Planning and Management Tasks of Innovation Projects in Production and Economic Systems

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Additional information is available at the end of the chapter

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Abstract

The chapter describes an approach for design and sufficient analysis of management and information models by implementing product innovation projects in production and economic systems (PESs). The obtained model and the set of parameters for project evaluation are unique and depend on the specific features of project, decision-maker preferences, and PES project. This chapter also broadly outlines criteria-based approaches to measure production risks and evaluate risks associated with PES planning. Embodied principles help to design specific simulation models and provide information support for sufficient decision-making in PES that was newly introduced at an enterprise and/or on the basis of available data systems.

Keywords: production planning, risk evaluation, simulation, model, innovation project, production and economic system, management, decision-making, algorithm, analysis

1. Introduction

The development of modern production and economics is generally based on newfound knowledge and scientific achievements that are integrated into technologies and products.

At the same time, companies are very responsive to any fluctuations in the market and consumer preferences. The situation on the market changes very rapidly, and the number of competitive products is vast. The companies have to launch new developments to catch up with modern trends, satisfy consumer preferences, and create new market segments. They should also bear in mind that product life time reduces as a result of increasing modifications and improvements in production and economic systems (PES). So, management sector that

deals with innovation projects, especially in small-scale companies, should always make decisions promptly and ensure high quality in their products. In real project and PES management, we encounter an increasing number of statistical data, lack of universal algorithms, and the sufficient software to operate them, and besides, there are problems for which the current solutions are insufficient. It is difficult to describe the relationship among projects, PES, and the environment; therefore, live data are essential for effective management in the decision-making process.

The problem of management decision-making in PES projects was initially taken up by Albert-Kalmes, as a problem of inventory and statistics in factories and commodity production; later on, Frederick Taylor and Henry Gantt laid the foundations for the methods of planning [1]. Mathematical calculations in this area are connected with system analysis (introduced by J. Von Neiman and L.V. Kantorovich [2]). Economical aspects are considered in this approach in terms of pricing, production planning, sequence scheduling, fixed price and time-and-materials cost, and procurement management. These aspects are dependent on market segmentation and internal structure of PES, well known as Wagner-Whitin algorithm that relates these aspects with market. The idea to integrate market selection and production planning was introduced in Ref. [3] and up till now, this problem has not been solved. It is NP-complete problem that can be solved only if we fix separate factors (in particular, Jean Tirole has successfully solved management task for markets segmentation).

In 1995, Pepall introduced Game theory [4] to describe duplicates and innovations; this theory considers the relationship among projects. Such an approach triggered change management. Today, this idea is used in innovation management in terms of agent simulation and forecasting.

In the 1950s, mathematical and algorithmic calculations helped experts work out methods of planning and management known as Just-in-time; this method still enjoys high popularity. Main achievements in the late 1960s are connected with the works of Oliver White, who suggested that production, supply, and sale departments can be considered altogether in automated industrial enterprises. In his publications and in the periodicals of American Production and Inventory Control Society (APICS), we can find the algorithms of planning, which are known today as MRP. In the 1970s, Eli Goldratt in Israel worked out the method OPT. The modification of the algorithms of planning MRP~II was considered as the final achievement of all these methods till the beginning of the 1980s. The idea of computer-based integrated production CIM appeared in the first part of the 1980s, due to the integration of flexible manufacturing and efficient management. The US Department of Defence introduced, in the 1980s, CALS methods to ensure that all operations with orders, production development and organization, supplies, and operation of military technique were efficiently managed and planned. In beginning of the 20th century, the ideas of intellectual enterprise were introduced [5]; at that time, multiagent systems that were developed to consider such factors as autonomy, external factors' dependency, flexibility, proactivity, social factor, and efficient intellectual management factor were not studied thoroughly enough to use them in complex information systems. In such an approach, it is difficult to ensure effective interaction among the parts of PES at an industrial enterprise. In particular, D.A. Novikov contributed greatly to the development of this area with his theory of active systems. This issue was also addressed by R.K.

