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HYBRID APPLICATION OF DECISION TREES, FUZZY LOGIC AND PRODUCTION RULES FOR SUPPORTING INVESTMENT DECISION MAKING (ON THE EXAMPLE OF AN OIL AND GAS PRODUCING COMPANY)

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ABSTRACT

During the last years, in most countries of Eastern Europe (and Ukraine in particular), even a simple reproduction of onshore hydrocarbon reserves was not ensured. Achieving the possible level of self-sufficiency in fuel and energy resources is a fundamental task of national economies, without which the successful implementation of economic, scientific, technical and social programs aimed at ensuring state independence and stability in Europe is impossible.
However, the onshore oil and gas industry of the countries of Eastern Europe with significant volumes of unexplored oil and gas resources, with the cost of oil and gas several times lower than world prices, the presence of a significant number of oil and gas industries, drilling and geophysical enterprises, oil refineries, and an extensive network of oil and gas pipelines , highly qualified production teams allows, with their effective use, not only to stabilize, but also to significantly increase the production of oil, gas and condensate in the future.
An important reason for the drop in oil and gas production volumes is insufficient management efficiency of the cycle of parallel business processes of the oil and gas company: field exploration, their arrangement and development, production and sale of oil and gas. The solution is the application of effective economic-mathematical modeling at the strategic level of management and the use of knowledge-oriented decision-making support tools as an integral component of the complex information system of an oil and gas company.
Objectives: *Therefore, the issues of: development of a complex system of economic and mathematical support for making fair and timely investment decisions at the macro level of an oil and gas production company, effective application of knowledge-oriented hybrid methods and technologies are becoming particularly relevant.*
Methods/Approach: *The paper uses a mathematical apparatus of the method of fuzzy logic, decision trees, data mining, knowledge-oriented decision support, theory of investment management and expertise in the field of management of oil&gas exploration and production local and international investment projects.*
Results: *first proposed the decision tree diagram of the effective investment management process of a oil and gas company in the search for hydrocarbons in modern economic conditions is proposed; received further development of the principles of hybrid application of intelligent technologies and knowledge-oriented basis and the problem of handling uncertainty while supporting investment decisions of an oil and gas company; first proposed two related prognostic models are proposed: the seismic impact model and a drilling impact model; first proposed two algorithms/models based on economic-mathematical modeling with elements of fuzzy knowledge to support decision-making of the tender&controlling committee of oil&gas production company.*
Conclusions: *Based on the foregoing, it can be concluded that it is efficient to use developed by authors hybrid, knowledge-oriented investment decision support for oil and gas production projects in Ukraine and other countries of Eastern Europe.*

Keywords: investment project, oil&gas exploration and production, decision tree, production rules, fuzzy inference

JEL classification: G11, D81, D83, L71

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INTRODUCTION

Over the past years, onshore hydrocarbon production in Eastern Europe has exceeded the growth of the resource base. The situation is complicated by the fact that with the constant deterioration of the structure of reserves at old deposits (Krasnyuk et al., 2022), the annual commissioning of new deposits with small reserves cannot compensate for the natural decline in production at old deposits. The only way to increase one's own production of gas and oil is a sharp increase in investments in the search for oil and gas, that is, geological exploration.

The process of making managerial decisions on investing in oil and gas exploration requires complex expert analysis, is associated with significant capital investments, has many branches of scenarios and nodes of decision-making, there is a need to take into account a huge amount of accumulated knowledge, existing open situations of uncertainty, specific industry risk and significant macroeconomic risks for the oil and gas industry of Eastern Europe.

It should be noted: methods of decision support have a significant prospect of application in current economic conditions (Krasnyuk et al., 2019) (liberalization of markets, globalization, increased competition, decrease in consumer loyalty, development of Internet and 24/7/365 digital technologies (Krasnyuk et al., 2022), Big Data, global and local crisis (Hraschenko et al., 2020) conditions etc). These methods should be based on a hybrid approach for using fuzzy logic, production rules decision trees etc). Since this approach is a powerful tool for solving complex specific problems of the national economies of Eastern European countries (in the oil&gas production industry).

Therefore, one of the necessary factors for increasing onshore hydrocarbon production in Eastern Europe and improving the efficiency, timeliness and fairness of the investment in exploration and production projects is the use of knowledge-oriented decision-making support tools.

