W_1, L_1, W_2, L_2\big). \tag{2.7}$$

The enterprise development script C_p can be presented as follows:

$$\text{C}_p = (V_p, W_0, \text{C}_s, \Theta(V_p)), \tag{2.8}$$

where V_p- development management; C_s- possible scenarios of environmental subjects behavior; Θ - set of parameters of enterprise development trajectory.

Theoretical-multiple representation of the processes of enterprise development allows to form practical problems of development management in terms of management theory in dynamic systems. These are definition tasks:

- control V_p for the required trajectory Θ,
- possible development trajectories under a given management,
- criteria for optimizing the development process at given parameters of controls V_p,
- C_s script and trajectories.

On the basis of the formed generalized model it is possible to carry out the analysis of processes of development of the enterprise that allows to consider from uniform positions functioning of elements and system of production both in the course of the main activity, and in the course of development.

2.2 Formation of variants for technological processes based on a precedent approach

When assessing the technological feasibility of enterprise development plans, information is needed, which is formed from the analysis of technological documentation of basic samples of past developments.

To solve this problem, an archive of past developments is used, in particular, technological solutions, which stores information necessary for decision-making at the pre-project stage of enterprise development planning. Of particular interest are the requirements for the equipment of the technological process with equipment and facilities, as well as labor intensity by type of work. This information can be obtained from the analysis of documentation of past developments, in particular, for the base sample, the most suitable in terms of parameters for the planned products. Search and selection of basic samples-analogues is made in the system of precedent type taking into account the degree of similarity to obtain the necessary information about the type of TP, the required equipment and complexity of the work. The difference between the individual parameters of the base sample and the planned depends on the volume and content of the upgrade.

In general, the procedure for assessing the feasibility of the development plan of the enterprise consists of solving a sequence of tasks:

- description of the scope and content of the planned innovation;
- search and selection of possible analogues in the works of past periods;
- selection of the basic sample-analogue and assessment of its degree of similarity with the planned one on the set of formulated parameters of comparison;
- development of models of functioning of subsystems and as a whole production process for an estimation of such parameters as productivity, rhythmicity, volume of unfinished production and others necessary for carrying out an estimation of technical and economic indicators;
- modeling and evaluation of technological equipment and control system depending on the planned volume of production.

A feature of the decision-making process when choosing an option for enterprise development is the need to analyze large amounts of information in the presence of time constraints to assess options and a significant level of uncertainty inherent in the pre-project stage. On the other hand, the process of forming options as a basis for selection is a non-trivial decision-making task, especially at the pre-project stage. The possibility of missing an acceptable option reinforces the importance and responsibility of this stage. When forming the list of possible options, various methods of information retrieval are used, including the method of analogies (precedents), based on the use of experience of past developments.

According to the provisions of precedent theory, also known as Case-Based Reasoning (CBR), a *precedent* is an information block that includes a basic situation, a corresponding solution, and a list of direct performers. In the process of professional activity in some area problem-oriented precedents are formed, which accumulate in the store, which can be traditional databases, specialized knowledge servers, multidimensional databases, archives, etc. The situation for which a precedent has been set is hereinafter referred to as the reference or baseline.

It is proposed to use a precedent approach [79] to make decisions on the choice of production development option, which allows to solve the problems of decision support in complex poorly structured systems. The choice of this approach is due to the fact that often at the production plant by the time of the problem of new products or its modernization has already accumulated considerable experience in solving similar problems that arose earlier [80, 81].

The solution of the problem by analogy is based on recognizing the current problem situation, information about which is presented in the form of an image (analogue), and finding similar images contained in the image store (precedent database), followed by their adaptation and reuse to solve research problems.

Decision-making based on a precedent approach involves solving the following set of tasks:

- the choice of how to present knowledge about the situation and possible solutions;
- determination of the method of search and selection of technological solutions in the store of precedents;
- development of a method for identification and adaptation of solutions.

A typical precedent is a structure that consists of a description of the problem that characterizes the situation at the time of activation of the precedent, and a solution that contains possible options for decision-making.

The algorithm for creating a base of precedents includes the following phases:

1) determination of the weights of the features to assess the level of significance of the precedent in the database under consideration;
2) clustering of precedents by identified features;

3) search for the required set of precedents based on the criterion of similarity of situations.

In phase 1, the evaluation function of the features is determined - the smaller (or larger) the value of this function, the more important the corresponding feature. The evaluation function allows further selection of relevant precedents, using a similarity relationship based on many of the most important features.

For a given set of feature weights $w_j \left(w_j \in [0,1], j = 1,...n \right)$ and a pair of precedents e_p and e_q, let's define a weighted measure of proximity as

$$d_{pq}^{(w)} = \left(\sum_{j=1}^{n} w_i^2 \left(x_{pj} - x_{qi} \right)^2 \right)^{\frac{1}{2}}, \tag{2.9}$$

and a measure of the similarity of precedents

$$SM_{pq}^{(w)} = \frac{1}{1 + d_{pq}^{(w)}}, \tag{2.10}$$

where x - features values.

If all weights w are the same and equal to 1, then the proximity measure corresponds to the Euclidean measure and is denoted as d_{pq}, and the corresponding measure of similarity – SM_{pq}.

The feature evaluation function is defined as follows:

$$E(w) = \frac{2\left[\sum_{p} \sum_{q(q<p)} \left(SM_{pq}^{(w)} \left(1 - SM_{pq} \right) + SM_{pq} \left(1 - SM_{pq}^{(w)} \right) \right) \right]}{N(N-1)}, \tag{2.11}$$

where N – number of precedents in the precedent base.

In phase 2, the precedent base is clustered.

The clustering of the precedent base is used to accelerate the sampling operations of similar precedents and the preliminary division of the precedent base into compact coverage sets.

The clustering algorithm is based on the category of similarity in expressions (2.9), (2.10) and has the form:

1) the significance level is set (threshold level) $\beta \in [0,1]$;

2) the modified similarity matrix is determined,

$$SM1 = \max_k \left[\min\left(SM_{pq}^{(w)}, SM_{kq}^{(w)} \right) \right]; \qquad (2.12)$$

3) if $SM1 \subset SM$, then individual clusters are defined based on the rule: "precedent p and precedent q belong to the same cluster if and only if $s_{pq} \geq \beta$, otherwise, the *SM* matrix is replaced by *SM*1 and a return to step 2 is performed".

After the original database is divided into separate clusters, it is possible to implement the procedure for searching for similar precedents based on the similarity relationship.

In a precedent-based decision support system, the time spent on finding a solution is significantly reduced, resulting in increased system performance.

The precedent selection function is the main function for the implementation of the mechanism for finding a technological solution, the appropriate equipment and performers, and is the technical side of decision-making.

To determine the list of potential options for work, it is necessary to describe the main TP of production in terms of existing categories. The objects of concepts describing the TA are classified according to the available categories, the connections between them are described and then the TP is searched in the database of technological solutions close to the described one. As a result, to search for TP options, an analysis of all technological solutions similar to the planned one is made on the basis of a given similarity ratio.

For pairwise comparison of initiating precedent with selected versions, deviations of characteristics of planned TP from reference ones, which we denote, are calculated Δx_i. Characteristics x_i must be normalized and lead to isomorphic appearance [82]. To do this, you can use the utility function (1.4).

The task of ranking and selection of precedents based on similarity assessment is carried out by multifactor generalized assessment of the "distance" of the characteristics of the planned TP from the reference, which has the form:

$$L = \sum_{i=1}^{n} a_i \Delta x_i , \qquad (2.13)$$

where a_i – weighting factors that determine the significance of individual characteristics in relation to others, $\sum_{i=1}^{n} a_i = 1$, $0 < a_i \le 1$.

The principle of optimality:

$$x^{\circ}{}_{\Pi} = \arg\min_{x \in X} \sum_{i=1}^{n} a_i \Delta x_i . \qquad (2.14)$$

According to this principle, the reference TPs are ranked according to the degree of similarity to the planned one.

2.3 Structural models of technological operations and processes

When looking for a solution on the best organization of the technological process, one has to deal with information of various nature, metrics and the degree of impact on the target criterion.

To use the experience of past developments, the information of the first stage of pre-project research should be formed and stored in a compact form in the amount required for operational analysis, modelling and management decision-making.

Since the technological operation is the main structural unit of the technological process and on its basis the principle of unified part and group technical process of processing is built, it is necessary to use a method of compact, informative and visual representation of the postoperative technological process and resources for its implementation [83]. Functional connections between TP operations depend on the type of operation performed and the composition of technical means.

The variety of technological processes of production significantly complicates their study, comparison and evaluation. Due to the many parameters inherent in different technological processes, it is difficult to formulate generalized evaluation criteria, as their significance will be different for the compared options. This circumstance significantly complicates the ways of presenting technological processes in the archive of precedents, especially the structural part of the TP. For the tasks of pre-project analysis of the structure and resource parameters of technological processes, it is necessary to be able to formalize the structures of TP for a set of generalized unified operations, which carry information on such parameters as labor intensity, required equipment and equipment. This information is necessary to assess the feasibility of the development plan of the enterprise in terms of equipment, composition of employees by type of work, etc.

An analysis of the technological processes of various industries shows that the operations of processing, assembly, disassembly (distribution), cutting (stamping), control, and testing exhaust their entire set. To create a unified structural model of the process operation, we will enter the following three characteristic parameters: number of inputs - n_{in}, number of outputs - n_{out} and registration coefficient of transfer of the process operation K_{ac}.

The registration transfer coefficient for the i-th input and the j-th output K_{reg}^{ij} will be called the coefficient of the countable number of physical units of materials, components, assemblies, etc. of the j-th output of the technological operation y_{outj} to the countable number of physical units of materials, assemblies and products y_{ini} received at the input of the technological operation.

Then we can give the following description of the types of technological operations and the structure of the TP in general.

Processing - an operation having for the workpiece one input $n_{in} = 1$ and one output $n_{out} = 1$; respectively, the registration transfer coefficient $K_{reg}^{ij} = 1$.

This means that the number of products received for the operation is equal to the number of products exited from it. The emergence of waste, marriage, etc. after the operation means that this operation is a set of operations "processing" and "control", even if the latter is not specified in the structure of the technological process. The purpose of the operation is to perform any technological processing procedure on the products, for example, to change the physical or geometric parameters of the product.

Assembly – an operation that has several inputs $n_{in} = N$ and one output $n_{out} = 1$ with a registration transfer coefficient $K_{reg}^{ij} < 1$. The purpose of the operation is the aggregation of products, for example - the manufacture of assemblies from parts.

Disassembly (distribution) - an operation that has one input $n_{in} = 1$ and several outputs $n_{out} \geq 2$ for the processed product with a registration transfer coefficient K_{reg}^{ij} for any output> 1. The purpose of the operation is to disaggregate the assembly units, to distribute a set of identical parts into several threads.

Cutting (stamping) - an operation that has one input $n_{in} = 1$ and several outputs $n_{out} \geq 1$ with a registration transfer coefficient $K_{reg}^{ij} \geq 1$. The purpose of the operation is the transition from group technology to single product processing.

Control - an operation that has one input $n_{in} = 1$ and several outputs $n_{out} \geq 2$ with a registration transfer coefficient $K_{reg}^{ij} > 1$ for any output. The purpose of the operation is to check the quality of products, aimed at sorting (ie distribution by groups) of products. For the control operation, the transfer ratio at the *i*-th input K_y^{ij} is a random variable with a mathematical expectation $M\left[K_y^{ij}\right]$ and a random deviation of σ_K.

Training - an operation that has one input $n_{in} = 1$ and one output $n_{out} = 1$, the registration transfer coefficient $K_{reg}^{ij} = 1$. The purpose of the operation is to improve the quality of products.

Test - an operation with one input and one output with a registration transfer coefficient $K_{reg}^{ij} = 1$. The purpose of the operation is to check the quality of the product.

For the operations considered above it is possible to make table 2.1.

Table 2.1 *Characteristic parameters of technological operations*

Operation	Number of inputs		Number of outputs		Registration transfer coefficient
	maximum	minimum	maximum	minimum	
Processing	1	1	1	1	1
Training	1	1	1	1	1
The test	1	1	1	1	1
Cutting	1	1	1	1	>1
Assembly	N	2	1	1	<1
Disassembly	1	1	N	2	>1
Control	1	1	N	2	>1

The table allows to analyze the structures of operations. From it, in particular, follows:

1) the structures of the operations "processing", "training", "test", "cutting", "disassembly" are special cases in relation to the operations "assembly" and "control" and therefore can be excluded from further consideration;

2) the minimum number of inputs in the structure of operations "assembly" and outputs in the structure of operations "control" may not be less than two.

Thus, the set of minimum unified structures of technological operations can be limited to two operations: A and B (fig. 2.1).

Since any technological operation at the output other than the main suitable products may have a marriage, waste, etc., i.e. have several outputs, which can be performed only in the presence of automatic or manual control, you can combine operations A and B into one unified operation, the minimum structure of which is shown in fig. 2.2.

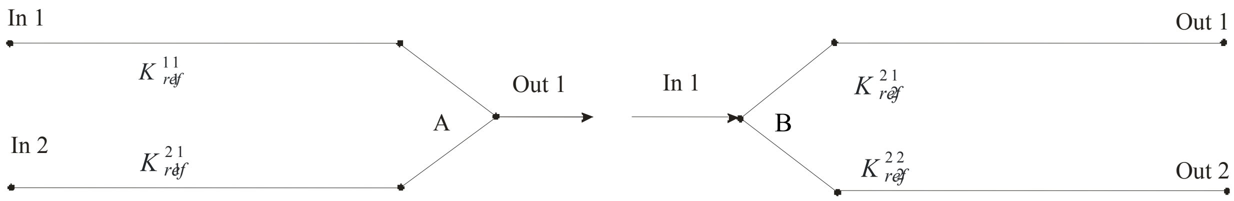

Fig. 2.1 Minimum structural model of generalized technological operations: A-assembly; B-control

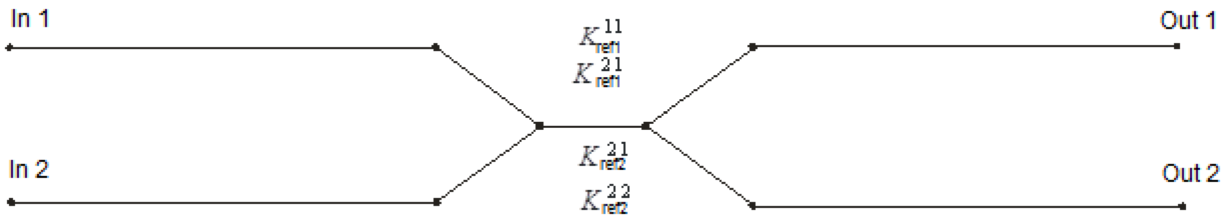

Fig. 2.2 Minimum structural model of the generalized technological operation (excluding resources)

The abovementioned models are used to synthesize the structures of production processes

On the basis of the minimum structure of the unified operation, the structures of any, more complex or simpler in structure technological operations can be formed. For example, operations "processing", "slicing", "training", "control" can be represented by a unified operation, which involves one input and one output. The structures of more complex operations are composed on the basis of the structure of a unified technological operation by sequentially connecting the inputs and outputs of the minimal structures (fig. 2.3).

Sometimes the structures of technological operations, formed on the basis of a unified structure, can be redundant. In this case, special structures with more than two inputs and outputs are used.

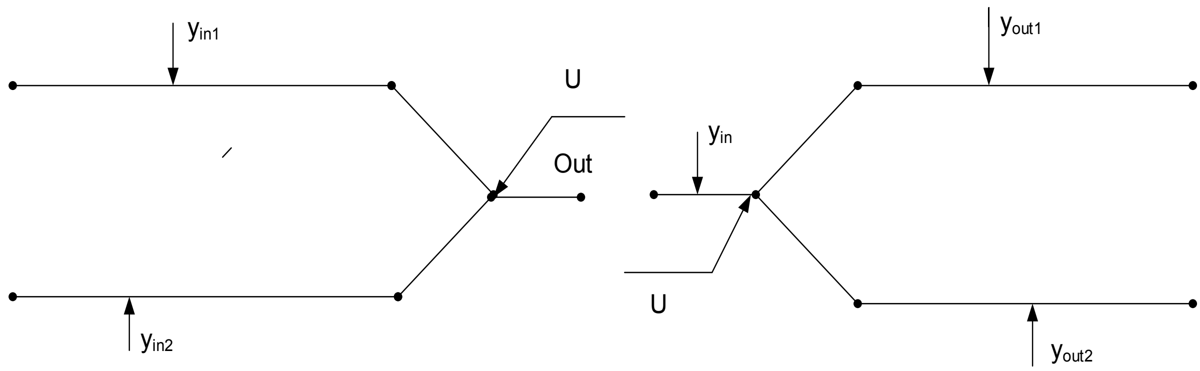

Fig. 2.3 The structure of the technological operation, formed on the basis of a unified structure

The unified structural model of the operation reflects the structure of the production process and does not allow to determine the management capabilities and the necessary resources. This is due to the fact that the operation model does not reflect the control effects. The main ones are:

- impact on operation performance management;
- management of technological parameters of operation.

