Modeling of Economic Factors of Light Aircraft Production

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***Abstract*—The paper presents mathematical tools for determining the equilibrium values of prices and quality of light aircraft by the criterion of profit maximization. A mathematical model of competitive interactions in the case of the dependence of price on quality manufactured goods allows to determine the equilibrium of the competitive strategy of participants of the market of light aircraft taking into account the main parameters of competition.**

For Russian aircraft manufacturers in a developing market and growing competition, it is important to determine the optimal economic factors affecting the operation of the production system, to quantify the quality and competitiveness of light aircraft produced, to determine the interdependence between the main parameters that form the demand for light aircraft. On the basis of a comprehensive analysis and forecast of market dynamics should be formed competitive strategy for the development of enterprises, as well as to choose the best price strategy that takes into account the position of competitors. The problem of modeling the choice of price strategy for the given target functions of the participants of the light aircraft market is reduced to the determination of equilibrium States and determination of the factors of stability of the competitive environment. Thus, the model of interaction between manufacturers of light aircraft, taking into account the specifics of the domestic industry, allows to determine the impact of individual factors on demand and on this basis to form a sustainable strategy for the development of the enterprise.

Keywords*—*Competition Model, Market Of Light Planes, Equilibrium Strategy, Competitive Interaction, Decision-Making Model, Stability Conditions.

I. Introduction

General aviation makes a significant contribution to the development of the national economy, creating new jobs, favorable conditions for the improvement of scientific and technical potential, improves the standard of living. In the United States of America alone, this industry produced more than 1% of GDP ($219 billion) in 2017.) direct and indirect revenues, while providing about 1.1 million jobs.

The main parameters of competition in the market of light aircraft for manufacturers of this equipment: the price and quality of the aircraft. For Russian private aircraft manufacturers and design bureaus, in the context of a developing market and growing competition, it is important to determine the optimal parameters of the production system, to quantify the quality and competitiveness of light aircraft, to determine the interdependence between the main parameters that form the demand for light aircraft. Competitive strategies for enterprise development should be formed on the basis of a comprehensive analysis and forecast of market dynamics.

The aviation industry is characterized by high marginal costs and a slow effect of the invested funds aimed at the development of the enterprise, so the definition and selection of optimal production parameters requires a balanced approach. Enterprises of the aircraft sector in the context of increasing competition in the market and declining profitability should increasingly take a responsible approach to decision-making on the choice of a competitive strategy of operation.

In this regard, there is a need to form an economic and mathematical model of interaction between manufacturers of light aircraft, taking into account the specifics of the domestic industry, which allows to determine the impact of individual parameters on demand and on this basis to form a sustainable strategy for the development of the enterprise.

II. Conceptual Framework

The constant strengthening of competition in the market for new products is an indisputable fact. This explains the desire of the manufacturer to reduce the risk associated with increasing competition by increasing the validity of decisions. Therefore, there is a need to have a predictable assessment of the quality of products [6].

Given that the main product of the production is a multi-purpose light aircraft in various modifications, we will form a model of the problem of determining the price for each modification, provided that the profit is maximized. Suppose that the demand in the market of light aircraft depends not only on the price but also on the quality of the products. In this case, the demand will depend on two parameters.

In the case of mixed competition for demand functions $q_{ij}(p,\omega), i=\overline{1,n},$ where p is the price vector, the following requirements are imposed $\frac{\partial q_i}{\partial p_i}<0; \frac{\partial q_i}{\partial p_j}>0; i,j=\overline{1,n}, i\neq j,$ that is, the higher the price of the product, the less demand for it and the higher the price of the product from a competitor, the higher the demand.

The change in the level of flight quality is associated with significant costs associated with the purchase of new equipment, the use of new materials and technologies, the modernization of technological processes. The transformation of the production system generally reduces the profitability of the production and, as a result, the manufacturer will increase the prices for the products. On the other hand, the increase in quality leads to an increase in demand, which also leads to an increase in product prices. In accordance with these assumptions, the price will increase with the growth of the quality of the light aircraft. Then the price function of the i-th manufacturer for the j-th modification will take the form:

$$p_{ij}(\omega_{ij}) = p_{ij} + \gamma_{ij}\omega_{ij}, i = \overline{1,n}, j = \overline{1,m}, \quad (1)$$

where γ_{ij} -the speed of price changes; p_{ij} - the initial price of a light aircraft.

