Mathematical model of high tech enterprise manufacturing subdivisions production plan optimization

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Abstract. For high tech enterprise manufacturing subdivisions challenge has been defined. Mathematical models have been developed. Implementation model algorithms have been researched. A step-by-step mechanism for algorithm implementation based on Johnson method is proposed. Developed models have been tested at the enterprises of the innovation-oriented cluster.

1. Introduction

At present, the key factor of Russian enterprises efficient function in turbulent economic environment and successful entering new markets is creation and utilization the system of innovations. Russian enterprises encounter numerous challenges including selection of development strategy focusing on diversification, improvement of flexible manufacturing systems as well as computerization and robotization of business processes.

The high tech enterprises focusing on utilization of the latest technologies, machinery, robotics, creation and development of innovation systems have been successful in meeting these challenges. The transition of Russian enterprises to the high tech enterprise category implicates profound modernization of all activities including manufacturing activity.

One of the most important challenges for Russian enterprises, in this context, is the innovation system formation. [1]. Basic element of this system is technological innovations which include new products (product innovations) and technology for their production (process innovations). The emergence of these innovations in enterprises inescapably generates other types of innovations: marketing innovations, management innovations as well as financial innovations and so on.

This raises the challenge to consolidate and manage innovations. Such an approach enables organize production modernization to the best advantage, by linking this modernization to computer-
aided process planning (CAPP) and continuous acquisition and life-cycle support (CALS) [7]. Ultimately, this guarantees enterprise capacity-building as well as increase in its fundamental value.

2. Production modernization problem statement

Production modernization is implemented under upgrading project and implicated replacement of outdated production capacity to modern ones. This aim is achieved through the establishment of manufacturing subdivisions focused on fully automated equipment utilization, the latest processes as well as information systems and so on.

The production modernization project development is preceded by enterprise technological auditing [2, 6]. The technological audit results allow verifying the technical feasibility of the proposed project solutions as well as establish market advantages, both the product being created and organizational and technological decisions. The scenario planning method utilization allows selecting the best strategy having formed a set of production modernization strategies. The choice is based on economic feasibility criteria and restrictions dictated by factors of the external and internal environment. Based on the findings, new subdivisions manufacturing diversified production are being created. Moreover, the important challenge for these subdivisions is formation of the production program, based on the enterprise order portfolio.

3. The results of solving problem

3.1. Production activity as enterprise functional strategy

According to the management process approach, the enterprise production activity is one of its functional strategy [3]. The production component appears as the essential feature of high tech enterprise competitive strategy, affecting not only the mechanism of current costs formation, but also the enterprise investment activity final indicators. Quality and competitiveness indicators of product innovations produced by an enterprise are formed, as part of the strategy production component implementation. Ultimately, the parameters characterizing enterprise activity production component participate in the formation of all economic and financial indicators (net proceeds, profit, financial viability, current capacity to pay, turnover and so on).

The order portfolio for enterprise products is formed in the process of developing its marketing strategy, with due regard for characteristics of the production capacity [4]. In terms of enterprise competitive strategy effective implementation, the components optimizing challenge raises of this strategy, that is to say functional strategies, including development of the effective production strategy. The solution to this challenge will provide the effective use of technological (process and product) innovations by enterprise and implies establishment of manufacturing subdivisions, as well as day-to-day management technologies.

The production processes operational management technology, in turn, requires mechanism for the production optimal program formation from the enterprise order portfolio as well as effective management of enterprise resources. Ultimately, this will provide technological equipment balanced workload as well as rhythmic production output. The solution to this challenge is most relevant for production diversification as flexible response of a high tech enterprise to the market demands provides it with necessary competitive advantages.

3.2. Mathematical model development

This paper proposes the formation of optimal production program algorithm for a manufacturing subdivision in accordance with the existing specialization, available production capacities as well as order portfolio in general.

The following symbols have been introduced in developing production program formation mathematical model:

\( i \) - position number in product range acceptable to inclusion in production plan, \( i = 1, \ldots, m \);

\( m \) - manufacturing subdivision product range;
In the process of developing the mathematical model, the assumption was made about the technological equipment cycle in the manufacturing subdivision does not irrespective of position number in the manufactured product range (variable $i$) and is equal to the average value $r$. This condition is met, firstly, the labor intensity range of manufacturing various types of products is not large, secondly, the production program includes the sufficiently large number of product items. It will be assumed that launches number of the $i$-th product (variable $z$) is equal to 1 for the period under review.

In terms of operational-calendar planning, the optimal program formation challenge for the manufacturing subdivision of a high tech enterprise is reduced to finding a column vector whose elements are binary variables $\alpha$.

First, the found column vector must meet the requirements:

$$r \cdot \sum_{i=1}^{m} \alpha_i Q_i + \sum_{i=1}^{m} \alpha_i T_i \leq W$$  

(1)

Second, must optimize the objective function of the following form:

$$\sum_{i=1}^{m} \alpha_i Q_i \rightarrow \text{max}$$

(2)

In terms of mathematical modeling, the formulated problem is a discrete programming issue [5]. For solution to the problem in practice, various heuristic algorithms are applied, which can be fully adapted to form the high tech enterprise subdivision optimal production program.

