

# Development of Models of Manufacturing Processes of Innovative Products at Different Levels of Management

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**Abstract**—The article presents the science, technologies and innovations as foundations of modern economic development. The purpose of establishing complex-structured innovation structure and their functions are analyzed. An effective organizational-economic structural model is proposed for the management of their performance. Production functions, allowing central management institution to use the resources effectively and enterprises within the institution to operate with the whole production strength, are developed. Parameters that cannot be assessed directly as innovation, innovation capacity, science capacity and environmental availability are included in the modeling process. Hierarchic models are developed corresponding to the problems posed to each structure. Among models with various levels, a conceptual algorithm is developed for the purpose of finding a coordinated solution on product/service output based on the efficient utilization of scarce resources. Some suggestions have been given on the basis of modeling the activity of innovative enterprises of different levels with complex structure on its perspective development directions.

**Index Terms**—Information and knowledge economy, innovation structure, innovation enterprises, models system, science-intensive product, manufacturing functions, management functions.

## I. INTRODUCTION

The global economy is developed with the application of new technologies and innovations. Hence, the formation and implementation of scientific-technological innovation policy in the development of advanced economies is deemed as a high-priority issue. Among modern tools with innovative influence on the globalization of economic relations and the development of new economy, the most important are science, technologies and innovations. Information and knowledge economy shaped as a result of the application of those tools is considered as the next stage of economic development [1].

Technological development and innovations act as a

driving force of long-term economic development during the transition to knowledge- and innovation-based economy [2] under the circumstances of information society [3]. Information and knowledge become main development factors of society. The sectors of manufacturing of knowledge and information products play a prominent role in the transition from industrial level of development to post-industrial level of development and the competitiveness of those sectors. The development of countries becomes more dependent on the development of science-intensive fields, including technological innovations [4]. A transition must be carried out to a stage characterized with the advancement of innovations in order to form an efficiency-based economy. The main driving force of economy is the shift from efficiency-based model to innovation-based model with the implementation of high technologies including smart devices and systems. The application of innovative technologies to newly established economic sectors, automated knowledge generation process, Internet vigilance, long-distance administration technologies, artificial intelligence and robotization, as well as the adaptation of management to the requirements of advanced technologies (bio, nano, information-communication, industry, finance, etc.) [5, 6].

The establishment of clusters and high-tech parks is one of the main targets boosting the development of innovation enterprises and innovation structures while building an innovation-oriented and knowledge-based economy [7]. Innovation structures and high-technology parks, scientific-technological innovation technoparks, as well as innovative centers and structures as their elements are main driving forces in the transition to digital or innovation economy. Hence, the development of new administrative mechanisms, the establishment and organization of complex-structured innovation centers, technological complexes, technoparks, and business-incubators is a very important and topical issue oriented towards strengthening mutual scientific-education-production relations in new economic environment.

The introduction of this article is described the official documents, processes and circumstances that condition the relevance of the problem. The next section provides information on the formulation of the problem and the

condition of learning the problem. Purpose of creation, functions and features of innovation structures have been commented. The organizational-economic structure of innovative enterprises management is given. In the following sections, the model of the center management organization and the activities plan of the low-level enterprise has been set up. Then, a conceptual coordinated scheme of solution algorithm of the system of the models is given.

## II. ABOUT FORMULATION AND STUDY LEVEL OF THE PROBLEM

As known, the solution of numerous problems posed to economy hinge on the activity of innovative structures (technoparks) [10]. The establishment of technoparks, organization and effective management of their activity are problems with complex content at various levels. The procedure and algorithm of establishment of innovative structures, as well as their organizational-administrative structure is regularly improved based on the analysis of development tendencies in world practice. At the same time, those are considered as an economic system with hierarchical structure and functions, and the problems of industrial enterprises, centers, services, training organizations, banking, investment and insurance institutions, resident companies with various profiles in their structure are dynamically updated on a regular basis.

Modeling tools are used in effective organization of complex structured enterprises of such character. The main activity of the enterprise in particular and within a more compound structure is modeled. The analysis of existing scientific literature in this field shows that modeling is mostly focused on either maximization of commercial revenues or minimization of expenses [10-19]. This time as manufacturing processes are mostly carried out with extensive methods, innovative processes, the application of innovations stay out of focus. The attention isn't paid to main parameters such as innovation capacity, scientific capacity, technological capacity, development sources in manufacturing process. Moreover, social and commercial interests, criteria, strategic aims and missions of the enterprises in particular are little coordinated with their current activity plans.

