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DEVELOPING THE MODEL FOR ASSESSING THE COMPETITIVENESS OF INNOVATIVE ENGINEERING PRODUCTS

Anna Tceplit[1,2,a], Antonina Grigoreva[1,b], Yuriy Osipov[3,c]

[1]Yurga Institute of Technology, TPU

Leningradskaya St. 26, Yurga, Kemerovo Region, Russia, 652050

[2]Kuzbass State Technical University named after T.F. Gorbachev

Vesennyaya St. 28 Kemerovo, Kemerovo Region, Russia, 650000

[3]Tomsk State University of Control Systems and Radioelectronics

Lenina St. 40 Tomsk, Tomsk Region, Russia, 634050

[a]anna777.88@mail.ru, [b]antonina505@mail.ru, [c]umo@main.tusur.ru

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Abstract. The authors suggest the models for assessing the competitiveness of innovative engineering products (IEP): a model for forecasting the consumer's preferences for IEP; a model for calculating fuzzy sets of alternatives of various competitiveness degrees at the early stages of research; integrated model for IEP competitiveness assessment with consideration to the stages of production, marketing and operation, the model for the rating assessment of alternatives. The paper considers the model for forming an expert committee involving fuzzy inference. The interrelation of models is shown with consideration to the life cycle of innovations.

Introduction

All over the world industry is one of the main initiators, customers and consumers of innovations. The innovations allow manufacturers producing goods with higher consumptive qualities. Yet any innovation requires money, time and effort to be developed and implemented. And what is more – the innovation of your own involves considerable risks as the new product may not be accepted by the market and all efforts may go down the wind. A principally new peculiarity of investment strategies today is the transition from the balanced distribution of investment resources between industries and companies to selective partial funding of certain production types according to the accepted system of criteria. Thus, completing validated assessment of an innovative project competitiveness at all stages of its lifecycle is a crucial task.

The methodological foundations of innovative development are described in the works of such USA and European scientists as N. Monchev, I.Perlaki, V.D. Hartman, E. Mansfield, R. Foster, B. Twiss, J. Schumpeter, E. Rodgers and other. Although the problem of innovation competitiveness assessment in various economic fields is being actively solved nowadays, the unifying vision of IEP competitiveness decision-making has not been worked out yet [1, 2, 3].

The problem of determining IEP competitiveness is multi-criteria and falls into the class of semi-structured problems which contain both quantitative and qualitative elements with the obscure and uncertain sides of the problem being likely to dominate. The model of the given problem can be developed on the base of additional information received from the decision-maker. In this case the opportunity of developing objective models is excluded. In this connection we can say that it is not going to be a single model but a system of models. The same can be concluded from the dynamic problem content as various models will be applied for obtaining competitiveness assessments at the basic stages of the product life cycle.

The founder of the fuzzy set theory L. Zadeh noted that conventional methods of system analysis and ECM modeling based on accurate numerical data processing are not able to encompass the immense complexity of human thinking and decision making processes. That is why when developing the models of decision making about product competitiveness, beside multi-criteria approach application it is necessary to apply fuzzy logic, fuzzy concepts and relations allowing to model the gradual changes of properties as well as unknown functional relationships expressed as qualitative [4, 5, 6, 7].

The model of forming an expert committee with the application of fuzzy logical inference

When estimating the IEP a special problem is forming a group of independent experts. To facilitate selecting candidates for experts participating in the project expertise let us apply the method of the multi-criteria alternative selection with the application of fuzzy logical inference [8, 9, 10, 11].

To estimate the candidates for experts condition-action rules of the following types were developed: d_1: "If the candidate is an experienced researcher who has some industrial work record and work experience as an expert in the field of economic and engineering disciplines he is satisfying (meeting the requirements)"; d_2: "If the expert is intuitive additionally to the previously described requirements he is more than satisfying"; d_3: "If, in addition to the requirements described in he is able to find a customer for the IEP, he is perfect"; d_4: "If the expert possesses everything described in d3 but intuition he is highly satisfying"; d_5: "If the candidate is a very experienced researcher, is able to find a customer and is a very good expert but he does not have any industrial work record he is still satisfying"; d6: "If the expert is not qualified as a researcher or does not have a proven ability for completing expert work, he is not satisfying".

