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Principles of Risk Management in Ensuring Balanced Development and Competitiveness of Knowledge-Intensive Industrial Holdings

Principios de la gestión de riesgos para garantizar el desarrollo equilibrado y la competitividad de las tenencias industriales intensivas en conocimiento

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ABSTRACT:
The paper proposes the main principles of risk management for ensuring balanced development and competitiveness of knowledge-intensive industrial holdings. A dynamic model of knowledge-intensive production considering risks is built for a holding comprising several enterprises. The management criteria for the proposed model are formalised by the methods of decision-making theory and optimisation theory.
Keywords: risk management, balanced development, competitiveness of a holding, risks, knowledge-intensive industry

RESUMEN:
El documento propone los principios fundamentales de la gestión de riesgos para garantizar el desarrollo equilibrado y la competitividad de las explotaciones industriales intensivas en conocimiento. Se construye un modelo dinámico de producción intensiva en conocimiento considerando los riesgos para una explotación que comprende varias empresas. Los criterios de gestión para el modelo propuesto se formalizan mediante los métodos de la teoría de la toma de decisiones y la teoría de la optimización.
Palabras clave: gestión de riesgos, desarrollo equilibrado, competitividad de una explotación, riesgos, industria intensiva en conocimiento.

1. Introduction

Forming a risk management system should be approached as a complex process involving the identification and assessment of risks and their main driving factors, as well as their active influence, to bring down their hazard levels. Major approaches to the risk management problem are described in Chursin et al., (2016b); Egorova, (2011); Chursin and Mechar, (2009); Chursin et al., (2016a). Enterprise management, including aspects related to risks, is addressed in Kalmakova, (2014); Koverga, (2014); Chursin and Mechar, (2009). The application of a balanced management system is described in Krasnikova, (2015; Timoshenko, (2018). Based on the nature of the occurrence and the level of manageability, risks can be grouped into two major classes, namely, internal and external risks. The impact of external risks is usually experienced by the whole holding, while internal risks are mostly experienced by particular enterprises. Internal risks are subdivided as internal risks of enterprises and external risks of enterprises, which are, at the same time, internal risks at the holding level. *Enterprise-level internal risks* include:

- Project risks (risks of error occurrence in project research or project documentation);
- Technical risks (risks of erroneous technical solutions and incorrect application of technical devices);
- Technological risks (risks of application of non-proven technology and methods, non-compliance with established standards and rules);
- Organisational risks (risks of planning errors, inefficient coordination, etc.);
- Financial risks (risks of budget overruns due to incorrect estimates, missed deadlines, errors of performers);
- Legal risks (risks of losses due to non-compliance with current law);
- Human factor risks (illnesses or malpractices of staff), etc.

The next group is *internal risks for the holding but external for the enterprises*. In respect of an enterprise, these primarily include risks related to the competition:

- a competitor adopts a new product;
- a competitor cuts product costs through lower component prices or lower labour spending, or both;
- a competitor attracts additional investment through new production positioning;
- a competitor changes the impact of one or more competitive parameters through marketing activities.

Internal risks for a holding include risks related to holding management:

- Organisational risks (risks of planning errors, inefficient coordination, etc.);
- Financial risks (risks of budget overruns due to incorrect estimates, missed deadlines, errors of performers);
- Legal risks (risks of losses due to non-compliance with current law);
- Human factor risks;
- Social risks (risks related to the divergence of the interests of various social groups and the growth of social activity of population).

Next, we shall define the main classes of *external risks*. For better visibility of designating this group of risks as external risks, here are some examples of responses to the possibility of occurrence (or actual occurrence) of a risk situation (Table 1).