These factors demonstrate once more that, innovative structures function by implementing coordinated development plans under the condition of the presence of various criteria based on multilevel management. Hence, as a rule, general problems posed to each stage and level are taken into consideration during the modelling of system functioning. It can be stated that, the functioning of innovative structures (technoparks) is carried out by adopting coordinated decisions at two levels. Central administrative institution of innovative structure utilizes a mechanism of effective distribution of deficit, rare and limited resources and distribute them among consumers with minimum cost. In this case, minimum values of functions are attempted to be obtained within specific constraint conditions. At the same time, the production of innovative, science-intensive new products must be

planned by using those deficit and limited resources such that, profitability, labor productivity, cost value, net income indicators would satisfy preliminarily specified conditions. Therefore, such models system must be built among various administrative levels and such solution options coordinated among those and satisfying the requirements of each two levels must be found that, specified constraint conditions would be satisfied.

## III. PURPOSES OF ESTABLISHMENT, FUNCTIONS AND FEATURES OF INNOVATION STRUCTURES

In accordance with new economic conditions, 1)reduction of resource dependence of non-oil sectors, 2) creation of competitive markets participants by facilitating a favorable business environment, 3) acquiring competition advantages for export-oriented sectors, 4) formation of import substitutions sectors, 5) capture of market share for specific products in global value chain, 6) conduction of research oriented towards the solution of pressing scientific problems and other intensive works will be carried out in innovation structures. The purpose of establishment of complex-structured innovation enterprises shaped in this aspect is to: 1) boost the sustainable development and competitiveness of economy, 2) expand innovation and high technologies sectors based on modern scientific and technological advancements, 3) create new jobs for highly skilled experts, 4) produce newly created science-intensive product and sell it in local and foreign markets, 5) convert scientific outcomes, knowledge and inventions into technologies and commercial product; 6) intensify the use of scientific-technical potential; 7) transfer of technologies to production sector via small science-intensive enterprises; 8) form and develop science-intensive enterprises in market; 9) attract direct investments, etc.

Based on the purpose of establishment, innovation enterprises [8]: 1) conduct scientific-research and development works, 2) form small innovation enterprises, 3) help enterprises to absorb new technologies, 4) train skilled employees for high-technology sector and create new job places for them. Moreover, they facilitate the formation of mutual relations between higher education institutions, scientific-research institutions and industry and discover new income sources, the manufacturing of science-intensive products and their sale in local and foreign markets.

The following main characteristics relate to innovation structures: 1) being an enterprise with innovative features, 2) maximum approximation of science, education, production and commerce, 3) application of various stimulation mechanisms and regimes, 4) increase in products and services based on high technologies including ICT, 5) development of science and technology-intensive sectors, 6) development of intelligent products, 7) development high-technology sector, 8) rapid implementation of scientific-research works, 9) transfer of innovative technologies, 10) protection of intellectual property, 11) formation of

collective utilization centers, etc.

IV. ECONOMIC-ORGANIZATIONAL STRUCTURE OF THE MANAGEMENT OF THE ACTIVITY OF INNOVATION STRUCTURES

Alongside regional and within-country factors, the development of national economy and its position in global economic system is influenced by economic-organizational forms of innovation structures. The consideration of those factors in the management of various sectors of public and economic life is important from the point of view of powerful policy-making. Natural resources have acted as a driving force of economic development for a long period. Hence, the main target is to reduce the existing dependence on resource reserves in the economy. For this purpose, it is an important issue to achieve the rapid development of competitiveness of economy and to apply resource-saving non-oil sector, increase the efficiency and technologies

for ensuring innovation-based development of the economy. Efficient resource utilization is closely related to administrative forms. The management of the complex activity of innovation structures hinges on its economic-organizational administrative structure directly. Several principles are to be followed while building organizational-administrative system of an enterprise [9]. An exemplary organizational-economic administration structure as a result of the investigation of organizational structural models of innovation structures with various profiles is proposed in Figure 1.