Most frequently, various algorithms are used to solve this class of discrete programming problems. First, it is an algorithm based on Johnson’s method. Second, an algorithm based on the method of increasing time spent on a technological equipment readjustment in manufacturing subdivisions. Third, an algorithm based on the method of decreasing product processing program included in the production plan.

### 3.3. Algorithm based on Johnson’s method

To do this, a given set of the products range potentially admissible for inclusion in the production plan should be systematized as follows:

In the first step, product for which $Q_i$ reaches max value is selected, and $i = 1$ is assigned for this product.

In the second step, among the remaining elements of the product set, position of product range is chosen for which $\max T_i$ condition is fulfilled and $i = m$ is assigned for this product.

In the third step, among the remaining elements of the set, the product is selected again for which $\max Q_i$ is achieved, and $i = 2$ is assigned for this product.

Obviously, if this process is continued, the arrangement of the entire product range manufactured in the manufacturing subdivision will be performed in m-steps.

Moreover, the production program formation is implemented as follows. Elements of formed sequence are included in the production program, starting from first until the constraints of the formulated model are fulfilled.

### 3.4. Selection of input data for the production program formation

As the input data necessary for calculating the production program are used effective working hours and throughput rate of technological equipment, the processed products range, launches number of the $i$-th product into production during the period under review.

For each item of the products range is set production output program, technological equipment readjustment expended time as well as the effective working hours required to process this type of product item.
The production plan (the actual quantity of produced products) of a high tech enterprise manufacturing subdivision is calculated as follows:

\[ Q_{Wj} = Q - Q_{\text{lost}j} - \frac{W_{j} - W_{ef}}{r} \]  

(3)

where: 
- \( j \) – sequence number of used production program formation algorithm \((j = 1, 2, 3)\);  
- \( Q_{A_j} \) – actual produced quantity of products according to the \( j \)-th algorithm for production plan formation;  
- \( Q_{\text{lost}j} \) – lost production output as a result of exceeding the product processing working hours included in the production plan over the available total equipment working hours;  
- \( W_{j} \) – total time fund for the entire products range included in production plan for \( j \)-th option of the production plan formation;  
- \( W_{ef} \) – manufacturing equipment effective working hours.

Calculations of volume product output produced by manufacturing subdivisions which used various algorithms, showed that the algorithm based on Johnson method is the most viable.

The results of solution to the formation optimal production program challenge for a high tech enterprise manufacturing subdivision have been applied in solving a number of particular challenges of operational-calendar planning as well as management of diversified production. In particular, for the Republic of Tatarstan engineering cluster high tech enterprises, the problem of establishing the optimal balance between flexibility and productivity of manufacturing systems utilized by cluster enterprises has been solved.

**Conclusion**

This paper considers the challenge of the high tech enterprise manufacturing subdivision production program selecting from an order portfolio. This challenge has been solved under assumption that the enterprise order portfolio exceeds the production capacity. Mathematical apparatus based on Johnson’s method has been developed. As selecting program parameters such characteristics as an order volume and equipment readjustment time have been utilized. The algorithm proposed in the paper was implemented at the Republic of Tatarstan engineering cluster high tech enterprises and demonstrated high efficiency, which is confirmed by the documents on the model application.

There is no doubt that in order to extrapolate the developed model and make extensive utilization of the results obtained at Russian enterprises, it is necessary to take into account the characteristics of each enterprise. This is achieved by the analysis and processing of statistical information on enterprises activities, statistical data verification and models using various statistical criteria. This might, for instance, require utilization the classical statistical methods. First, the Pearson chi-squared test for verification the data distribution hypothesis, and second, the Student’s \( t \)-test for verification the statistical significance of the obtained model coefficients, or verification the hypothesis of the equality or difference between two average values of two independent samples. These criteria are widely distributed in statistical and econometric studies. The main source of statistics is enterprise formal reporting, (financial and accounting statements, statistical reporting and so on), as well as data obtained by continuous permit monitoring or random monitoring. In the practice of European enterprises, various reports are used, the analysis of which reveals information about the environment, including data on the industrial enterprise activities. The results of such studies can be found in the scientific papers [8] and [9].

Such an approach is expected to be implemented in Russia, and at the national level. A similar initiative, for instance, is embedded in the Ministry of Economic Development of the Russian Federation strategy for the period 2019-2024. According to this strategy, in 2019 the Ministry submitted to the Government of Russia a draft law “On Public Non-Financial Reporting”. Currently, the law is undergoing legal examination at the Ministry of Justice of Russia.

The law stipulates that Russian enterprises will provide information not only on financial and economic indicators, but also on “social responsibility” and environmental aspects of activities, such as public non-financial reporting [10]. This reporting is a combination of information and indicators
reflecting the strategy, goals, management approaches, as well as the results of the enterprise in the field of social responsibility and sustainable development. It is assumed that the list of key indicators reflected in public non-financial reporting will be approved by the Government of Russia.

Public non-financial reporting will be required to provide state-owned corporations and companies, including state-owned unitary enterprises with more than 5-billion-ruble income, as well as organizations whose securities are admitted for trading on stock markets. Other organizations will generate public non-financial reporting on an optional basis.

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