Taking into account these influences, the mathematical model of the technological operation can be represented as

$$y_{out} = f(y_{in}, u, \Theta, \eta, \xi), \qquad (2.15)$$

where y_{out} – operation output status vector; y_{in} - operation input status vector; u - operation resource status vector; Θ - state vector of technological parameters; η, ξ - disturbing influence - the influence of controlled and uncontrolled factors.

At the stage of pre-design analysis, the state vector of technological parameters Θ in expression (2.15) may not be taken into account. The same can be done with disturbing influences. Then expression (2.15) takes the form:

$$y_{out} = f(y_{in}, u), \qquad (2.16)$$

In expression (2.16), u is the resource state vector, which carries information about the type of equipment and equipment involved, labor intensity and related financial resources.

From the point of view of a systematic approach, the construction of a structural model of TP is carried out by performing the following formalized stages:

1. The functions performed by the system can be formalized in the form of a set of tasks to be solved $E = \{E_i\}$. Each of the tasks $E_i, i = \overline{1,L}$ can contain $q = \overline{1,Q}$ stages. For each problem from the set E, there are possible solutions.

2. Connections between functions, tasks and their stages are given by graphs of the form $G_E = \left\{E_{q_i}\left(E_{q_i}, E^{`}_{q_i}\right)\right\}$, where $E_{q_i}, E^{`}_{q_i} \in E$. The arcs of the graph characterize the sequence of solving problems and reflect the direction of movement of production material flows. The main types of links in accordance with the structures of universal operations can be represented as the following types:

- sequential;
- assembly;
- branching.

Let's call tasks and stages *sequentially dependent* if the implementation of each subsequent task can begin only after the end of the previous and *parallel dependent* when the tasks are connected to each other of the assembly and branching type.

3. The types and characteristics of the technical equipment that can be used in the process or operation group for each variant of the possible construction

of the technical equipment are determined by the following sets: $A = \{Q_j\}$ - composition of technical equipment, $j = \overline{1, D}$ - the type of technical equipment.

The presentation of the structural model of the technological process on the basis of a unified technological operation makes it possible to analyze the technological process at the pre-design stage without the need to develop the parametric component of the model, which significantly reduces the time for assessing the feasibility of development plans.

Thus, the information required for analysis is grouped around the unified structure of the operation model, which greatly simplifies the organization of storage and access to the precedent archive. A presentation of the manufacturing process of a typical part, based on unified structural models, allows you to reduce the amount of information stored and simplify the procedure for analyzing it. In addition, it is possible to build models of individual technological processes and evaluate their characteristics, such as productivity, rhythmicity, loading, inter-shop and intra-shop routing and other dynamic characteristics of the production process, as well as quantitative characteristics of the process equipment.

On the basis of the obtained structural models of unified operations, it is possible to build flow models of technological processes and analyze and calculate parameters of the operation of the production process taking into account the characteristics of material flows.

2.4 Method for estimating the parameters of technological processes of mass production

2.4.1 Formation of criteria for assessing variants for technological processes

The ordered process flow determines the internal and inter-company routing of the workpiece flow, parts, tools, etc., depending on the TP variant and the nature of the operations. The modeling of the production process allows you to identify "weaknesses" in the system and decide whether to introduce any additional elements into it.

Simulation of the flow component of the production process makes it possible to evaluate its functioning according to technical and economic criteria, such as the volume of output, the volume of unfinished production, the amount of equipment, etc. In solving this problem, the use of the theory of mass service systems is effective to obtain appropriate characteristics, such as the current intensity of applications, the length of the queue, service time, etc.

By changing the input parameters of the process, it is possible to determine the ratio of the production cycle time and the cost of products for various TP options, and then select the option that is closest to the planned production parameters.

During the simulation, for each TP, the following are calculated:

- average waiting time for part processing;
- average equipment downtime;
- maximum queue length;
- equipment utilization rate;
- average time of a technological operation;
- maximum time of a technological operation.

When assessing the feasibility of the manufacturing process of the planned product, the use of the above information allows one to determine the qualitative and quantitative characteristics of the required equipment and tooling, taking into account which the analysis of TP options is carried out and the choice of the preferred one according to specified criteria, such as costs, timing, production volumes, etc.

Taking into account the stochastic nature of production processes, the solution of the formulated problems can be found on the basis of using the apparatus of queuing systems (QS) [84].

The flow of claims to be serviced, in general, can pass along different routes through one queue, through several queues, or through a combination of these two options.

The choice of route format depends in part on the structure of production and in part on the composition of operations of a particular TP. In practice, in most cases, route situations of these types are found: sequential, assembly and branched (fig. 2.4).

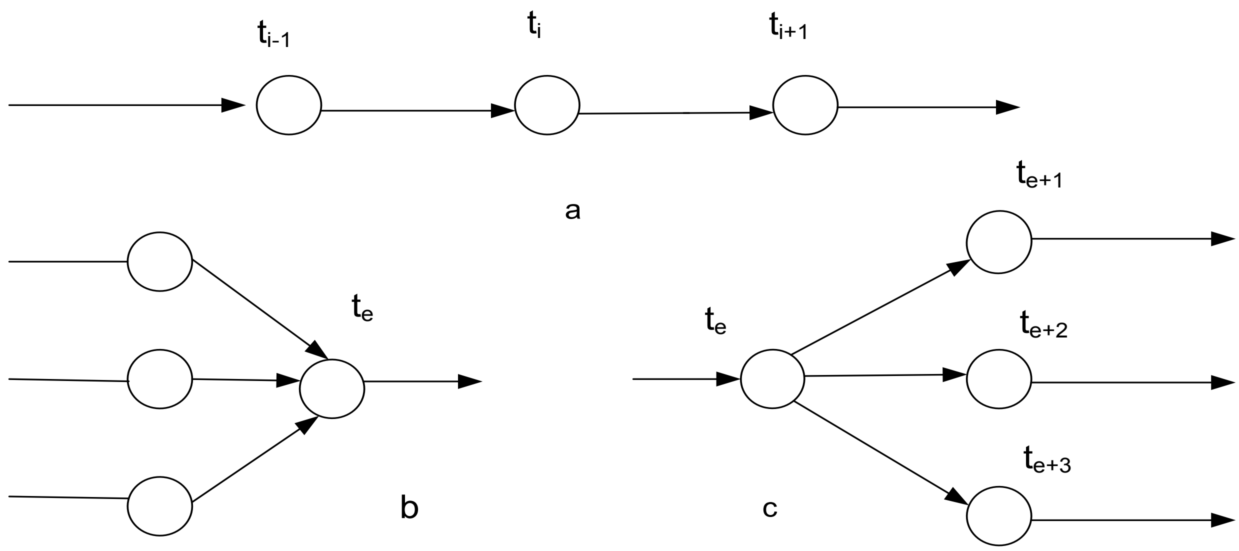

Fig. 2.4 Typical structures of production routes

To analyze the dynamics of the production process, it is necessary to solve two problems: to determine the productivity of the existing technological line and to choose a method of retrofitting the existing line for the release of new types of products. The apparatus of the QS theory can be used to construct models that allow us to consider options for solving the formulated problems.

There are various types of problems in the analysis of QS models [85]. They all correspond to different structures, and different descriptions are used to solve them. In this case, the assumption is fulfilled that the analyzed process at the moment is stable and unchanged.

Thus, the structures in fig. 2.4 are described by the following queuing models: option a) is a single-channel multiphase system, c) is a multi-channel single-phase, b) is an element of a combined structure with the transition of a multichannel system to a single-channel one.

To represent the technological process in the form of a sequence of operations that can be performed both on one piece of equipment and on several units operating in parallel, the characteristics of the following types of QS are of interest:

- single-phase model with single-channel or multi-channel,
- multiphase single channel model.

The last type of model is the most general for representing the technological process, taking into account the fact that the temporal and volumetric characteristics of hotel operations can be divided into the same type of parallel operating units of equipment.

2.4.2 Model of single-phase queuing system with parallel nodes

The structural routing model is the SMS, which has both an input flow and a request flow. Consider a structure in which *c* units (pieces of equipment) operate in parallel, so that at the same time *c* parts [86] can be processed at once. In this case, the pieces of equipment used in parallel for one process operation in terms of performance are assumed to be equivalent. Schematically, such a service system is shown in fig. 2.6.

Based on this model, it is possible to determine:

- the total productivity of the service unit, at which the queue does not exceed the specified value for different characteristics of the input flow determined by the performance;

- the queue on the available equipment with different volumes of output.

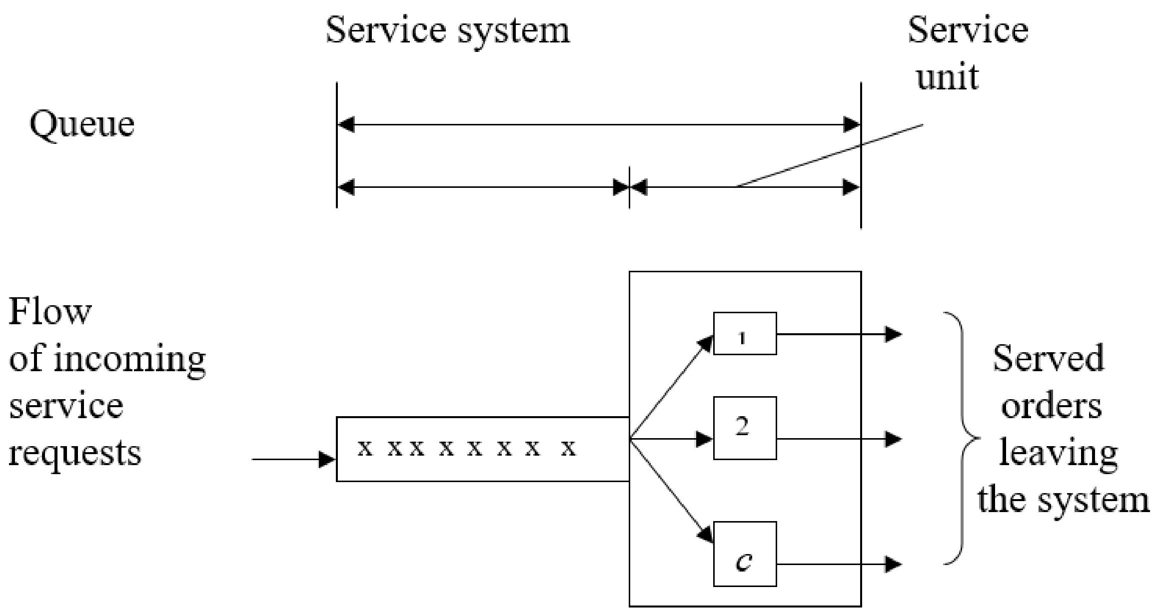

Fig. 2.6 Scheme of a service system with parallel nodes

Let's consider the structure *(M/D/c):(GD/N/∞)*. In accordance with the accepted notation, the structure characterizes the QS with a Poisson input flow (*M*), a fixed service time (*D*), and *c* parallel operating service nodes. Queue discipline is not regulated (*GD)*. Regardless of how many requests arrive at the input of the serving system, this system (queue + serviced requests) cannot accommodate more than N requests (products), i.e. applications that did not fall into the waiting block are forced to be serviced elsewhere (this is a limitation on the planned production volume). The source that generates service requests has the unlimited capacity (∞), which corresponds to the absence of a limitation on production resources.

The following operational characteristics will be considered:

P_n - probability that *n* products are in the process of treatment;

L_s – the average number of processed products (volumetric performance characteristic);

L_q - the average number of items in the intermediate warehouse (volume of work in progress);

W_s – the average processing time of a product (temporal performance characteristic);

W_q – the average duration of a product's stay in an intermediate warehouse (total non-production time).

A-priory

$$L_s = \sum_{n=0}^{\infty} np_n, L_q = \sum_{n=c}^{\infty} (n-c) p_n. \tag{2.17}$$

Between L_s and W_s (as well as between L_q and W_q) there is a functional dependence. If the frequency of receipt of service requests in the system is equal to λ (planned productivity - production rhythm), then we have:

$$L_s = \lambda W_s, \; L_q = \lambda W_q. \tag{2.18}$$

In cases where the frequency of arrival of claims for service is equal to λ, but not all claims have the opportunity to get into the serving system, the ratios (2.7) need to be modified. Let's introduce the parameter λ_{EFF} - the effective frequency of receipts, i.e. the number of requests actually admitted to the waiting block of the serving system, per unit of time. We get:

$$\lambda_{eff} = \beta\lambda, \; 0 < \beta < 1. \tag{2.19}$$

It is possible to establish the dependence of λ_{EFF} from L_S and L_q. By definition, the average duration of a technological operation is equal to the sum of the average duration of the product's stay in the queue and the average duration of processing the product. If the average service rate is μ and, therefore, the average service duration is 1/μ, then the following ratio is true:

$$W_s = W_q + 1 / \mu . \qquad (2.20)$$

Multiplying the left and right parts of this ratio by λ, we get

$$L_s = L_q + \lambda / \mu . \qquad (2.21)$$

Herewith, if λ is replaced by λ_{EFF}, we can write

$$\lambda_{eff} = \mu(L_s - L_q). \qquad (2.22)$$

When analyzing the models considered below, the main attention will be focused on obtaining formulas for p_n, since, knowing p_n, it is possible to determine the value of all the main operational characteristics of the queuing process of interest to us:

$$p_n \to L_S = \sum_{n-0}^{\infty} np_n \to W_S = \frac{L_S}{\lambda} \to W_q = W_S - \frac{1}{\mu} \to L_q = \lambda W_q . \qquad (2.23)$$

The considered queuing process is characterized by the intensity of the input flow λ and the fact that no more than c products can be processed in parallel. The average processing time for one product is $1/\mu$. The input and output streams are Poisson. The ultimate goal of using c units of parallel equipment is to increase (compared to a single-channel system) the processing speed of the product flow due to the simultaneous processing from the products. Thus, if $n = c$, then the intensity of the input (output) flow is equal to $c\mu$. On the other hand, if $n < c$, then the intensity of the input (output) flow is $n\mu < c\mu$, since not all equipment is engaged in the processing, but only n ($< c$) units. In fact, the use of several pieces of equipment is equivalent to the use of one piece of equipment, the performance of which varies, increasing by exactly c times in the presence of n items in production.

Let's consider a generalized single-channel model in which both the intensity of the input stream and the service rate would depend on n, using the values λ_n and μ_n. We obtain the formula for calculating the stationary values p_n. Considering $\mu_n = n\mu$ at $n < c$ or $\mu_n = c\mu$ at $n \geq c$, it is possible to get numerical estimates for the functional characteristics of the system. For given values λ_n and μ_n, after finding the value of p_n, results can be obtained for QS of other types.

If there are n requirements in the system for the single-channel model, the following statements are true:

a) if no receipts occur, $p_n = 1 - \lambda_n h$,

b) if no disposals occur, $p_n = 1 - \mu_n h$.