Sah and J. Stiglitz who proved the necessity of building complex structures in collective decision-making, for instance in organizational hierarchies.

2. Mathematical formalization of innovation in production and economic systems

The development of conceptual bases in management and simulation plays a significant role in PES and project management as it converts knowledge from object perspective into action [6].

Yu.A. Zelenkov introduced tuple description of goals and current possibilities of PES projects:

$$\Psi\{U, A, R, \Theta, w(\cdot), v(\cdot), I, \Gamma\} \tag{1}$$

where $U = (U_A, U_I)$ —is the managerial vector, that includes institutional and information management; A—multiple actions to achieve goals; R—the set of action results; Θ— nvironmental indicators; $w(\cdot) : A \times \Theta \to R$—the action result dependent on action and environment; $v(\cdot)$—agent preferences assigned by utility function; I—the information possessed by the agent at the time of decision-making; Γ—goals.

Within project approach in PES, it is recommended to use general purpose tuple [7]:

$$\Psi\{U, A, R, \Theta, w(\cdot), v(\cdot), I, \Gamma, \varphi\}, \tag{2}$$

where $U = (U_F, U_B, U_P, U_V, U_C, U_S, U_A, U_I)$ —the managerial vector that incorporates the management of finances, production, products, implementation, sales, R&D, institutional, and information management; where $\varphi = (\varphi_1, \varphi_2, \ldots, \varphi_n)$ is the project vector, where $\varphi_i = \{P, T\}$, consequently, P—the vector of management parameters; T—the set of project resource needs, i—the project number.

Sufficient management [8] requires formalized description of tuple parts (resulting in a lower degree of ambiguity).

In management, we should take into account that project and system develop over time and affect multiple PES. Therefore, it makes sense to consider the models for different points of time, levels, management types, and project stages that lead to necessity to study project identification and define decision points.

Such a task can be illustrated by determining managerial vector parameters U [9], project groups (φ) or one project (φ_i) using indicators or efficiency evaluation indicator (P_{ij}, where j is the number of key project parameter i and management level (see **Figure 1**) depending on the tasks taken into consideration.

By the set of parameters, decision points can be defined by PES data (equipment service intervals and internal technology cycles, etc.), statistical data, or forecasting data that describe a project or projects (the parameters of sales volume and price change, etc., are presented by innovation curves), see **Figure 2**.
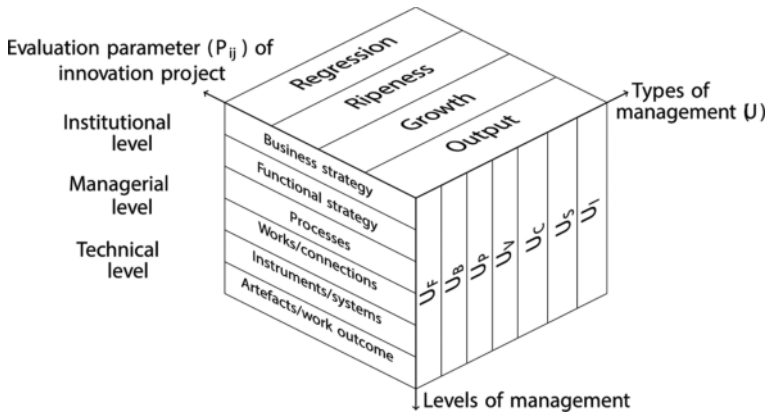
Figure 1. Scheme of current project state based on stages of project indicators, types, and levels of management.
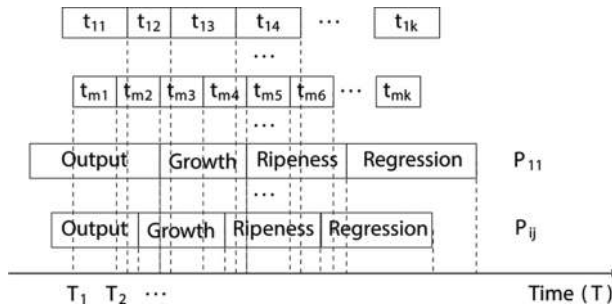

Figure 2. Decision points in PES projects.

