Optimization of the petrochemical enterprise control system focused on resource conservation

N V Barsegyan¹, E L Vodolazhskaya and E V Chekanova
Kazan National Research Technological University, Kazan, Russia

¹E-mail: n.v.barsegyan@yandex.ru

Abstract. The article assesses the efficiency of designing lean organizational management structures at petrochemical enterprises, taking into account the optimal number of employees at high-performance workplaces. The purpose of the article is to identify the main factors that affect the effectiveness of the design of the control system. The analysis of factors influencing the design of a lean organizational structures, the results of which the most significant factor to consider in the design and implementation of lean management is the factor that we named as "personnel innovative potential." This means that, despite the capital intensity of petrochemical production, the impact of the use of human resources become more important in digitalization.

On the basis of this study it is shown that taking into account the achievements of totals for the petrochemical industry cumulatively efficiency of innovation activity, expressed in the calculation of the shipment of innovative products in 1 high-performance workplace will increase from 0.7 million rubles on average, a petrochemical facility to 1.6 million rubles by 2024.

1. Introduction
Currently, the petrochemical complex is one of the leading sectors of the domestic economy. Petrochemical enterprises require the introduction of improved management methods and advanced production technologies. To ensure the efficiency of the petrochemical industry, it is necessary to design an optimal organizational structure and improve the level of technological processes using new resources and internal reserves of effective production organization, methods of stimulating labor, with the development of advanced production management methods in developed industrial countries.

In the modern conditions of the transition to Industry 4.0, the issues of organizing the production of the petrochemical industry based on the use of optimization models are becoming relevant, which requires taking into account new directions for improving the efficiency of the industrial complex [1,2]. Special attention is paid to the issues of resource conservation in the works of both foreign and domestic scientists. Thus, approaches and design of control systems in the context of digitalization are presented in the works of De sousa K and Evaristo J, Shinkevich A, Milgrom P and Roberts J, Thiry M and Matthey A [3-6]. Among domestic scientists dealing with the issues of resource conservation of petrochemical enterprises, the development of strategies for the development of organizational structures, one can distinguish the works of Shinkevich, Malysheva, Kudryavtseva, Dyrdonova et al. [7-10].

The relevance of our research is also justified by the fact that the transition to Industry 4.0 involves the formation of an updated management system for the organizational structures of petrochemical
enterprises and the improvement of appropriate models aimed at optimizing the use of resources, minimizing waste, and labor saving. According to table 1, it is clear that the development of new tools for increasing labor productivity is in demand in the chemical and petrochemical industries of the Russian economy.

Table 1. Assessment of the demand for tools to increase labor productivity in the chemical and petrochemical industries of the Republic of Tatarstan.

| Event                                                                 | Chemistry and petrochemicals |
|----------------------------------------------------------------------|------------------------------|
| Development and implementation of projects and programs for the development of production and development of new products | Relevant                     |
| Creation and organization of effective functioning of industry coordination and expert centers for the development of industry enterprises, industry and intersectoral cooperation and coordination of interaction in the "state – business - science” system | Created (of THICH)           |
| The introduction of information technologies in production management | Control systems ERP-level / MES - level Management Systems |
| Implementation of mechanisms of state support, public-private partnership | Support for investment development projects / Replenishment of working capital |
| Creation and development of production and technological centers for collective use, outsourcing of production activities | Relevant                     |
| Introduction of lean manufacturing tools                             | Relevant                     |

Optimization of management systems becomes feasible when taking into account existing tools and approaches in a comprehensive manner. Only with this approach, it is possible to determine the mechanisms, indicators, resources, and a system of measures to achieve the set goals. The key value of integration is that it promotes the transition to a set of production processes and improves them by applying innovative technologies and appropriate methods.

2. Materials and methods
The implementation of new concepts in the context of continuous development and improvement of the organization of production contributes to increasing resource efficiency and labor productivity, accelerating the creation of new products and entering the market, reducing production costs, meeting the needs of the population, as well as increasing the competitiveness of production.

Visually, the process of producing petrochemical products can be represented in the form of a functional model (figure 1).

From the point of view of the development of organizational management structures at petrochemical enterprises, we consider it appropriate to conduct modeling using the production function, which takes into account the indicators of the use of human and material capital in the organization of production [3-5]. Taking into account the directions of digitalization, increasing the level of innovation in production and the development of industry 4.0 as a result variable, as an indicator of the effectiveness of the production process, we suggest using such an indicator as "shipment of innovative products to one petrochemical enterprise"; as explanatory variables, the rate of use of labor resources, expressed by the proportion of jobs in total employment in the petrochemical industry and the utilization rate of material capital, as the coefficient of renewal of fixed assets in the petrochemical industry. Our calculations are based on the average values for the petrochemical industry, which includes such subspecies of activity as "chemical production" and "production of rubber and plastic products".
Figure 1. The process of production and sale of petrochemical products (built by the author).