The analysis of six information segments provides five criteria applied for decision making: X_1 — research skills; X_2 — industrial work record; X_3 — work experience as an expert; X_4 — intuition; X_5 — ability to find a customer. The expert was selected out of five candidates. When choosing an expert, satisfactoriness is found for each alternative and the corresponding point estimation is calculated on the base of the compositional inference rule. The results of the fuzzy inference work are shown in Table 1.

Table 1
The result of fuzzy logic system

Rule (result)	Alternatives				
	№1	№2	№3	№4	№5
Rule №1 (Satisfying)	0.5	0.6	0	0.1	0.3
Rule №2 (More than satisfying)	0.5	0.3	0	0	0
Rule №3 (Perfect)	0	0.3	0	0	0
Rule №4 (Highly satisfying)	0	0.5	0	0.1	0.1
Rule №5 (Not enough satisfying)	0	0	0	0.01	0
Rule №6 (Not satisfying)	0.4	0.4	0.5	0.9	0.7
Point estimation	0.553	0.554	0.425	0.298	0.391

The most preferable is candidate 2. The given expert has the maximum point estimation 0.554.

The model of forecasting the consumer preferences for IEP

The demand for the innovative products is generated by the needs (preferences) and abilities of the customers. When forecasting the demand the production cannot be orientated only at satisfying consumers' needs or preferences without considering the real paying capacity of those for whom the particular product is designed as well as the factors influencing consumer behavior (price, need for the product, quality, status, etc). Although it should be noted that the demand for the product is determined by its competitiveness from the consumer point of view. At the same time the competitiveness of the product is determined by its technical and economic features which are paid considerable attention to by the producer. That means that there is a dialogue between the consumer and the producer of the product and in the course of this dialogue consumer preferences are forecasted and their attitude to the product is revealed for the purposes of further influencing the demand. To estimate the consumer attitude to the technical and economic features of the product and optimize the dialogue between the consumer and the producer of the science-intensive we suggest a method which involves the following stages.

Stage 1. The list of possible consumer requirements-preferences (PR) to the studied product is made. The consumer requirements are formulated in the consumer's language.

Stage 2. Estimation of importance of every requirement, i.e. rating every customer requirement. It is achieved by expert surveying of potential customers. The labor intensity of this stage depends upon the number of respondents and the number of the perceived requirements.

Stage 3. Forming the complex of technical and economic features of the product (TEF) to be applied for estimating the competitive level of the product, first, and consumer attitude to the product, second. TEF are formulated in the professional language (producer's language).

Stage 4. A matrix of M N dimensionality is built (M – the amount of production TEF, N – amount of customer requirements (PR)). For convenience the customer requirements are ranged in the order of precedence.

Stage 5. Determining the flexibility of relation between PR and TEF. It is the most laborious stage of the method. First of all, there arises the question about the type of regressive dependence to be used. Analysis of references on quality function deployment showed that linear dependences are usually used as they are quite suitable for the first approximation. Statistical coefficient of correlation serves as the flexibility of relation measure. Second, it is necessary to choose the relative scale to estimate the flexibility of relation. Evidently, using expert analysis is best of all to avoid routine calculations. The choice of the discrete values of the scale is arbitrary and depends upon the expert's psychology. But to use the given values as the coefficient of correlation it is necessary to apply the scale with the limit from – 1 to 1. The negative correlation between the parameters means that growth of the customer requirement leads to reduction of the product TEF. On the contrary, positive correlation means that the growth of the customer requirement contributes to increase of the product TEF.

Stage 6. Determining the rating of the product TEF. At the given stage the resulting multifactor regressional dependencies of TEF upon PR are recorded. Assessments of TEF obtained this way may be used as the ratings of the product TEF. I.e. those assessments are key indices which allow choosing the features to be given special priority by the producer when solving the problem of maximum satisfaction of the customer requirements.

Stage 7. Determining the integral index of the product competitiveness. It can be presented as the weighted average of technical economic features. The weights can be the weights of the features according to the degree of their influence upon the competitive level of the product. The weight data can be also determined by expertise.

The forecasting model of the consumer preferences allows calculating the expectable demand, consumer motivation, their attitude towards the suggested product with enough consistency and confidence.