As a result, each decision point will be given a model that altogether will form a tuple Ψ ($\psi_k \in \Psi$), where k is the number of decision points for the examined project or PES.

This way to form a tuple, Ψ helps to take into account not only new data that occur in time but also obtain cognitive knowledge, and experience about PES and projects accumulated upon models modification.

Hence, project time management can be reduced to tuples formalization ψ_k in form of models (see the structure of such models in **Figure 3**). Model structure comprises several subtasks to forecast project parameters and formalize optimization task in terms of mathematical programming.

Forecasting tasks and the description of time series are studied by many authors, and there are many methods to solve this problem (mathematical regression model, functional description of parameters by innovation, and S-curves).

For mathematical formalization, we can refer to the scheme illustrated in the **Figure 4**.
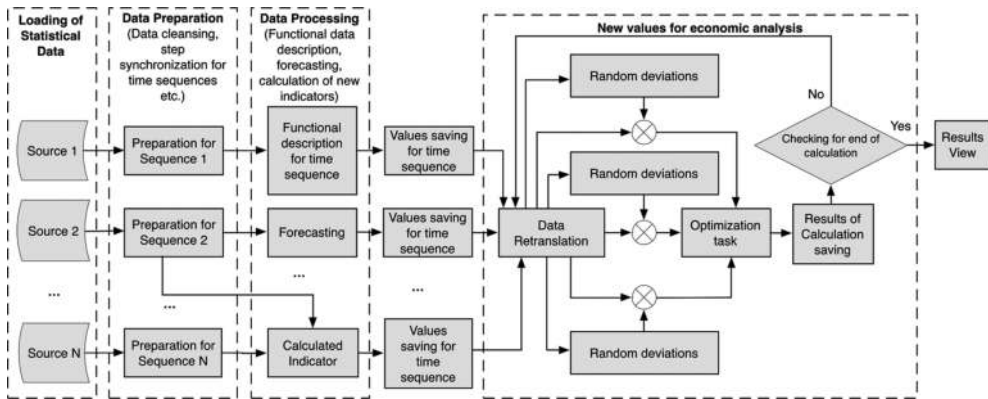
Figure 3. Project management process model at one of PES stages.

Formalization can be presented by selecting most efficient way to developing market segmentation when same project (a development way) can enter different markets (particularly, B2N, and B2C). This task has the following mathematical formula [10]:

$$\max_{1 \leq m \leq M, 1 \leq n \leq N} D_m(t) C_{nb}(t), \tag{3}$$

where $, a$—whole numbers, D_m—the market volume m, C_{nb}—the return from project production n in b PES. The market volume $D_m(t)$ is determined as a difference between the asymptote K and the market saturation $N_m(t)$ that is described by S-curve: $D_m(t) = K - m(t)$, and return is described as a difference between the sales price $Q_{nb}(t)$ and the production cost $Z_{nb}(t)$ of goods, n: $C_{nb}(t) = Q_{nb}(t) - Z_{nb}(t)$. Therefore, market segmentation problem will be written as follows:

$$\max_{1 \leq m \leq M, 1 \leq n \leq N} D_m(t)(Q_{nb}(t) - Z_{nb}(t)). \tag{4}$$

The selection of PES where this project will be implemented is another example (project can be transferred for implementation to existing PES or can be implemented independently by creating new legal entities). Based on PES tasks, we can deal with the task of return maximization from project implementation or handle the task of reducing production time. Therefore, we obtain two models.

