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Economic-Mathematical Model and Mathematical Methods for Substantiating the Choice of the Company Innovation Strategy

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Abstract

Objectives: The study considers mathematical methods applied to strategic management. The objective of this study is to develop economic-mathematical model to justify the innovation strategy selected by a company. **Methods:** Based on the suggested economic-mathematical model, the study develops a decision-making methodology for selecting the innovation strategy of a company. In the course of modeling, an innovation strategy is presented as an aggregate that consists of two-element formations that include the name of the strategy and the certainty factors that determine the degree of reliability of the selected strategy. **Findings:** Depending on the type of the company (production focused or scientific and innovative type), innovation strategies can be split into two sub-aggregates. In each of those sub-sets, innovation strategies are ranked based on their degree of aggressiveness. The choice of the innovation strategy is founded on the production rules of fuzzy logic, where the parameters are represented by the type of the organization and by the primary metrics of the innovation strategy components. Innovation strategy is decomposed into elementary indicators in such a way that the components of the company's innovative potential are represented by the investment, scientific and resource potentials. In turn, such categories as administrative, financial, company geopolitical and foreign economic risks are regarded as probable strategic risks of the innovative development. Economic conditions of the company are predetermined by the industry sector development indicators and by the investment attractiveness of the host region. It has been proved that the informed decisions on innovation strategy can be made relying on formalized expertise and on precision of fuzzy algorithms. **Applications/Improvements:** Suggested methods could be implemented employing the relevant software. The study aims to help businesses operate under the conditions of high risks and uncertainties related to the available information.

Keywords: Innovative Potential, Innovation Strategy, Soft Computing, Fuzzy Logic, Business Administration

1. Introduction

The most effective way to manage a business company under conditions of global market economy is founded on the strategic approach widely spread all over the modern world. The strategic approach makes it possible for a company to pursue its objectives in a consequential manner, rendering systematic nature to the process and reducing it to the tasks of strategic management.

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More complicated nature of production relations and the disposition of production forces in many modern economies and in different countries of the world resulted in reducing strategic business administration to implementing some types of strategies related to this or another area of the company's business. As a result, the company simultaneously has to manage competitive, marketing, innovative and other types of strategies. Notwithstanding the fact that all strategies of the company are closely interrelated, each of them needs special attention and requires a particular approach of its own. Under the conditions of developing markets and emerging new technologies, the key position now belongs to the innovation strategy (hereinafter InS) as to the one that most comprehensively encompasses various means for achieving the objectives of the company.

The issue of selecting InS needs to be addressed, because in business administration, there is always an intention to develop innovative potential following some certain strategy, specific and particular for each company. The nature of the methods for selecting InS is of paramount importance for managing any enterprise; therefore, first of all, this methodology should be scientifically justified and strictly formalized.

This study presents a theoretical investigation of InS selection mechanisms employed by business companies. Thereat, the type of activity of any particular company belongs either to the sector of scientific research and investigations or to making innovative products, or is aimed at creating and implementing organizational innovations, that is, belongs to innovatively developing macroeconomic system. It is exactly at the companies that belong to the abovementioned types that InS reveals itself most vividly.

The objective of this study is to identify the ways the companies should follow in selecting InS. Based on the suggested theses, the management of the companies will be in position to make better decisions on selecting a particular InS.

2. Literature review

From theoretical perspective, the methodology for making decisions on the InS selection is located at the interface between strategic and innovative management and economic-mathematical modeling. Strategic management is an independent discipline that came, at some stage of its development, from the theory of general management established in the 60s-70s of the 20th century.

Development of strategic management is associated with the development of mathematical methods and information technologies that are prerequisites for processing a huge amount of information to make the informed managerial decisions. The researchers and other authors mentioned in this study have developed mathematical modeling methods for decision generation and decision making processes exercised by the companies within the framework of solving the tasks of strategic management. A strategic approach to business administration has been developed thanks to the efforts of these authors.

Most of the authors never doubt that innovative activity is impossible without a strategy,[1] however, there are still some issues in this area. For example, comparing InS with standalone innovative activities in terms of their functional features is a matter of disputes. The controversy of most authors' opinions on the issue is manifested through the fact that, on the one hand, one should not confuse InS with innovations, and, on the other hand, they complement one another and, according to C.B. Dobni,[2] there appears a synergy effect due to close interaction between them. Some authors supplement the distinguished four types of innovations that include product, organization, process and marketing innovations,[3] with a new type of "strategic innovations"[4] that occupies an intermediate position between InS and innovation. This terminology helps understand the necessity of establishing a clear idea of what exactly has to come as an output from the decision-making process, because the difference between InS and innovations is not sufficiently distinguished.