Considering that a maximum of one co-existence (receipt or disposal) can occur in interval h, we find

$$p_n(t + h) \approx p_n(t)(1 - \lambda_n h)(1 - \mu_n h) +$$

$$+ p_{n-1}(t)\lambda_n h(1 - \mu_n h) + p_{n+1}(t)(1 - \lambda_n h)\mu_n h, \tag{2.23}$$

$$n > 0,$$

$$p_0(t + h) \approx p_0(t)(1 - \lambda_0 h)(1 - \mu_n h) + p_1(t)(1 - \lambda_1 h)\mu_n h,\ n = 0\,. \tag{2.24}$$

For stationary mode, we get the following equations:

$$-(\lambda_n + \mu_n)p_n + \mu_{n+1}p_{n+1} + \mu_{n-1}p_{n-1} = 0,\ n > 0\,,$$

$$-\lambda_0 + \mu_1 p_1 = 0,\ n = 0. \tag{2.25}$$

These equations can be brought to the form:

$$\begin{aligned} p_1 &= \lambda_0 p_0 / \mu_1, \\ p_{n+1} &= \left(\frac{\lambda_n + \mu_n}{\mu_{n+1}}\right)p_n - \left(\frac{\lambda_{n-1}}{\mu_{n+1}}\right)p_{n-1}, n > 0. \end{aligned} \tag{2.26}$$

Considering successively the equations for p_1, p_2, p_3, ... and reasoning according to the induction scheme, we arrive to the formulas:

$$p_n = \frac{\lambda_0 \lambda_1 ... \lambda_{n-1}}{\mu_1 \mu_2 ... \mu_n} p_0, n \geq 1,$$
$$p_0 = \frac{1}{1 + \sum_{n=0}^{\infty} \prod_{i=1}^{n} \frac{\lambda_{i-1}}{\mu_i}}. \qquad (2.27)$$

The expression for p_0 is obtained from the condition $\sum p_n = 1$.

To evaluate the operational characteristics of a multi-channel model, consider that

$$\lambda_n = \lambda\_\text{для\_всех}\_n \geq 0,$$
$$\mu_n = \begin{cases} n\mu\_\text{при}\_n \leq c, \\ c\mu\_\text{при}\_n \geq c. \end{cases} \qquad (2.28)$$

From the expression for p_n derived for the single-channel model at n ≤ c:

$$p_n = \frac{\lambda^n}{\mu(2\mu)(3\mu)...(n\mu)} p_0 = \frac{\lambda^n}{n!\mu^n} p_0. \qquad (2.29)$$

In the case when $n \geq c$, the formula takes the following form:

$$p_n = \frac{\lambda^n}{\mu(2\mu)...(c-1)\mu(c\mu)\underbrace{(c\mu)...(c\mu)}_{n-c}} p_0 = \frac{\lambda^n}{c!c^{n-c}\mu^n} p_0. \qquad (2.30)$$

Consider that $\rho = \lambda/\mu$, we find

$$p_n = \begin{cases} \left(\dfrac{\rho^n}{n!}\right) p_0, 0 \le n \le c, \\ \left(\dfrac{\rho^n}{c^{n-c} c!}\right) p_0, n > c, \end{cases} \tag{2.31}$$

$$p_0 = \left\{ \frac{\rho^n}{n!} + \frac{\rho^c}{c!(1-\rho / c)} \right\}^{-1},$$

where $\rho/c < 1$ (or $\lambda/\mu c < 1$).

Now

$$L_q = \frac{\rho^{c+1}}{(c+-1)!(c-\rho)^2} p_0 = \left(\frac{c\rho}{(c-\rho)^2} \right) p_c,$$
$$L_S = L_q + \rho, W_q = \frac{L_q}{\lambda}, W_s = W_q + \frac{1}{\mu}. \tag{2.32}$$

For an approximate method of finding p_0 and L_q (at $\rho << 1$), we can write

$$p_0 \approx 1 - \rho, L_q \approx \rho^{c+1} / c^2. \tag{2.34}$$

2.4.3 Multi-phase queuing system model

For multiphase QS, the indicators of the quality of traffic service are assessed - delays and/or loss of requests [87]. This work examines the characteristics of a sequential technological process - delays in individual sections (equipment).

Usually, for multiphase QS, the following characteristics are determined:

- average value of the delay time of claims;
- distribution function of the delay duration of claims.

Let’s consider a single-channel multiphase QS. In this system, the input flow - the intensity of the receipt of parts for processing is designed as μ_2. In parallel with the same intensity μ_1, production functions and finished products arrive at the warehouse. The necessary resources also come from the warehouse.

The state of the system is completely determined by the total number of i - products in the system [74].

$$P_g = \begin{cases} \rho^g \dfrac{1}{g!} \cdot p_0, & 1 \le g \le N, \\ \rho^g \dfrac{1}{N!N^{g-N}} \cdot p_0, & g > N, \end{cases} \tag{2.35}$$

$$P_0^{-1} = \sum_{g=1}^{N} \frac{\rho^g}{g!} + \frac{\rho^{N+1}}{N!(N-\rho)}, \quad \rho = \frac{\mu_2}{\mu_1} < N, \tag{2.36}$$

$$\overline{\nu} = \frac{N^N}{N!} P_0 \cdot \frac{\rho_\Sigma^{N+1}}{(1-\rho_\Sigma)^2} X_1, \ldots, X_n, \tag{2.37}$$

$$\overline{g} = \overline{\nu} + \rho \cdot p_0 \left[\left(1-\rho_\Sigma\right)^{-1} \frac{\rho^N}{N!} + \sum_{g=1}^{N-1} \frac{1}{g!} \rho^g \right], \ \rho_\Sigma = \frac{\mu_2}{\mu_1 \cdot N} < 1. \tag{2.38}$$

Let’s consider the case when the loss of requests is unacceptable, and the device aggregates do not start the next cycle if the result of the previous one is not used (the equipment is idle awaiting the end of the previous operation).

The source units are considered to be of the same type as the service units $k = \overline{1, N_1}$. As a state variable $i, i = \overline{0, N_1 + N_2}$, let us choose the sum of the number of idle source aggregates and busy service device aggregates. This variable uniquely determines the state of the system.

If $i \ge N_1$, then the number of busy service devices is i, and the number of idle sources is zero. If $i > N_1$, then all N_1 service devices are busy, and the number of idle sources is $(i - N_1)$. The idle source is possible only after it has completed the specified operation, so that each idle source is at the same time an accumulator, which contains one request (unprocessed item). Then

$$\lambda_i = \begin{cases} N_2\mu_2, & 0 \le i \le N_1, \\ (N_1 + N_2 - i)\mu_2, & N_1 < i \le N_1 + N_2; \end{cases}$$
$$\nu_i = \begin{cases} i\mu_1, & 1 \le i \le N_1, \\ N_1\mu_1, & N_1 \le i \le N_1 + N_2. \end{cases} \tag{2.39}$$

The main conclusion is that the coordination of the operation of sequentially connected units by leveling the average capacities is unacceptable if in each phase there is one unit with the parameters μ_1 and μ_1, since the queue grows indefinitely. If we restrict the average number of applications in the system by a normative constant $\overline{g}_c$, then

$$\rho = \frac{\overline{g}_c}{1 + \overline{g}_c}. \tag{2.40}$$

The limiting intensity of the unit-source of the flow of applications, if it can be selected, is limited by the throughput of the unit-service device and the standard $\overline{g}_c$ so as

$$\mu_2 \le \frac{\overline{g}_c}{1 + \overline{g}_c}\mu_1. \tag{2.41}$$

The results remain valid for a multichannel QS, that is, in the presence of a group of aggregates in each phase with the condition of replacing the intensities with total.

To calculate the probabilistic characteristics of the QS, we use the Kleinrock assumption [85] at the obtaining the distribution of the exponential flow of applications at the output of the TP. Assuming a stationary QS mode, one can find the average number of requests L_i or for the entire network ($L_1, L_2, ..., L_i, ..., L_n$), $i = \overline{1, M}$ for each node.

The probabilities of network states are determined by the formula:

$$P_j = \prod_{i=1}^{M} P_{ij}, \tag{2.42}$$

where P_j – the probability that j products are being processed, P_{ij} – the probability that j products are processed at the i-th site.

The integral characteristics of production are as follows:

1. Average volume of work in progress:

$$L = \sum_{i=1}^{M} L_i . \tag{2.43}$$

2. Average production cycle time:

$$T = \sum_{i=1}^{M} T_{c_i} , \tag{2.44}$$

In a balanced network $\rho_1 \approx \rho_2 \approx ... \approx \rho_M$, $\rho_i = \frac{\lambda_i}{\mu_i}$.

For an unbalanced network, the bandwidth is determined by the bottleneck $\rho^* = \max(\rho_i, i = \overline{1, M})$.

2.4.4 Determination of cost characteristics of queuing systems for variants of technological processes

The above analysis of the dynamics of the functioning of the process for various variants of structural construction requires an assessment of the options for cost characteristics.

The cost models of queuing are aimed at determining such a level of functioning of the production system at which a "compromise" is achieved between the following indicators:

a) the profit obtained through the production (and sale) of products;

b) losses profits due to delays in the production process.

Let’s consider the models for assessing the technical characteristics of the technological process for various options for TP structures and different production targets.

1. The task of determining the composition of the equipment to ensure a given performance.

The solution to this task is associated with finding a compromise in an environment where increasing productivity due to new equipment or expanding the existing fleet leads to a significant increase in costs.

To make a decision, costs must be weighed against income. Let’s consider a single-channel queuing model with an average rate of arrival of requests equal to λ and with an average service rate equal to μ. It is assumed that the rate of service is amenable to regulation by upgrading or increasing the number of equipment; it is required to determine its optimal value based on the cost model. We introduce the following notation: C_1 - the gain expressed in value form due to an increase in the value of μ by one during a unit time interval; C_2 - "cost" of waiting per unit of time and per item; TC(μ) - the value indicator determined by the formula

$$TC(\mu) = C_1\mu - C_2L_S\,. \tag{2.45}$$

The service costs assigned to the time unit are directly proportional to the μ. Since μ is a continuous quantity, its optimal value can be obtained by equating to zero the first derivative of $TC(\mu)$ by μ. For example, for a single channel system with unlimited buffer

$$TC(\mu) = C_1\mu - C_2\lambda/(\mu - \lambda)\,, \tag{2.46}$$

and therefore, for the optimum value of μ we have

$$\mu = \lambda + \sqrt{C_2\lambda / C_1} \, . \tag{2.47}$$

In a situation where the amount of work in process cannot supply more than N products, the value model can be modified to reduce production costs by increasing the value of N. In this case, the value of N is considered as a control variable, the optimal value of which (together with μ) is determined by minimizing

$$TC(\mu, N) = C_1\mu - C_2L_s - C_3N - C_4\lambda p_N, \tag{2.48}$$

where C_3 - "cost" of increasing (per unit time) the volume of work in the process, C_4 - economic losses due to the inability to increase the volume of work in the process by one unit.

2. The task of determining the required quantity of the same type of equipment.

This task is associated with obtaining a compromise solution, taking into account the fact that an increase in the number of equipment entails an increase in the costs of their maintenance (operation, maintenance and depreciation), but at the same time there is an economy due to a decrease in the downtime of other equipment in the technological chain, it becomes possible to increase the volume of production.

Consider a multichannel model. The cost model of queuing is focused on determining the optimal amount of equipment, which we denote by c. It is assumed that the values of λ and μ are fixed. The integral cost of indicators is given by the formula

$$TC(c) = cC_1 + C_2L_s(c), \tag{2.49}$$

where C_1 - the cost per unit of time for the operation of one additional piece of equipment, $L_S(c)$- average number of processed items.

Optimal value c find from conditions

$$TC(c - 1) \geq TC(c) \text{ и } TC(c + 1) \geq TC(c), \tag{2.50}$$

which is equivalent to inequality

$$L_s(c) - L_s(c + 1) \leq C_2/C_2 \leq L_s(c - 1) - L_s(c). \quad (2.51)$$

The C1/C2 value is an indicator of where the search for the optimal value of *c* should begin.

Let us formulate the main stages of the proposed method using the above models.

1. Determine the average number of products in the queue with the original amount of equipment.

2. Determine the loss of working time in value terms.

3. Make an assumption about the increase in equipment by one unit.

4. Determine the waiting time in the queue (at the intermediate warehouse) with an increase in the amount of equipment.

5. Compare the cost of using additional equipment with the time saved for performing the TP.

3 MODELS AND METHODS OF MULTI-CRITERIAL EVALUATION OF VARIANTS FOR TECHNOLOGICAL PROCESSES

3.1 Generalized system model of the technological process

When forming enterprise development plans, it is necessary to evaluate their feasibility in the technological aspect at the pre-design stage. Since product upgrades are usually carried out within the existing enterprise specialization and on the basis of previous design and production experience, the reliability assessment will mainly relate to the part of the product and technological processes (TPs) that belong to the innovative part.

The modernization and renewal of the products are mainly aimed at improving their operational, ergonomic characteristics and design. As a result, different criteria and parameters for evaluating TP variants are involved in the evaluation of decision options.

Depending on the goals of the analysis and the level of abstraction, the technological process C can be considered as a system consisting of a set of N elements, on which a set of connections R are implemented, which determine a structure with a set of properties P [88]:

$$C = (N, R, P). \tag{3.1}$$

The procedure for deciding on the selection of characteristics and their evaluation criteria for comparison is the central issue of the analysis of TP variants.

The general task of deciding on the selection of the TP type can be represented by the following stages:

1) definition of target - a type of final product;

2) target analysis - determination of target characteristics and selection of TP type to obtain the required result;

3) identification of possible TP variants for the realization of the set goal;

4) formation of an estimate allowing comparing allowable solutions with each other.

Sources of information, its content, method of presentation and degree of detailing are usually different for each of the stages and at a descriptive level can be analyzed in the terms below.

1. Determination of the goal. The goal for each variant of the technological process is the final product with the required parameters. Information about the characteristics of the object of manufacture is contained in the design documentation.

2. Purpose analysis implies the determination of the functional purpose of the product planned to be manufactured, the requirements for the accuracy of manufacture, the materials used, etc. The source of information for this stage of information support of the solution is the design documentation and expert opinion.

3. Formation of a set of criteria that allow you to compare different options for achieving the goal. The choice of a system of partial criteria that characterize the options for technological solutions is a poorly formalized heuristic problem, which is characterized by contradictory requirements, such as the completeness, minimality and non-redundancy of a set of criteria [88].

A generalized representation of a set of information, functional and structural parameters of a technological process can be a system model of a technological process (fig. 3.1):

$$S(T)=\{\mathrm{Idn}^T, \mathrm{Prp}^T, \mathrm{Str}^T, X^T, Y^T, Q^T, C^T\}, \quad (3.2)$$

where Idn^T – process identifier - is a combination of two fields: <designation of TP> and <name>, Prp^T – purpose of TP; $\mathrm{Str}^T=\{F, T, R^T\}$ – TP structure, where F is the production phase, T are the elements of the process (operations); R^T – connections between the elements of the technological process; X^T – input parameters of the technological process, which primarily include: technological documentation, means and objects of labor; $Y^T = \{y_1^T, y_2^T, ..., y_m^T\}$ – output technical and economic characteristics of the technological process, such as the range and volume of products, rhythm, profitability, etc.; $Q^T = \{q_1^T, q_2^T, ..., q_k^T\}$ – the impact of the external environment, the parameters of which are often random in nature and manifest themselves in the form of risks that lead to a change in the material, energy and information parameters of production processes; $C^T = \{c_1^T, c_2^T, ..., c_h^T\}$ – internal properties of the technological process, such as the composition of technological equipment, rhythm, flexibility, productivity, resource intensity, etc.

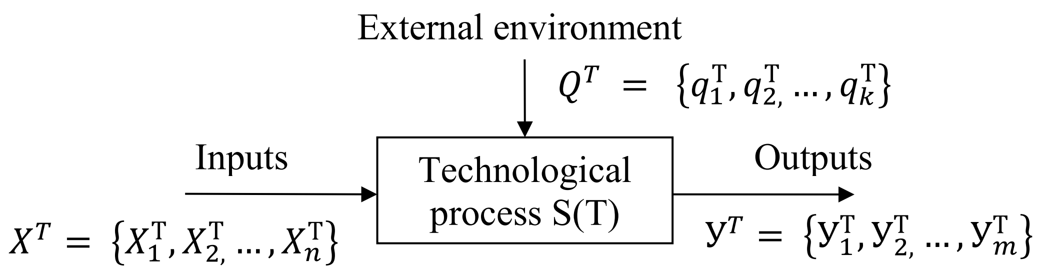

Fig. 3.1 The structure of the generalized system model of TP

Thus, the technological process should be considered as a system, the properties of the elements of which should include many values of the process parameters, such as, for example:

- nomenclature and volume of output of commercial products,
- means of technological equipment;
- professional staff and number of work performers;
- consumption of materials and components;
- resource intensity,
- environmental characteristics, etc.

The amount of information required to select criteria for evaluating TP options and technological operations is stored in the appropriate database.

