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DEVELOPMENT OF TWO-STAGE MODELS SYSTEM OF PRODUCTION PROCESS IN INNOVATION ENTERPRISES WITH COMPLEX STRUCTURE

The article presents the science, technologies and innovations as foundations of modern economic development. The purpose of establishing complex-structured innovation enterprises and their functions are analyzed. An effective organizational-economic structural model is proposed for the management of their performance. Hierarchic models are developed corresponding to the problems posed to each structure. A conceptual algorithm is developed to find an agreed solution on product/service output among the models with various levels based on the efficient utilization of scarce resources.

Keywords: *information and knowledge economy, innovation enterprises, models system, science-intensive product, manufacturing functions, administrative functions.*

Introduction

The global economy develops with the introduction of new technologies and innovations. Therefore, the formation and application of scientific and technological innovation policy for the development of the economy in advanced countries is a priority. Science, technology and innovation are the most important mechanisms and tools for today that will further facilitate the globalization of economic relations and the growth of new economy. Information and knowledge society formed as a result of their application represents the next stage of economic development [1].

In terms of information society [2], technological development and innovations act as a long-term driving force of economic growth in transition to knowledge- and innovation-based economies [3]. Information and knowledge are becoming a key factor of the society's development. knowledge and information production fields play a crucial role in the economic development and competitiveness of the countries transitioning from industrial development to post-industrial era. The level of economic development of countries depends largely on scientific areas, including technological innovations [4].

The transition to the stage characterized by the superiority of innovation should be ensured for the formation of an efficient economy. The key driving force of the economy is the transition from a profitable model to an innovative model with the use of high technologies, including smart devices and systems. Automated knowledge generation process, Internet control, remote control, artificial intelligence and robotics, bio/nano management, and other innovative technologies should be applied in newly emerging economies [5, 6].

Creation of clusters and high-tech parks that promote the development of experts and innovative structures is of great importance for the establishment of the innovation-oriented and knowledge-based economy [7]. Innovative structures and their key elements, namely high-tech parks, scientific and technological innovation technology parks, innovative centers and structures are the driving forces for the transition to the digital or innovative economy. Therefore, the development of new management mechanisms to strengthen the interaction of science-education-production in the new economic environment, the establishment and functioning of innovative centers with complex structure, technological complexes, technoparks and business incubators is one of the most important and topical issues.

Objectives, functions and features of establishing innovation structures

Innovation structures includes the implementation of intensive activities, such as reducing resource dependency on non-oil sectors in accordance with new economic conditions, creating competitive market environment, creating competitive advantages for export-oriented sectors, forming import-compensating sectors, acquiring market shares on specific products in global value chains, conducting researches in solving actual scientific problems, etc. In this aspect, the creation of innovative enterprises with complex structure has the following objectives:

1. to raise continuous development and competitiveness of the economy;
2. to expand the fields of innovation and high technologies based on modern scientific and technological achievements;
3. to create new jobs for highly qualified specialists;
4. to manufacture new products and to organize their sale at local and foreign markets;
5. to transform scientific results, knowledge and inventions into technology and commercial product;
6. to intensify the use of scientific and technical potential;
7. to transfer technology into production through smaller scientific enterprises;
8. to form scientific companies and to organize their positioning in the market;
9. to attract direct investments, etc.

Innovative enterprises, depending on the purpose of their establishment [8],: 1) conduct scientific-research and experimental-constructive work; 2) form small innovative companies; 3) assist enterprises in mastering new technologies; 4) prepare highly-qualified personnel, and create new jobs for them. They also provide the establishment of mutual relations among higher education institutions, research institutes and industries, and ensure the creation of new sources of income for them, the production of innovative products, and their sale at local and foreign markets.

The main features of the innovation structures include: 1) their innovative nature; 2) closeness to science, education, production and commerce; 3) application of various motivation mechanisms and regimes; 4) increase of products and services based on high technologies, including ICT; 5) development of science and technology; 6) development of intellectual products; 7) development of the high-tech sector, 8) fast realization of the results of scientific research; 9) transfer of innovative technologies; 10) protection of intellectual property; 11) formation of the centers for collective use, etc.