First model is built for mitigating the production cost:

$$Z_{nb}(t) = \sum_{g=1}^{l_h} z_{nkg}(t) \rightarrow min, \ b = \overline{1, K} \tag{5}$$

where l_h—the number of operations in PES k for manufacturing goods n, z_{ngk}—the operation cost g in PES k by manufacturing goods n.
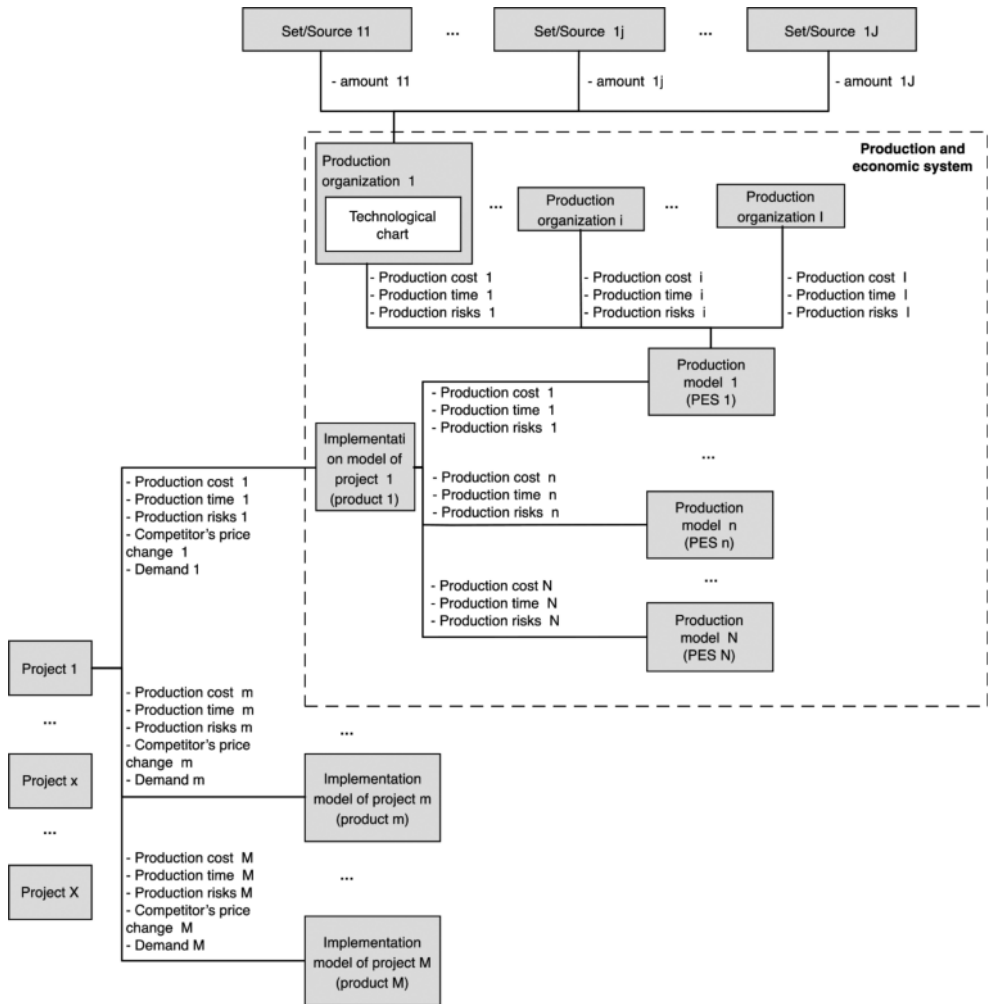
Figure 4. Optimization task structure in production planning.

Second model is designed for mitigating time required. We need to note that certain operations can be performed simultaneously (see **Figure 5**).

The model for mitigating the time required can be given as follows:

$$\sum_{d=1}^{v}\sum_{s=1}^{s_d} max \sum_{f=1}^{w_{de}} T_{z_{nkdef}} \rightarrow min, \qquad (6)$$

where d is the number of sequences of performed operations by manufacturing goods n in PES k, s—the number of parallel sequences in the consequence d, w_s—the number of operations in
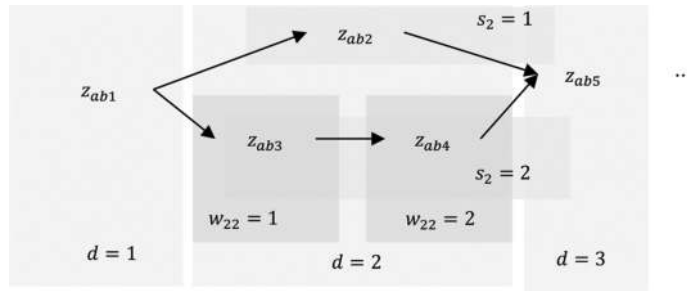
Figure 5. Example of operation sequences by project implementation in PES [10].