Variants of possible types of TP are mainly associated with the use of new materials and increased requirements for processing accuracy, which, as a result, gives rise to the need to modernize technological equipment and tooling, master new TP modes, resolve personnel issues and take environmental measures. These and other tasks serve as criteria for evaluating various TP options for making management decisions based on alternatives for mastering innovative products.

For the selected set of options, it is necessary to concentrate each and build a ranked number of options according to the value of the alternative quality indicator.

Taking into account the multivariance of the problem and the multi-criteria description of the options, the most acceptable apparatus for solving this problem may be the application of the theory of multi-criteria assessment and optimization using the concept of the utility function of alternatives [89, 90].

To assess each TP option and select an acceptable one, it is necessary to formulate the composition of criteria for assessing alternatives to technological processes. This problem is solved by experts and decision makers, based on the characteristics of the parts, the required equipment, production volumes, planned dates, economic parameters, etc. To simplify the procedure for selecting criteria for assessing TP in a specific situation, the general list of possible criteria is divided into classes of community.

3.2 Phenomenological model of the problem of supporting decision-making on the choice of a technological process

For a formalized representation of the TP selection problem, it is proposed to use a phenomenological model of the decision support problem. The model makes it possible to systematize the process of TP analysis with varying degrees of detailing and at various levels, depending on the specific features of the practical problem.

Let’s define the main parameters of the mathematical model for a formalized presentation of the procedure for selecting options for technological processes.

Let’s denote:

Z - general task of choosing TP by evaluating and ranking alternative options,

Z' – local task of preliminary selection of variants by TP types,

Z_i, $i = 1.3$ – separate tasks of selecting TP elements (for procurement, processing and assembly phases of production).

$K = \{k\}$ – a set of criteria for evaluating TP options;

$M = \{m\}$ – a set of characteristics of the planned products for preliminary selection of TP options, taking into account the type of TP, the corresponding equipment, etc.

$X = \{x\}$ – initial set of TP options for product manufacturing;

$X' \subset X$ – a set of TP options for multicriteria assessment;

x^* - preferred TP option.

Let us define the criteria for evaluating the TP options. Let us introduce the function F as a measure of the preference of the TP variant by the set of criteria as a mapping of the Cartesian product $K \times X'$ in the set of estimates, i.e. $F: X' \times K \rightarrow x^*$ [91]. Then the problem Z can be represented as the problem of choosing the option $x^* \in X' \subset X$. Thus, x^* is a solution to Problem Z where X' is the set of feasible solutions.

Task Z is characterized by a set (X', K, F). The element $x^* \in X'$ is a solution to the problem Z and is determined by the predicate

$$P(x^*, Z) \equiv (x^* \text{ is a solution of } Z). \quad (3.3)$$

Let's designate the task of preliminary selection of the type of TP and equipment as Z', it is characterized by a set of parameters (X, K', F'). Problem Z can be considered as a restriction of problem Z' on the set X'.

Separate problems of choosing TP elements, taking into account its type Z_j, $j=\overline{1,N}$ can also be characterized by sets (X_j, K_j, F_j). In the general case, the number of problems Z_j is equal to N.

Let's consider the formulation of these separate tasks for the three main phases of production. Let us designate the task of choosing the type of surface treatment of the part, as well as the method of obtaining and the type of workpiece for the blank phase as Z_1, the choice of the type of TP, equipment and devices for the processing phase as Z_2, and the choice of equipment for the assembly phase as Z_3. We will characterize the tasks Z_1, Z_2 and Z_3 by the sets (X_1, K_1, F_1), (X_2, K_2, F_2) and (X_3, K_3, F_3). It is possible to consider $Z' = Z_1 \times Z_2 \times Z_3$, $K' = K_1 \times K_2 \times K_3$ and to consider a problem Z_1 as narrowing of a problem Z' on a set of X_1, Z_2 as narrowing of a problem Z' on a set of X_2, Z_3 as narrowing of a problem Z' on a set of X_3.

Denote the set of task solutions Z_j, $j=\overline{1,N}$ by the vector $S_r=(x_1, \ldots\ x_N)$. When defining S_r, $x_r \in X_r$ will be defined, and this fact will be described to operators Θ_r:

$$x_r = \Theta_r(S_r). \tag{3.4}$$

Using the entered symbols, we formalize the basic principles of TP selection.

1. The choice of technological processing operations for the manufactured part, as well as sets of equipment, are carried out in order to ensure indicators of the production efficiency of the product.

When solving problems Z', a vector S is formed, which generates a solution of the task Z, minimizing the cost of developing and manufacturing a product.

In turn, when solving problems of a lower level - tasks Z_j, $j=\overline{1,N}$, a vector S' is formed, which generates a solution to the problem Z'. In formalized form, this can be written as follows:

$$\exists(Z_j, x_j, j=\overline{1,N}): P(x_j, Z_j) \Rightarrow P(x', Z')\Bigg|_{\substack{x' = \Theta'(S') \\ S' = (x_1,\ldots,x_N)}} \quad (3.5)$$

The choice of the most effective option corresponds to the problem of the extremum of the objective function F' defined on the set of solutions of the task Z'. In this case, instead of (3.3), we have:

$$\begin{gathered}\exists(Z_j, x_j, j=\overline{1,N}): P(x_j, Z_j) \Rightarrow \\ \exists\left(S_m^* = (x_1^*,\ldots,x_N^*), x_j^* = \{x_j\}, j=\overline{1,N}\right): F'\left(\Theta'(S^*)\right) = \underset{x\in H'}{extr}\, F'(x')\end{gathered} \quad (3.6)$$

The method for selecting options for technological processes should satisfy the principle of hierarchy, as well as the principles of coordinating local search tasks with respect to tasks of a higher level, compatibility and modifiability of technological process elements. Let’s consider these principles.

2. Hierarchy of the structure.

In terms of set-theoretic modeling, the set Θ of technological processes can be represented as belonging to the Cartesian product of sets:

$$\Theta \subset M \times D \times W \times K \times \{Z_j \mid j=\overline{1,N}\} \times \{Z'\} \quad (3.7)$$

where M – set of search parameters in low-level tasks, for example, geometrical dimensions of a part, technological properties, accuracy characteristics of a part, and others:

$$M = \{\times M_j \mid M_j = \{m_j\}, j = \overline{1,N}\} \quad (3.8)$$

where D, W, K - a set of results of solving local problems, for example, selected technological operations; types, characteristics of machine-tool equipment; values of criteria for local optimization problems and others:

$$D = \{\times D_j \mid D_j = \{d_j\}, j = \overline{1,N}\}; \quad (3.9)$$

$$W = \{\times W_j \mid W_j = \{w_j\}, j = \overline{1,N}\}; \; K = \{k\}. \quad (3.10)$$

We define selection problems as follows:

- for the task of choosing the type of processing and the type of workpiece in the procurement phase

$$Z_1 : K_1 \times \{\times M_{1j} \mid j \in N_1\} \to \{\times D_{1j} \mid j \in N_1\}; \quad (3.11)$$

- for the task of selecting operations of the technological process, equipment, fixtures and technological parameters of manufacturing in the processing phase

$$Z_2 : K_2 \times \{\times M_{2j} \mid j \in N_2\} \to \{D_{2j} \times W_{2j} \mid j \in N_2\}; \quad (3.12)$$

- for the task of choosing equipment at the assembly phase

$$Z_3 : K_3 \times \{\times M_{3j} \mid j \in N_3\} \to \{\times W_{3j} \mid j \in N_3\}. \quad (3.13)$$

3. Coordination.

Tasks of the lower level must be coordinated with those of the higher level.

This means that the tasks of the upper level and the set of tasks of the lower level must have a solution, i.e.:

$$\forall j = \overline{1,N} \exists (x_j, m_j) : [P(m_j, Z_j(x_j)) \wedge P(m', Z'(x')) \wedge P(Z(x))]. \quad (3.14)$$

4. Compatibility.

Note that the direct use of information about the design parameters and the product manufacturing process (in the form of structural models of products and manufacturing processes) has only subordinate tasks. Tasks of a higher level can influence the process of choosing a TP only through tasks of a lower level. Therefore, the achievement of the goals of the global task is possible only if the lower tasks are coordinated with respect to the global.

The higher task Z', coordinating the tasks of Z_j, pursues its own goals (achieving maximum efficiency from the implementation of the selected TP). Therefore, the tasks Z_j, $j=\overline{1,N}$ must be coordinated in relation to the task Z'.

Taking into account the specified features of the task of choosing for the compatibility of goals, the coordination of lower tasks relative to the higher level should be associated with a global task. Therefore, we introduce the operator *f*, which maps *m* into signals that affect the manufacturing process of the product:

$$f: M \rightarrow X \text{, i.e. } (x_j, j=\overline{1,N}) = f(m). \tag{3.15}$$

We will assume that the inverse operators f^{-1} are known that make it possible to determine m by x_j, i.e.

$$(m)f_j^{-1} = (x_j, j=\overline{1,N}). \tag{3.16}$$

Then the requirement of compatibility of tasks in a hierarchical system is formulated as:

$$\begin{gathered}\forall j=\overline{1,N}\exists(m_j,x_j)\wedge\exists(x):[P(m_j,Z_j(x_j))\wedge P(M,Z')]\Rightarrow\\ \Rightarrow[P(m_j,Z_j(x_j))\wedge P(f_j^{-1}(m_j,j=\overline{1,N}),Z].\end{gathered} \tag{3.17}$$

Condition (3.17) means that the lower-level tasks Z_j are adjusted with respect to the global task Z, when they are adjusted with respect to the task Z'.

5. Modifiability.

In the case when coordination is absent in a multi-level system, the tasks of the lower level must be modified so that coordination takes place. In other words, it is required to find such sets of coordinating signals $\overline{M}$ and such sets of tasks $\{\overline{Z_j}\}, j = \overline{1, N}$, as well as $\{\overline{Z'}\}$, under which conditions (3.14) and (3.17) are satisfied. Let's introduce the predicates P_1 = (*condition (3.14) is satisfied*) and P_2 = (*condition (3.17) is satisfied*), then the modifiability requirement takes the form:

$$\begin{gathered} \exists(\overline{M} \subseteq M; \{\overline{Z_j}\} \subseteq \{Z_j\}, j = \overline{1, N}; \{\overline{Z'}\} \subseteq \{Z'\}): \\ (\forall(x_j \in \overline{X}; Z_j \in \{\overline{Z_j}\}, Z' \in \{\overline{Z'}\}) \to [P_1 \wedge P_2]. \end{gathered} \tag{3.18}$$

Conditions (3.14, 3.17, and 3.18) require that the original sets of problems $\{\overline{Z_j}\}, j = \overline{1, N}$ be powerful enough. This means that by choosing subsets of these sets, compatibility and coordination of selection problems can be achieved.

When choosing technological processes, the level of formalization of separate tasks is determined by the availability of information: about the routing of technological operations, their duration and labor intensity; rules and techniques for making decisions. Algorithms for solving interrelated selection problems should ensure that a solution is found with an accuracy corresponding to the accuracy of the initial information. The development of procedures for solving problems of selecting options for technological processes based on the proposed model simultaneously solves the question of the composition of particular criteria for each option of TP, which is necessary in the future to evaluate options and make a decision on choosing the preferred one.

3.3 Models of formation and multi-criteria assessment of variants for implementing enterprise development strategies

The decision-making procedure can be represented as a sequence of the following tasks [92]:

• determination of the purpose of the decision and its analysis;

• determination of the set of feasible solutions X;

• setting a metric, i.e. criteria for assessing the quality $K(x)$ of acceptable solutions $x \in X$;

• determination of the best (extreme) at $K(x)$ solution $x^{\circ} \in X$.

We will call each of the possible options a solution, and denote x, and many possible solutions - X^{B}. Not all decisions $x \in X^{B}$ are acceptable for economic, technological or environmental reasons. Based on this, a set of acceptable solutions X should be distinguished from the set X^{B}:

$$X \subset X^{B}. \tag{3.19}$$

The set of valid solutions X can be given both by enumeration and by characteristic functions in the form of limiting inequalities or equalities, but the ultimate goal of synthesizing an effective solution is to choose from a set of acceptable solutions for the optimal

$$x^{\circ} \subset X. \tag{3.20}$$

The solution to the problem of choosing the best solution x° is associated with the problem of choosing a metric, in which the efficiency of feasible solutions can be quantified.

Each decision is characterized by a set of criteria that characterize some particular aspects of the solution's effectiveness, and their totality quite fully characterizes the quality of the solution as a whole. Such criteria are usually called private or local [29]. They have different meanings, dimensions and are measured on different scales. Thus, the solution x in the general case is characterized by a set of particular criteria

$$K(x) = \{k_i(x)\},\ i = \overline{1,n}. \tag{3.21}$$

Finding the optimal solution x° in the general case is associated with solving the problem

$$x^\circ = \arg \underset{x \in X}{extr}\, K(x) \equiv \arg extr \{k_i(x)\},\ \forall i = \overline{1,n}. \tag{3.22}$$

The solvability of the problem (3.22) is due to the structure of the set of permissible solutions X. This set consists of two subsets [107]: consistent X^S and contradictory (compromise) X^C solutions

$$X = X^S \cup X^C;\ X^S \cap X^C = \varnothing. \tag{3.23}$$

Note that many contradictory solutions form such solutions in which the improvement of any particular criterion leads to the deterioration of at least one or other particular criterion. Problem (3.13) has an unambiguous solution only on a set of consistent solutions.

The selection procedure by the decision maker (DM) from the initial set of particular criteria $K(x) = \{k_i(x)\}$, $i = \overline{1,n}$ one of the most important $k_B(x)$ is called *the principle of the main criterion*. In this case, all other particular criteria $(n-1)$ are transformed into restrictions. As a result, the multicriteria optimization problem is transformed into a scalar optimization problem of the form

$$x^\circ = \arg \underset{x \in X}{extr}\, k_B(x) \setminus k_i(x)(\le)(\ge)(=)k_i^*,\ \forall i = \overline{1,n}. \tag{3.24}$$

where k_i^* - admissible value of the *i*-th particular criterion.

The sequential optimization scheme consists in transforming the original multicriteria problem into a sequence of scalar optimization problems [94]. In this case, the decision maker ranks the particular criteria $K(x)=\{k_i(x)\}$, $i=\overline{1,n}$ in descending order of their importance:

$$k_1(x) \succ k_2(x) \succ \ldots \succ k_n(x). \tag{3.25}$$

The optimal solution to problem (3.22) is determined by sequentially solving the following scalar optimization problems:

$$\begin{aligned} x_1^o &= \arg \underset{x \in X}{extr}\, k_n(x); \\ x_2^o &= \arg \underset{x \in x_1^o}{extr}\, k_2(x); \\ &\ldots \\ x_i^o &= \arg \underset{x \in x_{i-1}^o}{extr}\, k_i(x); \\ &\ldots, \end{aligned} \tag{3.26}$$

where x_1^o, x_2^o, x_i^o - subsets of solutions equivalent with respect to the corresponding particular criterion.

The optimization procedure continues until a unique solution to the original problem (3.22) is obtained. If all particular criteria are considered, and the solution is not obtained, additional criteria should be formulated.

In the *functional-cost analysis*, a set of particular criteria $K(x)=\{k_i(x)\}$, $i=\overline{1,n}$ is divided by the decision maker into two subsets: one of them $K^{\Pi}(x)=\{k_i(x)\}$, $i=\overline{1,m}$ includes all the criteria that characterize the useful functional (target) qualities of the solution, and the second $K^{3}(x)=\{k_i(x)\}$, $i=\overline{1,m+1}$ - criteria characterizing the "costs" of implementing a solution. Thus, the original n-criterion problem is transformed into a two-criterion problem. Reducing it to scalar form is carried out using the following alternative criteria:

- additive

$$x^o = \arg\max_{x \in X}[\overline{K}^P(x) - \overline{K}^3(x)] \tag{3.27}$$

- multiplicative

$$x^o = \arg\max_{x \in X}[\overline{K}^P(x) / \overline{K}^3(x)]. \tag{3.28}$$

where $\overline{K}^P(x)$ and $\overline{K}^3(x)$ - scalar scores of criteria.

In the additive criterion (3.27), both terms must have the same dimension.