Economic-organizational structure of the management of innovation structures

The development of the national economy, its position in the global economic system is affected by the regional and domestic factors, including the economic-organizational forms of innovation structures. Consideration of these factors in the management of different areas of social and economic life is important for the formation of an effective economic policy. Natural resources have been the main driving force behind economic growth for a long time. Therefore, the main task is to eliminate existing dependence on resources in the economy. In this regard, it is crucial to use of resource-saving technologies to achieve the rapid development of the non-oil sector, to enhance the competitiveness and sustainability of economy, and to promote its innovation-based advancement. Effective use of resources is associated with management forms. The management of innovation structures depends directly on its economic and organizational structure [9]. Many basic principles must be followed in the organization of the enterprise management system. As a result of the study and synthesis of organizational and structural models of various innovative structures, its organizational and economic management structure is proposed in Figure 1.

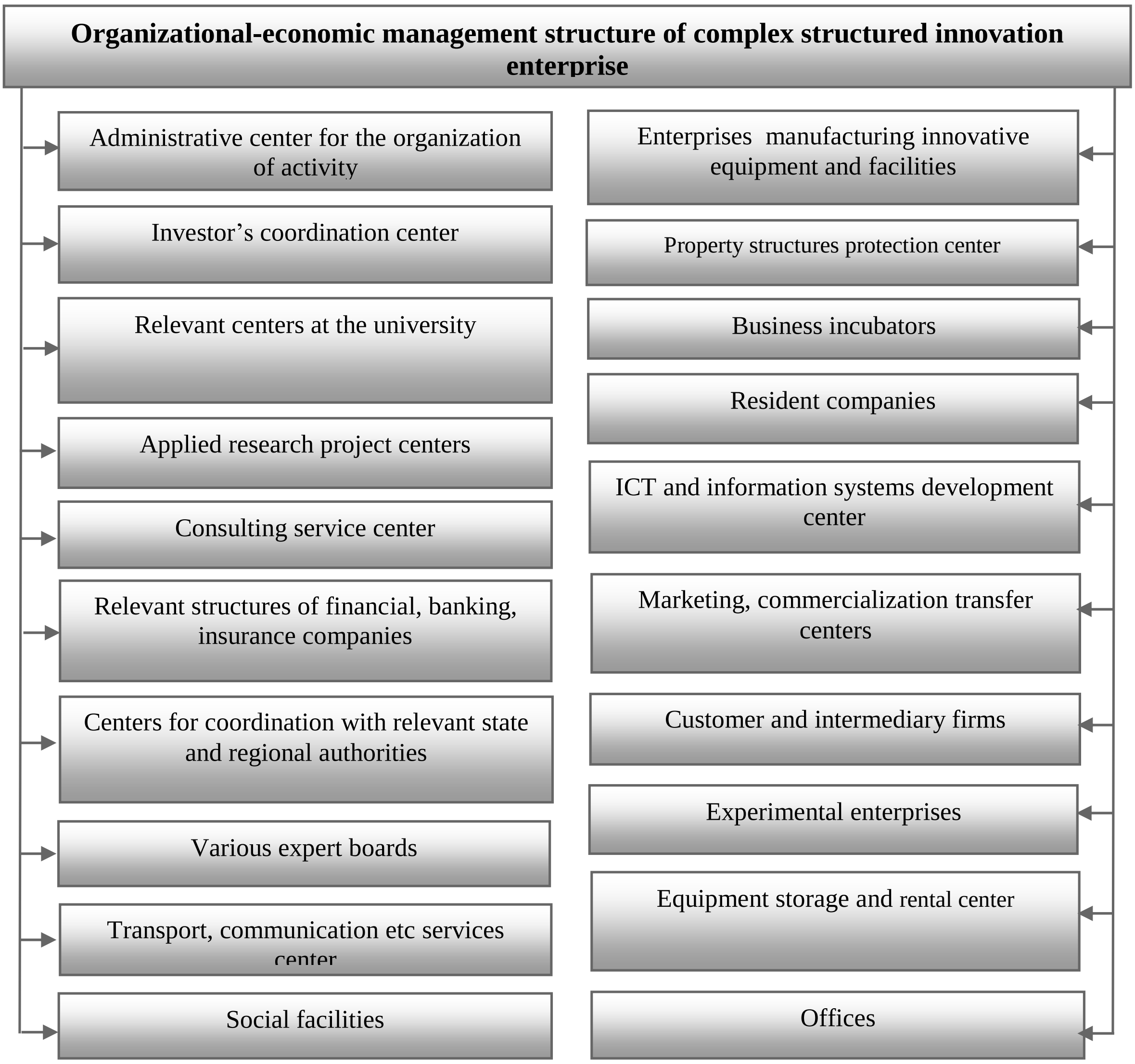

Figure 1. Organizational and economic management structure of the complex structured innovation enterprise

It should be noted that Sumgayit Chemical Industry Technology Park, Sumgayit Technology Park, Pirallahi High Technology Park, Balakhani Eco-Industrial Park, and High Technology Park of ANAS, as well as agrarian and other high technology parks have been built for the expansion of high technologies, to conduct researches, to develop new technologies, and to form innovative products or service production in Azerbaijan. All of this requires the development of a comprehensive framework for the general functioning of complex structured innovation facilities in the Information Society and for the modeling of innovative products/services in these enterprises.

The problem statement

Obviously, solution of many issues in economy depends on the activity of innovative structures (technoparks) [10]. Their creation, organization and effective management are complex multi-layered problems. The procedure and algorithm for the creation of innovative structures based on the analysis of the development trends in the world practice, as well as their organizational and management structure are regularly improved. Moreover, when they are viewed as a hierarchical economic system, and the functions and issues of the industrial enterprises, centers, services, educational institutions, banks, investment, insurance companies and resident companies of various profiles are constantly and dynamically updated. All of these once again show that innovation structures operate by implementing the balanced or agreed development