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ІНФОРМАЦІЙНО-КОМУНІКАЦІЙНІ ТЕХНОЛОГІЇ ТА МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ

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MODELING THE OPTIMIZATION PROCESS OF INVESTMENTS IN DEVELOPMENT OF THE ENTERPRISE TAKING INTO ACCOUNT RANDOM COSTS

Purpose. The study aims at substantiating the method to determine the optimal volume of investments for improving basic economic indicators of the enterprise's performance selected by the company management at random costs at each stage of its development. **Methodology.** The proposed methodology for determining the optimal investment volume is based on simulation modeling methods and optimal control theory, in particular, the dynamic programming procedure, since the controlled process of the enterprise`s development is a multi-step one. Using step-by-step planning with generation of costs for transitions and statistical processing of results, a solution to optimization problem was obtained, to which the methods of mathematical analysis cannot be applied. **Findings.** An algorithm has been developed for calculating the minimal volume of capital investments for improving selected economic indicators and constructing the optimal trajectory for the enterprise`s development from the initial economic state to the final desired state. This takes into account unforeseen intermediate costs in the process of enterprise development. **Originality.** It is shown that using the methods of the theory of optimal control and simulation modeling, it is possible to calculate the minimal amount of capital investments to improve the selected economic indicators that determine the efficiency of the enterprise performance, taking into account the random costs of intermediate transitions by the development stages. Such calculation does not depend on the specific content of economic indicators. **Practical value.** The proposed methodology for calculating the minimal volume of capital investments is quite simple, but at the same time it allows, on the one hand, determining the priority areas of the enterprise's investment activities. On the other hand, it increases the manageability and transparency of the enterprise's economic activity, and increases the manager's confidence in the correctness of the decisions made.

Keywords: optimal control; simulation modeling; economic indicators; efficiency; optimal investment volume; optimization; competitiveness; manageability; dynamic programming; optimal trajectory; random costs

Introduction

The main economic indicators of reflect the results and success of the enterprise performance. On the other hand, the effective activity of the enterprise in the long term, ensuring high rates of its development and increasing competitiveness is largely determined by its investment level and the range of investment activities [1, 2, 6].

Investment activity depends on many factors. For example, on the distribution of the income received to increase working capital, improve various profitability, consumption and savings indicators. In conditions of low per capita incomes, most of them are spent for consumption. The growth of income increases their share, aimed at savings, which serve as a source of investment resources. Consequently, increase in the share of savings causes a corresponding increase in the volume of investments and vice versa. Also, the expected net profit margin has a significant influence on the investment volume. This is due to the fact that profit is the main incentive for investments. The

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higher the expected net profit margin, the correspondingly higher will be the volume of investments, and vice versa [3–5, 7].

As you know [6–8], before starting investment, you need to perform a set of work to justify the effectiveness of investments in the enterprise, called the investment project. Investment project preparation is a lengthy and sometimes very expensive process consisting of a number of acts and stages [1, 2, 6, 7, 9–13].

The main goal of investment project aimed for the enterprise development, as a rule, is to increase net profit and profitability ratios, therefore, increase its efficiency to the desired level. Consequently, one of the stages of its preparation can be the determination of the optimal (minimal) volume of investments. The methodology for solving this problem using the methods of optimal control theory [4, 5] is given in the works [3, 8].

Let us note that the solution to this problem is significantly complicated at unforeseen (random) costs at the stages of enterprise development. Therefore, the methodology developed in the works [3, 8] is not applicable in this case. This work is a continuation of the work [8]. It provides an algorithm for determining the optimal (minimum) volume of investment at random costs according to the stages of enterprise development, developed on the basis of simulation modeling methods.

Purpose

The main goal of this study is to substantiate the method for determining the optimal volume of investments for improving basic economic indicators of the enterprise's performance selected by the company management at random costs at each stage of its development.

Methodology

Let

$$a_{i,j} = a_{i\to i+1,j}; \quad b_{i,j} = b_{i,j\to j+1};$$

$$c_{i,j} = c_{i\to i+1,j\to j+1}$$

the costs for transitions from the level (P_i, R_j) of profit values and the profitability ratio to the levels (P_{i+1}, R_j), (P_i, R_{j+1}), (P_{i+1}, R_{j+1}), where $i = 0,1,..., N_k$; $j = 0,1,..., M_k$, are the number of calculation steps, respectively, and the calculation step is a month, quarter or year. These costs can be calculated using the so-called discounting method, i.e. reduction the incomes obtained at different times and expenses incurred within the framework of the investment project to a single (base) time point [6, 7]. All calculations are carried out in announced, target and estimated prices.

In this paper, we give a methodology for calculating the minimal volume of investments to achieve the set values of P_k – net profit and R_k – profitability ratio of the enterprise with unforeseen (random) costs at each stage of enterprise`s development, i.e. when the values

$$a_{i\to i+1,j}, \; b_{i,j\to j+1}, \; c_{i\to i+1,j\to j+1}$$

are random with given distribution laws.

The basis of the proposed methodology is the procedure of dynamic programming and simulation modeling [4, 5]. This procedure, using step-by-step planning, allows not only to simplify the solution of optimization problems, but also to solve those to which the methods of mathematical analysis cannot be applied.

The procedure for optimizing the volume of investments with known transition costs

$$a_{i\to i+1,j}; \quad b_{i,j\to j+1}; \quad c_{i\to i+1,j\to j+1}$$

is given in the author's paper [8].