Criteria (3.27) and (3.28) in this study are used to solve the problems of technical and economic assessment of options. It is possible to apply the reduced criteria obtained on the basis of (3.27) and (3.28) by applying the principle of the main criterion (3.26)

$$x^o = \arg\max_{x \in X} \overline{K}^P(x) \text{ given that } \overline{K}^3(x) \le \overline{K}^3_D(x)$$

$$x^o = \arg\min_{x \in X} \overline{K}^3(x) \text{ given that } \overline{K}^P(x) \le \overline{K}^P_D(x), \tag{3.29}$$

where the D index is the permissible level of costs and expected effect (benefit), respectively.

The method of the generalized scalar criterion uses a quantitative multivariate assessment formed on a set of particular criteria. This approach is based on the hypothesis [94] that for any multicriteria solution there is a generalized scalar estimation of the form:

$$P(x) = F[k_i(x), A], \tag{3.30}$$

where A – a tuple of model parameters for which the following condition is satisfied:

$$x_1, x_2 \in X \text{ and } x_1 \succ x_2 \text{, then } P(x_1) > P(x_2). \tag{3.31}$$

The sign "$\succ$" means the relation of order.

Thus, the utility function is a quantitative measure of the relative preference of solutions.

The implementation of any of the above methods for solving the multicriteria optimization problem assumes that a tuple of values of particular criteria is known for the solution $x_j \in X$:

$$K(x_j) = < k_i(x_j) >, \; i = \overline{1,n}, \; j = \overline{1,m}. \qquad (3.32)$$

This means that simulation models are known that establish a relationship between controlled variables (solutions x) and the values of particular criteria, i.e.

$$k_{ij}(x) = f_i(x_j), \; i = \overline{1,n}, \; j = \overline{1,m}. \qquad (3.33)$$

In the general case, the problem under consideration can be represented by a mathematical model in terms of the well-known utility theory in the form:

$$\mathrm{F}(x) = \mathrm{P}[Z(a_j)K_i(x)], \; i = \overline{1,n}, \qquad (3.34)$$

where $K_i(x), \; i = \overline{1,n}$ - particular criteria; $Z(a_i)$ - subjective information about the preference of particular criteria for decision makers.

The main thing in building a model of this type is to determine the type of operator P (model structure), for which it is necessary to have information about the significance and form of representation of partial criteria. These issues are addressed when building a model for each specific case.

Using the concept of the utility function of particular criteria, the mathematical model for the formation of a multivariate assessment of an alternative $x \in X$ can be represented as:

$$\mathrm{F}(x) = \mathrm{P}[Z(a_i)', m_i[K_i(x)]], \; i = \overline{1,n}, \qquad (3.35)$$

where $m[K_i(x)]$- utility function of particular criteria; $Z(a_i)'$ - information about the relative importance of the utility function of particular criteria.

Each alternative $x \in X$ is characterized by a set of particular criteria, which have their own interval and different dimensions. Based on this, a specific alternative can be described by nonlinearities of various types. This fact must be taken into account when choosing the utility function of particular criteria.

The above requirement is met by a utility function of the form:

$$m_i[Ki(x)] = \left(\frac{K_i(x) - K_{iW}}{K_{iB} - K_{iW}} \right)^{\alpha_i}, \tag{3.36}$$

where $K_i(x)$- value of a particular criterion; K_{iB}, K_{iW} - respectively, the best and worst value of the frequent criterion, which it takes on the region of feasible solutions $x \in X$; α_i - parameter defining the type of dependence: at 0<α_i<1 – convex upward; при α_i=1 – linear; при α_i>1 – convex downward.

The main source of information about the mutual importance of particular criteria is the decision maker or experts. This information is presented in the form of dimensionless coefficients $a_i, i = \overline{1,n}$, $\sum_{i=1}^{n} a_i = 1$ where n is the number of particular criteria with a limited interval of variation $a_i \in [0,1]$ - taking into account the relative importance of particular criteria.

Next, it is necessary to investigate the procedures for generating information about the relative importance of the utility functions of particular criteria and the form of their presentation, taking into account the specific features and specifics of the application area.

3.4 Method for evaluating technological process options and choosing the preferred

The numerical value of the utility function of a single solution (alternative) x can be considered to be determined by particular criteria $K_i(x)$.

For the decision maker, each of these particular criteria has a varying degree of importance relative to the others. Consequently, the basis for assessing the options for the possible construction of a technological process for a given composition of particular criteria can be the expression:

$$P(x)=\sum_{i=1}^{n} a_i \frac{K_i(x)-K_{iw}}{K_{ib}-K_{iw}}, \tag{3.37}$$

where $K_i(x),\ K_{iw},\ K_{ib}$ – respectively, the current, worst and best values of the particular criterion, $a_i, i=\overline{1,n}$ – coefficients of importance of particular criteria, $\sum_{i=1}^{n} a_i = 1$.

After bringing the partial criteria to an isomorphic form, the expression (3.37) can be written as:

$$P(x)=\sum_{i=1}^{n} a_i K_i^{н}(x), \tag{3.38}$$

where $K_i^{н}(x)$ – normalized values of particular criteria.

The values of the importance coefficients, particular criteria are determined by experts and decision makers on the basis of their own experience, a specific problem and existing limitations of a different nature. Most often, information about the value of the importance coefficients of particular criteria can be presented in a deterministic or probabilistic form. Differences in the forms of presentation of information on the coefficients a_i determine the differences in the methodology for assessing the alternatives of the decisions made.

The experience of analyzing technological processes and the practice of applying assessment methods allows us to draw several conclusions.

1) in the process of evaluating the options for constructing technological processes, it is advisable to consider all options and provide the decision maker with

a ranked number of evaluations of options for choosing an acceptable one;

2) information on the values of the importance of the coefficients a_i is mainly presented in a deterministic form according to the classes of homogeneous particular criteria;

3) the estimates of the weight coefficients of importance a_i are set in the interval [0, 1] and the values of the coefficients are independent of each other.

The deterministic form of representation of the coefficients of significance is largely determined by the peculiarities of the functional content of particular criteria for assessing alternatives of technological processes (TP). In the construction of TP, typification of modes, group processing of universal parts are widely used. These circumstances allow experts, on the basis of the established experience, to more reasonably determine the values of the coefficients of the significance of particular criteria in various situations.

In the practice of solving the problems at this study, the most common situations are deterministic assignment of weight coefficients and the use of appropriate models for determining utility functions.

For a situation when the exact quantitative values a_i of particular criteria $K_i(x)$ and their utility functions $m_i[K_i(x)]$ are known, the mathematical model of the problem of forming a multifactorial assessment of the alternative $m_i[K_i(x)]$ will have the form:

$$\mathrm{F}(x) = \sum a_i m_i[K_i(x)], \quad \sum_{i=1}^{n} a_i = 1, \tag{3.39}$$

and the principle of optimality is

$$x^{\circ} = \arg\max_{x \in X} \sum_{i=1}^{n} a_i m_i[K_i(x)], \quad i = \overline{1,n}, \quad \sum_{i=1}^{n} a_i = 1, \tag{3.40}$$

or

$$x^{\circ} = \arg\min_{x\in X} \sum_{i=1}^{n} a_i \overline{m}_i[K_i(x)], \quad i = \overline{1,n}, \qquad (3.41)$$

where $\overline{m}_i[K_i(x)] = 1 - m_i[K_i(x)]$, is a utility loss function.

A common situation at the evaluating technological process options is the problem in which experts cannot determine the exact quantitative values of the weight coefficients a_i, but are able to provide qualitative information regarding the mutual importance of the evaluated criteria [95]:

$$K_1(x) \succ K_2(x) \succ \ldots \succ K_n(x). \qquad (3.42)$$

In such a situation, a *method of determining the best solution is proposed*.

1. From the original set of variants *X*, a subset $x^{\circ}{}_1$ of solutions equivalent to the most important criterion is distinguished. For this purpose, the following single-criterion optimization task is performed:

$$x^{\circ}{}_1 = \arg\max_{x\in X} m_i[K_i(x)]; \qquad (3.43)$$

or

$$x^{\circ}{}_1 = \arg\min_{x\in X} \overline{m}_i[K_i(x)], \qquad (3.44)$$

where $\overline{m}_i[K_i(x)]$ - is a utility loss function.

2. If $x^{\circ}{}_1$ consists of more than one candidate, we proceed to the next stage, that is, we solve the problem of choosing equivalent solutions from a set $x^{\circ}{}_1$ according to the second most important criterion. In general, the optimization task will have the form:

$$x^{\circ}{}_1 = \arg\max_{\substack{x\in X \\ x\in x^{\circ} i-1}} m_i[K_i(x)]; \quad i = \overline{1,n} \qquad (3.45)$$

$$x^{\circ}_1 = \arg \min_{\substack{x \in X \\ x \in x^{\circ}_{i-1}}} \overline{m}_i[K_i(x)]; \quad i = \overline{1,n}. \tag{3.46}$$

3. Optimization continues until a single solution is obtained or the criteria are completed. The resulting decision is taken as the optimal.

4. If the assessment requires ranking of the entire set of options, the best solution obtained is excluded from X and the procedure described above is repeated on the remaining solutions.

For the case when the decision maker does not have either qualitative or quantitative information about the coefficients a_i, the condition of equality or quasi-equality of the importance of the criteria $a_i = \frac{1}{n}$, $i = \overline{1,n}$ can be accepted, and the model for assessing the generalized utility of the alternative $x \in X$ will have the form:

$$\mathrm{F}(x) = \frac{1}{n}\left\{\sum_{i=1}^{n} m_i[K_i(x)]\right\}, \quad i = \overline{1,n}, \tag{3.47}$$

and the principle of optimality will be:

$$x^{\circ} = \arg\max_{x \in X} \frac{1}{n}\left\{\sum_{i=1}^{n} m_i[K_i(x)]\right\}, \quad i = \overline{1,n}, \tag{3.48}$$

or

$$x^{\circ} = \arg\min_{x \in X} \frac{1}{n}\left\{\sum_{i=1}^{n} \overline{m}_i[K_i(x)]\right\}, \quad i = \overline{1,n}. \tag{3.49}$$

In the practice of analysis, there are also cases when at evaluating options for some criteria $K_i(x), i = \overline{1,n}$ the weight coefficients are known, and for others, there is no preference assessment. In this case, it is proposed to consider two sets of criteria: the set of criteria R with known weight coefficients a_i and the set Q of criteria for which a_i is not known.

The powers of the sets are r and q, respectively. Then the effective solution $x^\circ \in X$ can be determined by a mathematical model of the form:

$$x^\circ = \arg\max_{x\in X} = \left\{ \sum_{\substack{i=1 \\ K_i(x)\in R}}^{r} a_i m_i[K_i(x)] + \frac{1}{q}\left[1 - \sum_{i=1}^{r} a_i\right] \sum_{\substack{j=1 \\ K_j(x)\in Q}}^{q} m_j[K_j(x)] \right\}. \quad (3.50)$$

It is easier for people participating in the assessment to express their opinion on the importance of a particular criterion not in the form of a point assessment, but in the form of intervals. $[a_{i\min}, a_{i\max}]$, wherein $\sum_{i=1}^{n} a_{i\min} \neq 1$, $\sum_{i=1}^{n} a_{i\max} \neq 1$ [111].

In this case, to solve the problem, a two-level procedure for choosing a compromise solution is performed. First, we solve n optimization problems of the form:

$$x^\circ = \arg\max_{x\in X}\left[a_{i\max} m_i[K_i(x)] + \sum_{j=1}^{n} a_j m_j[K_j(x)] \right] \quad (3.51)$$

$$\sum_{j=1}^{n} a_j = 1 - a_{i\max}, \ a_j \in [a_{j\min}, a_{j\max}],$$

$$j \neq i, \ j = \overline{1,n}, \ i = \overline{1,n}.$$

Then by values x_i° $i = \overline{1,n}$ calculate:

$$K'_{iB} = \max_i K_i(x_i^\circ); \ K'_{iW} = \min_j K_i(x_j^\circ), \quad (3.52)$$

$$i = \overline{1,n}, \ j = \overline{1,n}, \ j \neq i.$$

Thus, the boundaries of the area from which the compromise solution is determined are established.

The multi-criteria of the process is determined by various factors of its functioning. These factors can be conditionally divided into groups of factors having some commonality of the area of existence and the degree of influence on the final result determined by the goal and parameters of the investigated process. Such groups of factors include, for example, the following:

- technical, determining the equipment of TP with equipment and accessories;
- economic, affecting the cost and return on investment;
- environmental, determining the amount of resources to ensure environmental protection;
- human resources - the volume and quality of human resources for the implementation of the planned work.

The criteria for evaluating TP options are closely related to each other aimed at achieving a common goal and can be expressed both by technical characteristics and by cost. Another feature of the criteria that determine the characteristics of technological processes is the assessment of continuity, typification, manufacturability, flexibility, etc.

The past experience in the application of technological solutions is stored in the database of the decision making system (DMS) in the form of a structure of universal operations and the required equipment. To obtain information about the project of past developments, it is necessary to form an "image" of the conditional basic operation of new developments and, according to the degree of proximity with a similar part of past works, extract a list of technological processes for manufacturing the basic part.

Thus, information will be obtained to evaluate the values of the criteria for various options for the required equipment with equipment and tooling, volumes and types of materials and components, labor intensity by type of work, quantity and quality of labor resources.

The obtained values of the utility function of the particular criteria make it possible to carry out the procedure of multi-criteria evaluation of options. There are two main ways of presenting the results of multicriteria assessment of decision options - obtaining the only, best estimate of the alternative and building a ranked series of assessments of alternatives by the value of the utility function in the form:

$$P(x) = \sum_{i=1}^{n} a_i P_i[K_i(x)],\ i = \overline{1,n},\ \sum_{i=1}^{n} a_i = 1,\ a_i \in [0,1]. \qquad (3.53)$$

The optimality principle, depending on the formulation of the problem of obtaining the best value x^o, will have the form:

$$x^o = \arg \min_{x \in X} \sum_{i=1}^{n} a_i P_i[K_i(x)],\ i = \overline{1,n},\ \sum_{i=1}^{n} a_i = 1 \qquad (3.54)$$

or in the case when the best option is the result of the minimum value of the utility function of the alternative:

$$x^o = \arg \min_{x \in X} \sum_{i=1}^{n} a_i \overline{P}[K_i(x)],\ i = \overline{1,n}, \qquad (3.55)$$

where $\overline{P}[K_i(x)] = 1 - P_i[K_i(x)]$ is a utility function.

It is more convenient to present the results of calculating the values of the utility function of alternatives for further analysis in the form of a ranked series with the corresponding directions of dominance. This is due to the fact that in accordance with the formed a list of options for organizing technological processes from past developments and newly proposed in the form of a ranged series in accordance with the values of the utility function of the alternatives. The final determination of the values of the utility function of alternatives is associated with the assessment of the magnitude of the significance coefficients.

In a ranked list by the value of the utility function of alternatives $P_1(x) >$

$P_2(x) > P_3(x) >$ ... the number of the position occupied characterizes the relative importance of the corresponding option.

Further, a ranked number of technological process options must be assessed by environmental parameters.

Situations are possible when it is desirable to have an assessment of the difference between options according to individual criteria and characteristics of options. For this, an analysis of the degree of proximity of the main characteristics x_{ij} is carried out, where i is the serial number of the characteristic, j is the serial number of the basic part, $i = \overline{1,n}$, $j = \overline{1,m}$. It is assumed that the description of the reference and planned samples is formed from identical sets of characteristics. The deviation of the values of the characteristics of the reference sample and the planned one is denoted Δx_i.

The characteristics of the samples considered were previously normalized and given an isomorphic appearance based on the utility function of the particular criteria.

As a result, a multifactorial generalized assessment of the discrepancy between the characteristics of the reference sample and the designed one can be obtained as a weighted sum of the discrepancies for each parameter:

$$Q = \sum_{i=1}^{n} a_i \Delta x_i , \tag{3.56}$$

where a_i - coefficients that determine the relative importance of the characteristics of the option, $\sum_{i=1}^{n} a_i = 1$, $0 \le a_i \le 1$.

The optimality principle will have the form:

$$x^o = \arg \min_{x \in X} \sum_{i=1}^{n} a_i \Delta x_i . \tag{3.57}$$

The x^o value is used to rank the options based on the degree of similarity of the reference sample with the planned one.

Evaluation of options for constructing technological processes according to environmental safety criteria is carried out in the same way, taking into account the specifics of solving environmental problems.