plans in the context of multiple criteria based on multilevel management. Therefore, the general issues that are set before each phase and level are often considered when modeling such a system. It can be assumed that the innovative structures (technoparks) are functioning by making agreed decision on two levels. The centralized managing entity of the innovative structure distributes the deficit, depleted and limited of resources among consumers at minimum of cost through effective distribution mechanisms. Here, the minimum prices of functions are searched within certain restrictive conditions. Moreover, new innovative and scientific products have to be produced with the use of these deficit and limited resources, so that the values of the additional indicators, such as expected profitability, productivity and main capital, will provide initial conditions. Thus, a system of different models must be built between different management levels, and different solutions, that are agreed between them - that meet the requirements of both levels, should be found, so that restrictive conditions will be provided.

The model for effective use of limited resources (MACROMOD) of the Managing Entity

For certainty, assume that the technopark *T* consists of a large number of enterprises M_i with different $i=\overline{1,n}$ number of profiles. These enterprises produce variety of innovative products or provide services using a variety of different $j=\overline{1,m}$ number of resources. Based on existing legislation and international practice, the activities of these entities are believed to be coordinated not only by their own managing body, but as well as their managing company [11].

Let's denote some signs as follows: R_j - the volume of the *j*-th resource in the limited amount; *M* - the maximum limit of the normative production capacity of the innovative structure (technopark):

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

M_i - the maximum production capacity of the *i*-th enterprise. *P* – actually realized production capacity of the innovative structure, in other words, the total volume of its products and services.

P_i - realized production capacity of the *i*-th enterprise.

r_{ij} - the amount of the *j*-th type of resource allocated to the *i*-th enterprise: $\sum_{i=1}^{n} r_{ij}=R_j\left(j=\overline{i,m}\right)$.

$r_{ij}^{\min}, r_{ij}^{\max}$ - minimum and maximum limit of allocation of the *j*-th type of resource to the *i*-th enterprise;

$F_i\left(IM_i, RS_i, r_{i1}, r_{i2},..., r_{im}\right)$ is a production function that characterizes the final costs of the *i*-th enterprise, depending on the certain parameters of innovation IM_i and resource capacity RS_i.

$f_i\left(IM_i, RS_i, r_{i1}, r_{i2},..., r_{im}\right)$ is a product/service release function that characterizes the final product/service production in the *i*-th enterprise in a particular innovative environment and in terms of effective use of resources.