METHODOLOGY

The paper uses a mathematical apparatus of the method of fuzzy logic, decision trees, data mining, knowledge-oriented decision support (Kulynych et al., 2022), theory of investment management and expertise in the field of management of oil&gas exploration and production local and international investment projects.

RESULTS

On the basis of the conducted research, performed Data Mining on industry Data Sets, industry experts interview and many years of experience of the authors, a decision tree diagram of the effective investment management process of a oil and gas company in the search for hydrocarbons in modern economic

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conditions (significant receivables and payables in the industry, which hinders the effective current and strategic activities of oil and gas companies) is proposed (Appendix A).

Considering the above-mentioned problems, the need to forecast the impact of geological exploration on the future growth of reserves and the reverse task will naturally arise.

A study of the results of geological exploration projects in Ukraine over the last two decades was conducted and expert experience and Data Mining methods were used (Krasnyuk et al., 2018).

As a result, the following two related prognostic models are proposed: the seismic impact model and a drilling impact model (1) and (2):

$$\begin{Bmatrix} Z_{yp-3} = 100 \times (S_{yp-8} \div 21) \\ S_{yp-8} \leq FS(yp-8) \\ FS_{yp-8} = S_{y-8} \times Zs_{y-8} \end{Bmatrix} \tag{1}$$

where:

yp is the base year of the start of production, *yp-3* is the year in which the reserves should be increased by the amount *Z*, *FS* (*yp* -8) is a function of the available capacities from seismic research, $S_{yp\text{-}8}$ - that is, in the *yp -8th* year it is necessary to perform *S* km of seismic exploration works in order to increase the reserves in the year *yp*-*3* by *Z* million cubic meters of gas. $FS_{yp\text{-}8}$ - necessary funding for seismic exploration in Euro in the *yp-8th* year in order to achieve an increase in reserves in the year *yp-3* by *Z* million cubic meters of gas, the $Zs_{yp\text{-}8}$ indicator is used for calculation - the price of 1 km of seismic works in thousand Euro in year *yp-8*.

$$\begin{Bmatrix} Z_{yp-3} = 98{,}2 \times B_{yp-5} \\ V_{yp} = Z_{yp-3} \times 0{,}05 \\ B_{yp-5} \leq FB(yp-5) \\ FB_{yp-5} = B_{yp-5} \times Zb_{yp-5} \end{Bmatrix} \tag{2}$$

where:

yp - the year in which the production should reach the value of *Vyp*, *FB(y)* - a function of the available drilling capacities (certain restrictions are imposed on the increase of drilling volumes: economic, technological, natural, organizational, etc.). Byp_{-5} - that is, in the *yp-5th* year, it is necessary to perform *B* meters of exploratory drilling in order to increase reserves in the year *yp-3* by *Z* million cubic meters of gas and increase in production after another 3 years of *Vyp* million cubic meters of gas. $FB_{yp\text{-}5}$ - necessary funding for drilling in Euro in the *yp-5th* year, the $ZByp_{-5}$ indicator is used for calculation - the price of 1 linear meter of drilling works in thousand Euro's.

Therefore, the mathematical models (Krasnyuk et al., 2021) mentioned above provide the necessary support when making strategic investment decisions of an oil and gas production company, make it possible to solve

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predictive tasks of long-term planning with economic resources, technological and organizational production capacities for their optimal use and the fulfillment of the tasks set to increase the growth of reserves and production.

However, despite the above formalized economic and mathematical models, after analyzing the developed decision tree, its components and experts' knowledge, a proposal is put forward, a proposal was put forward regarding the need to use the fuzzy logic apparatus in the construction of fragments of a rule-oriented support system (Krasnyuk M., Krasnyuk S., 2021) for making a complex of investment decisions in the search for oil and gas deposits and their production.

The mechanism of logical conclusion of fuzzy rule-oriented decision support systems is based on a knowledge base formed by experts of an oil and gas company in the form of a set of predicate rules:

Rule $_1$*: if x is* A_1*, then in y is* B_1*,*

Rule $_2$*: if x is* A_2*, then in y is* B_2*,.*

……

Rule $_n$*: x is* A_n*, then y is* B_n*,*

where:

x is an input variable; *y* - output variable; A and B are membership functions defined as x and y.