Table 1
Major classes of external risks

Classification of risks	**Description of risks**	**Methods of management**
Natural risks	Risks related to natural or social phenomena (force majeure)	Such risks are not manageable to the extent they cannot be averted. They may be partially manageable, though, as their consequences and the resulting damage can be mitigated via preventive measures
Political and geopolitical risks	Risk related to unstable policies of authorities, changes of the global and political situation and legislation governing foreign economic relations	Such risks are only manageable at the macro level, while management at the holding level should involve analysis and monitoring of such risks to mitigate potential damage in case they materialise

Social risks	Risks related to the divergence of interests between social groups and the growth of social activity of the population	Management involves the substantiation of the social dimensions of the project and effective PR campaigns, as well as focused targeted motivation of labour resources
Economic risks	Risks related to the government's economic policy; financial risks arising from crises of the monetary system, inflation; currency risks due to changing exchange rates	Such risks are only manageable at the macro level, while management at the holding level should involve analysis and monitoring of such risks to mitigate potential damage in case they materialise
Legal risks	Risks of losses due to deficiencies of applicable statutory requirements	Management at the holding level involves monitoring the sound legal operation of the holding and the constituent enterprises, initiation of improvements in the legislative field

This is an approximate classification since risk management, in most cases, is handled on three levels, namely, by the state, industry (corporation, holding) and enterprise.

Among the main goals of risk management, the following dimensions may be emphasized: maintaining (or increasing) the overall output of the holding; building competitive advantages for the holding's enterprises; market expansion; increasing the share of knowledge-intensive products, etc. That said, the main risk affecting performance on each of the goals and pertaining partially to each of the identified classes of risks is the competitiveness risk.

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2. Methods

The problem of managing risks and competitiveness of knowledge-intensive holdings is a multicriteria decision-making problem referring to wide-ranging information and various types of objects, including cases of incomplete information. The methodology of the *systems analysis* is used to analyse such complex systems. The application of the systems analysis is meant to provide better rationalisation of a decision and expand the range of alternatives while simultaneously establishing the methods to identify inferior decisions (i.e., simultaneous restriction of choice).

A system consists of *elements* and *relations* between them. The simplest types of relations are sequential, parallel, and inverse relations. Discerning a system as a group of elements and relations between them determines the *system structure*. The simplest structure is a tree structure comprising chains of sequential arrangements; it particularly represents clear hierarchical levels.

The following principles of the systems approach should apply in complex systems analysis methods:

- the principle of the ultimate goal: absolute priority is attached to the ultimate goal;
- the principle of unity: the system is approached as a whole and a combination of its constituents;
- the principle of coherence: each constituent part is considered in combination with its relations with the surrounding elements;
- the principle of modular structure: approaching the system as a combination of modules, i.e., representation of the system in parts larger than its individual nodes;
- the principle of hierarchy: ranking elements, rendering the system as a tree structure;
- the functionality principle: simultaneous analysis of the structure and the function prioritising the latter;
- the development principle: taking into account changes of the system;
- the decentralisation principle: combining centralisation and decentralisation in management and decision-making;
- the uncertainty principle: taking into account uncertainties and casual events in the system.

The hardware implementation of the systems analysis for our object will be the development of a model as a map of procedures (submodels and operations with submodels) and relations between them. The procedures can be classified as formalised and non-formalised. Formalised procedures are studied by the methods of applied mathematics (mathematical modelling), while non-formalised models correspond to the instances of human factor coming into decision-making (e.g., an expert opinion).

The following constituent parts should be considered in building a mathematical model:

- management object (objects),
- boundaries of the analysed system,
- managing variables,
- management goals,
- system controllability,
- efficiency evaluation.

We shall reiterate that the general goals are as follows: maintaining (or increasing) the overall output of the holding; building competitive advantages for the holding's enterprises; market expansion; increasing the share of knowledge-intensive products. These goals can be formalised by adding their respective quantitative values as the indicators of production of the holding and determining, based on their relations, the specific competitiveness coefficients. Accordingly, the main management object in the problem is the competitiveness of the holding, and the first (primary) group of managed variables is the special coefficients of competitiveness determined based on production indicators. Now, we shall build a dynamic model of knowledge-intensive production of a holding comprising N enterprises.