IM_i is the parameter that characterizes the innovative environment, innovation and production conditions in the enterprise. Its definition and identification are influenced by many factors and can be specified based on different methods. Based on various expert approaches, it can be assumed that the minimum/maximum limits of that parameter, i.e. $IM_i^{\min} \le IM_i \le IM_i^{\max}$ or $IM_i \in [IM_i^{\min}, IM_i^{\max}]$ can be known to the centralized authority of the innovation structure.

In some cases, the calculation of this parameter can be implemented as follows, by replacing the synthesis of both the innovative environment and the resource capacity parameters by the coefficient of efficient use of resources:

$$IM_i = \frac{P_i'}{\sum_{j=1}^{m} r_{ij}'} / \frac{P_i''}{\sum_{j=1}^{m} r_{ij}''} = \frac{P_i' \cdot \sum_{j=1}^{m} r_{ij}''}{P_i'' \cdot \sum_{j=1}^{m} r_{ij}'}$$

here P_i', P_i'' denotes the volume of predicted and actual product in previous years; r_{ij}', r_{ij}'' - the predicted and actual resource utilization in previous years.

If the similar valued are calculated by G number of previous years or defined by the expert opinions, then

$$IM_i^{\min} = \min_g IM_{ig}, \quad IM_i^{\max} = \max_g IM_{ig}, \qquad g = \overline{1,G}$$

Here, IM_{ig} denotes the summarized resource capability in the analyzed g-th year and is calculated as IM_i. In many cases, the parameter E_i is added to IM_i to regulate the management. E_i may be taken as a directive of the managing company for the enhancement (reduction) of that parameter based on the analysis of the trends of the use of resources in the i-th enterprise.

Thus, taking into account the above-mentioned signs and notes, the model (MACROMOD) for the overall cost reduction (OCR) of the managing entity of the innovation structure (technopark) can be summarized as follows:

$$OCR = \sum_{i=1}^{n\Sigma} F_i(IM_i, r_{i1}, r_{i2}, \ldots, r_{im}) \to min, \; 0 \le P \le \sum_{i=1}^{n} f_i(IM_i, r_{i1}, r_{i2}, \ldots, r_{im}) \le M,$$

$$0 \le \sum_{i=1}^{n} r_{ij} \le R_j$$

$$0 \le r_{ij}^{\min} \le r_{ij} \le r_{ij}^{\max} \left(i = \overline{1,n}; j = \overline{1,m}\right).$$

Effective product/service release model of innovation enterprises (MICROMOD)

In this section, activities of the resident enterprises (12) or other unit, which operates within the innovative structure, guided by the managing body under certain conditions and at the same time making decisions independently under certain circumstances, are modelled. Correspondingly, at the other lower management level – when modeling the process of finding an efficient product/service production plan in the enterprise, it may be desirable to maximize the volume (MXI_i) of the final product/service production in terms of restricted resources in the i-th enterprise for optimality criteria. Within the framework of the relevant limitation of labor productivity, cost value, profitability, scientific and technological innovation capacity, the following is a system of business modeling (MICROOM):

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

$$0 \le \sum_{k=1}^{L_i} a_{ijk} y_{ik} \le r_{ij}, \; \sum_{k=1}^{L_i} \lambda_{ik} y_{ik} \ge P_i,$$

$$\sum_{k=1}^{L_i} y_{ik} \le M_i^p = \alpha_i^1 \cdot M_i^b, \; \sum_{k=1}^{L_i} C_{ik} y_{ik} \le CC_i^p = \alpha_i^2 \cdot CC_i^b,$$

$$\sum_{k=1}^{L_i} \lambda_{ik} y_{ik} / PP_i \ge \cdot PT_i^p = \alpha_i^3 \cdot PT_i^b,$$

$$\sum_{k=1}^{L_i} P_{ik} y_{ik} \ge PR_i^p = \alpha_i^4 \cdot PR_i^b,$$

$$\sum_{k=1}^{L_i} l_{ik} y_{ik} \geq E_i^p = \alpha_i^5 \cdot E_i^b$$

$y_{ik}^{\min} \leq y_{ik} \leq y_{ik}^{\max} \left(i = 1, n;\ j = \overline{1, m}; k = \overline{1, L_i}\right)$, where k=1, 2, ... , L_i - the index of product in the i-th enterprise; y_{ik} - the k-th product in the i-th enterprise; $y_{ik}^{\max}, y_{ik}^{\min}$ - lower and upper limits on the relevant product release;