There are several modifications of the fuzzy inference algorithm: Mandani, Tsukamoto (for monotonic resulting functions), Sugeno (used when the conclusion of the rule is a function of the input variables x and y: z' = a'x + b'y), Larsen (the implication uses the multiplication operator), a simplified fuzzy inference algorithm.

Based on the conducted research and experiments by authors, it was concluded that the following combinations proved to be universal approximators and are recommended for use in the subject area under consideration:

- Gaussian membership function, composition using the product, implication according to the Larsen algorithm and the centroid defuzzification method;

- symmetric triangular membership functions, composition using the minimum operation and the Mamdani algorithm.

We present a simplified fragment of the designed fuzzy base of rules for supporting making investment decisions by an oil and gas production company, namely: a decision on the industrial development (development) of a field:

Rule 1: if the gas reserves in the field are small and the debit is small and the depth of the deposit is large and inflation is average, then further development is impractical (the payback period is very long);

Rule 2: if the gas reserves in the field are average and the average debit, depth is very large and inflation is low, then further development is appropriate (the payback period is average).

For this set of rules, it is appropriate to apply the Larsen algorithm.

Further in the explanation: x, y are the names of the defined input variables in a specific decision-making situation regarding field development (field reserves, debit, deposit depth, etc.); z – the name of the output variable (expediency of development (field development) based on the payback period); *A1, A2, ..., B1, B2, ..., C1, C2 ...* - heuristically found membership functions.

The possibility of using the fuzzy logic apparatus in fuzzy decision support systems is based on the following:

- a description of the conditions and decision method in a language that is close to natural;
- efficiency (related to universality) and is explained in particular by a theorem proved by Wang in 1992:
- for each material continuous function g, which is defined on the compact U, and for an random ε>0, there exists a fuzzy system that forms the original function *f(x)* such that: $\sup_{x \in U} \| g(x) - f(x) \| \leq \varepsilon$
- universality: according to the Fuzzy Approximation Theorem, which was proved by B. Kosko in 1993, any mathematical system can be approximated by a system based on fuzzy logic;

Note that the disadvantages of the considered hybrid systems are the following: the ascending set of fuzzy rules is formulated by a human expert and may be incomplete or contain contradictions; the type and parameters of the membership function describing the input and output variables of the system are chosen subjectively and may not adequately reflect the surrounding reality.

One of the aspects of the above and an important scientific and practical task in current economic conditions (crisis in the field of energy supply and high prices for energy resources) is the holding of objective, effective and fair tenders and flexible controlling of tender contracts as one of the necessary factors for ensuring investment and logistics activity of oil&gas production companies in Eastern Europe.

Thus, the task is to determine the business plan that most fully meets the objectives of the tender, and to choose the optimal solution. This will ensure the maximization of relevant production indicators, compliance with environmental requirements, the use of modern technologies and the development of the region's infrastructure. Experience shows that making such a complex decision in most sectors of the national economy requires the use of qualitative elements - vague goals and limitations, which is an insufficiently resolved aspect of the problem area under consideration. That is, the task is a multicriterial optimization system in fuzzy circumstances.

Two algorithm's/models developed by authors involves the hybrid application of knowledge-oriented technology and the theory of fuzzy sets to support the decision-making.

Therefore, the set task of the current research determines the selection of two levels of the problem:

- analysis and assessment of the proximity of the business plan to one global goal of the tender;
- the task of choosing from a set of business plans based on the criterion of proximity to the target area.

Therefore, the set task of the current research determines the selection of two levels of the task:

- analysis and assessment of the proximity of the business plan to one global goal of the tender;
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Therefore, some basic designations are:

k - business plan number in the competition ($k = 1, 2, ..., K$);

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$X = \{X_j\},\ j = (\overline{1, J})$ - set of global target parameters, where each parameter Xj is a linguistic variable.

For example, global evaluation parameters: X_1 - technological, X_2 - economic, X_3 – ecological.