consequence, $T_{z_{nkdef}}$ —the time required to perform the operation z_{nkdef} in PES k by manufacturing goods n. To use this model, we need to refer to the rendition table between the margins g in Eq. (5) and $d, e,$ and f in Eq. (6).

In PES, project management is aimed at return optimization [11] via portfolio selection for goods. At the same time, not all the economically justified goods can be produced at each technological enterprise.

In order to cover these particular features, we need to give sound suggestions based on the set of criteria. For instance, criteria function and limitations will be given for volume scheduling of production planning as follows:

$$\sum_i \sum_l K_{il} \sum_t (C_l(t)x_l(t) + C_i(t)x_i(t)) \to \max$$

$$\sum_i \sum_t R_{ij}x_i(t) \leq P_j(t), \ j = \overline{1,M}$$

$$\sum_i \sum_t S_{ki}x_i(t) \leq T_k(t), \ k = \overline{1,K}$$

$$\sum_i \sum_t \alpha_i^q x_i(t) \leq G^q(t), \ q = \overline{1,Q} \tag{7}$$

$$\sum_l \sum_t R_{lj}x_l(t) \leq P_j(t), \ j = \overline{1,M}$$

$$\sum_l \sum_t S_{kl}x_l(t) \leq T_k(t), \ k = \overline{1,K}$$

$$\sum_l \sum_t \alpha_l^q x_l(t) \leq G^q(t), \ q = \overline{1,Q}$$

where K_{ih} —the ratio of conformity of goods i and h; x_i, $i = \overline{1,N}$ —the vector of unknowns, each component of which defines the number of released products of type i; C_i, $i = \overline{1,N}$ —the net income from production of i goods; R_{ij}, $j = \overline{1,M}, i = \overline{1,N}$ —the production technology cycle-based capacity need for each equipment type per unit of final product; P_j, $j = \overline{1,M}$ —the total

capacity resource for each type of machinery, obtained from data of calculated average productivity of all the equipment of this type; S_{ki}, $k = \overline{1,K}, i = \overline{1,N}$—the product specification-based need in key materials per unit of final product; T_k, $k = \overline{1,K}$—the storage and procurement planning-based volume of available key materials; $\alpha_i^q = \begin{cases} 1 - \text{if product } i \text{ belong to } q \\ 0 - \text{if product } i \text{ does not belong to } q \end{cases}$; G^q, $q = \overline{1,Q}$—market restrictions.

Otherwise, criteria function can be written the following way:

$$\sum_i \sum_l K_{il} \sum_t ((Q_{lb}(t) - Z_{lb}(t))C_l(t)x_l(t) + (Q_{ib}(t) - Z_{ib}(t))C_i(t)x_i(t)) \to \max \qquad (8)$$

by $n = h$ and $n = i$ models of market segmentation and portfolio formation can be merged, and we receive the task of optimal project distribution among PES.

$$\sum_i \sum_l K_{il} \sum_t \left(\left(Q_{lb}(t) - \sum_{g=1}^{l_{h_l}} z_{lbg}(t)\right)C_l(t)x_1(t) + (Q_{ib}(t) - \sum_{g=1}^{l_{h_i}} z_{ibg}(t))C_i(t)x_i(t))\right) \to \max \qquad (9)$$

The amount of costs $Z(t)$ not only demonstrates financial costs but also indicates costs for materials, parts, etc., excluding time required Eq. (6).

If it is necessary to consider these costs and the time required Eq. (6), we can complement the model with respective criteria of type Eq. (5).

The costs are specified by technological charts of product n in PES k. These charts are illustrated in **Table 1**.