$\varphi_{ik}(...)$ - production function characterizing the appropriate final net product derived from the release of the k-th product, depending on the innovative environment in the i-th enterprise;

α_{ijk} - the cost coefficient of the resource used in the production of the relevant product;

λ_{ik} - the value of the relevant product unit;

M_i^p, M_i^b - characterize the production capacity of the enterprise for the planned (expected, prospective) and basic period;

C_{ik} - the cost value of the relevant product unit in the relevant enterprise;

CC_i^p, CC_i^b - the cost value of production of all products/services in the relevant enterprise for the planned (expected, prospective) and basic period;

E_i^p, E_i^b - scientific and technological innovation capacity of the final activity of the relevant enterprise for the relevant period;

l_{ik} - the coefficient of scientific and technological innovation capacity expected in the production of the relevant unique product;

PP_i - the amount of workforce in the enterprise for the calculation of labor productivity;

PT_i^p, PT_i^b - the limits of labor productivity for the relevant periods;

P_{ik} - the amount of revenue earned on the unique product in the relevant;

PR_i^p, PR_i^b - the amount of the final revenues of the enterprise for the appropriate periods;

$\alpha_i^1, \alpha_i^2, ..., \alpha_i^5$ - the growth rate by relevant indicators (production capacity, cost value, labor productivity, profitability, scientific and technological innovation capacity).

Modeling based on capital balance approach

Note that, using the inter-fields capital balance modeling approach, a model of product and service production processes of innovative structures with hierarchical and complex structure can be built [13]. Assume that X_j amount of production is released in the j-th production area using K_j amount of capital (production buildings, tools, equipment, etc.). Then, the capital per unit of product release can be defined as follows:

$$f_j = \frac{K_j}{X_j}, j = 1,2,...,n \ .$$

Here, f_j is a direct capital (funds) coefficient or capital accumulation coefficient. In other words, f_j represents the major production funds spent during the release of the unique amount of production in the j-th production area. The direct funds coefficients defined as the correlation of K_j to X_j is placed as the main diagonal elements of the square matrix of dimension (n x n):

$$f = \begin{pmatrix} f_1, ..., & ..., & 0 \\ 0, ..., & f_i, & ..., 0 \\ 0, ..., & ..., & f_n \end{pmatrix}$$

This matrix is called the direct capital capacity coefficient matrix.

The following matrix equation is obtained from the matrix expression *f*- and from the correlation of K_j to X_j:

$$f * \overline{X} = \overline{K} \ .$$

This is called a balance of major production funds in the value expression. Here, $\overline{X} = (X_1, X_2, ..., X_n)^{\tau}$ is a general transposon release vector, and $\overline{K} = (K_1, K_2, ..., K_n)^{\tau}$ is a major transposon production funds. Analogous to inter-fields labor balance, statistical inter-fields balance model can be extended by the major production funds balance:

$$\begin{cases} X = AX + Y \\ \overline{K} = f * \overline{X} \end{cases}$$

Here *A* is the direct expense coefficients matrix in the inter-fields balance equations. This expression is called an inter-fields balance model expanded with the major production funds balance.

As other inter-fields balance models, here, in most practical problems, the final product vector is given as an exogenous variable, and a general release vector is found as an endogenous variable with the first part of the given system. Then, the major production funds $\overline{K}$ is found by placing the obtained general release vector $\overline{X}$ in the second part of that system. In other words, the endogenous vector variables $\overline{X}$ and $\overline{K}$ are calculated with the exogenous vector variable *Y*:

$$\begin{cases} \overline{X} = B * \overline{Y} \\ \overline{K} = f * B * \overline{Y} \end{cases}$$

where, *B* is a matrix obtained from the overall expense coefficients.