Let the set of local ones be defined for the global parameter X_j:

$$X_j = \{X_i^j\}, i = (\overline{1, I}) \qquad (3).$$

For example, (for the oil and gas production industry):

X_1^1 – average volume of production;

X_1^2 – technological efficiency of the intensification method;

X_2^1 – economic efficiency of the recommended reservoir stimulation method;

X_2^2 – profit share for the benefit of the state;

X_2^3 – annual capital costs per 1,000 cubic meters of gas;

X_2^4 – total investments of the investor;

X_3^1 – general investments in environmental safety;

X_3^2 – investmens in the system of transportation and preparation of hydrocarbons.

An important and necessary stage of methodological preparation for the activities of the tender&controlling committee as such is the expert determination of linguistic variables (parameters of business plan evaluation) of both levels and their functions of affiliation.

Also, a critical stage of methodological preparation is the use of expert information for the purpose of forming a knowledge base for determining global parameters through local ones. This expert engineering knowledge is conditionally permanent and changes little in tenders. For example, (for the oil and gas industry):

IF average volume of production = "high" AND technological efficiency of the intensification method = "high" THEN business plan = "high-tech";

IF the average production volume = "low" AND the technological efficiency of the intensification method = "low" THEN the business plan = "low technological".

On the basis of the conducted research on the possibility of applying fuzzy logic in the problem formulation under consideration, we will use the elements of the fuzzy algorithm of Larsen's logical conclusion.

So, the first algorithm based on economic-mathematical modeling with elements of fuzzy knowledge to support decision-making of the tender and controlling committee was proposed for the first time:

Membership functions defined on local variables *Xij*,

1) The membership functions defined on the local variables X_i^j, are applied to the actual values of the local indicators from the business project.

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$$X^{ijt}(y_0^{ijk}), \quad i=(1,2,...,I), \quad t=(1,2,...,T), \tag{4}$$

where:

$t=[1, 2, ..., T]$ – is the term set of the linguistic variable $X^{i,j}$;

X^{ijt} – application of the membership function of the linguistic variable of the local parameter i of the global parameter j on the value t of the term set;

y_0^{ijk} – input parameter of the i -th local j -th global indicator of the k -th business plan.

2) The calculated values are applied to the conclusions for each rule (which formalizes the extent to which the local parameters belong to the global parameter) and the coefficients are determined (an example for two rules):

$$\alpha_{rule\,1}^{jk} = X^{i=1,j,t=1}(y_o^{i=1,j,k}) \wedge X^{j,i=2,t=1}(y_o^{i=2,j,k}),$$
$$\alpha_{rule\,2}^{jk} = X^{j,i=1,t=2}(y_o^{i=1,j,k}) \wedge X^{j,i=2,t=2}(y_o^{i=2,j,k}), \tag{5}$$

where:

α^{jk}rule 1 is the coefficient – the result of applying rule 1.

Further, using these coefficients and the composition operation for each rule, we obtain fuzzy sets:

$$\alpha_{rule1}^{jk} \times X^{j,\,t=1}(y_\Sigma^{jk}),$$
$$\alpha_{rule2}^{jk} \times X^{j,\,t=2}(y_\Sigma^{jk}), \tag{6}$$

where: y_Σ^{jk} - is an argument – partial resulting fuzzy set of the global parameter j, k-th business plan, the result of applying the rule;

3) All fuzzy subsets assigned to each output variable (in all rules) are combined together to form one fuzzy subset by the "Max Combination" method for each global linguistic parameter variable Xj of tender k:

$$X^{jk}(y_\Sigma^{j}) = (\alpha_{rule2}^{jk} X^{j,\,t=2}(y_\Sigma^{j})) \vee (\alpha_{rule1}^{jk} \times X^{j,\,t=1}(y_\Sigma^{j})) \tag{7}$$

4) Reduction to the clarity of the final membership functions of global parameters by the centroid method:

$$\alpha_\Sigma^{kj} = \int_\Omega y_\Sigma^{jk} \cdot X^{jk}(y_\Sigma^{jk}) \Big/ \int_\Omega X^{jk}(y_\Sigma^{jk}), \tag{8}$$

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where:

α_{Σ}^{kj} - is a clear assessment of the global parameter *j* of the *k*-th business plan.