It is to be noted that, Sumgait Chemical Industry park, Sumgait Technology park, Pirallahi High technologies park, Balakhani Eco-industrial park, ANAS High Technologies park, agricultural and other high technology parks have been established in Azerbaijan and serve to the expansion of high technology sectors, conduction of scientific research, development of new technologies, as well as the formation of innovative product or service production. All these factors necessitate the development of general foundations of the modelling of complex activity of complex-structured innovation enterprises and processes of innovative product/service production in those enterprises under circumstances of information society.

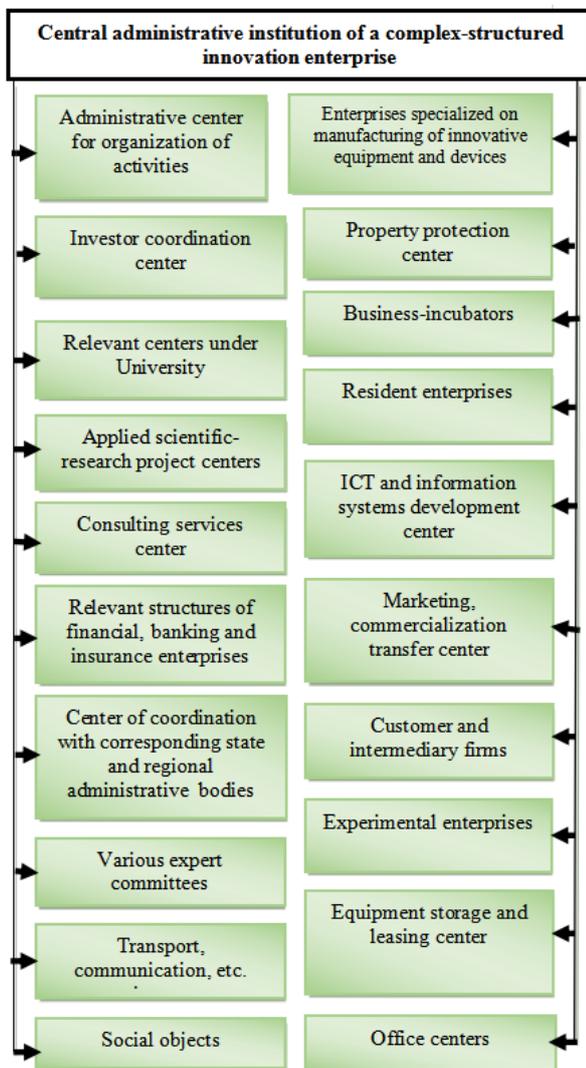


Fig.1. Organizational-economic administrative structure of complex-structured innovation enterprise

V. MODEL OF EFFECTIVE UTILIZATION OF ADMINISTRATIVE AUTHORITY RESOURCES (MACROMOD)

For accuracy, assume that, T technoparks is constituted of  $i=1, n$  number of enterprises with  $M_i$  production capacity. These enterprises produce various innovative products or provide services by utilizing specific resources with  $j=1, m$  characteristics. According to existing legislation and world practice, it is considered that, the activity of those enterprises are coordinated by administrative company (administrative authority) alongside with own administrative structure [11].

Let us adopt some notations.  $r_j$  is the limited volume of  $j$ -th resource.  $M$  it is maximum level of normative production capacity of an innovative structure (technopark):

$$M = \sum_{i=1}^n M_i \tag{1}$$

$M_i$  is maximal production capacity of  $i$ -th enterprise.  $P$  is realized production capacity of innovation structure, in other words, it is the total volume of goods and services produced.

$P_i$  is realized production capacity of  $i$ -th enterprise.

$r_{ij}$  is the quantity of  $j$ -th resource appointed for  $i$ -th enterprise;

$$\sum_{i=1}^n r_{ij} = R_j \quad (j = \overline{1, m}) \quad (2)$$

$r_{ij}^{\min}, r_{ij}^{\max}$  is the minimum and maximum threshold of  $j$ -th product dedicated to  $i$ -th enterprise;

$F_i(IM_i, RS_i, r_{i1}, r_{i2}, \dots, r_{im})$  is a production function characterizing total costs in  $i$ -th enterprise based on specific  $IM_i$  innovation capacity and  $RS_i$  resource capacity parameters.