Many authors note the connection existing between InS and product-related innovations. In such product-based approach, InS selection belongs to the product level decision-making.[5] Notwithstanding the fact that new approaches to strategic management have, to a large degree, replaced the conventional InS,[6] the authors would still abide by the traditional approach in terms of interpreting InS as a chain "objectives – means – plan to achieve objectives".

According to D. Foray and other authors,[7] the InS selection in the company depends on the general character of research and development activities in the country or in the region where the company is located. In the authors' opinion, the regional factor is not a decisive one, as the role of the innovative potential of the company and the emerging risks are by no means less significant.

Nevertheless, one should not deny the effects produces on the InS selection process by the specific factors of the investment and industry climate and by the dynamics of development of the industrial sector, to which this particular company belongs, in the region where this company is located. Given the external environment, the important role of the risks should be especially highlighted in the course of selecting the InS for the company. Thus, according to R. Adner,[8] any reevaluation of risks makes for the revision of the company's InS.

Studying the ideas of business InS, the following approaches to InS engineering have been developed[9]:

- internal evaluation of the company, evaluation of external opportunities, formulating objectives and selecting tasks;[10]
- establishing the mission of the company, generating the objectives of the company, evaluation and analysis of the external environment, managerial analysis of strengths and weaknesses of the company, analysis of strategic options;[11]
- analysis of the external environment, analysis of internal situation, ultimate aggregate valuations of the environment, forecasting, determining the mission and the objectives, finding strategic "discrepancies" between the objectives and the forecasts;[12]
- establishing the sphere of business and formulating the strategic mindsets, setting strategic objectives and the tasks to be accomplished;[13]
- determining the objective, evaluating external and internal environment, discovering and analyzing the problems of the company;[14]
- analysis of the environment, establishing the mission and the objectives;[15]
- analysis of the external and internal environment, setting the mission and formulating the objectives, planning and setting the tasks.[16]

Given the abovementioned review, the InS engineering is reduced to formulating the objectives and to analyzing the factors affecting the InS. The result of InS engineering should be formalized as a document, a table or a chart. Before formalizing, the InS has to be selected with the help of special mathematical methods. An optimal InS should be selected upon compiling a list of all available alternatives that would ensure, together with other priorities and criteria, the novelty of the suggested economic-mathematical model.

Thus, the study is theoretically founded on the strategic approach to business administration supplemented by special mathematical methods developed below.

3. Methods

For the purposes of selecting InS, it seems advisable to apply some methods of the so-called "soft computing" and the expert evaluation (Delphi) method due to several reasons.

First, the necessity to apply fuzzy logic has been stipulated by the fact that this fuzzy logic ensures adequacy and practicability of the results of the calculations owing to the introduction of the linguistic variable, obtained as a result of combining fuzzyfied (i.e. reduced to fuzzy condition, from an adjective "fuzzy") quantitative metrics. One of the problems one faces in the course of selecting the InS for the company is represented by the decisions that have to be made under conditions of uncertainty caused by deficiency, insufficiency, or by distortion of the initial data. Any such-like uncertainty can be eliminated by applying mathematical methods that are founded on fuzzy logic. The production rules of fuzzy logic make it possible to obtain the interim metrics that characterize, to a different degree of detail, the components of InS: the innovative potential and risks.

Second, while making a decision on selecting the InS, it is necessary to identify the most dangerous risks and to minimize the potential losses associated with those risk-related situations. Evaluation of risk metrics is founded on expert methods that make use of the experience and intuition of the experts to forecast threats and potential risks instead of mere substitution of the parameters in analytical equations. In the course of expert evaluation, the rules of heuristics should be applied based on the non-formalized knowledge of the experts about the company in question and about its environment, which is too complicated to be described applying descriptive methods. Thus, applying expert evaluations to justify the InS selection makes it possible to use the individual experience of the experts instead of just relying on the intuition of the decision-maker or on the background secondary aspects.

In this study, the InS selection in the company is considered as a process of decision-making that is modeled by means of mathematical methods implying the processing of fuzzy sets. A decision to select the InS represents the company's response to the current situation, there-

fore, here one should rely rather on a situational approach than on a process-based one. The situation reflects the conditions of the enterprise and the external environment that affects the company management decision to revise the InS. The company's InS should be revised periodically, once in several years. The InS can also be changed in an unplanned manner, should there appear a special urgency to do so, dictated by some reasons of emergency. Initial data here are the conditions that reflect the real state of the company and its environment in statics as of some definite period. However, the situational approach makes it possible to fix the factors affecting the InS selection not only in statics but in dynamics as well, as it also accounts for the past period dynamic metrics of the development of the sector of the economy the company belongs to.

Company's InS is decomposed within the framework of the component approach. The component approach is a method for decomposing complex systems into primary elements reflecting, in this case, the metrics of innovative potential and risks. The results of InS engineering assisted by the component methodology are represented in the objective tree which is the graphical means for describing structures.