5) Since the importance of the global tender criteria is a variable value determined by the tender committee in each specific case, it is advisable to use the method of weighting coefficients to the obtained estimates of the global parameters in order to calculate the final assessment of the business plan:

$$\alpha_{\Sigma}^{k} = \sum_{j=1}^{J} v^{j} \alpha_{\Sigma}^{jk},$$

$$\sum_{j=1}^{J} v^{j} = 1, \tag{9}$$

where:

- α_{Σ}^{k} is the clear weighted assessment of the optimality of the *k*-th business plan;

v^j – is the weight of the global parameter *j* according to the terms of the tender.

The optimal of the proposed business plans is determined according to the following criterion:

$$\max \alpha_{\Sigma}^{k}, \; k = 1, 2, \ldots, K.$$

It is worth noting that the algorithm proposed above has received practical approval at enterprises of the oil and gas production industry of Ukraine.

The second fuzzy economic-mathematical model for effective investment management of an oil and gas company was also developed for the first time (using Data Science methods) and proposed by the authors - the cost of conducting exploration works is proposed to be determined according to the following formula:

$$V_{seis} = V_{dog}^{seis}\left(1 + 0{,}05 \times \left(KS_{prkilf} + KS_{prqf}\right)\right) \times D_{qual}^{seis}, \tag{10}$$

where:

V_{seis} - the cost of exploration works;

V_{dog}^{seis} - basic cost of exploration works;

KS_{prkilf} - tracking coefficient of the number of horizons;

KS_{prqf} - average coefficient of horizon tracking;

D_{qual}^{seis} - fuzzy "penalty-incentive" coefficient of the quality of performed exploration works (Figure 1).

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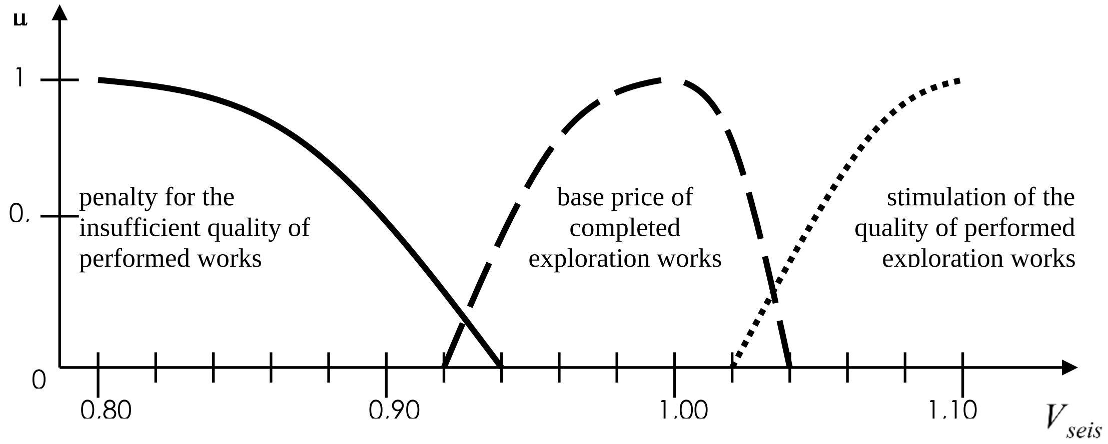

Figure 1. Membership functions of the target linguistic variable "penalty-incentive" coefficient of the quality of performed exploration works for oil and gas"

When calculating the fuzzy "penalty-incentive" coefficient for the quality of performed exploration works, fuzzy rules (Appendix B) are used, which operate on the following technological assessments: the probability of the existence of a hydrocarbon trap screen, compliance with the work deadline, and the quality of the geological task.

DISCUSSION

Advantages of using in the field of oil&gas investment projects the above proposed knowledge-oriented approach and models, based on fuzzy inference:

- different dimensions of global and local parameters do not play a role;
- the direction of optimization of the parameter (max or min) is not important, as the algorithm maximizes the degree of belonging to an exemplary fuzzy set.

Therefore, knowledge-oriented decision support systems should not be used if: the required result can be obtained in another (standard) way; an adequate and easily researched mathematical model has already been found for the object or process.

It is worth using the considered systems in the following cases: if expert knowledge can be formulated mainly in linguistic form; for complex processes in the absence of a simple mathematical model.