In turn, there is a negative feedback between the rise in prices for light aircraft and the fall in demand. In this situation, the demand function of the i-th manufacturer in a mixed type of competition will take the form

$$q_{ij}(p(\omega)) = q_{0ij} - a_{ij}p_{ij}(\omega_{ij}) + \sum_{k\neq i}^{n} b_{kj}p_{kj}(\omega_{kj}), i = \overline{1,n}, j = \overline{1,m}, \quad (2)$$

where a_{ij}, b_{kj} -the coefficients characterizing the rate of increase and decrease in the volume of demand from changes in price and flight quality for light aircraft from the i-th manufacturer and competitors.

The introduction of new technologies into the production system allows to achieve not only the improvement of the quality of products, but also is a tool for optimizing technological processes. Therefore, it can be assumed that with the growth of quality, the cost of manufacturing light aircraft will decrease to a certain extent. Suppose that the cost function of the i-th manufacturer will be expressed by the following dependence:

$$c_{ij}(q_{ij}(p(\omega))) = (c_{ij}^{q} - h_{ij}\omega_{ij})q_{ij}(p_{ij}(\omega_{ij})) + c_{ij}^{\omega}\omega_{ij}, i = \overline{1,n}, j = \overline{1,m}, \quad (3)$$

where c_{ij}^{q} -the cost of production of the j-th modification of the light aircraft i-th firm; c_{ij}^{ω} - the cost factor for improving the quality of the j-th modification of the i-th firm.

In the market of light aircraft involved " n "companies that produce" m " different versions of light aircraft, each company is interested in maximizing profits. With a known demand function for each modification of the aircraft in the case of mixed competition (price and quality level) and a known cost function, the problem of choosing a competitive strategy is determined from the following set of decision-making models:

$$\begin{aligned}
&\Pi p_{ij}(p(\omega)) = \sum_{j}^{m}\left[p_{ij}(\omega_{ij})q_{ij}(p(\omega)) - c_{ij}(q_{ij}(p(\omega)))\right] \to \max, i = \overline{1,n},\\
&q_{ij}(p(\omega)) = q_{0ij} - a_{ij}p_{ij}(\omega_{ij}) + \sum_{k\neq i}^{n} b_{kj}p_{kj}(\omega_{kj}), i = \overline{1,n}, j = \overline{1,m},\\
&p_{ij}(\omega_{ij}) = p_{ij} + \gamma_{ij}\omega_{ij}, i = \overline{1,n}, j = \overline{1,m},\\
&c_{ij}(q_{ij}(p(\omega))) = (c_{ij}^{q} - h_{ij}\omega_{ij})q_{ij}(p_{ij}(\omega_{ij})) + c_{ij}^{\omega}\omega_{ij}, i = \overline{1,n}, j = \overline{1,m},\\
&q_{ij}(p_{ij}(\omega_{ij})) \le \overline{q_{np}}, i = \overline{1,n}, j = \overline{1,m},
\end{aligned} \quad (4)$$

where $\Pi p_{ij}(p(\omega))$ the profit of the ith producer for the production of the j-th modification of a light aircraft; $q_{ij}(p(\omega))$ – the market capacity of i-th producer at the j-th modification of the product; $a_{ij}, b_{kj} > 0, i = \overline{1,n}, j = \overline{1,m},$ – the sensitivity coefficients of the demand function to changes in the price of products depending on changes in the level of performance of the j-th modification of the product; h_{ij} – the coefficient of reducing the cost of production of the j-th modification to light aircraft, the i-th producer; p_{ij} is the initial price of the j-th modification of the products manufactured by the i-th enterprise.

If the demand exceeds the production capacity of the enterprise producing light aircraft $q_{ij}(p_{ij}(\omega_{ij})) > \overline{q_{np}}$ the optimal output corresponds to the current demand for light aircraft and is equal to: $q_{ij}(p_{ij}(\omega_{ij})) = \overline{q_{np}}$.