Assume there are N competing enterprises. Let $u_i = u_i(t) \ \ (i = 1,\ldots,N)$ denote investment in innovation at i-th enterprise at time t, and $p_i = p_i(t) \ \ (i = 1,\ldots,N)$, the innovation of i-th enterprise. As can be logically suggested, innovation will comprise new technical solutions and improve the competitiveness of the products. We shall assume

$$p_i(t) = f_i\left(u_i(t)\right) \quad (i = 1,\ldots,N), \tag{1.1}$$

where $f_i : \mathbb{R} \to \mathbb{R}$ is a monotonic increasing odd function. In particular, in the simplest case, it can be assumed that $f_i(u) = a_i u$, where $a_i > 0$ are constants.

Note that each enterprise is not aware of the investment of its competitor, as long as it constitutes a trade secret. However, this report will not require specific investment information on competitor enterprises or other indicators pertaining to trade secrets. Our aim is a qualitative study of the system of nonlinear ordinary differential equations derived below and, particularly, the analysis of influences on the holding development trends.

Let $x_{i1j} = x_{i1j}(t) \ \ (j = 1,\ldots,J_1)$ denote the production indicators of i-th enterprise, for which their increase is associated with improvements in competitiveness. Such indicators may include, for instance, product quality, labour productivity, etc. Let $x_{i2j} = x_{i2j}(t) \ \ (j = 1,\ldots,J_2)$ denote the production indicators of i-th enterprise, for which their decrease is associated with improvements in productivity $(i = 1,\ldots,N)$. Such an indicator may be product costs. The coefficients of competitiveness for j-th production indicator for i-th enterprise, for which their growth promotes the improvement of competitiveness, is determined according to the equation:

$$K_{i1j}(x(t)) = \frac{x_{i1j}(t)}{M_j(t)} \qquad (i = 1,\ldots,N; j = 1,\ldots,J_1), \tag{1.2}$$

where $M_j(t) = \max\limits_i x_{i1j}, \qquad x(t) = \left\{x_{ilj}(t)\right\}, \qquad (l = 1,2),$ (1.3)

See Chursin et al., (2016b).

The coefficient of competitiveness for j-th production indicator for i-th enterprise, for which its decrease promotes the improvement of competitiveness, is determined according to the equation:

$$K_{i2j}(x(t)) = \frac{M_j(t)}{x_{i2j}(t)} \qquad (i = 1,\ldots,N; j = 1,\ldots,J_2), \tag{1.4}$$

where $m_j(t) = \min\limits_i x_{i2j}$. (1.5)

The coefficient of competitiveness of i-th enterprise for the analysed product type is determined as follows:

$$K_i\left(x(t)\right) = \sum_{l=1,2} \sum_{j=1}^{J_l} \alpha_{ilj} K_{ilj}\left(x(t)\right), \tag{1.6}$$

where $\alpha_{ilj} > 0$ are weight coefficients, $\sum\limits_{l,j} \alpha_{ilj} = 1$.

These relations show that the second class of managed variables are production indicators. Let us formalise the relations for such variables.

Assume the pace of change for the first group of production indicators $x_{i1j}(t)$ is proportional to innovation at a specific constant coefficient $b_{i1j} > 0$, i.e.,

$$\frac{dx_{i1j}(t)}{dt} = b_{i1j} p_i(t) \qquad (i = 1,\ldots,N, \ j = 1,\ldots,J_1), \tag{1.7}$$

For the second group of production indicators $x_{i2j}(t)$, it can be logically assumed that their pace of change is proportional to innovation with constant coefficients $-\ b_{i2j} < 0$, i.e.,

$$\frac{dx_{i2j}(t)}{dt} = -\ b_{i2j} p_i(t) \qquad (i = 1,\ldots,N, \ j = 1,\ldots,J_2), \tag{1.8}$$

Apparently, investment $u_i(t)$ depends on the coefficients of competitiveness of the products $K_i(t)$. It is logical to suggest that investment $K_i(t)$ is made into innovation development only if the coefficient of competitiveness $K_i(t)$ is above some threshold value $c_i > 0$ and investment is proportional to $K_i(t) - c_i$ with a constant coefficient $d_i > 0$, i.e.,

$$u_i(t) = d_i\left(K_i(t) - c_i\right), \qquad (3.1.8)$$

In the case of $K_i(t) < c_i$, negative investment corresponds to enterprise spending out of internal reserves to sustain innovation activities.