Works in the field of ecology are regulated by various standards, industry regulations, and other directive documents [98, 99]. Environmental impact assessment is carried out during the development of pre-project and project documentation for all alternative options for achieving the goals of the planned activities in accordance with regulatory documents.

During the feasibility study of expansion, modernization, technical re-equipment of production, the standards of maximum permissible loads on the environment must be taken into account. Environmental requirements for technologies, materials and production products are established in the standards for these products.

Environmental impact assessment includes such characteristics as levels and scale of environmental impact, indicators of the state of the environment and environmental, social and economic consequences of possible changes in the environment and other characteristics stipulated by legislation. In order to reduce the level of negative impact on the environment, limits are set on emissions of pollutants into the environment.

These parameters can be considered as particular criteria for assessing TP by environmental characteristics.

In each specific case of pre-design analysis of technological process options based on environmental characteristics, the list of harmful emissions and their quantitative characteristics are selected depending on the type of planned work, materials and equipment for TP, means of protecting the environment from negative impacts.

The information necessary for making a decision on evaluating the options for technological processes can be stored in the database for standard solutions and evaluated according to the composition of materials used for the first time and their processing modes.

In each specific situation, experts determine a list of parameters for assessing the environmental factors of the process and the numerical values of particular criteria for options for technological processes. Particular criteria of TP options for further work should be normalized.

An assessment of the options for technological processes according to environmental criteria will be obtained on the basis of the generalized usefulness of the alternative in the form of an additive function:

$$P(x) = \sum_{i=1}^{n} a_i P_i[K_i(x)],\ i = \overline{1,n},\ \sum_{i=1}^{n} a_i = 1. \tag{3.58}$$

The principle of optimality is used in the form:

$$x^o = \arg\ \max \sum_{i=1}^{n} a_i P_i[K_i(x)],\ i = \overline{1,n},\ \sum_{i=1}^{n} a_i = 1. \tag{3.59}$$

The analysis of the assessment of technological processes by environmental parameters is distinguished by the peculiarities of determining the values of the coefficients of the importance of alternatives - a_i. Features of assessing the importance of environmental characteristics for each TP option are characterized by certain specific features.

All factors pose a certain threat from the point of view of impact on the environment, and then the degree of their significance may be the same. The difference may lie in the level of these harmful effects and the cost of developing protective equipment. In addition, the composition of harmful factors can be different and with different levels for individual options for organizing technological processes. Consequently, the cost of creating measures to protect the environment from possible harmful effects or paying fines and compensatory sanctions can be used as criteria for assessing the options for technological processes by environmental parameters. In this case, it is possible to build a ranged series of displayed options according to the value of the total costs for solving environmental problems in each TP option.

Then expression (3.58) can be written in the form:

$$P(x) = \sum_{i=1}^{n} Q_i \, , i = \overline{1, n} \, , \tag{3.60}$$

where Q_i – total costs for solving environmental problems in each TP of the options under consideration.

The optimality principle will have the form:

$$x^o = \arg \, min \sum_{i=1}^{n} Q_i \, , \; i = \overline{1, n} \, . \tag{3.61}$$

In accordance with expression (3.60), it is possible to construct a ranged series of preferences of TP options for ecological parameters of the form:

$$P_1(x) < P_2(x) < P_3(x) < \ldots \tag{3.62}$$

As a result, there is a ranged number of preferences of TP options by technological parameters and a ranged series of the same TP options by environmental characteristics.

Joint consideration of these two series will make it possible to evaluate the selected options for technological processes according to technological and environmental criteria.

To determine the utility function of each variant of the technological process, the ordinal numbers of the variants in the lists by belonging, estimated, for example, in points and having passed the standardization procedure, can be considered as evaluation criteria.

The generalized assessment of each option will be determined by the value of the utility function of the form:

$$\psi(K_i) = C_1 P(K_i) + C_2 Q(K_i),\ 0 \le C_1 \le 1,\ 0 \le C_2 \le 1,\ C_1 + C_2 = 1, \quad (3.63)$$

where $P(K_i)$, $Q(K_i)$ – particular criteria for technical and environmental indicators of TP options, respectively. Each of them is normalized and has the same range of possible values [0, 1].

The values of the coefficients C_1 and C_2 are determined by experts or decision makers. Based on expression (3.58), a list of technological processes is formed according to a generalized criterion as an order relation:

$$\psi(K_1) > \psi(K_2) > \ldots > \psi(K_n). \quad (3.64)$$

The considered approach to assessing the feasibility of a development plan at the pre-design stage of planning strategies allows us to systematize the types of work, deadlines and amounts of costs, planned work.

4 INFORMATION TECHNOLOGIES FOR FORMING AND EVALUATING DECISION-MAKING ALTERNATIVES

4.1 The main functions of information technology for the formation and evaluation of alternatives to the decisions made

Information technology for the formation and evaluation of alternatives for decisions made (IT FEADM) is designed to automate the procedures for searching, storing and processing information necessary for making management decisions at the pre-project stage of planning the development of new competitive products.

The main functions of IT are as follows:

- storage of a complete systematized set of technical documentation;
- information search of technological documentation;
- output of information about technological solutions for a given set of characteristics;
- comparison of characteristics of technological processes with a given "standard" and ranking based on multi-criteria optimization procedures.

Information technology allows to work in an interactive mode, in which the user sets his search conditions and analysis tasks. Requests and work with information is carried out in a user-friendly form [100].

Thus, IT FEADM solves the following tasks:

- formation, storage and processing of information (document) regarding TP, developments of past periods (technological archives);
- search for design and technological solutions for the given characteristics and the degree of proximity to the planned works;
- comparative assessment and ranking of selected TPs according to the degree of closeness to the reference sample.

The basis for solving the problem of searching for TPs close to the planned developments is based on the principle of analogies, according to which TPs or individual technological solutions are selected from the experience of past developments, which are close according to the specified criteria to the newly arisen task or "standard". Thus, a set of TP options is searched for in the base of past developments, which are subject to further evaluation by a set of criteria.

IT FEADM is implemented in three blocks:

- information support block - "Analogues",
- block for modeling the characteristics of technological processes - "Model",
- block for selection and evaluation of technological process options - "Options".

The "Analogue" block provides information support for decision-making by using an integrated enterprise database, as well as storing, coding and classifying documentation of past developments based on the enterprise's automated archive.

The "Model" block is a system of simulation modeling of technological processes in the form of an open-loop queuing system and provides the calculation of functional and cost characteristics of the planned production options.

The "Options" block provides evaluation and ranking of technological process variants according to the specified list of values of specific criteria and is a decision-making system.

The search for information in the archive of the enterprise and its classification is carried out on the principles of analogy according to a given set of attributes.

The blocks "Analog", "Model" and "Option" included in the IT FEADM operate using the information base described below and implement the processes of searching for variants by analogies, evaluating and ranking the selected variants.

4.2 The structure of the technological database in the "Analog" block

Information support for IT FEADM is provided by the operation of the "Analog" block, which includes the following modules:

1. The "Plan" module displays the structure of the production development plan in the form of a hierarchy of work performed. Contains information about the types of work and the calendar dates for their implementation.
2. The "TP" module presents the main technological processes with detailing to technological operations, describes material flows and the composition of the required resources. Data on the terms of work, labor intensity and the amount of required resources are refined on the basis of archival information from the database of analogous precedents.
3. The module "Properties, parameters" provides information on the properties of purchased and characteristics of components, materials, assemblies and assemblies in analogue products. At the pre-project stage, this information is necessary to determine the composition of suppliers.

The listed modules provide information for assessing the feasibility of development strategies in terms of such indicators as the timing of work, the required equipment, the amount of resources, the list of suppliers, and some others.

An important component of the "Analog" block for the selection of production development options is the technological database (TDB), which consists of separate specialized databases and includes an archive of technological solutions precedents. The use of TDB provides an automated assessment of TP options taking into account their features based on data analysis, from design and technological descriptions of products to technical and economic indicators of their production [101].

The TDB conceptual model is organized according to the tiered principle (fig. 4.1). TDB segments provide the information needs of the task of selecting options for technological processes and include:

- request identification module,

- documentary database (DDB),
- factual database (FDB),
- response generation module [102].

The product infological model reflects information about the different versions of an object of production. As a result of the aggregation of the product model and the production environment, we obtain a model consisting of separate fragments, each of which contains information related to one subject area, to one of the product versions and having a certain degree of detail, which corresponds to the pre-design stage of production planning.

The use of the product model makes it possible to search for technological solutions in the TDB based on information about the design features and other properties of the planned product [103].

Description of production facilities and their identification is based on existing classifiers. The use of classifiers ensures the implementation of a variant analysis of products and technological processes of their production [104, 105]. When choosing a TP-analogue at the pre-design stage, mainly structural search is carried out [106].

Thus, the information support of the tasks of analysis, selection and assessment of production development options forms a TDB, which includes the following information:

- a library of typical technological processes for various types of industries.
- technological operations, according to the classifier and the required parameters;
- equipment classifier;
- classifier and questionnaires of technological equipment;
- types of billets;
- used basic and auxiliary materials;
- normative and reference information presented in the form of technological tables and formulas for an integrated definition of resource consumption.

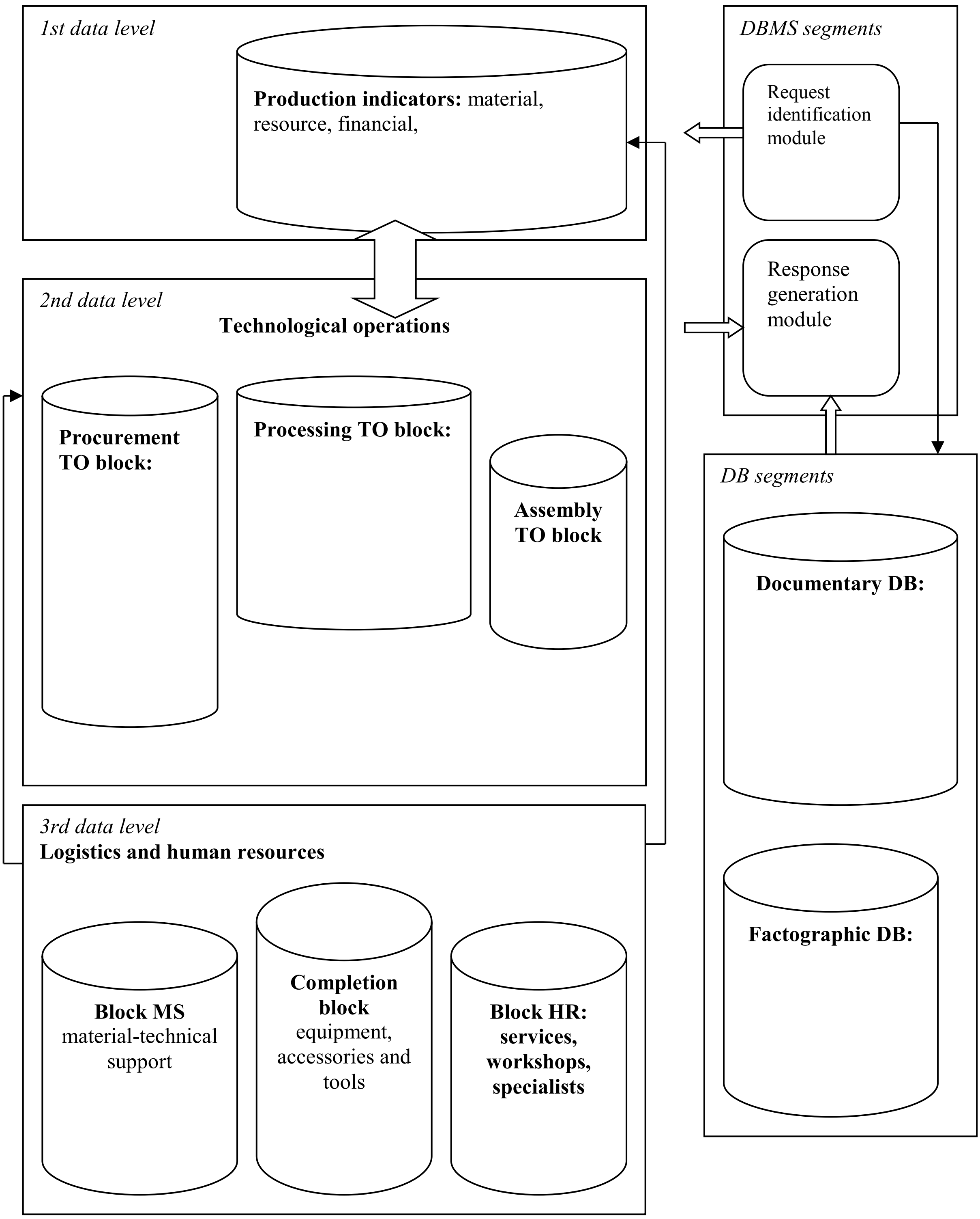

Fig. 4.1 Conceptual diagram of the enterprise TDB

At the pre-design stage, aggregated data are formed on the basis of summary sheets; data on labor input by type of work are entered, etc.

The technical support block contains information about what equipment and tooling is available at the enterprise, and contains not only the nomenclature, but also the characteristics and parameters of the equipment. This information is necessary to assess the cost of replenishment in each of the options under consideration and an overall assessment of the feasibility of the development plan based on their system classification.

The factographic part of the database contains information about the products of own production and the technological processes of their manufacture. The evaluation of existing technological processes and their modernization options is preceded by an analysis of products manufactured at the enterprise, which allows you to identify the composition of the initial data, form databases of the archive of products, directories and classifiers at a particular enterprise.

4.3 The structure of the "Options" block in the form of a precedent decision-making system

The main modules performing the analog search procedure are as follows:

- a module for processing the description of the developed TP and similar TP-analogues;
- a module for presenting technological solutions, which implements interface functions to describe the main characteristics of the planned product;
- a module for searching for close TP, which searches for similar ones to the developed TP based on the specified similarity ratio.

The search engine performs functions based on archives (DB) of technical documentation. The formation and management of such an archive is carried out by the existing at the enterprise software package for planning and project management for the creation of new technology.

The search procedure for TP analogs consists of the following stages:

- description of TP in the form of a structured object;
- identification from the resulting structure of elements from the available categories;
- clustering of found items;
- search for TP, which is close in structure to the planned one, according to a given measure of proximity;
- narrowing the search due to the inclusion of additional TP characteristics in the search;
- ranking of found analogs according to the degree of proximity to the planned object.

4.3.1 Extended CBR cycle of precedent decision-making system

Let us highlight the main functions of an intelligent system that ensures the solution of problems with the help of a plausible conclusion based on precedents.

1. Formation of a model of a use case - a description of the problem and its solution.

2. Choice of description language

3. Presentation of technological documentation from the archive of the enterprise in the language of an intelligent system.

4. Search for a solution based on precedents. When searching, they are guided by the usefulness of a particular image for solving a new problem. Utility is approximated by the measure of similarity of image descriptions, calculated as the distance between images in a multidimensional feature space.

The system that implements inference by precedents by implementing the above functions contains the following main modules (fig. 4.2):

- use case modeling module - provides the ability to create, modify use cases, generate and update the archive of use cases based on existing models;
- internal memory - provides storage of precedents in the archive;
- precedent inference engine - allows you to search for objects by describing the current situation;
- control module - provides interaction between modules and provides interfaces for interacting with the external environment.