The company's InS selection process is in need of clarified and specified terminology required for describing the components of the InS. Thus, strategic planning should mean the decisions and actions to be undertaken by the management of the company encompassing the choice and the engagement of potential funding sources and other means to achieve the set strategic tasks within a specified period.[17] The company's strategy should be understood as the art of the management exercised in making use of all available means to achieve the set objectives.[18] The InS is itself a means for achieving the objectives of the company which is different from other means in that it is new for this particular company, for this particular type of activity and for the consumers of the products the company makes.[19] The novelty should rest not with the InS itself, but with the focus of the InS on developing new competitive products, developing a new efficient management model and other innovations. According to R.G. Cooper and S.J. Edgett,[20] the InS is predetermined by the objectives, by the sphere of business, by resource capabilities and by the measures employed to achieve these objectives.

It is essential that the InS should determine the directions for innovations in both production and organizational activities. All types of strategies, including InS, are focused on developing and utilizing the potential of the company and they respond to the changes occurring in the environment, therefore the varied and multiple options of the InS are stipulated by the mix of the components of the company's internal environment, especially by potential opportunities and threats. Thereat, the InS should be regarded separately, irrespectively of other types of strategy and taking into account the nature of innovative activities at the company.

Innovative potential is represented by multiple interdependent and interrelated elements that enable continuous innovative activity at different levels.[21] Particularly, innovative potential is set at the level of the company and here it is called a corporate innovative potential. Affiliated types of the company's innovative potential are investment, scientific and resource potentials which characterize the investment, the research and development and the resource capabilities for innovative activity performed by the company.

Risk is a numerically measured possibility of facing unfavorable situations and the associated consequences represented by losses, damages and wastes related to uncertainty.[22] Applying risk classification by the spheres of their occurrence one can identify administrative, financial, external economic, geopolitical and other types of risks.

The policy measures for developing sectors and spheres of the economy are generally understood as the legal and administrative arrangements aimed at regulating and managing their development by means of adopting programs, laws, regulations, instructions and also aimed at encouraging and stimulating the activities of the companies belonging to these sectors and spheres.

Investment climate represents an aggregate of the factors that are specific for each particular location and that predetermine the opportunities for the businesses and establish their stimuli for productive investments, for creating jobs and for operational expansion.[23] Consequently, industry-related investment climate is regarded as the investment climate established at the companies within one particular sector of the economy.

The InS selection does not require developing any extra terminology; the above given terms are quite sufficient for the purpose. The most difficult issue is to describe the InS decision making process applying "soft computing" and expert methods.

Employing mathematical methods for the purposes of substantiating the InS choice makes it possible, for any particular company, to gain competitive advantages amidst other businesses. Competitive advantages are

Table 1. Classification of types of business innovation strategies

Code of group/ innovation strategy	Name of group/ innovation strategy	Features of group/ innovation strategy
S_1	Strategies for performing research and development, design and experimental activities in scientific innovative companies	They are associated with developing applied studies in the company; predetermine the ways of applying ideas, of investing in research and development, design and experimental activities, of interrelations existing between these activities and the types of the produced innovative products
$S_{1.1}$	Turning down the investigations in the areas of little promise	Excluding unprofitable areas from the program of investigations. It helps save resources. Initial financial investments are recognized as sunk costs.
$S_{1.2}$	Acquiring intellectual property rights	Saving resources for internal investigations. It helps avoid duplicating research and development activities. Extra high expenses can be incurred if the provisions of the agreements are unfavorable.
$S_{1.3}$	Copying external research and development results	Developing analogues of other companies' inventions. One has a clear vision of the research practicability and a clear idea of the results. There is a possibility of intellectual property rights conflicts.
$S_{1.4}$	Narrow specialization of research and development, concentration of resources	Consolidating resources at the most promising areas of investigation. It helps gain profit from internal studies. Achieving good results in a number of particular projects may not necessarily bring about general success.
$S_{1.5}$	Focus on absolute leadership in the sphere of research and development	Monopolizing the investigations in some particular area. Leaves no chances for the competitors to attain these high levels of development. There is a risk of maximum concentration of resources under conditions of uncertainty.
S_2	Strategy for introducing and adapting innovations in production companies	Represents a combination of the production facility upgrade, promoting the products in new markets and making use of technological advantages
$S_{2.1}$	Wait-and-see attitude	There is a possibility to win better terms and to understand the situation better. It is not associated with any capital expenditures. It is not efficient under time pressure conditions.
$S_{2.2}$	Employing outdated innovations	The first steps to introduce innovations. It helps save time and facilitates innovations at the initial stage. Outdated innovations are detrimental to the image of the company from the perspective of both customers and investors.
$S_{2.3}$	Revamping the existing product line	Partial modifications of the products employing innovative technologies. It is efficient under the conditions when the competitive struggle is slow and the budget is small. It will be defeated by the competitors who apply stronger innovations.
$S_{2.4}$	Borrowing innovative ideas	Making use of other companies' innovative ideas. It only requires practicing good competitive intelligence. Other companies' innovative ideas may not fit the existing operations.
$S_{2.5}$	Following the situation in the market	Monitoring market changes in supply and demand for innovative products. The most widespread strategy under modern market conditions. Passive behavior will be defeated by progressive competitors.
$S_{2.6}$	Innovation exchange	Acquiring other companies' innovations and providing internal innovations on commercial terms. It makes for establishing relationships with other businesses. There is a risk of excessive openness of internal expertise to the external environment.