In such a situation, enterprises determine the optimal competitive strategy in accordance with the restrictions on the volume of output from the allowed values. Note that the restriction on the maximum possible volume of production of products of each name in the model (7) depends on the type and volume of resources used, taking into account the specifics of the production of multi-purpose all-composite light aircraft. The range of acceptable solutions for the choice of the optimal price for products, based on the production capabilities of the enterprise, are represented by the following set of inequalities:

restrictions on material resources:

$$\sum\nolimits_{j=1}^{m} \beta_{ij}^{k} q_{ij} \le M_{ki}, k = \overline{1,K}, i = \overline{1,n}, \quad (5)$$

where β_{ij}^{k} -the standard k-th type of material used, i-m manufacturer per unit of the j-th product; M_{ki} - the available volume of the k-th type of material used by the i-th manufacturer;

restrictions on human resources:

$$\sum\nolimits_{j=1}^{m} t_{ij}^{l} q_{ij} \le T_{li}, l = \overline{1,L}, i = \overline{1,n}, \quad (6)$$

where t_{ij}^{l} -the standard of time spent on the execution of the l-th type of work i- manufacturer per unit of the j-th product; T_{li} -

available working time Fund from the i-th manufacturer to perform works of the l-th type;

restrictions on production facilities:

$$\sum_{j=1}^{m} a_{ij}^{s} q_{ij} \le A_{si}, s = \overline{1,S}, i = \overline{1,n}, \quad (7)$$

Where a_{ij}^{s} -the standards of production space per unit of the j-th product; A_{si} - the total area of production sites required for the production of a given volume of light aircraft;

restrictions on the number of molding equipment:

$$\sum_{j=1}^{m} w_{ij}^{v} q_{ij} \le W_{vi}, v = \overline{1,V}, i = \overline{1,n}, \quad (8)$$

Where w_{ij}^{v} -the standard number of matrices for forming composite parts per unit of the j-th product; W_{vi} - the total number of tooling for molding.

The solution of the problem model will allow to form an acceptable area of decision-making by each manufacturer and to justify the iterative procedure of market interaction between them.

So, if each company produces one modification of light aircraft, the permissible range of decision-making for each manufacturer is determined from the following equation:

$$q_i^{\max} = \overline{q_{ij}} = \min(q_i^{K\max}, q_i^{L\max}, q_i^{S\max}, q_i^{V\max}), i = \overline{1,n}, \quad (9)$$

where $q_i^{K\max} = \min_k \left(M_{ki} / \beta_i^k, k = \overline{1,K} \right), i = \overline{1,n}-$ the maximum possible output of products based on existing volumes of material resources; $q_i^{L\max} = \min_l \left(T_{li} / t_i^l, l = \overline{1,L} \right), i = \overline{1,n}-$ the maximum possible output of products taking into account the existing Fund time to perform l-th type of work; $q_i^{S\max} = \min_s \left(A_{si} / a_i^s, s = \overline{1,S} \right), i = \overline{1,n}-$ the maximum possible volume of output taking into account the existing production areas of production; $q_i^{V\max} = \min_v \left(W_{vi} / w_i^v, v = \overline{1,V} \right), i = \overline{1,n}-$ the maximum possible volume of production of light aircraft, taking into account existing snap-in.

For optimal competitive strategies formed for each company functions Lagrange $L_i(q,\lambda), i = \overline{1,n},$ optimization which allows to justify the choice of output products of each modification of drugs in accordance with the necessary conditions of optimality and resource constraints of the equations:

$$\frac{\partial L_i(q,\lambda)}{\partial q_i} = 0, \frac{\partial L_i(q,\lambda)}{\partial \lambda_i} = 0, \quad (10)$$

where $q_i = q_{ij}, j = \overline{1,m}-$ a vector of production by the i-th producer; $\lambda_i = (\lambda_{i\alpha}, \alpha = K + L + S + V)$ is the vector of undetermined Lagrange multipliers.

If $q_{ij}(p_{ij}(\omega_{ij})) \le \overline{q_{np}}$, the solution of the problem of determining the equilibrium strategies for the choice of the price of the product is reduced to the calculation of partial derivatives of profit equations and the subsequent formation of a system of equations with respect to unknown prices for the product.

III. CONCLUSION

The obtained equilibrium values of flight quality will allow to determine the optimal values of output and prices for light aircraft.

The proposed models of competitive interaction between enterprises for the production of light aircraft, which are a set of interrelated models of management decisions on the choice of output volumes, prices, level of flight quality of each product name, provide a reasonable choice of production parameters, taking into account resource constraints and various types of competition. The obtained equations for determining the equilibrium values are functionally related to the parameters of demand functions, economic parameters of the production system and can be easily implemented in solving practical problems.

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