Operation number	Operation name	Operation cost	Previous operations	Subsequent operations	Performance time	Need in parts	Need in materials	Need in equipment
⋮								
g	...	z_{vkg}	...	...	$T_{z_{nkdef}}$	...	S_{gv}	R_{gv}
⋮								

R_{gv}—the need in capacity of each type of equipment per unit of final product, S_{gv}—the need in key materials per unit of final product.

Table 1. Structure of technological chart.

Forecast data are used for market conditions. Therefore, value scheduling parameters are C_i and G^q that are determined by forecast data (in particular, curve-based forecasts [12]).

As a result, we receive a portfolio and product release schedule that stipulate the amount of expected return from one product and accumulated effect from a released group of products.

This way of formalization helps distinguish projects in terms of specific features of PES and expected change of market conditions or other critical project parameters that were used in criteria function.

However, we must emphasize that on each stage critical for the task to be tackled (time sequence is restricted by decision points), we might need multiple solution of the problem as a number of parameters is determined by forecast data, and the situation can be changed over the time.

Therefore, the problem can be solved by making a table with time function. Due to lack of analytical methods that can be used nowadays to solve obtained tasks, we suggest use multiple cyclic numerical solution with time period Δt to deal with this problem. This time sequence can be specified based on minimal time required for each enterprise in terms of production cycle or planning time.

Received solutions and time sequence selection can require additional research though, as we can encounter periodical change of production volume that leads to additional expenses for preparation and/or modification of production system.

Despite all the advantages of mathematical programming, in general, it is not easily solved (especially in case of multiple criteria). Such tasks are considered as NP-complete problems (for instance, for market segmentation task [3]). Due to forecast errors, complex tasks obtained by mathematical programming can be solved by approximate methods. That is why it is very important to study sensitivity of gained solutions to the level of market and PES parameters' deviation and take into account production and planning risk evaluation; the stipulated parameters can have Markov property (Markov process) and can be designed by Monte-Carlo method.

Due to considerable restrictions nowadays, we can take advantage of other ways to formalize such groups of tasks. A vast amount of Nobel laureates focus on this problem (L.V. Kantorovich, 1975; R. Solow, 1987; H. Markowitz, 1994; J. Stiglitz, 2001; J. Tirole, 2014). Besides, management and sufficient formalization principles in management and applications greatly contribute to existing approaches and theories.

3. Risk evaluation

The analysis of gained results plays a significant role in managerial decision-making. Many authors make big efforts to tackle tasks with risk analysis of segregate solutions. For example, for project portfolio risk evaluation, we can use capital asset pricing model (CAMP) introduced by Sharpe [13], Lintner [14], and Mossin [15] based on the theory of Markowitz described in Refs. [16, 17]. For risk evaluation, we can also use the approach covered in Ref. [18], when we use function-based parameters obtained by forecast margins.

Over-time consideration of parameters makes it possible to mitigate risks associated with the selection of innovation projects (managerial and organizational), for which membership function may be identified for every moment of time.

In this case, the expected return of product portfolio can be determined as is evident from:

$$E(R_p) = \sum_{v=1}^{u} x_v E(R_v), \tag{10}$$

where R_p—the product portfolio, and x_i—the output volume.

$$VAR(R_p) = \sum_{i=1}^{I} \sum_{j=1}^{J} x_i x_j COV(R_j, R_i). \tag{11}$$

Correlation factor can be calculated by the formula:

$$k_{ij} = \frac{COV(R_j, R_i)}{\sigma_i \sigma_j}. \tag{12}$$

Then the risk evaluation for p project portfolio is:

$$\sigma_p = \sqrt{\sum_{i=1}^{I} \sum_{j=1}^{J} x_i x_j k_{ij} \sigma_i \sigma_j} \tag{13}$$

Forecast data can be calculated by the formula [19]:

$$\mu^2 = \int_{-\infty}^{+\infty} x f(x) \, dx, \tag{14}$$

and

$$\sigma^2 = \int_{-\infty}^{+\infty} (x - \mu)^2 f(x) \, dx, \tag{15}$$

where x is the production volume at a certain moment of time.