$S_{2.7}$	Copying innovative solutions of the competitors	Internal implementation of the innovations that have already been implemented by the competitors, with some delay. Not every innovative solution can be copied and reproduced without damage; the competitors profit from the inevitable lag.
$S_{2.8}$	Developing complex innovations	Creating complex, large, expensive innovations that represent combinations of several well-proven innovations. It attracts big clients and customers. However, a complex innovation can be useless if its engineering takes too long.
$S_{2.9}$	Front-running in innovations	Introducing innovations breaking away considerably from the nearest competitors. It helps gain decisive competitive advantages. If the investments are scarce and the efforts are insufficient, the advantages will be lost in a while.
$S_{2.10}$	Revolutionary innovative breakthrough	Occupying completely new markets with unusual products and services. It will bring about considerable profit under favorable conditions. However, success will come only if some extraordinary and outstanding ideas are realized.

obtained by utilizing the available resources in the most efficient way for implementing innovation development within the framework of the strategic approach in corporate management. The suggested approach facilitates evaluating the components and the interim metrics characterizing InS.

Before starting to formalize mathematical methods, it seems advisable to make a list of all known types of InS, as the classification of those types will make for more profound understanding of what InS is and of how it can be shaped in the companies.

4. Results

4.1 Classification of Business Innovation Strategies

The InS classification by the stages of its implementation provides a criterion for making decisions on the InS selection. The classification attribute is not depicted in the objective tree, as there is no particular method to calculate it. The attribute is determined as the external constant parameter affecting the company's InS choice on a par with the evaluations of the components and the interim metrics.

There are different InS classification methods. Thus, the study developed by K.V. Poretskova[24] presents the types of classifications based on the responses to the external and internal environments, on behavioral models of the company under the new conditions, on the stage of the strategy implementation, on the ways of diversification, on the competitive position of the company in the market, on the market situation and on the characteristic features of the InS implementation. In his study, A.A. Skovorodko [25] notes that such researchers as A. Bogdanov, L. Vodachek, O. Vodachkova, B. Santo, B. Twiss have suggested various options of InS classifications by the degree of its aggressiveness. The classification method shown in Table 1 approximates the classification based on the stages of implementation, described in the monograph study by S.A. Agarkov. [26]

According to Table 1, the InSs should be split in two groups depending on the stage of their implementation in the production process and then they should be ranked with respect to their aggressiveness from the defensive strategy up to the offensive strategy. Double classification attribute makes for more comprehensive interpretation of the results that are obtained at the outcome of the InS decision-making procedure. It has been assumed that both scientific-innovation and production-innovation activities can be performed in parallel in sufficiently large companies. In this case, it can be recommended that such diversified enterprises should employ two or more InSs. A strategy for scientific-innovation activities from the first group of InSs do not interfere with the strategies for production-innovation activities from the second group of InSs, because they belong to different business spheres.

Correlations between the InSs and the manufactured products are explained by the mutual relations existing between the InSs and product-related innovations that have already been mentioned in the review section of this study. The discovered connection manifests itself through indirect reference in the name of InS specifying the nature of the manufactured product (or of the product that is put out of production). The name of the InS indicates the

focus of the enterprise on producing the unique products, on producing modern products with unique services, on copying the products of the competitors, on implementing new organizational forms of business, or on total upgrade of production facilities. Different opinions on the nature of the InS result in differently formulated names for almost similar strategies. There are strategies that imply almost the same: research and development turndown and production shutdown, research and development specialization and focus on particular market segment, developing complex innovations and wide differentiation.

Strategies $S_{1.1} - S_{1.5}$ and $S_{2.1} - S_{1.10}$ can be regarded as a set S of possible InSs.

In her study, S.D. Ilyenkova[27] describes the following methods for selecting InS at the company:

- method of structural and morphological analysis which identifies the new products and developments within the sector of the economy and, based on this, generates recommendations on scientific and technical policy of the company;
- method of identifying the features of publication activities, which considers the information flow as a unified system going through certain lifecycles, and the recommendations on introducing innovations are provided based on the investigations of those cycles;
- method of analogue patents, according to which the InS development should take into account general directions of the patented ideas that are believed to be promising from the perspectives of the world experience;
- method of terminological and lexical analysis, that accounts for the transition of terms and lexical units from one sector of the economy into another, thus making it possible to forecast the development of the new branch and to plan the strategy accordingly;
- method of metrics, where the recommendations are prepared based on studying the documents about the dynamics of the indicators of the world technical systems.