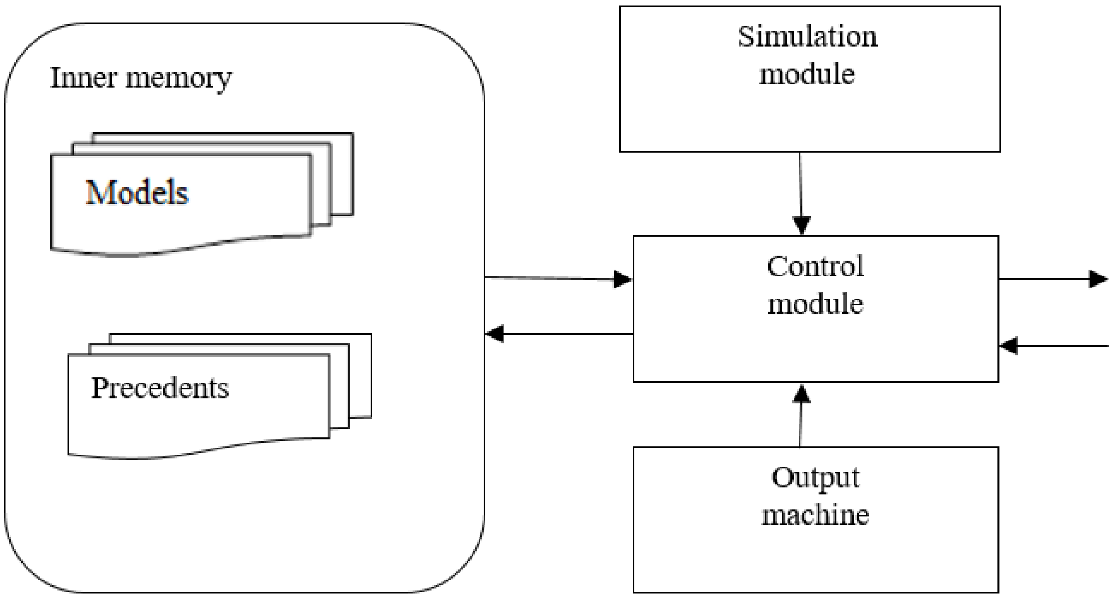

Fig. 4.2 Architecture of the system implementing precedent output

The process of functioning of precedent DMS (PDMS) is represented in the form of a CBR cycle, consisting of four main phases (4-R), which, in accordance with the terminology adopted in the theory of precedent systems [107], are designated as follows:

- RETRIEVE - selecting from the store the most relevant precedent or set of precedents,
- REUSE - use of selected precedents for decision-making,

- REVISE - verification and forming a new precedent,
- RETAIN - preservation of the decision and problem situation as a new precedent.

To implement the PDMS it is necessary:

- form the structure of the main phases of the PDMS,
- determine the main tasks and input parameters for each phase;
- define many stages for the implementation of individual tasks of the PDMS.

Let's define the main phases of PDMS. Some properties of the production situation are unknown at the pre-design stage and may be refined as development options are analyzed, other properties may be determined imprecisely or unclearly. Therefore, for use in a DMS with the specified features, the CBR cycle must be extended [79, 107], by adding the revision (REVIEW) and reconstruction (RESTORE) phases of the use-case store to the existing phases. PDMS in this case can be divided into two interacting subsystems - a search subsystem (RETRIEVE, REUSE, REVISE) and an adaptation subsystem (RETAIN, REVIEW, RESTORE).

4.3.2 Model of the functioning of the precedent decision-making system

In accordance with the above main stages of DMS construction, after determining the phases of the CBR cycle, it is necessary to decompose them into problem components, while determining the input parameters for each phase. As a result, a hierarchical structural-parametric model of PDMS functioning will be formed, which is a sequence and interconnection of the phases of the CBR cycle, aimed at realizing the main goal of the system - choosing the best solution from a structured base of precedents. Thus, the generalized hierarchical structure of the functional model contains three levels (fig. 4.3).

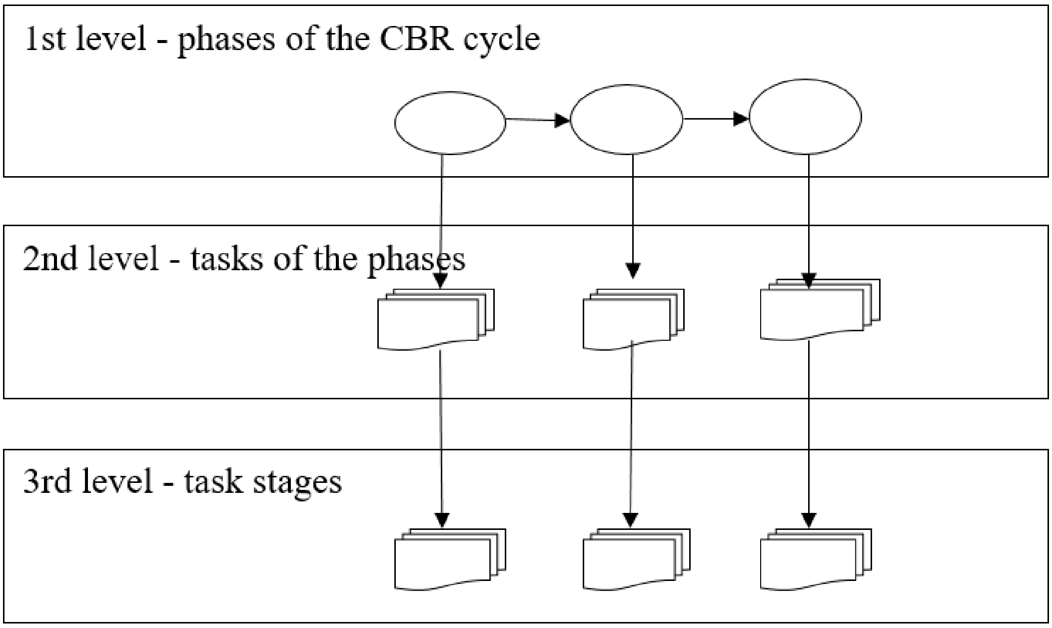

Fig. 4.3 Generalized hierarchical structure of the APDMS functional model

CBR-cycle can be formally presented as a set of sequentially executed phases:

$$CBR = \langle F_1, F_2, F_3, F_4, F_5, F_6 \rangle \qquad (4.1)$$

where F_1 – the phase of selection of precedents similar to initiating object based on similarity assessment; F_2 – decision-making phase in a problem situation by using the derived precedent; F_3 – verification and adaptation phase of the derived precedent; F_4 – a phase of saving the newly adopted decision in the store of precedents; F_5 – a phase of revision of precedent store based on the assessment of precedent quality using syntactic or semantic measures; F_6 – the recovery (reconstruction) phase of the precedent store.

The "input" for the first phase is the initiating object P from the precedent store D:

$$\langle P, D \rangle \to F_1 . \tag{4.2}$$

The result of this phase is a lot of similar precedents S_p, which in turn is the source for the second phase, which formally write in the form of a display:

$$F_1(SIM) \xrightarrow{S_p} F_2 . \tag{4.3}$$

The intermediate result of the second phase is a ranked set of precedents S_r and a reference precedent P_o for subsequent adaptation of the formed solution. The end result is the R_s solution, which is the starting point for the third phase. Present the specified transformations as a display:

$$F_2 \xrightarrow{S_r, P_o} A_2(REL) \xrightarrow{R_s} F_3 , \tag{4.4}$$

where A_2 – intermediate part of the second phase.

The problems of the third phase are solved using the utility function, which characterizes the relative contribution of the reference solution R_s to the generated solution $R_{\hat{s}}$ and serves as an indicator of the need to make changes in the store of precedents. The result of this phase is the formed solution $R_{\hat{s}}$, which is the initial for the fourth phase:

$$F_3(U) \xrightarrow{R_{\hat{s}}} F_4 . \tag{4.5}$$

In the fourth phase, a new precedent P_s is synthesized from the initiating object P and the generated solution $R_{\hat{s}}$; it is the starting point for the fifth phase:

$$F_4(P) \xrightarrow{P_s} F_5 . \tag{4.6}$$

The entrance to the fifth phase is a new precedent Ps. The result is an evaluation of the quality of DMS S_q:

$$F_5(Q) \xrightarrow{S_q} F_6 . \tag{4.7}$$

In the sixth phase, the precedent store is managed. Taking into account the many permissible operations of changing the precedent store, information is summarized and classified, and then the system quality estimates are recalculated:

$$F_6 \xrightarrow{M} D\|(C)\,,\ (P),(C) \longrightarrow (Q)\,. \tag{4.8}$$

If the quality assessment of the system decreases, return to the fifth phase, if not - the system stops until the next problem situation is detected.

The structural model of phase interaction in the process of system operation is presented in fig. 4.4.

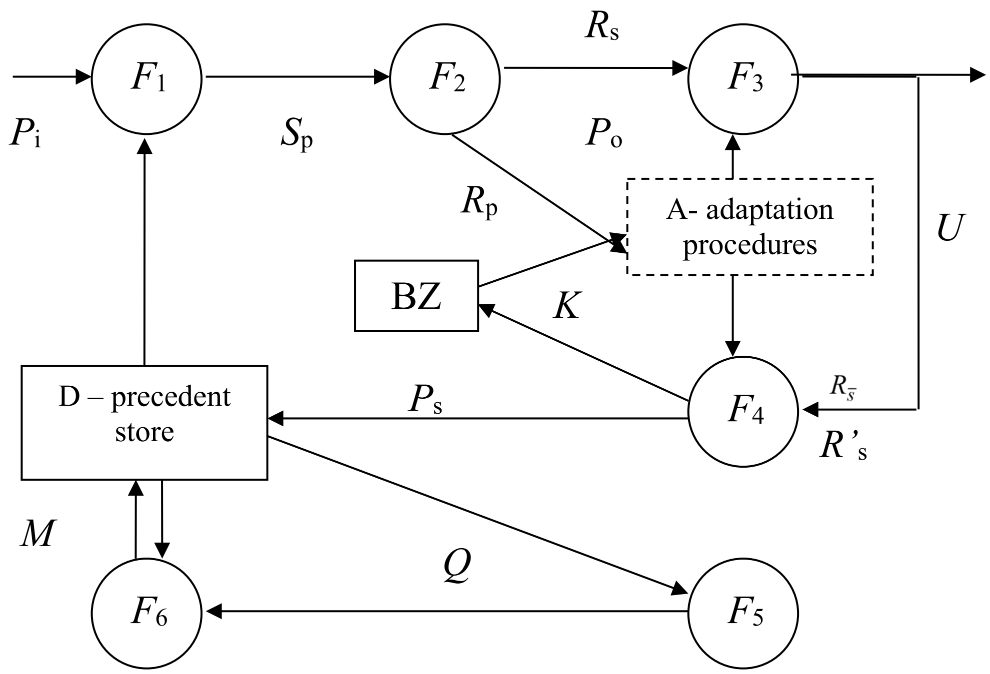

Fig. 4.4 Structural model of the DMS operation process

CONCLUSIONS

The analysis of tasks in the field of decision-making on the development of the enterprise justifies the need to assess the feasibility of options for the development of the enterprise at the pre-project planning stage on the main technical and economic indicators.

The phased development model of an enterprise determines the sequence of mapping the stages of the interconnection of the required resources in order to achieve the specified goals of innovative development. At the pre-design stage, the formation of technological process variants and the assessment of the technological feasibility of development plans should be carried out based on the experience of past developments, using the apparatus of the general theory of precedents, taking into account the specifics of the field of application and methods of describing technological processes in the archive of analogues. For this purpose, a minimal structural model of a generalized process operation is used. The model of representation of process variants in the precedent base is based on unified structural models of technological operations, which reduces the time spent searching for information for decision making.

Models of technological routes are used to estimate the values of technical and economic parameters of the planned production process. The method of estimating the characteristics of sequential technological processes based on queuing systems allows you to estimate the time and cost parameters for decision-making on the choice of their implementation.

The model of system representation of technological process and step-by-step procedure of information support of decision-making process serves as a basis of a choice of technological process by a comparative estimation of a set of variants on the set of criteria. A phenomenological model of step-by-step selection of TP components is used to describe the process of making an informed decision.

Models of formation and evaluation of options for enterprise development strategies are based on the experience of past developments and the calculation of similarities to compare multi-criteria options, which increases the validity and reliability of management decisions made at the pre-project stage of development planning.

The model of the precedent system of decision-making on the choice of variants of plans of development of the enterprise allows to reduce quantity of the analyzed variants.

Information technology of formation and estimation of alternatives of the accepted decisions can be used as information support and methodical maintenance of processes of acceptance of administrative decisions on a choice of variants of plans of development of the enterprise.

REFERENCES

1. Bazhin I.I. Information management systems / I.I. Bazhin. - M : SU – Higher School of Economics, 2000. - 688 p.
2. Grinev V.F. Commodity and innovation policy of the enterprise / V.F. Grinev. - K : MAUP, 2004.- 160 P.
3. Vikhansky O.S. Strategic management: textbook, 3rd edition / O.S. Vikhansky. - M .: Gardariki, 2008 - 296 p.
4. Khodakov V.E. Management of enterprise development in terms of risk / V.E. Khodakov, D.V. Khodakov//Collection of scientific works of IFDTUNT. - 1998. - Iss. 35 (7). - P. 156-162.
5. Strategic management. 17-module program for managers "Organization Development Management". Module 4. - M. : INFRA – M, 2000. –304 p.
6. Khomenko L.M. R&D strategy and its relationship with other levels of strategies in the pyramid of enterprise strategies/L.M. Khomenko//Formation of a market economy. 2011. № 25 - P. 116 - 124.
7. Thompson A.A. Strategic management: concepts and situations - trans. from English/A.A. Thompson, A.J. Strickland - M .: Publishing house "Williams", 2002. - 928 p.
8. Guidelines for assessing the effectiveness of investment projects and their selection for financing. - M.: 1994. - 120 p.
9. Fatkhutdinov R.A. Innovation management. - SPb: Peter, 2003.- 400 p.
10. Samochkin V.N. Phases of the life cycle of products and planning of flexible development of an enterprise / V.N. Samochkin // Marketing in Russia and abroad. - 1998. - P.111-118.
11. Artiukh R.V. Models for the formation of development strategy options/R.V.Artiukh, A.A. Belotsky// Information processing systems: col. of sc. w. KNUAF - Iss. 8 (98) - Kharkiv, 2011. – Page 263-265.

12. Cleland D. System analysis and target management: tr.from English / D. Cleland. - M: B.I., 1974. - 280 p.

13. Fatkhutdinov R.A. Strategic management: textbook, 5th iss., Revised. and add./R.A. Fatkhutdinov. - M.: Delo, 2002. -- 180 p.

14. Vlasenko S.N. Examination and monitoring of innovation processes. Methodical and legal aspects / S.N. Vlasenko, B.M. Golovatyuk, S.A. Egorov and others - K .: Ukr. Publ. Center, 2006. - 178 p.

15. Lyasko V.I. Strategic planning of enterprise development: a textbook for universities / V.I. Lyasko. - M.: publ. house "Exam", 2005. - 288 p.

16. Valik V.G. Methods of analysis and synthesis of structures of control systems: monograph/V.G. Valik, B.B. Buyanov, N.V. Lubkov. - Energoatomizdat, 1988. – 296 p.

17. Artiukh R.V. Hierarchical System of Indicators of a Comprehensive Criterion for the Effectiveness of Production Development Strategies/Artiukh R.V., Belotsky A.A.//Modeling, Identification, and Synthesis of Control Systems 2011 (MISCS 2011): Fourteenth International Scientific and Practical Conference - Kanaka, Crimea, 2011. – P. 196.

18. Petrov E.G. Management of sustainable development of enterprises: monograph/Petrov E.G., Podmogilny N.V., Sokolova N.A., Khodakov V.E. - Kherson: KHNTU, 2009. – 558 p.

19. Filatov V.A. Assessment of the feasibility of enterprise development plans/A.V. Filatov, R.V. Artiukh//" Modern information technologies in the economy and management of enterprises, programs and projects ": abstracts of reports of the IX International Scientific and Practical Conference. - Kharkov, 2011. – P. 129-130.

20. Drobitko N.A. Influence of the external environment on activity of the enterprise/N.A. Drobitko//Bulletin of the East Ukrainian National University named after V. Dahl. – 2001. – №12(46). - P. 279 - 282.

21. Belozertsev R.V. Assessment of the influence of environmental factors on the functioning of coal mining enterprises/R.V. Belozertsev//Scientific works of DonNTU. Series: economic. – 2005. - Iss. 100-1. – P. 198 – 207.

22. Sergeeva L.V. Design features of the logistics information system of the enterprise. Science vector of Togliatti State University. 2009. № 3(6). P. 15–21.

23. Filippova S.V. Infrastructure of functional and resource support for the management of transformational processes in industrial production/ S.V. Filippova//Proceedings of Odessa Polytechnic University. - 2005. - vol. 2 (24). - P. 240 - 247.

24. Chase R.B., Production and Operations Management: tr. from English/Chase R.B., Equiline N.J., Jacobs R.F.- M.: Publication. Williams House, 2001. – 704 p.

25. Valtsev S.A. System analysis in economics and organization of production/S.A. Valtsev, V.N. Volkova, A.P. Gradov and others - L.: Polytechnic, 1991. - 398 p.