CONCLUSION

Therefore, in this paper there are following results: first proposed the decision tree diagram (appendix A) of the effective investment management process of a oil and gas company in the exploration for hydrocarbons in current economic and geological conditions; received further development of the principles of hybrid application of intelligent technologies (Krasnyuk et al., 2020) and knowledge-oriented basis and the problem of handling uncertainty while supporting investment decisions of an oil and gas company; first proposed two related prognostic models are proposed: the seismic impact model and a drilling impact model; first proposed

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two algorithms based on economic-mathematical modeling with elements of production rules to support decision-making of the tender&controling committee of oil&gas production company.

On the basis of the above, it is possible to conclude about the need to use a fuzzy knowledge-oriented investment decision support for oil and gas production projects in Ukraine and other countries of Eastern Europe.

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All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy issues.

Conflict of interests

The authors declare no conflict of interest.

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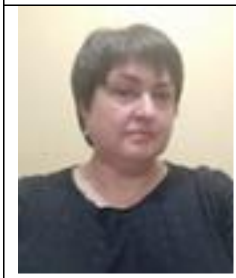
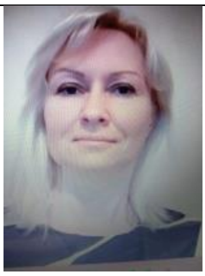
	**Svitlana GONCHARENKO**, senior lecturer in Kyiv National University of Technologies and Design, Kyiv, Ukraine. **Research interests:** FinTech, technical and business translation, technical and business English teaching, methods of educational process optimization. **ORCID ID:** https://orcid.org/0000-0002-7740-4658
	**Svitlana KRASNIUK**, senior lecturer in Kyiv National University of Technologies and Design, Kyiv, Ukraine. **Research interests:** EdTech, modern methods of teaching foreign languages of professional orientation, the use of advanced technologies in the teaching of foreign languages, modern management technologies in education and in social sphere. **ORCID ID:** https://orcid.org/0000-0002-5987-8681