All enumerated methods are mostly of a generally applicable nature and are quite distant from the problems of strategic management in real companies. Instead of simply relying on indirect indicators and secondary metrics in the course of selecting the InS, as all abovementioned methods suggest, the authors believe that it seems advisable to develop an economic-mathematical model that would deal with the set objectives in a more specific manner.

4.2 Economic-Mathematical Model for Making Decisions on Selecting Innovation Strategy at the Company

Given the most common assumptions about the environment, the company has to operate in and about the belonging of the company to a certain type of economic activity, a set of factors is formed affecting company's InS choice:

- level and degree of risk in business development;
- accumulated experience in strategic management;
- characteristic features of development in this sector of the economy.

Hence, the principle foundational components of the business InS are represented by innovative potential and risks. Innovative potential stipulates the availability of opportunities for the company (or its positive development factors). The risks predetermine the internal and external threats counteracting the company's opportunities, namely, the restraining negative factors affecting the development of the enterprise. Each of the components of the InS means to cover one individual factor that affects the substantiation of the InS choice. This study assumes that the InS is developed by the management of the company, that is, in "top-down" manner, as it is shown in the objective tree decomposed in Figures 1 and 2.

The upper part of the objective tree made of the components of innovative potential and risks is shown in Figure 1.

The lower part of the objective tree covering the details of the targeted indicators of the company's innovative potential from the upper level is shown in Figure 2.

InS S should be selected from a certain aggregate S of alternative InSs. Normally, this aggregate (set) is formed out of several fuzzy InSs $\tilde{s}$, but applying the criterion for identifying the strongest certainty factor that proves that this particular InS belongs to the fuzzy set of the strategies of this particular type, a single InS S can be selected.

This model is formalized by introducing the set (aggregate) $\widetilde{S} = \{\tilde{s}_1, \tilde{s}_2, ..., \tilde{s}_N\}$ that includes fuzzy InSs $\tilde{s}_i$. The aggregate of the preselected InSs represents a set, because the InS does not contain in itself any quantitative estimation, as, for example, the innovative potential does.

Table 2. The production rules of fuzzy logic for selecting business innovation strategy

IF	THEN
(TUPE (Compani) = "Scientific – Innovative organization") ∧ $(\left(P_i < 0.25 \wedge P_s < 0.25\right) \vee Q < 0.25)$	$s = s_{1.1}$
(TUPE (Compani) = "Scientific – Innovative organization") $\wedge\ P \geq 0.25 \wedge P < 0.75 \wedge Q < 0.25$	$s = s_{1.2}$
(TUPE (Compani) = "Scientific – Innovative organization") ∧ $\left(\left(P_s < 0.25 \wedge P_r > 0.75\right) \vee Q < 0.75\right)$	$s = s_{1.3}$
(TUPE (Compani) = "Scientific – Innovative organization") ∧ $\left(P_i \geq 0.75 \vee P_s > 0.25\right)$	$s = s_{1.4}$
(TUPE (Compani) = "Scientific – Innovative organization") $\wedge\ P_i \geq 0,75 \wedge P_s \geq 0.75$	$s = s_{1.5}$
(TUPE (Compani) = "Production company") $\wedge\ P \geq 0,25 \wedge P < 0.75 \wedge P_r \geq 0.25 \wedge P_r < 0.75$	$s = s_{2.1}$
(TUPE (Compani) = "Production company") $\wedge\ P < 0.25 \wedge Q \geq 0.75$	$s = s_{2.2}$
(TUPE (Compani) = "Production company") $\wedge\ P \geq 0.25 \wedge P < 0.75 \wedge Q \geq 0.25$	$s = s_{2.3}$
(TUPE (Compani) = "Production company") $\wedge P_s < 0.25$	$s = s_{2.4}$
(TUPE (Compani) = "Production company") $\wedge Q \geq 0.75$	$s = s_{2.5}$
(TUPE (Compani) = "Production company") $\wedge(P_i \geq 0.75 \wedge \quad \geq 0.25 \wedge P_s < 0.75 \wedge \ _r < 0.25)$	$s = s_{2.6}$
(TUPE (Compani) = "Production company") $\wedge\ P_i \geq 0.75 \wedge Q \geq 0.25 \wedge Q < 0.75$	$s = s_{2.7}$
(TUPE (Compani) = "Production company") $\wedge\ P_s \geq 0.75 \wedge P_r \geq 0.75 \vee Q \geq 0.75$	$s = s_{2.8}$
(TUPE (Compani) = "Production company") $\wedge P_r \geq 0.75 \wedge Q \geq 0.75$	$s = s_{2.9}$
(TUPE (Compani) = "Production company") $\wedge P_s \geq 0.75 \wedge P_r \geq 0.75$	$s = s_{2.10}$

Consequently, it is impossible to describe the InS applying a qualitative scale: "low", "average", "high"; therefore, a set comprised of one-element subsets N and fuzzy InS of pair-wise differing types should be used as the data structure instead of the linguistic variable.