For retrospective data:

$$\sigma^2 = \frac{\sum_{i=1}^{n} (x_i - x_i^*)^2}{n}, \tag{16}$$

where x_i—production volume forecasting at a certain moment of time.

Correlation ration can be defined upon statistical data (**Table 2**) and Slope One algorithm [20].

Period (day, month, quarter, year, …)	Product 1	Product 2	…	Product a	…	Product n
1	O_{11}	O_{21}	…	O_{a1}	…	O_{n1}
⋮	⋮	⋮	⋱	⋮	⋱	⋮
N	O_{1N}	O_{2N}	…	O_{aN}	…	O_{nN}

N—the number of periods, O_{ij}—the sales volume of product i in the time period j.

Table 2. Sales volume matrix.

In this case, the angle cosine between vectors formed by columns of values for each product (item-to-item algorithm) can be used as the correlation factor:

$$S = \cos(T_1, T_2) = \frac{\vec{T_1}\vec{T_2}}{|\vec{T_1}||\vec{T_2}|}, \tag{17}$$

where T—vectors (columns) corresponding to products.

These calculations can be subsequently used to fill in the product correspondence table.

In this case, portfolio will be chosen on the assumption that the expected return can be also determined by the following formula [21]:

$$E(R_p) = R_f + \frac{E(R_m) - R_f}{\sigma_m}\sigma_p, \tag{18}$$

where R_f—the guaranteed risk-free return, $E(R_p)$—the expected return of p portfolio, $E(R_m)$—the expected return of m market portfolio, σ_p—the standard deviation for p portfolio, and σ_m—the standard deviation for m portfolio.

4. Forecasting risks

When we use forecasts in decision making, we face risks on whether the forecasts are reliable and how the result will guarantee the quality of decision-making. Forecasting can be performed only by a certain degree of assurance; however, long-term forecasts produce low degree of accuracy (the intervals of potential deviations will increase). The magnitude of deviations can be calculated for normal distribution parameters based on the maximum margin of error when forecast can be regarded as accurate [18]:

$$F = \sum_{j=1}^{n} E_i^2, \tag{19}$$

where $E_i = (Y_i^T - Y_i^*)$—the margin between forecasting and real values, Y_i^T—forecasting data, Y_i^*—data about parameter margin changes (project experiment data for forecasting).

Let us find $\sigma = \sqrt{\frac{F}{n}}$, where n—the number of experiment points. Due to normal distribution law, the hypothesis proves adequate by reaching the interval $(Y^* - \sigma \leq Y^T \leq Y^* + \sigma)$—68% experiment data and more, the interval $(Y^* - 2\sigma \leq Y^T \leq Y^* + 2\sigma)$—not less than 95% experiment data, the interval $(Y^* - 3\sigma \leq Y^T \leq Y^* + 3\sigma)$—not less than 99% experiment data. Hence, taking into account indistinct forecast given above, lets us introduce forecasting values with fuzzy numbers. Let us assign to each value of forecast curve, a membership function. That is the way to mathematically describe forecast-based risk assets. First of all, let us determine the risk assets.

The fuzzy set A to U is the set of pairs $(u, \mu_A(u))$, where $u \in U$, and $\mu_A(u)$—denotes membership function of fuzzy elements A, $\mu_A : U \to [0,1]$. Here, U is a universal set of elements.