Conceptual scheme of solution algorithm of models' system

Before solving the management problem of higher level of innovative structure, the enterprises determine the current value S_i of the coefficient IM_i. Since they do not have the opportunity and not interested in making accurate estimates, the relevant problem is solved depending on the value of the parameter, i.e. the results to be obtained depending on the value S_i.

Thus, the managing company generates r_{ij}, p_i and $k_i(\alpha_i^1, ..., \alpha_i^2)$. Here, the tension rate of implementing the plan α_i^t according the *t*-th indicator; and k_i - the tension rate of the plan in the *i*-th enterprise.

When k_i is defined r_{ij}, p_i and other directives are accepted as the basics. Their determination methods improve the management of the relevant enterprises. Once r_{ij}, p_i, k_i are determined, in the following step, each low-level element solves the certain problem.

Since the variables r_{ij}, p_i depend on the value of S_i, solution of the problem also depends on S_i. Therefore, r_{ij}, p_i differ for each different value of S_i. However, managing company considers all the values as an occupied option.

Based on r_{ij}, p_i, k_i , the optimization problem is solved for each *i*-th enterprise. Although all results obtained principally provide the managing company, these solutions may not provide the enterprises. Therefore, the enterprise attempts to find the optimal plan option by specifying the value of the variable S_i each time. The enterprise solving the MACROMOD problem can determine the current value of IM_i as follows, by projecting the amount of product release as y_{ik}:

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

Where Δ_i^T indicates the increase in the rate of efficient resource usage, the innovation of the environment, and the innovation capacity of the activity. This quantity is empirically determined by the expert assessments based on the quality indicators of the enterprise.

P_i^*, r_{ij}^* - denotes the acceptable solution values of other level models of the relevant variables. Newly obtained value of IM_i^T is presented to the managing company.

Generally, solution algorithm of the MACROMOD and MICROOMOD model systems in the successive phases can be established in the following way. First, the functions F_i and φ_i are determined [14, 15]. Based on the factorial analysis of variables, it can be assumed that the correlation-regression dependence between them is linear. Therefore, they can be written as linear multidimensional regression functions:

$$F_i = \frac{1}{IM_i} \sum_{j=1}^{m} a_{ij} r_{ij} + a_{io} \ ,$$

$$\varphi_i = IM_i \sum_{j=1}^{m} b_{ij} r_{ij} + b_{io}$$

The coefficients of the corresponding functions are calculated by the least squares method. Obviously, the above modeling system can be essentially formulated as a linear programming problem. Separately achieved solutions should be coordinated among themselves according to the inter-model levels. This process is performed based on the iterative clarifications between the levels by means of information exchange. To achieve a coordinated solution, $r_{ij}(l), P_i(l)$ are included to the enterprise model in each iteration model, and a new value of the coefficient of the efficient resource usage $IM_i(l)$ is included to the model of the managing company (indicates the number of iteration *l*).

The initial distribution of resources $r_{ij}(l)$ and the initial production plans $P_i(l)$ are based on the coefficient of the relevant resource usage of the managing system model $IM_i(l)$ and directive values P, R_j, r_{ij}. In each subsequent iterative approximation process, $y_{ik}(l)$ is found at each enterprise level, so that they allow obtaining maximum net product in terms of restriction of separated resources. Essentially, this iterative process is suspended when the subsequently achieved solutions do not differ from previous ones much or the results obtained satisfy decision makers. Solutions achieved in the last stages are considered as agreed solutions.

Conclusion

Production of innovative products/services in the economic development of each country is of great importance. Therefore, the activity of innovative enterprises established in the relevant field should be efficiently carried out [16]. One of such aspects is the application of mathematical models and econometric methods in planning the production processes in the innovative enterprises with complex structure based on effective use of limited resources. At the enterprises with the proposed structure, the activity of both the managing entity and the production/service facilities is modeled based on different criteria.

Iterative algorithm is developed for the solution agreed between the levels using the dynamically changing values of parameters, such as scientific and innovative capacity, which characterize the favorable economic environment. The problems can be solved based on real indicators by using software packages through computer modeling. Such solutions create additional opportunities for more efficient management of innovative structures and more economic benefits.

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