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APPENDIX A

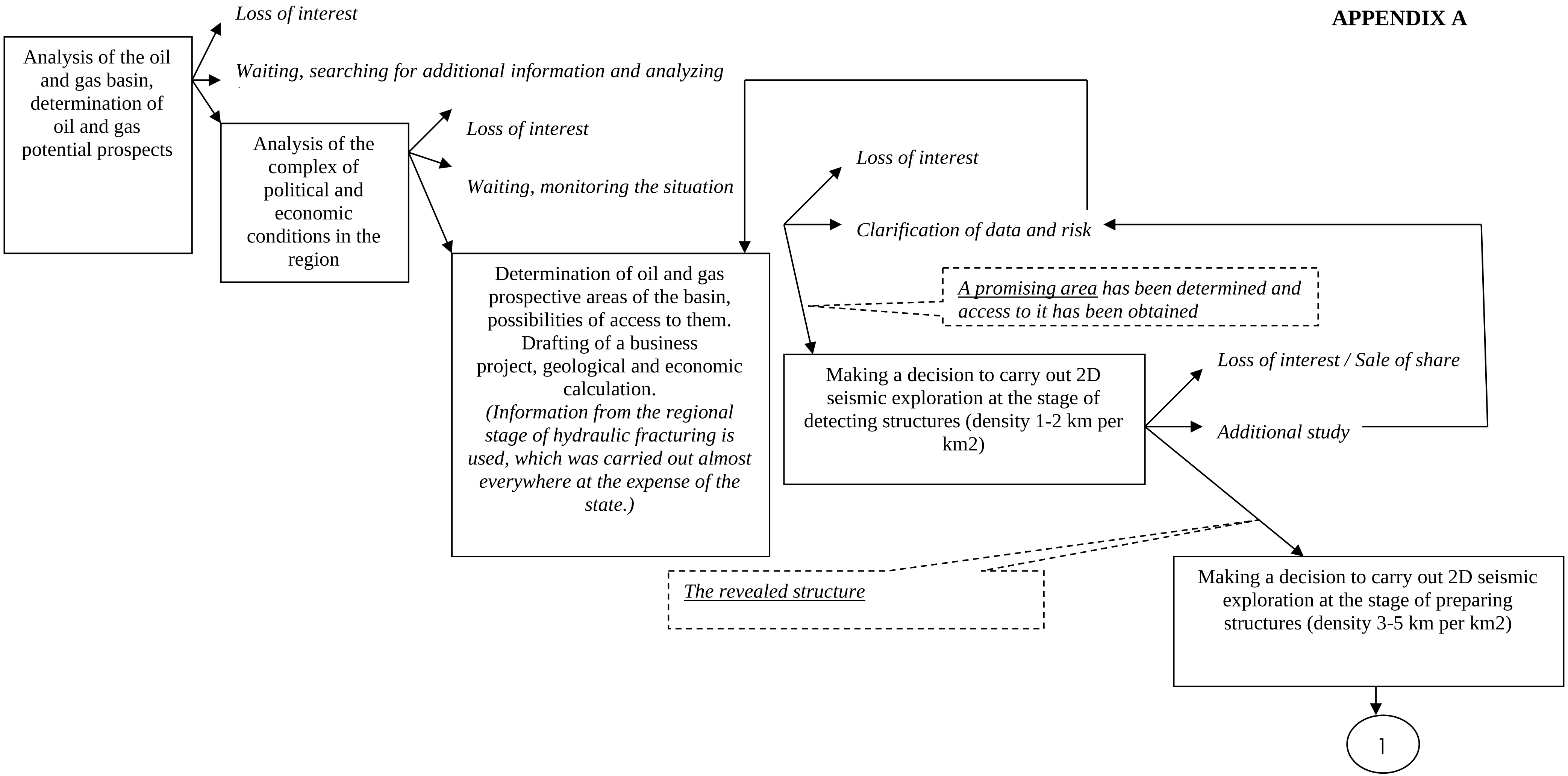

Figure 2, sheet 1. Decision tree of the oil and gas company's investment management process in the search for hydrocarbons

Source: Developed by Author's

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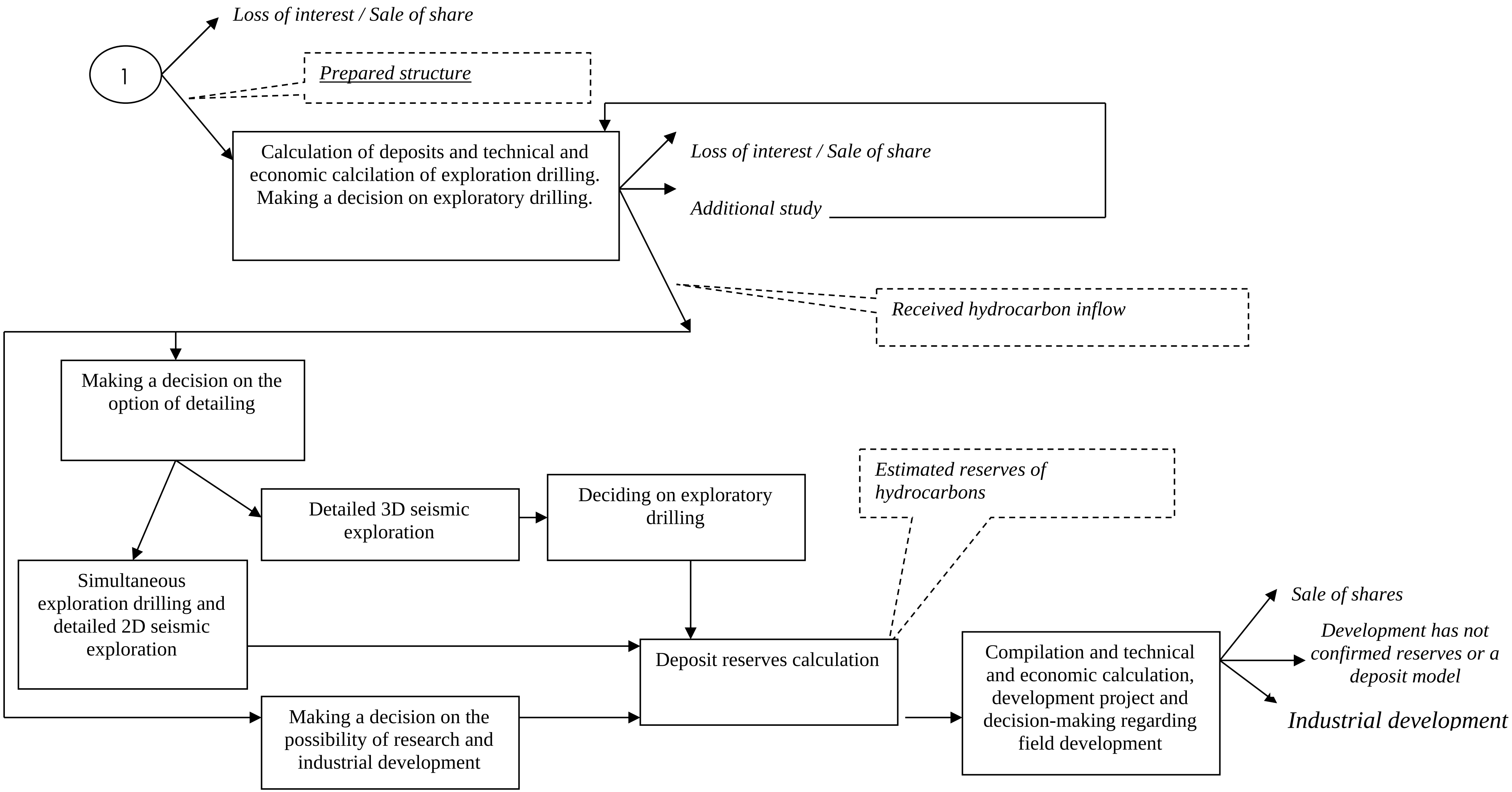