The choice of these parameters for the simulations were resulted from the component and factor analysis, which showed the greatest influence on the design of organizational structures of management in the petrochemical industry such factors as staffing is an innovative, technological and material capacity production and will be taken into account when constructing a production function.

We will use the classical model of the production function proposed by Cobb-Douglas:

\[ Y = A \times K^\alpha \times L^\beta, \]

where in our case:

- \( Y \) – the volume of innovative products shipped to one petrochemical enterprise, million rubles;
- \( K \) – coefficient of renewal of fixed assets (material component);
- \( L \) – the share of high-performance jobs in the total number of employees at petrochemical enterprises, percentage (personnel component);
- \( \alpha, \beta \)– elasticity coefficients of the model;
- \( A \) is an independent variable of the model.

The initial data for the simulation, as well as the logarithms for the indicators, are summarized in table 2.

Table 2. Initial data for building a production function model.

| Year | Innovative products were shipped to 1 enterprise, million rubles. | The share of high-performance jobs in the total number of employees, % | The coefficient of renewal of fixed assets | \( L_n \) |
|------|---------------------------------------------------------------|---------------------------------------------------------------|------------------------------------------|---------|
| 2010 | 4.3                                                          | 42.4                                                         | 5.9                                      | 1.5     |
| 2011 | 5.4                                                          | 45.7                                                         | 6.4                                      | 1.7     |
| 2012 | 6.0                                                          | 54.7                                                         | 6.5                                      | 1.8     |
| 2013 | 5.7                                                          | 57.7                                                         | 6.9                                      | 1.7     |
| 2014 | 5.6                                                          | 60.0                                                         | 6.9                                      | 1.7     |
| 2015 | 7.3                                                          | 55.1                                                         | 6.3                                      | 2.0     |
| 2016 | 8.6                                                          | 57.4                                                         | 5.2                                      | 2.1     |
3. Results and discussion

As a result of the simulation, the following model of the production function was obtained:

$$Y = 0.75 \times K^{1.22} \times L^{1.08}$$

This model is statistically reliable, as indicated by the statistical significance of the coefficients of the equation (p-value less than 0.05); the coefficient of determination was 89%; the Fisher criterion also corresponds to the standard-p-value less than 0.05; the average model residuals tend to zero, there is no autocorrelation in the model residuals, which is confirmed by the Darbin-Watson criterion, which was 2.1 (with the standard value equal to 2).

**Table 3.** Results of modeling the production function of petrochemical enterprises (calculated by the author).

| Year | L  | K   | Y   | 2017 | 7.7 | 65.3 | 5.9 | 2.0 | 4.2 | 1.8 |
|------|----|-----|-----|------|-----|------|-----|-----|-----|-----|
| 2018 | 9.1| 71.6| 5.7 | 2.2  | 4.3 | 1.7  |
| 2019 | 10.0| 78.4| 5.7 | 2.3  | 4.4 | 1.7  |

The unstable dynamics of the renewal of fixed assets affected the negative sign for the variable that characterizes the material capital. At the same time, the growth in the share of high-performance jobs reflected an increase in the number of innovative products shipped per petrochemical enterprise. Consequently, the component of human resource management was crucial in the development of innovative activities in the petrochemical industry. Therefore, when designing organizational management structures at petrochemical enterprises, the programs of these developments should be focused primarily on the goals of innovative development with the dominant factors of labor costs and their productivity.

The results of modeling the production function allowed us to make a medium-term forecast of the shipment of innovative products at petrochemical enterprises. Given the current trends, in which the average rate of growth of the share of high-tech jobs accounted for 2010-2019. 2% and the average rate of decline of the coefficient of renewal of fixed assets of 1%, substituting the values of the independent variables in the model were calculated forecast values shipment innovative products on one petrochemical company for the period up to 2024, which is projected to increase from 10 million rub per petrochemical enterprise in 2020 to RUB 18.4 million per petrochemical enterprise in 2024.

Thus, the design of organizational structures of management in petrochemical enterprises, taking into account the level of technological production and staff involved in high-performance workplaces, will ensure the growth of shipped innovative products, forming competitive advantage petrochemical plants due to a more flexible factors of production – labour and its component such as the use of high-tech aspect of the production activities of the skills, knowledge and abilities of the staff.