The model of determining IEP competitiveness on the base of the pair-wise comparison method

The specific feature of the given model allows applying it at the initial stages of the lifecycle of the products. Comparison of the alternatives can be completed according to the "weight of the engineering decision" criterion or according to production in general [8, 9, 10, 11].

Let us solve the following problem: to estimate the competitiveness of seven types of powered stoping complexes we apply the linguistic variable β-"competitiveness" with a range of basis values T={«low», «medium», «high»}; base set $X=\{K_1, K_2, K_3, ..., K_7\}$ where K_i is the model of the powered complex. The complexes under study are those produced by Yurga engineering plant, by Polish manufacturers and their foreign counterparts:

K_1 – DBT; K_2 – JOY; K_3 – JOY-1; K_4 – GLINIK (Poland); K_5 – KM138/2; K_6 – 3KM138; K_7 – K – 500Yu (Yurga engineering plant). The term «low» is characterized by fuzzy variable ⟨low, X, $\widetilde{C}$ ⟩.

It is necessary to construct a membership function μ_c of fuzzy set $\widetilde{C}$, describing term "low".

Membership function μ_c is determined from the pair-wise comparison matrix M=$\|m_{ij}\|$ which elements m_{ij} represent some assessments of elements membership intensity $x_i \in X$ *to the fuzzy set* $\widetilde{C}$ in comparison to the elements $x_j \in X$: $\mu_c(x_i) = 1/\sum_{j=1}^{n} m_{ij}$.

After processing the expert assessments we obtain the "low competitiveness" fuzzy set:

$\widetilde{C}$={(1/K-500Yu (YuEP)), (0,53/3KM138), (0,33/KM138/2), (0,19/Joy-1), (0,12/ GLINIK), (0,1/DBT), (0,07/Joy}, i.e. 1 corresponds to the powered stoping complex with the lowest competitiveness.

Integrity model of IEP competitiveness assessment

The given model promptly and objectively reflects the market position of the product during the production, sales and operational stages. The basis for product competitiveness calculating is assessment of four group competitiveness criteria: "significance of the engineering decision" (S_{ed}) [12], financial priority of the product (F_p), production efficiency (E_p) and marketing operations efficiency (E_{mo}). To ensure the representativeness the criteria have weightage coefficients [8, 9, 10, 11]. The given coefficients are determined by the pair-wise comparison method considered above.

The criteria and the competitiveness ratio are calculated according to the formulas:

$$C_p = a_1 \cdot E_p + a_2 \cdot F_p + a_3 \cdot E_{mo} + a_4 \cdot S_{ed}, \tag{1}$$

where C_p – product competitiveness ratio;

E_p – value of company production efficiency criterion;

F_p – value of production financial priority criterion;

E_{mo} – value of marketing operations efficiency criterion;

S_{ed} – value of "significance of the engineering decision" criterion;

a_1, a_2, a_3, a_4 – weightage coefficients (degree of membership).

The algorithm of calculating the integrated competitiveness ratio includes 3 stages:

1. Calculating simple competitiveness indices and converting them into points. For this purpose the indices are compared to the basic indicators: industry average, competing analog, for the previous period, competitor market leader. For the purposes of converting the indices into relative values (points) the decimal scale from 0 to 1 is usually used.
2. Calculating criteria according to the corresponding formulas.
3. Calculating the competitiveness coefficient according to formula 1.

Modified integrated model of IEP competitiveness assessment

The main aim of innovative product introduction is maximization of the welfare of the innovatively active company, i.e. growth of the commercial value of the company and growth of the dividend amount. The criterion of net present value (NPV) is the closest to the commercial value of the company. NPV can be considered as the price at which the investor could sell the innovative product to receive normal economic profit. Application of NPV as estimation criterion is preferable because it reflects the real economic effect of investments into innovations, i.e. discounted cash flow less costs and characterizes the cash inflow that can be put into savings (capitalized) and consumed (paid as dividends). It is especially important as the innovation policy of an industrial company is implemented via successful realization of specific innovative projects. In connection with this we shall use the criterion of net present value instead of the criterion “weight of the engineering decision”, so the integrated model will look as follows:

$$C_p = a_1 \cdot E_p + a_2 \cdot F_p + a_3 \cdot E_{mo} + a_4 \cdot NPV, \quad (2)$$

where *NPV* – net present value.