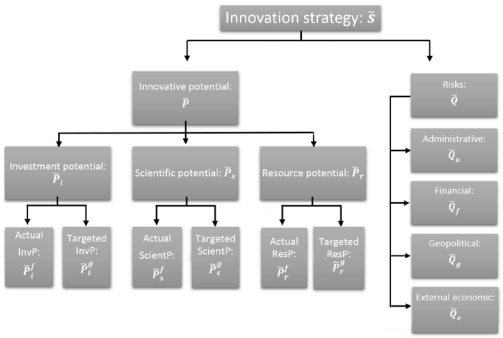

Figure 1. The upper level of the objective tree in selecting the company innovation strategy

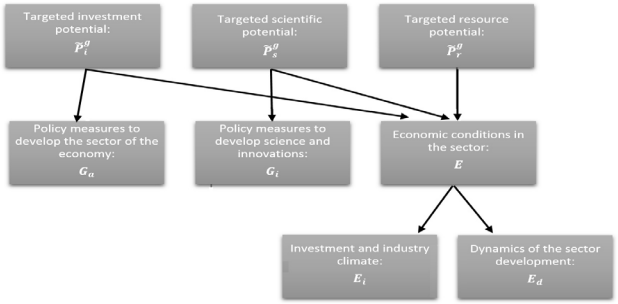

Figure 2. The lower level of the objective tree in selecting the company innovation strategy

InS s is selected applying the production rules of fuzzy logic from Table 2.

Interval values in the production rules are found by applying the heuristic method. Interval values in Table 2 have been set by default; if required, they can be altered depending on the specific features of the sector of the economy, depending on specific characteristics of any particular company or other external and internal factors.

Certainty factor cf_s of the selected InS is calculated with regard to the certainty factor of the innovative potential cf_p and with regard to the certainty factor of the integrated risk evaluation cf_Q, taking into account the conjunctive dependency of those factors observed in the course of decision-making process, according to the formula that follows:

$$cf_s = \frac{cf_P \times cf_Q}{100} \quad (1)$$

The sum of certainty factors cf_{si} of all In Ss s_i should not necessarily amount to the maximum constant value of 100; it would be enough to superimpose this condition on InS subsets of the first and the second groups in conformity with the relevant classification.

In turn, evaluations of InS components are affected by a number of factors. InS components are generated out of primary metrics that are calculated applying the method of interpreting the scales of expert evaluations.

Similar to InS, the rest of fuzzy metrics will be presented as tuples $\tilde{x} = \langle x, cf_x \rangle$.

Numeric evaluation of the company's innovative potential P will be calculated according to the formula as follows:

$$P = \frac{P_i + P_s + P_r}{3} \quad (2)$$

where P_i – investment potential; P_s – scientific potential; P_r – resource potential of the company.

Each of the components P_x, $x \in \{i,s,r\}$ of the company's innovative potential P, will be calculated as a ratio of the actual P_x^f and targeted P_x^g values of the company in terms of this type x potential:

$$P_x = \frac{P_x^f}{P_x^g} \quad (3)$$

The certainty factor of the innovative potential cf_p of the company is calculated according to the formula below:

$$cf_p = (cf_{p_i} + cf_{p_s}) + cf_{p_r} \quad (4)$$

where the operation of summation $\dot{+}$ of certainty factors cf_{p_i} cf_{p_s} cf_{p_r} of the investment, scientific and resource potentials means the following:

$$cf_a + cf_b = cf_a + cf_b - \frac{cf_a \times cf_b}{100} \quad (5)$$

Certainty factors cf_{Px}, $x \in \{i,s,r\}$ of the components of the company's innovative potential are calculated based on the actual P_x^f and targeted P_x^g values of the company in terms of this type x potential:

$$cf_{Px} = \frac{cf_{P_x^f} \times cf_{P_x^g}}{100} \quad (6)$$

Actual value of P_x^g potential is calculated based on the aggregated expert evaluations $Ex_m^{(P_x^g)}$ and based on the degree of the competence Co_m, of M experts, $m \in 1...M$.

$$P_x^g = \frac{\sum_{m=1}^{M} Co_m \times Ex_m^{(P_x^g)}}{\sum_{m=1}^{M} Co_m} \quad (7)$$