$f_i(IM_i, RS_i, r_{i1}, r_{i2}, \dots, r_{im})$  is product/service output function characterizing final product/service production in  $i$ -th enterprise in specific innovative environment and under the circumstances of effective utilization of resources.

$IM_i$  is a parameter characterizing innovative environment, innovation capacity and production environment in  $i$ -th enterprise. Several factors affect its specification and determination and it can be approximated based on various methods. According to numerous expert approaches, it can be reckoned that, central administrative authority of innovation structure can be informed about the minimum/maximum threshold of this parameters, that is,

$$IM_i^{\min} \leq IM_i \leq IM_i^{\max} \text{ or } IM_i \in [IM_i^{\min}, IM_i^{\max}]. \quad (3)$$

In some cases, both innovative environment and resource intensity parameters can be substituted by efficient resource utilization coefficient, which can be calculated as follows:

$$IM_i = \frac{P_i^I \cdot \sum_{j=1}^m r_{ij}^{II}}{P_i^{II} \cdot \sum_{j=1}^m r_{ij}^I} = \frac{P_i^{II}}{\sum_{j=1}^m r_{ij}^I} / \frac{P_i^{II}}{\sum_{j=1}^m r_{ij}^{II}} \quad (4)$$

here  $P_i^I \rightarrow P_i^f(I \rightarrow f)$  denotes actual product volume,  $P_i^{II} \rightarrow P_i^g(I \rightarrow f)$  denotes expected – actual and expected product volume in previous years.

$r_{ij}^I, r_{ij}^{II}$  - denotes actual and expected volume of utilized resources in previous years.

If we calculate similar values for  $G$  number of previous years or determine based of expert opinions, then

$$IM_i^{\min} = \min_g MI_{ig}, \quad IM_i^{\max} = \max_g MI_{ig} + E, \quad g = \overline{1, G} \quad (5)$$

Here,  $MI_{ig}$  is expressed total resource intensity in  $g$ -th year and calculated as  $IM_i \cdot E_i$ .  $E_i$  can be considered as a directive of administrative authority towards the increase (reduction) of that parameter based on the analysis of resource utilization tendencies in  $i$ -th enterprise.

So, considering the notations and notes above, the model of performance (MACROMOD) on the reduction of total costs (TC) of administrative authority of innovation structure (technopark) can be expressed as below:

$$UMX = \sum_{i=1}^n F_i(IM_i, r_{i1}, r_{i2}, \dots, r_{im}) \rightarrow \min, \\ 0 \leq P \leq \sum_{i=1}^n f_i(IM_i, r_{i1}, r_{i2}, \dots, r_{im}) \leq M \quad (6)$$

$$0 \leq \sum_{i=1}^n r_{ij} \leq R_j \quad (7)$$

$$0 \leq r_{ij}^{\min} \leq r_{ij} \leq r_{ij}^{\max} \quad (i = \overline{1, n}; j = \overline{1, m}) \quad (8)$$

## VI. PRODUCT/SERVICE OUTPUT MODEL OF INNOVATION ENTERPRISES (MICROMOD)

Let's now attempt to model the activity of resident enterprises or other designated structural entities functioning under innovation structure, directed by administrative authority within specific circumstances and adopting independent decisions within own conditions at some extent at the same time [12]. Similar to the functioning of administrative authority,  $MXI_i$  maximization of final product/service production with limited resources in  $i$ -th enterprise can be taken as an optimization criterion while modeling the process of finding a solution of an efficient product/service manufacturing plan in an enterprise at relatively lower administrative level.

Enterprise models system (MICROMOD) can be expressed as below with constraint conditions based to labor productivity, cost value, profitability and scientific-technological innovation capacity:

$$MXI_i = \sum_{k=1}^{L_i} \varphi_{ik}(IM_i, y_{ik}) \rightarrow \max \quad (9)$$

$$0 \leq \sum_{k=1}^{L_i} a_{ijk} y_{ik} \leq r_{ij}, \quad \sum_{k=1}^{L_i} \lambda_{ik} y_{ik} \geq P_i \quad (10)$$