Membership function assigns to each element a membership degree based on formalized fuzzy set. In mathematics, a fuzzy set is defined as follows:

$$A = U \frac{\mu_A}{u}, u \in U. \tag{20}$$

Let us assume that a risk is calculated for a certain set of project parameters taking into account all risk factors, i.e., multivariable risk:

$$r = f(a_1, a_2, \ldots, a_k, \varphi_1, \varphi_2, \ldots, \varphi_m), \tag{21}$$

where let us say, a_1 is the unit cost, a_2—the unit price, and a_3—the sales volume, etc. In this case, if risk is calculated for the 1st parameter, r_1 can be a function of the following factors: φ_1—the production decline (interruptions in the supply of crude, materials, parts, human faults, machine malfunction, supply of poor quality crude, materials, parts, accidents, natural disasters, strikes, and wars); φ_2—the productivity progress; φ_3—the change of prices for crude, materials, and parts; φ_4—the change in the price of labor; φ_5—the change in the price of outsourcing services for packing, storage, transportation, and sales, etc.; φ_6—tax changes; φ_7—inflation-deflation processes; φ_8—the poor working capital, that leads to taking a loan and paying interests on it; φ_9—the payment of fines, default interests, penalties [18], and so on.

Furthermore, let us suppose that risk is measured over a certain risk set:

$$r = 1 - \frac{a}{a^*}, \tag{22}$$

where a—fixed, planned unit cost value without risk factors; a^*—the defined index of unit cost.

Defined index that is used in this formula should be determined by either expert evaluations or forecast margins generated by diverse methods; all these margins are based on various original data. Hence, we use these data to define margin range of an interested parameter (i.e., risk measured by this method will uniquely be placed in the range, that generates fuzzy set), and membership function is built on Gaussian function (used by the description of normal distribution law).

To define function parameters, let use Gaussian function $(\mu(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(\frac{(x-c)^2}{2\sigma^2})})$ and gained margins. c can be assigned, if known, retrospective data or most accurate forecasting data, and arithmetic average of obtained forecasts (same like W.S. Gosset (Student) did with measurement results). To determine the margin σ, let us use the property of full width at half amplitude:

$$\sigma = \frac{c_{max}}{\sqrt{2ln2}}, \tag{23}$$

where $c_{max} = \max_{1 \le j \le n} |c - c_i|$, i—the number of alternative margins for c obtained by forecasts and expert evaluations. The formula of membership function is then as follows (for normal distribution law parameters):

$$\mu(x) = \frac{\sqrt{ln2}}{c_{max}\sqrt{\pi}} e^{-\left(\frac{ln2(x-c)^2}{c_{max}^2}\right)} \tag{24}$$

For the parameters, that do not obey normal distribution law, we can use triangular functions, generic Bell function, and sigmoid function for asymmetric distributions, etc.

Based on membership function and taking into account potential risky events that influence each of the margins, we measure risk evaluation margin [18] for the described parameter value:

$$r = 1 - \frac{\displaystyle\int_{\alpha}^{\beta} \mu_1(x)dx}{\displaystyle\int_{\alpha}^{\beta} \mu_2(x)dx}, \tag{25}$$

where r—the risk evaluation; $\mu_1(x)$ and $\mu_2(x)$—membership functions for different margins of c (for instance, c_1—historical margins and c_2—arithmetic average data); α, β—boundaries of value range.

We should take into consideration that obtained risk evaluations do not consider the risks of previous stages.

Such forecasting risk evaluation can be applied only in the case if we know all the parameter values that we need to assess; that is a disadvantage of this method.

5. Conclusion

A simulated model can help forecast features and behavior of object of inquiry both inside the area, where the model is simulated, and (by proved application) outside this area (forecasting role of a model); manage the object by selecting most efficient model-based impacts (managerial role); recognize the phenomenon or the object that was used for simulating the model (cognitive role of a model); obtain skills to manage the object by using the model as a training simulator or a game (training role); and enhance the object by modifying and testing the model (project role).

In practice, the stipulated task management in PES helps design simulation models for certain tasks avoiding NP-complete problem (for instance, Wagner-Whitin algorithm); furthermore, the use of sequential stage-to-stage transitions of forecast parameters or production cycles as described in Ref. [7] as crucial points in decision-making helps to avoid infinite-horizon problems [22] and exclude innovative regression in PES introduced by the corresponding member of RAS D.A. Novikov [23].

The described approach for management decision-making helps study PES processes at any accuracy degree. At the same time, the model complies with each management algorithm or system behavior and assesses risk margin for decision-making models.

Acknowledgements

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