Relations (1.1) – (1.7) produce a system $N(J_1 + J_2)$ of nonlinear ordinary differential equations describing a dynamic model of change of production indicators x_{ilj} $(i = 1,\ldots,N,\ l = 1,2,\ j = 1,\ldots,J_l)$.

$$\frac{dx_{ilj}(t)}{dt} = (-1)^{l+1} r_{ilj} f_i\left(K_i\left(x(t)\right) - c_i\right) \qquad \left(i = 1,\ldots,N, l = 1,2,\ j = 1,\ldots,J_l\right). \qquad (1.9)$$

Here, $r_{ilj} = b_{ilj} d_i$ and c_i are positive constants.

Note also that product competitiveness is influenced by some internal and external factors: equipment at the enterprise, energy costs, costs and quality of raw materials, quality and timely delivery of components from suppliers, etc. Some of the mentioned factors can be felt even more profoundly during crises. Such factors can be added as parameters determining the coefficients of equations. Therefore,

$$r_{ilj} = r_{ilj}\left(g,h\right),\ \alpha_{ilj} = \alpha_{ilj}\left(g,h\right),\ c_i = c_i\left(g,h\right),$$

where $g = (g_1,\ldots,g_{N_1})$ is a vector of indicators corresponding to internal factors; $h = (h_1,\ldots,h_{N_2})$ is a vector of indicators corresponding to external factors. Besides, coefficients r_{ilj}, α_{ilj} and c_i can depend on time, which makes the system a time-varying system.

Note that the resulting model does not require that all enterprises of the holding have a similar set of production indicators. Where an indicator is unavailable for any of the enterprises, it can be included in the model as having a zero value. The second method of consideration is the analysis of aggregate production indicators, which allows to operate uniform data on the enterprises and bring down the dimension of the model.

The impact of risks on the system can be described with additional variables. Such modelling principle has two major drawbacks. Firstly, such variables are not manageable (fully manageable). Secondly, the introduction of such variables will considerably increase the dimension of the model. It is worth noting that production is characterised by a great number of indicators. An increase in the number of analysed variables will make the analytical or software implementation of the model more complicated. Moreover, given the probabilistic nature of risk situations, the introduction of risk variables will *considerably* increase the difficulty of analytical and numerical solution of the problem, particularly where such variables are added in the system multiplicatively. Here are some examples of risk manifestation and rendering them in the mathematical model:

1. Risks posed by competitors:

1.1. a competitor l (or competitors $l_1, l_2, \ldots$) adopt(s) new products, which change the production indicators and parameters; the risk may be modelled as disturbance of all parameters of the model f_l, b_{lzj}, d_l, c_l $\left(l \neq i, l \in \{1,\ldots,N\}; z = 1,2;\ j = 1,\ldots,J_z\right)$;

1.2. a competitor cuts product costs through lower component prices or lower labour spending, or both; the risk is modelled by disturbance of b_{lzj} $\left(l \neq i, l \in \{1,\ldots,N\}; z = 1,2;\ j = 1,\ldots,J_z\right)$;

1.3. a competitor has decreased the investment threshold; the risk is modelled by disturbance of c_l;

1.4. a competitor has changed the impact of one or more competitiveness parameters through marketing activities; the risk is modelled by disturbance of α_{izj} $\left(i = 1,\ldots,N;\ z = 1,2;\ j = 1,\ldots,J_z\right)$.

2. Internal enterprise risks:

2.1. application of labour incentives or technical refurbishment of production have led to the higher efficiency of investment utilisation; the risk is modelled by positive disturbance of $f_i\left(i \in \{1,\ldots,N\}\right)$;

2.2. labour policy drawbacks have led to lower efficiency of investment utilisation, longer equipment downtime and other disruptions of the technological cycle; the risk is modelled by negative disturbance of $f_i\left(i Œ\{1,\ldots,N\}\right)$ and disturbances in b_{izj} $\left(i Œ\{1,\ldots,N\}; z=1,2;\ j=1,\ldots,J_z\right)$;

2.3. negligence has caused damage to the equipment; the risk is modelled by disturbance of the functions f_i $\left(i Œ\{1,\ldots,N\}\right)$ or the corresponding production indicator.