26. Gornostaeva A.N. Theoretical foundations of management./ A.N. Gornostaeva - Bryansk: BSTU, 2005. – 198 p.

27. Artiukh R.V. The choice of a supplier of material resources taking into account the stochastic change in parameters/Artiukh R.V., Baranov M.V.//Integrated computer technologies in mechanical engineering ICTM-2011: international scientific and technical conference - Kharkiv, 2011. - P. 43.

28. Yastremsky A.I. Some issues of optimal distribution of resources in the performance of complex scientific and technical developments/Yastremsky A.I., Krashikova L.I., Gritsenko E.G. - Kiev, 1986. – 12 p.

29. Larichev O.I. Theory and methods of decision-making ./O.I. Larichev - M.: Logos, 2002. – 392 p.

30. Mazur I.I. Restructuring of enterprises and companies: ref. manual/Mazur I.I., Shapiro V.D. and others - M.: Higher School, 2000. – 300 p.

31. Akimova I.M. Restructuring of enterprises in the industry of Ukraine: -monograph/I.M. Akimova - K.: Business-inform, 1999. – 284 p.

32. Gerasimchuk V.G. Strategic enterprise management. Graphic modeling: textbook / V.G. Gerasimchuk - K .: KNEU, 2000. - 360 p.

33. Budnik M.M. Adaptation of industrial enterprises to market conditions of management: abstract of the dissertation of the candidate of economic sciences: 08.03.02 / M.M. Budnik - Kh: KhNEU, 2002. - 19 p.

34. Batkovsky A.M. Management of innovative development of enterprises of the radio-electronic industry / A.M. Batkovsky - M.: Onto Print, 2010. -- 248 p.

35. Al-Salameih M.A. Market conditions and marketing planning at the enterprise: abstract of the dissertation of the candidate of economic sciences: 08.03.02/M.A. Al-Salameih - Kh. KhNEU, 2002 - 19 p.

36. Automated information technologies in economics: textbook / Ed. I.T. Trubilina - M.: Finance and Statistics, 2003.- 416 p.

37. Milaev V.A. Automation of the control process in the conditions of multi-product small-scale production / V.A. Milaev, A.A. Fatkin, T.V. Rulaeva // Systems of design, technological preparation of production and management of the stages of the life cycle of an industrial product: materials of the Intern. conf. and exhibition CAD/CAM/PDM-2001. - M., 2001.- P. 261 - 270.

38. Rudenko A.I. Strategic planning at the enterprise. KF / A.I. Rudenko - Simferopol: KIEU, 1997.- 196 p.

39. Parkhomenko O.M. Management of a machine-building enterprise: functions, organizational structure, personnel: Text book / Parkhomenko O.M., Osievsky A.G. - Kharkov: Nat. aerospace un-ty "KhAI", 2000. - 160 p.

40. Buslenko N.P. Lectures on the theory of complex systems / Buslenko N.P., Kalashnikov V.V., Kovalenko I.N. - M .: Sov. radio, 1973.- 440 p.

41. Fatkhutdinov A.R. Production management / A.R. Fatkhutdinov - M. : Infra-M, 2007.- 544 p.

42. Garifullin R.F. Strategies for innovative development of a machine-building enterprise / R.F. Garifullin // Issues of innovative economics. - 2011. - No. 6. - P. 27-34.

43. Automated systems for technological preparation of production for flexible production systems for machining: method. recommendations - M. : VNIITEMR, 1985.- 108 p.

44. Grisha S.M. Making decisions on the basis of reaching the sub-activity factor / Grisha S.M., Gnatenko N.S. // Science of the NTUU "KPI". - 2008. - No. 4. - P. 62 - 75.

45. Admirov Yu.D. Manufacturability of product structures: a reference book / Yu.D. Admirov - M.: Mashinostroenie, 1990. - 768 p.

46. Litovka Yu.V. Modeling and optimization of technological objects in CAD: lab. workshop / Litovka Yu.V., Kuznetsov A.A. - Tambov, TSTU, 1996 .-- 54 p.

47. Kulikov D. D. Modeling of objects and processes in automated systems for technological preparation of production in mechanical engineering and instrument making (methods and tools): author. dis.for Dr. Tech. Sciences // D.D. Kulikov - SPb.: SPb. Institute of Precision Mechanics and Optics, 1992. 38 p.

48. Pospelov D.A. Logical-linguistic models in control systems / D.A. Pospelov – M.: Energiya, 1981. - 167 p.

49. Fishburne P. Utility theory for decision making / P. Fishburne – M. : Nauka, 1978 .-- 352 p.

50. Berestneva O.G. Construction of logical models using decision trees / Berestneva O.G., Muratova E.A. // Bulletin of the Tomsk Polytechnic University. - 2004. - V. 307. - No. 2. - P. 154 - 160.

51. Neumann D. Theory of games and economic behavior / D. Neumann, O. Morgenstern – M.: Nauka, 1970.- 708 p.

52. Mozhaev A.S. Theoretical foundations of the general logical-probabilistic method of automated systems modeling / Mozhaev A.S., Gromov V.N. - SPb. VITU, 2000. –145 p.

53. Larichev O.I. Human-machine procedures for solving multicriteria problems of mathematical programming (review) / Larichev O.I., Polyakov O.A. // Economics and Mathematical Methods. - 1980.- V.XVI, issue 1.- P. 129-145.

54. Lotov A.V. Multicriteria decision making problems / Lotov A.V., Pospelova I.I. - M .: MAKS Press, 2008 .-- 197 p.

55. Saati T. Decision-making. Method of analysis of hierarchies: tr.from English / T. Saati - M .: Radio and communication, 1993. - 320 p.

56. Plaksin M.A. Some difficulties in applying the method of analysis of hierarchies and ways of overcoming them. / M.A. Plaksin // The First International Conference "System Analysis and Information Technologies" SAIT-2005: Conference Proceedings - M .: KomKniga.- 2005. V.1. - P. 291-297.

57. Podinovskiy V.V. On the incorrectness of the hierarchy analysis method / Podinovskiy V.V., Podinovskaya O.V. // Control problems. 2011. No. 1. P. 8. 13.

58. Jones J.K. Design methods / J.K. Jones - M .: Mir, 1986. - 326 p.

59. Müller I. Heuristic methods in engineering developments: tr.from Germ. / I. Müller - M .: Radio and communication, 1984.- 142 p.

60. A.I. Polovinkin Methods of engineering creativity / A.I. Polovinkin - Volgograd: VPI, 1984.-365 p.

61. Ueno H. Representation and use of knowledge: trans. from Japan. / H. Ueno, M. Isizuka - M .: Mir, 1989 .-- 286 p.

62. Popov E.V. Artificial Intelligence. Book. 2. Models and methods. / E.V. Popov - M .: Radio and communication, 1990 .-- 237 p.

63. Kokoreva L.V. Dialogue systems and knowledge representation: a reference guide / L.V. Kokoreva, O.L. Perevozchikova, E.L. Yushchenko - K. : Nauk. Dumka, 1992. -- 448 p.

64. Brand E. Naive-Bayes and Nearest Neighbor / Brand E., Gerritsen R. - DBMS. - 1998. - № 7. – P. 48-57.

65. Alexandrov L.V. Program-targeted approach to the development of technical solutions / Aleksandrov L.V., Blinnikov V.I., Karpova N.N. - M. : VNIIPI, 1989.- 78 p.

66. Vvedenskaya N.A. Application of the decision planning system in the design of complex energy objects / N.A. Vvedenskaya // Methods and decision-making systems. Expert systems in computer-aided design. - Riga: Riga. Polytechnic, in-t. - 1990. - P. 10-15.

67. Vermishev Yu.H. Methods of automatic search for solutions in the design of complex technical systems / Yu.H. Vermishev - M .: Radio and communication, 1982. - 152 p.

68. Balashevich V.A.Mathematical methods in production management / V.A. Balashevich - Minsk: Higher school, 1986. - 211p.

69. Taha Kh. A. Introduction to Operations Research, 7th edition: tr.from English / Kh.A. Taha - M .: Publishing House "Williams", 2005. - 912 p.

70. Kuritskiy B. Ya. Optimization around us / B. Ya. Kuritsky - JI. : Mechanical Engineering, 1989. - 119 p.

71. Artiukh R.V. Criteria analysis with incomplete information / R.V. Artiukh, A.A. Belotsky, O. N. Zamirets // Problems of information technologies. — 2011. - Iss. 9. - S. 95 - 99.

72. Kudryavtsev E.M. Research of operations in tasks, algorithms, programs / E.M. Kudryavtsev - M .: Radio and communication, 1984. - 226 p.

73. Artiukh R.V. Evaluation of alternative production development options taking into account environmental factors/Artiukh R.V., Belotsky A.A.// Modern information technologies for environmental safety management, nature management, emergency measures: 10th International scientific-practical conference - Kharkiv-Crimea, 2011. - P. 232-235.

74. Dechtyarenko V.A. Algorithmic model of multicriterial evaluation of decisions on a set of vectors of constraints/A.A. Dehtyarenko//Methods and decision-making systems. Issues of creating expert systems - Riga: Riga. polytech. in-t, 1988. - P. 52-58.

75. Carr Ch. Quantitative methods of decision-making in management and economics / Carr Ch., Hove Ch. - M .: Mir, 1966. - 355 p.

76. Moiseev N.N. Elements of the theory of optimal systems / N.N. Moiseev - Moscow: Nauka, 1974. -- 526 p.

77. Sokolenko A. N. Optimization methods in statistical control problems / A.N. Sokolenko - M .: Mashinostroenie, 1974 .-- 134 p.

78. Goryacheva T.V. Functional cost analysis as one of the methods to improve the efficiency of integrated preparation of production [electronic resource] - Access mode: http://quality.eup.ru/DOCUM3/funcanaliz.html.

79. Sherstyuk V.G. Formal model of hybrid scenario-precedent DSS / V.G. Sherstyuk // Automation. Automation. Electrotechnical complexes and systems. - 2004. - Iss. 1. - P. 114-122.

80. Pavlov A.I. Component approach: module of plausible inference based on precedents / A.I. Pavlov, A. Yu. Yurin // Software products and systems. - No. 3. - 2008. - P. 11-14.

81. Aamodt A. Case-based reasoning: foundational issues, methodological variations, and system approaches / A. Aamodt, E. Plaza //AI Communications. – 1994. – Vol. 7. – №1. – P. 39-59.

82. Korovin D.I. On finding the utility function in the theory of Neumann-Morgenstern / D.I. Korovin // Bulletin of the Ivanovo State Energy University. - 2005. - Iss. 4. - P. 83 - 88.

83. Artiukh R.V. Structural models of technological operations and processes / R.V. Artiukh, A.A. Belotskiy // Bulletin of the Kherson National Technical University. - 2011. - No. 4 (43). - P. 124-127.

84. Saati T.L. Elements of the theory of queuing and its application / T.L. Saati - M .: Sov. Radio, 1971. - 520 p.

85. Kleinrock L. Computing systems with queues / L. Kleinrock - M .: Mir, 1979. - 319 p.

86. Sadovnichy A.S. The method of imitation modeling in the tasks of analyzing production systems / Sadovnichy A.S., Popov A.V. // Aviation and space technology and technology. –2003. - No. 8 (43). - P. 149-154.

87. Zamirets O.N. Analysis of dynamic and cost characteristics of production processes with a sequential technological chain / O.N. Zamirets, A.A. Belotsky, R.V. Artiukh // Radio electronic and computer systems. - 2011. - No. 3 (51). - P. 102-107.

88. Gorskiy Yu.M. System-information analysis of management processes / Yu.M. Gorsky - Novosibirsk: Nauka. Sib. branch. - 1988. -- 327 p.

89. Ovezgeldyev A.O. Synthesis and identification of models of multivariate estimation and optimization / Ovezgeldyev A.O., Petrov E.G., Petrov K.E. - K. : Naukova Dumka, 2002. - 163 p.

90. Dubov Yu.A. Multicriteria models of forming the choice of system options / Dubov Yu.A., Travkin S.I., Yakimets V.N. - Moscow: Nauka, 1986. - 296 p.

91. Malygin E.M. Information and procedural models for the synthesis of environmentally friendly technological processes of chemical-thermal treatment of metal products: textbook / E.N. Malygin, V.A. Nemtinov, S. Ya. Egorov, et al. - Tambov: Publishing house of Tamb. state tech. University, 2007. - 108 p.

92. Fedorovich O.E. Methods and models of decision-making in managing complex industrial complexes: monograph / Fedorovich O.E., Nechiporuk N.V., Prokhorov A.V. - Kh .: National Aerospace University "KhAI", 2005. - 235 p.

93. Steuer R. Multicriteria Optimization. Theory, calculation and applications / R. Steuer - M .: Radio and communication, 1992. - 504 p.

94. Podinovskiy V.V. Optimization according to consistently applied criteria / Podinovskiy V.V., Gavrilov V.M. - M .: Sov. radio, 1975.- 192 p.

95. Zamirets O.N. Model for assessing the options for development strategy / O.N. Zamirets, R.V. Artiukh, A.A. Belotskiy // Collection of Science Practitioners of Kharkiv University of Powers. - Iss. 3 (29). - H., 2011. - P. 107–109.

96. Beshelev S.D. Expert estimates / S.D. Beshelev, F.G. Gurvich - Moscow: Nauka, 1973. - 263 p.

97. Dobrov G.M. Expert assessments in scientific and technical forecasting / Dobrov G.M., Ershov Yu.V. and others - Kiev: Naukova Dumka, 1974.- 223 p.

98. GOST 30773-2001. Resource saving. Waste management. Stages of the technological cycle. Basic provisions. - Introduction. 07/01/2002 / M. : Publ. house of standards, 2001.- 11 p.

99. Girich O.A. Regulatory legal acts for handling low-quality and hazardous products withdrawn from circulation [Electronic resource] / O.A. Girich, R.V. Lokhmachev // Cooperation for solving the problem of waste: abstr. report at the 1st Int. conf. - Kharkiv, 2004. - Access mode: http://waste.com.ua/cooperation/2004/thesis/girich.html.

100. Shamsha B.V. Shamsha B.V. Mathematical support of information and control systems: textbook for students of higher educational institutions/ B.V. Shamsha, A.M. Gurzhiy, Z.V. Dudar, V.M. Levikin. - Kh .: SMIT Company LLC, 2006. - 448 p.

101. Mukhin A.V. The concept of building and structure of the knowledge bank for technological design and production management / A.V. Mukhin, O.V. Spiridonov // ACS TP. The world of new technologies. - 2001. - No. 6. - P. 48 - 61.

102. Nevlyudov I.Sh. Information modeling of the subject area of the computer-aided design system for technological equipment of production / I.Sh. Nevlyudov, E.I. Litvinova, V.V. Usik, O.V. Buyvol // Radio electronics, informatics, management. - Zaporizhzhia: ZNTU. - 2004. - No. 1. - P. 127–133.

103. Artiukh R.V. The structure of information support of the precedent system for making technological decisions / Artiukh R.V., Belotskiy A.A. // Current information technologies in the management and professional preparation of operators of folding systems: materials of the 6-th International Scientific and Practical Conference - Kirovograd, 2001. - P. 72.

104. Gnedenko V.G. All-Russian technological classifier of assembly units for instrument making and instrument making (OK 022-95) / Gnedenko V.G., Dukarsky S.M., Taller S.L. and others - M .: Publishing house of standards, 1996. - 81 p.

105. Mashina E.S. Product cataloging in the CALS concept / E.S. Mashina, P.S. Shilnikova // Systems of design, technological preparation of production and management of the stages of the life cycle of an industrial product: coll. of rep. thesis at Int. conf. and exh CAD / CAM / PDM-2001 - M., 2001. - P. 29-30.

106. Bergmann R. Developing industrial case-based reasoning applications: the INRECA methodology / R. Bergmann, S. Breen, M. Goker etc. // Lecture notes in artificial intelligence, LNAI-1612 - Berlin: Springer-Verlag. – 1999. – P. 93 – 101.

107. Roth-Berghofer T. Towards a maintenance methodology for case-based reasoning systems / T. Roth-Berghofer, I. Iglezakis //Proceedings of the 9th German Workshop on Case-Based Reasoning (GWCBR): in Professionelles Wissensmanagement: Erfahrungen und Visionen. – Shaker-Verlag. – 2001. – P. 198–208.

R. Artiukh, V.Kosenko, I. Nevliudov

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Monograph

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