The certainty factor $cf_{P_x^f}$ of the actual value of the potential is calculated based on the aggregated degrees of the experts' competence Co_m:

$$cf_{P_x^f} = 100 \times \sqrt[M]{\prod_{m=1}^{M} Co_m} \quad (8)$$

Expert evaluation $Ex_m^{(P_x^f)}$ of potential x is estimated applying a qualitative scale as follows:

$$\left\{\begin{matrix}\text{very low; low; medium}\\ \text{high; very high}\end{matrix}\right\},$$

And then it is reduced to numerical type accordingly: $\{0;0.25;0.5;0.75;1\}$.

$$0 \le Ex_m^{(P_x^f)} \le 1. \quad (9)$$

Thus,

The degrees of competences of the experts can be estimated by different methods that are not included in the scope of this study; see, for example, the works of M.M. Butakova [28]

Thereat:

$$0 \le Co_m \le 1. \quad (10)$$

The targeted value P_x^g is set depending on economic conditions of the sector of the economy E; its components E_i and E_d will be considered below. Thereat:

$$0 \le P_x^g \le 1. \quad (11)$$

Certainty factors $cf_{P_i^g}$, $cf_{P_s^g}$, and $cf_{P_r^g}$, and of the targeted values of the investment, scientific and resource potentials depend on components G_a and G_d, on governmental policies in the sector of science and on innovations in the related industries. The nature of these dependencies will be considered below.

Thus, economic conditions of the sector of the economy E depends on the investment and industry-specific climate E_i and on the dynamics of the sector development E_d:

$$E = \frac{E_i + E_d}{2} \quad (12)$$

Evaluation of the investment and industry climate E_i is a result of aggregation based on expert evaluations $Ex_m^{(E_i)}$ and the degrees of competence Co_m, of M experts:

$$E_i = \frac{\sum_{m=1}^{M} Co_m \times Ex_m^{(E_i)}}{\sum_{m=1}^{M} Co_m} \quad (13)$$

Expert evaluation $Ex_m^{(E_i)}$ of the investment and industry climate is estimated applying the qualitative scale as follows:

$$\left\{\begin{matrix}\text{extremely unfavourable; unfavourable; normal}\\ \text{favourable; extremely favourable}\end{matrix}\right\},$$

And then it is reduced to numerical type accordingly: $\{0;0.25;0.5;0.75;1\}$..

Thus,

$$0 \le Ex_m^{(E_i)} \le 1. \quad (14)$$

Evaluations of governmental policy G_x, $x \in \{a,i\}$ are calculated depending on the number of performed K_x^p, current K_x^c and scheduled K_x^f governmental policy measures aimed at developing the relevant sectors of the economy:

$$G_x = 100 \times \frac{K_x^p + K_x^c}{K_x^p + K_x^c + K_x^f} \quad (15)$$

The metric of the sector development dynamics E_d is calculated based on statistical data that help estimating it by applying the scale as follows:

$\{\text{crisis, decline, stability, rise, confident growth}\}$, that is translated into numeric scale:

$\{0;0.25;0.5;0.75;1\}$..

Thereat, the following inequations are observed:

$$\begin{cases} 0 \le E \le 1 \\ 0 \le E_i \le 1. \\ 0 \le E_d \le 1 \end{cases} \quad (16)$$

Target values of P_x^g are set applying the rules from Table 3.

And it goes on further in the same manner.

Given (15), the following formulae can be obtained:

$$\begin{cases} cf_{P_i^g} = G_a \\ cf_{P_s^g} = G_i \end{cases}. \quad (17)$$

Certainty factor $cf_{P_r^g}$ of the target value of resource potential P_r^g is calculated based on aggregating the degrees of the experts competence Co_m:

$$cf_{P_r^g} = 100\sqrt[M]{\prod_{m=1}^{M} Co_m}. \quad (18)$$

Evaluation of the integrated risk Q of the company is performed based on the evaluations of administrative Q_a, financial Q_f, external economic Q_e and geopolitical Q_g risks:

$$Q = \frac{Q_a + Q_f + Q_e + Q_g}{4} \quad (19)$$

Certainty factor cf_Q of the integrated risk is calculated based on certainty factors $cf_{Q_a}, cf_{Q_f}, cf_{Q_e}$ and cf_{Q_g} of four types of risk from the objective tree shown in Figure 1.

$$cf_Q = \left(\left(cf_{Q_a} + cf_{Q_f}\right) + cf_{Q_e}\right) + cf_{Q_g} \quad (20)$$

Where $\dot{+}$ is set in the same manner as it is set in (5).