3. External risks:

3.1. *Natural risks*: natural conditions have led to a disruption in technological cycles; the risk is modelled by disturbance of b_{izj} $\left(i=1,\ldots,N;\ z=1,2;\ j=1,\ldots,J_z\right)$.

3.2. *Political and geopolitical risks*:

1) production costs have changed in the wake of changes in taxation; the risk is modelled by disturbance of $b_{izj}\ (i=1,\ldots,N,\ z=1,2,\ j=1,\ldots,J_z)$;

2) production costs have changed in the wake of changes in customs duties; the risk is modelled by disturbance of b_{izj} $(i=1,\ldots,N,\ z=1,2,\ j=1,\ldots,J_z)$;

3) changed international outlook has affected the markets of the products; the risk is modelled by disturbance of b_{izj} and a_{izj} $(i=1,\ldots,N,\ z=1,2,\ j=1,\ldots,J_z)$;

4) changes in the political and economic outlook (or possibly international situation) have helped attract new investors; the risk is modelled by disturbance of d_i and c_i $(i=1,\ldots,N)$.

3.3. *Social risks*: social and political situation has led to a change in the quantitative or qualitative profile of labour resources; the risk is modelled by disturbance of functions f_i $(i=1,\ldots,N)$ or disturbance of the indicator 'labour resources'.

3.4. *Economic risks*: product costs have changed as a result of changed tariffs (e.g., energy tariffs); the risk is modelled by disturbance of b_{izj} $\left(i=1,\ldots,N;\ z=1,2;\ j=1,\ldots,J_z\right)$.

3.5. *Legal risks*:

1) changes of legislation have led to changed business rules; depending on the structure of changes, the risk can be modelled by disturbance of one or more parameters of the system and disturbance of production indicators.

These examples demonstrate that a majority of risk cases occur in steps or impulses. Step impact here refers to the cases when the system shifts to a new level as a result of risk occurrence nearly immediately; meanwhile, impulse impact usually occurs as a short-lived disturbance that will not normally change the system parameters but will affect the production indicators in steps. Therefore, where possible, it may be practicable to consider sets of deterministic models rendering potential consequences of risk occurrences rather than the dynamics of stochastic processes.

The limitations on the number of variables set the first restriction on the applicability of the model. Also, the limits of consideration of the model are determined by the minimum and maximum levels of competitiveness, risks, production indicators derived from heuristic data before building the model and may be refined along the way during implementation.

3. Results and Discussion

Managing holding development may rely on tangible or intangible production stimuli. Such stimuli may include both direct investment (either in funds or labour resources), legislative initiatives (tax deductions, customs duties), social and moral incentives for the staff, etc. Direct investment can be a convenient management variable (deliberate management). Other stimulation measures create staged or impulse impact; therefore they are best addressed as the system parameters. However, in situations when such stimulation methods are fundamental, they should be added as management variables and the methods of impulse management should be applied to the model.

The notion of system manageability implies the possibility of bringing the system from its initial state to the preset state within a finite amount of time. Studying this issue as part of risk management modelling for balanced development of a holding to ensure its competitiveness will help to determine the limitations of the model applicability (probably as rough approximations). The presence of unmanageable stochastic variables means the model will not be fully manageable. Model stabilization limits and non-stabilizable factors need to be determined. For a risk management model, special focus is warranted on the following aspects:

1) time required to attain a specific level of competitiveness (time constraints for the holding are often determined by global technological progress; it is particularly important for a country with several industries lagging behind by the level of development of scientific and technological base compared to global averages);

2) maximum achievable production indicator levels and coefficients of competitiveness (representing the boundaries of holding development for a fixed time period);

3) fluctuation range for the coefficients of competitiveness (big downside amplitude changes may lead to a bankruptcy of an enterprise of the holding, meanwhile a wide amplitude range itself may signal of the inconsistency of the model with the actual situation);

4) potential risk amplitude (a narrow risk amplitude not only simplifies the numerical implementation of the model but also corresponds to a more attractive production profile for investors).