When designing lean management structures at petrochemical enterprises, the issue of optimizing the number of employees and their redistribution in the manufacturing sector, taking into account the level of technological efficiency of production, is of no small importance. For these purposes, we have proposed an optimization model of the organizational structure of management in the petrochemical industry. The following indicators were used as initial indicators:

- **Y** – shipped innovative products of own production to 1 enterprise, million rubles (dependent variable);
K – costs of technological innovations per 1 enterprise, million rubles (capital expenditures, independent variable);
L – high-performance jobs per 1 enterprise, units (labor costs, independent variable).
At the same time, 2 sectors of the petrochemical industry were considered (table 4):
1-production of chemicals and chemical products;
2-production of rubber and plastic products.

Table 4. Data for building an optimization model of the organizational structure of management in the petrochemical industry.

| Year | Production of chemicals and chemical products | Manufacture of rubber and plastic products |
|------|---------------------------------------------|-------------------------------------------|
|      | $Y_1$, K, L | $Y_2$, K, L |
| 2010 | 8.5, 1.6, 14 | 1.0, 0.4, 4 |
| 2011 | 10.6, 2.1, 15 | 1.6, 0.4, 4 |
| 2012 | 11.2, 2.8, 17 | 2.2, 0.2, 5 |
| 2013 | 11.2, 4.7, 19 | 1.9, 0.4, 5 |
| 2014 | 11.1, 4.2, 19 | 1.9, 0.2, 4 |
| 2015 | 14.6, 3.3, 18 | 2.4, 0.4, 3 |
| 2016 | 18.7, 3.6, 25 | 3.0, 0.2, 4 |
| 2017 | 15.8, 4.3, 25 | 3.1, 0.3, 5 |
| 2018 | 17.1, 6.2, 29 | 4.2, 0.6, 7 |
| 2019 | 18.8, 7.6, 32 | 5.1, 0.7, 7 |

The partial regression equations that characterize the volumes of shipped innovative products for chemical production and the production of rubber and plastic products have the form:

\[
\begin{align*}
Y_1 &= 0.33 - 1.23 \times L_1 + 0.86 \times L_1^2; \\
Y_2 &= -1.41 + 1.32 \times K_2 + 0.72 \times L_2.
\end{align*}
\]

To build an optimization model for each industry, second-order polynomial regression equations were calculated, reflecting the dependence of the shipped innovative products on labor costs:

\[
\begin{align*}
Y_1 &= 0.33 - 1.23 \times (-6.5 + 1.36 \times L_1 - 0.018 \times L_1^2) + 0.86 \times L_1; \\
Y_2 &= -1.41 + 1.32 \times (10.1 - 3.75 \times L_2 + 0.43 \times L_2^2) + 0.72 \times L_2.
\end{align*}
\]

Further differentiating both equations we get the following relation:

\[
\begin{align*}
Y_1' &= -1.23 \times (-6.5 + 1.36 \times L_1 - 0.018 \times L_1^2) \times 2 \times L_1 + 0.86; \\
Y_2' &= 1.32 \times (10.1 - 3.75 \times L_2 + 0.43 \times L_2^2) \times 2 \times L_2 + 0.72.
\end{align*}
\]

The optimized number of employees at high-performance workplaces, taking into account the shipped innovative products, in 2019 will be:

\[
\begin{align*}
18.8 &= -0.82 \times 0.0447 \times L_1; \\
5.1 &= -4.3 \times 1.153 \times L_2.
\end{align*}
\]

Thus, at the enterprises of the petrochemical industry, the need for high-performance jobs per 1 enterprise will amount to a total of 448 employees, of which – 439 at the enterprises of chemical production and 8 at the enterprises for the production of rubber and plastic products. As you can see, the data on chemical production is very different from the calculated data, reflecting the need for high-performance jobs, taking into account the existing capital costs and the shipped innovative products. In rubber and plastic manufacturing enterprises, the deviations between the actual and optimal number of employees employed in high-performance workplaces are minimal.

Further, within the framework of designing lean management structures at petrochemical enterprises, the objective function of the optimization model will have the following form:
that is, the amount of innovative products shipped at the existing capital costs and the optimal number of employees employed in high-performance workplaces will tend to the maximum value.