Evaluation of each of four types of risk $Q_x, x \in \{a, f, e, g\}$, is performed based on aggregating expert evaluations $Ex_m^{(Q_x)}$ and the degrees of competence Co_m, of M experts, $m \in 1...M.$:

$$Q_x = \frac{\sum_{m=1}^{M} Co_m \times Ex_m^{(Q_i^*)}}{\sum_{m=1}^{M} Co_m} \quad (21)$$

Expert evaluation of risk $Ex_m^{(Q_x^*)}$ is formed of internal risk $Ex_m^{(Q_x)}$ that is estimated applying the qualitative scale as follows:

$$\begin{Bmatrix} \text{very low; less probable; medium} \\ \text{probable; very high} \end{Bmatrix},$$

And then, it is translated into numerical representation applying the scale as follows:

$\{0; 0.25; 0.5; 0.75; 1\}$. .

Besides, the degree of potential damage that can be caused by the risk $Dang_m^{(Q_x)}$ is set similarly applying the scale as follows:

$$\begin{Bmatrix} \text{mininum; small; medium} \\ \text{high; catastrophic} \end{Bmatrix};$$

$$Ex_m^{(Q_x^*)} = Dang_m^{(Q_x)}.Ex_m^{(Q_x)} \quad (22)$$

Thus,

$$0 \le Ex_m^{(Q_x^*)} \le 1. \quad (23)$$

Certainty factors cf_{Qx} of the risk value x are calculated similar to formula (8) based on aggregating the degree of the experts competence Co_m:

$$cf_{Qx} = 100\sqrt[M]{\prod_{m=1}^{M} Co_m}. \quad (24)$$

The numerical parameters (intervals, etc.), and the production rules proper are the results of the analysis of the considered popular types of InS. It this respect, it seems advisable to suggest additional types of InS that have not been included in the list above. In this case, the available set of the production rules will have to be enhanced. Based on the values of the metrics obtained applying the method of expert evaluations, InS should be selected from the list of available options.

Table 3. Production rules for obtaining target values of the company's innovative potential components

IF	THEN
E ≥ 0.90	$P_x^g = 1;$
E ≥ 0.80 and E < 0.90	$P_x^g = 0.95;$
E ≥ 0.70 and E < 0.80	$P_x^g = 0.95;$
E ≥ 0.60 and E < 0.70	$P_x^g = 0.80;$
E ≥ 0.50 and E < 0.60	$P_x^g = 0.75;$

Fuzzy logic makes it possible to improve the efficiency of conventional expert evaluations, insofar as it possesses several advantages as compared to classical logic. Due to the use of fuzzy factors of certainty in the course of calculating the quotients of the experts competence, the credibility of expert evaluations improves significantly, which is important, as these evaluations are provided by the persons who have different professional experience and are formulated under real conditions, for instance under conditions of staff shortage or distractive factors.

Fuzzy logic smoothes out differences between extremely high and extremely low expert evaluations of the components and primary metrics of InS. However, reducing the InS to fuzzy representation only means that there are chances to select the InS successfully.

The veracity of calculations in the course of selecting the InS depends on the adequacy of the provided expert evaluations. In turn, expert evaluations are not statistical values; therefore, in this case, it is impossible to estimate the accuracy of measurements applying classical methods. Besides, it is also important that the quotients of the experts competence should be identified scrupulously. Certainty factors do not affect the numeric values of the basic metrics; certainty factors are meant to supplement basic indicators with probability evaluations that are obtained quite roughly. Thus, the best proof of the precision of the suggested mathematical methods will come with empirical confirmation of the efficiency of the created economic-mathematical model, as it is put into practice.

5. Discussion

This study demonstrates how the InS obtained initially by the decision-making process based on qualitative judgment has been formalized through quantitative metrics. Solutions to the tasks of this study reveal the process of making decisions on selecting one of the best alternatives under the conditions of uncertainty by means of combining the method of expert evaluations with fuzzy logic.

Connection between expert evaluations and fuzzy logic is realized in such a way that both methods complement each other. Fuzzy logic compensates the discreteness of expert evaluations and expert evaluations help calculate the values in cases when calculating is methodologically complicated due to the qualitative nature of the subject of evaluation.

Mathematical methods should be developed further to enhance the complexity of the two-level objective tree, to develop fuzzification procedures, to improve the production rules of fuzzy logic, etc. It should be noted that there is a possibility to realize the InS selection methodology by software tools in the course of creating the smart system to support the decision-making process.

6. Conclusion

Principal results of the undertaken investigation are represented by the developed economic-mathematical model and by the mathematical methods for making decisions on selecting the InS in a business company. The suggested approach makes it possible for a company to gain strategic advantages in the competitive struggle, thereat, establishing interrelations with the companies in other sectors of the economy due to the need to apply both microeconomic and macroeconomic metrics. The suggested methods could help businesses select the efficient InS based on adequate evaluations of the current economic situation, taking into account the opportunities available in different types of innovative potential as well as the threats related to considerable risks.

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8. References

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