$$\sum_{k=1}^{L_i} y_{ik} \leq M_i^p = \alpha_i^1 \cdot M_i^b, \quad \sum_{k=1}^{L_i} C_{ik} y_{ik} \leq CC_i^p = \alpha_i^2 \cdot CC_i^b \quad (11)$$

$$\sum_{k=1}^{L_i} \lambda_{ik} y_{ik} / PP_i \geq \cdot PT_i^p = \alpha_i^3 \cdot PT_i^b \quad (12)$$

$$\sum_{k=1}^{L_i} P_{ik} Y_{ik} \geq PR_i^p = \alpha_i^4 \cdot PR_i^b \quad (13)$$

$$\sum_{k=1}^{L_i} l_{ik} Y_{ik} \geq E_i^p = \alpha_i^5 \cdot E_i^b \quad (14)$$

$$y_{ik}^{\min} \leq y_{ik} \leq y_{ik}^{\max} \quad (i = 1, n; j = \overline{1, m}; k = \overline{1, L_i}) \quad (15)$$

here  $k=1,2,\dots, L_i$  is the product index of  $i$  th enterprise;  $y_{ik}$  is  $k$  th product in  $i$  th enterprise;  $y_{ik}^{\max}, y_{ik}^{\min}$  lower and upper threshold on specific product output, respectively.

$\varphi_{ik}(\dots)$  is a production function characterizing final net production obtained from  $k$  - th product output depending on the innovation capacity of  $i$  - th enterprise environment;

$\alpha_{ijk}$  is a cost coefficient of resources used in specific product production;

$\lambda_{ik}$  is a value of specific product unit;

$M_i^p, M_i^b$  is characterizes production capacity of an enterprise of planned (expected, prospective) and base year, respectively;

$C_{ik}$  is unit cost of specific product in corresponding enterprise;

$CC_i^p, CC_i^b$  is final cost on product/service manufacturing of planned (expected, perspective) and base period in a specific period;

$E_i^p, E_i^b$  is scientific-technological innovation capacity of final activity in various periods in a specific enterprise;

$l_{ik}$  is a coefficient of scientific-technological innovation capacity employed in specific unit product production;

$PP_i$  is volume of labor force in an enterprise for the calculation of labor productivity;

$PT_i^p, PT_i^b$  enterprise's labor productivity thresholds in corresponding periods;

$P_{ik}$  volume of income obtained from unit product manufacturing in corresponding enterprise;

$PR_i^p, PR_i^b$  volume of final income of enterprise in corresponding periods;

$\alpha_i^1, \alpha_i^2, \dots, \alpha_i^5$  is growth rate of various indicators (production capacity, unit cost, labor productivity, profitability, scientific-technological innovation capacity).

## VII. CONCEPTUAL SCHEME OF SOLUTION ALGORITHM OF MODELS SYSTEM

Enterprises determine current  $S_i$  value of  $IM_i$  coefficient before solving the administrative part pertaining to the higher level of innovative structure. As those are not capable and not interested in presenting this

value accurately, the corresponding problem is solved in parametric form. That is, obtained results are formed depending on  $S_i$  value.

Therefore, administrative company forms  $r_{ij}, p_i$  and  $k_i(\alpha_i^1, \dots, \alpha_i^2)$ . Here,  $\alpha_i^t$  is a tension indicator of plan according to  $t$ -th indicators, whereas  $k_i$  is a tension indicator in  $i$ -th enterprise.

While determining  $k_i, r_{ij}, p_i$  and other directive indicators are taken as basis. The methods of their determination serves to the improvement of the management of enterprises pertaining to corresponding sectors. At next step following the determination of  $r_{ij}, p_i, k_i$ , each lower level element solves the problem corresponding to this level.

As  $r_{ij}, p_i$  variables hinge on the value of  $S_i$ , the solution of a problem is linked to  $S_i$ . Hence, different  $r_{ij}, p_i$  are obtained at various values of  $S_i$ . However, administrative company can deem all values as optimal.