NPV is determined as the difference of discounted cash flows, inflows and payments made in the process of the innovative project realization. The economic substance of NPV can be presented as the result obtained immediately after making the decision of innovative project implementation. The positive value of NPV indicates the reasonability of the decision on financing and implementation of the innovative project and, alternative variants compared, the one with the largest NPV is considered economically sound.

The given models can be applied under the conditions of individual choice with fuzzy source information.

Mathematical model of IEP competitiveness rating assessment

The model is based on the method of calculating the degree of preference with the consideration of the preferred competitive threshold [8, 9, 10, 11]. The following assumptions are accepted for the model: existence of the certain expert competency level; characterizing the product by *p* parameters; variation of the significance level of the parameters (criteria) when rating the given product by the experts; preferring one kind of products to another if its parameters are closer to the expert rating in terms of significance level.

It is supposed that $X=\{x_1, x_2, ..., x_n\}$ – the range of experts, $Y=\{y_1, y_2, ..., y_p\}$ – the range of parameters (criteria) of the product and $Z=\{z_1, z_2, ..., z_m\}$ – the range of the product types (alternatives).

The operating algorithm of the model is as follows:

1) inputting the data on alternatives;

2) inputting the data on the parameters (product competitiveness criteria);

3) forming the matrix of parameter significance (weight) by the experts;

4) forming the matrix of compatibility levels of the product types (alternatives) with the parameters;

5) calculating the matrix of the weighted expert degrees of preference of the product;

6) calculation of the preferred competitive threshold of the product;

7) calculating and aggregating the rating assessments of the alternatives.

The given model can be applied at all stages of the IEP lifecycle with the system of criteria being changed. At the initial stages (market research, synthesis of idea, research and development) the following criteria are applied: R_p – relevance ratio of the solved engineering problem; P_w – ratio of the solved engineering problem relevance to the programs of the most important technological development works; C_p – complexity factor of the engineering problem; P_u – point-of-use ratio of the solved engineering problem; S_a – the scope of application ratio of the solved engineering problem; S_p – the scope of protective measures ratio of the solved engineering problem.

At the stage of production, distribution, operation the following criteria are used: “significance of the engineering decision” (S_{ed}), financial priority of production (F_p), production efficiency (E_p), marketing operations efficiency (E_{mo}). It is possible to use the feature of the innovative product NPV – net present value – instead of the criterion “significance of engineering decision” (S_{ed}).

Assessment was completed by ten experts (x_i). The following models of roof support (alternatives) were assessed: z_1 – M -138 /2 (YuMZ), z_2 – Fazos 25/53 Poz (Polland), z_3 – 1UKP (Ukraine), z_4 – JOY (USA). The products were assessed according to the following criteria: y_1 – “significance of the engineering decision" S_{ed}, y_2 – "financial priority of the product" F_p, y_3 – "marketing operations efficiency" E_{mo}, y_4 – "production efficiency" E_p.

After completing the calculations with $w = 0{,}527$ (differential threshold) we obtain the following aggregate of expert assessments for the alternatives:

$$P_1=\{ x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10} \};$$
$$P_2=\{x_1, x_2, x_7, x_9\};$$
$$P_3=\{x_1, x_7, x_9\};$$
$$P_4=\{x_1, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10} \}.$$

Due to the peculiarities of production (Fazos 25/53 Poz) it is preferred by a small number of experts who attach great importance to *"high financial priority"* and *"high marketing operations efficiency"*. According to these two positions production (Fazos 25/53 Poz) for experts x_1, x_2, x_7, x_9 is the *"most competitive"*. The general low compatibility level of z_3 production (1UKP (Ukraine)) with all four parameters also restricts its degree of preference. Although z_1 production (M-138/2 (YuMZ)) and z_4 production (JOY (USA)) have similar aggregates of expert assessments but the high degree of compatibility of z_1 production (M-138 /2 (YuMZ)) with the parameters *"high quality of science-intensive products"* and *"high production efficiency"* make it more preferable. As a result it will occupy the top line of the competitive product alternatives rating.