In our case, the optimization model looks like this:

\[ F = 0.33 \times 1.23 \times 7.6 + 0.86 \times L - 1.41 \times 1.32 \times 0.7 + 0.72 \times L, \]

under the following restrictions:

\[
\begin{align*}
0.33 \times 1.23 \times 7.6 + 0.86 \times L & \geq 18.8; \\
1.41 \times 1.32 \times 0.7 + 0.72 \times L & \geq 5.1; \\
L & \geq 0; \\
L & \text{whole.}
\end{align*}
\]

At the same time, we also take into account that in total, the number of people employed in high – performance jobs in 2019 amounted to 4271.2 thousand people, and the number of enterprises working in the industry – 297452 (of which 10345 relate to chemical production, 17740-to the production of rubber and plastic products). In addition, we will also take into account the above medium-term forecast of shipped innovative products per 1 petrochemical complex enterprise for the period up to 2024 (the five-year forecast period).

4. Conclusions

Thus, the design of organizational management structures at petrochemical enterprises, taking into account the level of technological production and the personnel involved in high – performance workplaces, will provide an increase in the shipped innovative products, forming a competitive advantage due to a more flexible factor of production-labor and the use of the skills, knowledge and skills of personnel in the high-tech aspect of production activities.

Taking into account the limitations of capital and labor costs, the total demand of the petrochemical industry for high-performance jobs will be 152 people per enterprise. At the same time, the total shipped innovative products will be the maximum allowable value – 250 million rubles for a five-year period per 1 petrochemical enterprise. A comparative analysis of the efficiency of designing lean organizational management structures at petrochemical enterprises, taking into account the optimal number of employees in high-performance workplaces, is presented in table 5.

**Table 5.** Evaluation of the efficiency of designing lean organizational management structures at petrochemical enterprises, taking into account the optimal number of employees in high-performance workplaces (calculated by the author).

| Period                              | Innovative goods of own production were shipped to 1 enterprise, million rubles | High-performance jobs per 1 enterprise, units | The effectiveness of the lean design of organizational structures of management, million rubles |
|-------------------------------------|--------------------------------------------------------------------------------|---------------------------------------------|-----------------------------------------------------------------------------------|
| Average for 2015-2019 (fact)        | 20.6                                                                         | 31.0                                        | 0.7                                                                                |
| Achievement of indicators in total by 2024 | 250.0                                                                        | 152.0                                       | 1.6                                                                                |

Thus, in view of achieving totals for the petrochemical industry cumulatively efficiency of innovation activity, expressed in the calculation of the shipment of innovative products in 1 high-performance workplace will increase from 0.7 million rubles on average, a petrochemical facility to 1.6 million rubles by 2024.
The proposed methodology can be used not only at the industry level when designing lean management structures in the petrochemical industry, but also at the micro level for individual enterprises in the industry.

Acknowledgments
The research was carried out within the framework of the grant of the President of the Russian Federation for state support of leading scientific schools of the Russian Federation, project number NSH-2600.2020.6.

References
[1] On approval of the program "Digital economy of the Russian Federation" [Electronic resource] Order of the Government of the Russian Federation, July 28, 2017 №1632-r
[2] Shinkevich A, Kudryavtseva S and Ershova I 2020 Modelling of Energy Efficiency Factors of Petro-chemical Industry International Journal of Energy Economics and Policy 10(3) 465-70
[3] Desouza K and Evaristo J 2006 Project management offices: A case of knowledge-based archetypes International Journal of Information Management 26 414-23
[4] Shinkevich A, Barsegyan N, Dyrdonova A and Fomin N 2020 Key directions of automation of petrochemical production Journal of Physics: Conference Series 1515 022016
[5] Milgrom P and Roberts J 2013 Economics of modern manufacturing: Technology, strategy, and organization The American Economic Review 80 (3) 511-28
[6] Thiry M and Matthey A 2005 Delivering business benefits through Projects, Programs, Portfolios and PMOs Proceedings of the Asia-Pacific PMI Global Congress 89–91
[7] Kudryavtseva S, Galimulina F, Zaraychenko I and Barsegyan N 2018 Modeling The Management System Of Open Innovation In The Transition To E-Economy Modern Journal of Language Teaching Methods 8(10) 163-71
[8] Lubnina A, Shinkevich M, Yalunina E, Gaidamashko I, Savderova A and Komisarova M 2018 Innovative strategy for improving the efficiency of industrial enterprises management Espacios 39(9) 25
[9] Malysheva T, Shinkevich A, Ostanina S, Vodolazhskaya E and Moiseyev V 2016 Perspective directions of improving energy efficiency on the meso and micro levels of the economy Journal of Advanced Research in Law and Economics. 7(1) 75
[10] Dyrdonova A, Shinkevich A, Galimulina F, Malysheva T, Zaraychenko I, Petrov V and Shinkevich M 2018 Issues of Industrial Production Environmental Safety in Modern Economy Ekoloji 27(106) 193-201