Figure 2, sheet 2. Decision tree of the oil and gas company's investment management process in the search for hydrocarbons

Source: Developed by Author's

APPENDIX B

Fragment of production rules base for determining the "penalty-incentive" coefficient the quality of oil and gas exploration

Rule 1: IF compliance with the deadline for oil and gas drilling works = timely execution of drilling works AND execution of the OG for oil and gas drilling works = excellent execution of the OG for drilling works THEN the "penalty-incentive" coefficient for the quality of the performed oil and gas drilling works = stimulation of the quality of performed drilling works.

Rule 2: IF meeting the deadline for oil and gas drilling works = timely execution of drilling works AND execution of OG for oil and gas drilling works = excellent execution of OG for drilling works THEN the coefficient of "penalization-incentive" for the quality of the performed oil and gas drilling works = stimulation of the quality of performed drilling works.

Rule 3: IF compliance with the deadline for oil and gas drilling works = delay in drilling works AND execution of the GZ for oil and gas drilling works = satisfactory execution of the GZ for drilling works THEN the "penalty-incentive" coefficient for the quality of the performed oil and gas drilling works = penalty for insufficient quality of the performed drilling works

Rule 4: IF compliance with the deadline for oil and gas drilling works = timely execution of drilling works AND execution of the OG for oil and gas drilling work = satisfactory execution of the OG for drilling work THEN the "penalty-incentive" coefficient for the quality of the performed oil and gas drilling work = penalty for insufficient quality of the performed drilling works

Rule 5: IF compliance with the deadline for oil and gas drilling works = delay in drilling works AND execution of the GZ for oil and gas drilling works = excellent execution of the GZ for drilling works THEN the "penalty-incentive" coefficient for the quality of the performed oil and gas drilling works = base price of completed drilling works

Rule 6: IF meeting the deadline for oil and gas drilling works = timely completion of drilling works AND execution of the OG for oil and gas drilling works = satisfactory execution of the OG for drilling works THEN the "penalty-incentive" coefficient for the quality of the performed oil and gas drilling works = base price of completed drilling works

Rule 7: IF compliance with the deadline for oil and gas drilling works = timely completion of drilling works AND execution of the OG for oil and gas drilling work = good execution of the OG for drilling work THEN the "penalty-incentive" coefficient for the quality of the performed oil and gas drilling work = base price of completed drilling works

Rule 8: IF compliance with the deadline for oil and gas drilling works = timely execution of drilling works AND execution of the OG for oil and gas drilling work = good execution of the OG for drilling work THEN the "penalty-incentive" coefficient for the quality of the performed oil and gas drilling works = base price of completed drilling works

Rule 9: IF compliance with the deadline for oil and gas drilling works = delay in the execution of drilling works AND execution of the GZ for drilling works for oil and gas = good execution of the GZ for drilling works THEN the "penalty-incentive" coefficient for the quality of the completed oil and gas drilling works = base price of completed drilling works