$R_{cp}(z_1) = 0{,}5373;\ R_{cp}(z_2)= 0{,}2516;\ R_{cp}(z_3)= 0{,}1385;\ R_{cp}(z_4)= 0{,}5226.$

It has been revealed that the competitiveness of the product is different at different segments of the market. That means that the producer must first complete correct segmentation of the consumer market and then calculate the rating of the product.

The interrelation of the IEP assessment models

The work suggests IEP assessment models which allow making an efficient managerial decision about producing innovative engineering product under the conditions of insufficient and fuzzy information.

The model based on the fuzzy inference concerning selecting the candidates for experts allows improving the quality of expert assessments and finally advancing decision-making.

The customer preferences forecasting model allows calculating the expectable demand, consumer motivation, their attitude towards the suggested product with enough consistency and confidence.

The model of determining IEP competitiveness on the base of the pair-wise comparison method allows the managers obtaining fuzzy sets of alternatives with various competitiveness degrees at the early stages of research. The product specifications serve as criteria.

The integrated model of product competitiveness assessment allows objective reflection of the product market position at production, marketing and operation stages. The model has two modifications. The criteria are: E_p – value of company production efficiency criterion; F_p – value of production financial priority criterion; E_{mo} – value of marketing operations efficiency criterion; Sed – value of "significance of the engineering decision" criterion. Additionally to the listed above criteria in the first modification Sed – value of "significance of the engineering decision" criterion is added, and in the second modification – NPV, net present value.

The rating model of innovation priority assessment will ensure rational choice of alternatives under collective selection at the stages of idea synthesis, its development by a progressive businessman when the information about criteria and alternative assessment ratios is not determined or is inaccessible by nature (criteria R_p – relevance ratio of the solved engineering problem, P_w – ratio of the solved engineering problem relevance to the programs of the most important technological development works, C_p – complexity factor of the engineering problem, P_u – point-of-use ratio of the solved engineering problem, S_a – the scope of application ratio of the solved engineering problem, S_p – the scope of protective measures ratio of the solved engineering problem) as well as at the stage of product manufacturing and marketing when the potential producer can influence the levels and values of particular efficiency and price assessments of alternatives (criteria E_p, F_p, E_{mo}, S_{ed}).

All that allows selective partial financing of particular products manufacturing on the base of the accepted system of criteria. The interrelation of the models and the criteria of IEP assessment is presented in Table 2.

Table 2
The interrelation of models and criteria of IEP assessment

Stage	The model of innovation competitiveness assessment	Criteria	Result
Preliminary stage	The model of selecting experts on the base of fuzzy inference	An experienced researcher, ability for expert review, intuition, industrial work record	Point and linguistic estimation of the alternatives
Market research	The model of consumer preferences	Technical and economic features of the product (TEF), preferences-requirements (PR)	Multifactorial regressional dependences of TEF upon PR
Idea synthesis, research and development	The model of rating assessment of the product competitiveness	R_p, P_w, C_p, P_u, S_a, S_p	Innovative production rating
	The model on the base of pair-wise comparisons	Performance attributes of the product	Fuzzy sets of alternatives of various competitiveness degrees: “low competitiveness”, “medium competitiveness”, “high competitiveness”
Manufacturing, marketing, operation	The integrated model of assessing the innovations	S_{ed}, F_p, E_p, E_{mo}	The integrated coefficient of competitiveness
	The 2nd modification of the integrated model of assessing the innovations	NPV, F_p, E_p, E_{mo}	
	The model of the rating assessment of the product competitiveness	S_{ed} (NPV), F_p, E_p, E_{mo}	Innovative production rating

Conclusion

The suggested system of models allows covering all stages of the lifecycle of the product. The output information of IEP competitiveness assessment at the initial stages of the product lifecycle becomes the input information for assessing competitiveness at the next stages of the product lifecycle. There is an opportunity of processing qualitative information and converting it into quantitative assessments which is especially important at the stages of idea synthesis and market research. According to the aim of competitiveness research of innovations the decision-maker can stop at any of the system levels while even the first (traditionally qualitative) level allows obtaining fuzzy sets of various degree of competitiveness (“low competitiveness”, “medium competitiveness”, “high competitiveness”). The decision-maker decides independently, according to the current situation, which criteria should be paid attention to and included into analysis.

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