Optimization problem is solved for each  $i$ -th enterprise based on  $r_{ij}, p_i, k_i$ . Although obtained results satisfy the administrative authority, those solutions may not satisfy enterprises. Thus, an enterprise attempt to find an optimal plan option by approximating the value of  $S_i$  variable each time. An enterprise solving MACROMODE problem can construct the volume of product output as  $Y_{ik}$  and determine the current value of  $IM_i (IM_i^T)$  as follows:

$$IM_i^T = \frac{P_i \cdot \sum_{i=1}^m r_{ij}^*}{P_i^* \cdot \sum_{j=1}^m r_{ij}} + \Delta_i^T \quad (16)$$

Here,  $\Delta_i^T$  denotes the level of efficient resource utilization, innovation capacity of environment and the growth (reduction) in innovation capacity of an activity. This quantity is determined empirically with expert assessment based on quality indicators of an enterprise.

$P_i^*, r_{ij}^*$  denotes the optimal value of corresponding variables. Newly obtained value of  $IM_i^T$  is presented to administrative authority.

In general, the solution algorithm of MACROMOD and MICROMOD models system can be constructed as below. Initially,  $F_i$  and  $\varphi_i$  form is determined [14-20]. The linear correlation between the variables can be adopted based on variable analysis. Hence, those can be written as a multidimensional regression function.

$$F_i = \frac{1}{IM_i} \sum_{j=1}^m a_{ij} r_{ij} + a_{i0} \quad (17)$$

$$\varphi_i = \text{IM}_i \sum_{j=1}^m b_{ij} r_{ij} + b_{i0} \quad (18)$$

The coefficients of corresponding functions are calculated with least squares method. It is evident that, above mentioned models system can be formalized as a linear programming problem. Separately obtained solutions can be adapted according to the levels among models. This process is carried out based on the approximations iteratively between levels via information exchange. In order to find a coordinated solution, new values of the coefficient of efficient resource utilization are entered as  $r_{ij}(l)$  in enterprise model and as  $\text{IM}_i(l)$  in  $P_i(l)$  administrative authority model at each iteration ( $l$  – denotes the number of iterations).

The initial distribution of  $r_{ij}(l)$  resources and preliminary production plans are formed based on the values of  $\text{IM}_i(l)$  coefficient of efficient utilization of corresponding resources of the model of  $P_i(l)$  administrative company and directive  $P, R_j, r_{ij}$  values. Each iterative approximation process determines such  $y_{ik}(l)$  at enterprise level that, those allow for obtaining maximum net product under the circumstances of scarce resources and product output devoted to those enterprises. Practically, this iterative process stops when future obtained results are not significantly different from previous results or obtained results satisfy the requirements of the decision-maker. Solutions obtained in last stages are adopted as coordinated solutions.

### VIII. CONCLUSION

The production of innovation products/services plays a prominent role in the economic development of each country. Therefore, the performance of innovation enterprises established in corresponding fields must be carried out based on efficiency principle [20, 21]. One of those directions is the application of mathematical models and econometric methods in the planning of production processes in innovative enterprises with complex structure based on the effective utilization of scarce resources. The activity of both administrative institution and production/service enterprises is modeled based on various criteria enterprises with proposed structure.

In the modeling process firstly production functions are set depending on the innovativeness and resource, scientific and technological capacity of the central institution involved in management. At the same time minimum/maximum ranges of the parameters characterizing innovativeness are determined by fuzzy assessment method. Relevant production functions are also set on enterprise level. Effective activity plan is tried to be formed on the basis of base and current values, also expert values assessments of the most parameters.

The approach shown to the modeling of interaction of such character of innovative structures is new. Most

economic parameters used in this approach can't be measured directly and are assessed under conditions of uncertainty. The effective modeling of the manufacturing process by the method of assessment of the efficiency level of innovative environment, the conceptual solution algorithm for building relevant level models and getting balanced solution between the models are the essence of this approach and can be considered as a beginning for new investigations in this direction.

By the way, it should be noted that in this article suggested in the theoretical character, has been studied only the commentary of the economic essence of the process, its modeling and the conceptual solution. In subsequent studies the proposed approaches will be enriched with experimental data and will be analyzed in a more specific production and enterprise sample.

An iterative algorithm has been developed for obtaining coordinated solution between levels by using dynamically changing values of such parameters as science capacity and innovation capacity characterizing the favorableness of economic environment. Problems can be solved by employing applied software packages via computer modelling based on real indicators. Such solution options create additional opportunities for the more effective administration of innovative structures and obtaining higher incomes.

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*Areas of interest:* innovative, information and knowledge