The model for managing risks and competitiveness was predetermined as a multicriteria one. Building the management criteria for the proposed model is based on the management objectives and formalised by the methods of decision-making and optimisation theory. The proposed basic mathematical management criteria may include the following:

1. maintaining the achieved level or ensuring the attainment of the set production levels over a fixed time period;
2. determining minimum investment to enable the attainment of the set production levels;
3. determining the schedule and allocation of investment to minimize risks and attain the set production level;
4. determining investment attractiveness trends of the holding and extra-budgetary money raising, etc.

A gauge to evaluate the quality of management will be the quality of compliance with a specific criterion or a weighted total of the quality of attainment of management criteria; the weights should be assigned by expert opinion based on the level of significance. For setting the functional profile of a management optimisation problem for the holding, a criterion should be identified, which should contain a weighted characteristic including the estimate of the total output of the holding, the percentage of knowledge-intensive production, the minimum required production volumes of certain product types, etc.

The building of functionals to determine such measures and the methods of finding optimum solutions for such functionals are studied in the optimisation theory and the optimal control theory.

The problems of finding optimum solutions can be classified depending on:

1. the dimension of variables: single- or multidimensional optimisation;
2. the essence of variables: decision-making under certainty or uncertainty;
3. the type of the target functionals: linear and nonlinear; among the latter, quadratic and convex and continuous (lower hemicontinuous) nonlinear functionals are often distinguished;
4. the dimension of the target functionals: single-purpose decision-making and multipurpose decision-making.

Here is an example of a possible target function and its application. Let denote a target function, e.g., the total cost of the holding's output and , the minimum acceptable level of the output cost. If at the moment *t* the value is , the holding management should make decisions to bring down the thresholds of borrowed investment for the enterprises with declining production levels. This is attained primarily through the reduction of taxes for investors of such enterprises, the extension of loans on preferential terms, etc. Moreover, such a situation warrants measures for more efficient financing policy and developing innovation (increasing the coefficients and the derived) and improvement of innovation implementation in the production of knowledge-intensive products (increasing coefficients).

Given the multicriteria management approach and the presence of several diverse manageable variables, the model of managing risks and competitiveness will probably correspond to a multidimensional stochastic target function, which will probably be materially nonlinear due to the complexity of the constituent relations of the system. This leads to the need to structure the management process.

4. Conclusion

The creation of a mathematical model of risk management in a holding should be based on mapping a graph of managerial decision-making, with nodes representing the submodels of risk management and (or) competitiveness and procedures (operations) over such submodels. As long as the discussed complex system comprises all three types of the basic relationship patterns, its structure will not be a tree structure but will comprise complex cycles. The relations between the parts of the model will operate based on common shared data, which can represent the parameters of one submodel and the variables of another submodel. Stochastic components are rendered as quite simple submodels of a linear or quasi-linear type, with the requisite designation of the scope where such linearization holds.

The graph of the management model will include the nodes of non-formalised decision-making procedures. The higher the level of elaboration of the model, the less non-formalised procedures it contains. Complete elimination of non-formalised procedures is not practicable at the current level of computing technology. It comes with the nondeterministic and materially nonlinear nature of the model, which inevitably results in building a quite complicated computational process. Meanwhile, the identification of an optimum solution (optimum strategy) may come at a greater cost compared to the resulting benefit from the application of such a strategy in contrast to the benefit of a proximal strategy. The discontinuation of the computational process in the optimisation may be triggered either via an informal procedure (decision-making by the user in a computer dialogue) or via an automated procedure, in which case the formalisation of the discontinuation trigger is required by the application of an additional criterion.

Refining the parameters and values of the variables (both manageable and management variables) can be achieved by multiple repetition of the computer experiment until a near-threshold state is attained, or by overdetermination of the overall model, i.e., where specific data is considered in several independent models and the findings concerning the real condition of the system are derived through the comparison of thus produced results. The principle of overdetermination was developed in the system survivability theory; it allows to estimate and mitigate both the error of computational methods and the error of building the submodel itself.

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