According to this procedure, the process of making an investment decision starts with the last k-th step. At this step, one chooses a solution that makes it possible to get the greatest effect (reaching the final level (P_k, R_k) with the minimal investment volume). After planning this step, one can add the penultimate $(k-1)$-th step, to which, in turn, add the $(k-2)$-th, etc.

In order to plan the k-th step, one must know the level (P, R) of the enterprise at the $(k-1)$-th step. If the level of the enterprise (P, R) at the $(k-1)$-th step is unknown, then all sorts of levels are considered at this step. For each possible level, one chooses the so-called sub-optimal decision at the last, k-th step.

Let it be planned k-th step investment process and $(P_{k-1,1}, R_{k-1,1})$,

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$$(P_{k-1,2},\ R_{k-1,2})\ ,\ldots,\ (P_{k-1,r},\ R_{k-1,r})$$

are possible levels at the $(k-1)$-th step. At the last step, we find a sub-optimal decision for each of them. Thus, the k-th step is planned. Indeed, whatever the level $(P,\ R)$ at the penultimate step, it is already known which solution should be applied at the last step. We proceed similarly at the $(k-1)$-th step, but we have to choose the sub-optimal decisions taking into account the ones that have already been chosen at the k-th step, etc. As a result, we come to the initial level $(P_0,\ R_0)$ of net profit and profitability ratio.

For the first step, we do not make any assumptions about the possible level $(P,\ R)$, since the level $(P_0,\ R_0)$ is known, and we find the optimal solution, taking into account all sub-optimal decisions found for the second step. Going from $(P_0,\ R_0)$ to $(P_k,\ R_k)$, we obtain the desired optimal decision, which ensures the minimal volume of investments and their best distribution according to calculation steps.

A model example is given in the work [8], which demonstrates the efficiency of this procedure.

Often, in practice, the values of parameter (transition costs)

$$a_{i,j} = a_{i\to i+1,j}\,,\quad b_{i,j} = b_{i,j\to j+1}\,,$$

$$c_{i,j} = c_{i\to i+1,j\to j+1}$$

are random ones. In particular, they can be determined using formulas

$$a_{i,j} = \alpha_{i,j}a^0_{i,j}\,,\quad b_{i,j} = \beta_{i,j}b^0_{i,j}\,,$$

$$c_{i,j} = \sigma_{i,j}c^0_{i,j}\,,$$

where

$$\alpha_{i,j} \in \left[\alpha^1_{i,j},\ \alpha^2_{i,j}\right],\quad \beta_{i,j} \in \left[\beta^1_{i,j},\ \beta^2_{i,j}\right],$$

$$\sigma_{i,j} \in \left[\sigma^1_{i,j},\ \sigma^2_{i,j}\right]$$

– random correction factors for transition costs with given distribution laws, $a^0_{i,j}$, $b^0_{i,j}$, $c^0_{i,j}$ – basic values of transition costs for this sector of the economy. Parameters $a_{i,j}$, $b_{i,j}$, $c_{i,j}$, $d_{i,j}$, $e_{i,j}$, $f_{i,j}$ can be determined with the help of statistical analysis of changes in prices for products and services, force majeure circumstances (including, for example, changes in legislation related to the economy).

Thus, by one going from $(P_0,\ R_0)$ to $(P_k,\ R_k)$ we will not get the optimal decision, which ensures the minimal volume of investments and their best distribution according to the calculation steps, due to the randomness of the transition costs.

In this paper, to solve this problem, it is proposed to use simulation methods, namely, the Monte Carlo method. The essence of this method is as follows. Let $X_1, X_2, ..., X_n$ be the random input parameters with the given distribution laws, and Y is the output parameter of the system:

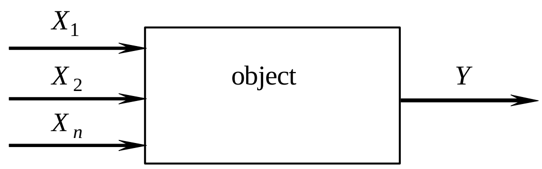

Fig. 1. The structural diagram of the object operation

It is assumed that the type (law) of dependence of Y parameter on the input parameters is known (Fig. 1):

$$Y = F\left(X_1,\ X_2, ..., X_n\right). \tag{1}$$

Algorithmically simulation model of the object functioning process is a software implementation of formula (1) by generating random variables $X_1, X_2, ..., X_n$.

In our case, input parameters are the transition costs

$$a_{i,j} = \alpha_{i,j}a^0_{i,j}\,,\quad b_{i,j} = \beta_{i,j}b^0_{i,j}\,,$$

$$c_{i,j} = \sigma_{i,j}c^0_{i,j}\,,$$

Y – is minimal investment volume calculated using the procedure of the dynamic programming method (function *F*), which is described in the work [8].

Findings

According to this algorithm, it is convenient to search for the optimal decision (transition) from $(P_0,\ R_0)$ to $(P_k,\ R_k)$ geometrically on the *POR* plane, or rather, on the rectangle bounded with right lines

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$$P = P_0,\ P = P_k,\ R = R_0,\ \ R = R_k$$

which is the area of acceptable levels. The initial $(P_0,\ R_0)$ and final $(P_k,\ R_k)$ levels are well defined as two points of the plane (Fig. 2) [1].

In Fig. 2, vertical segments show increase in profitability ratio at a constant profit value, horizontal segments show increase in profit at a constant value of profitability ratio, and diagonal segments show simultaneous increase in profit and profitability ratio.

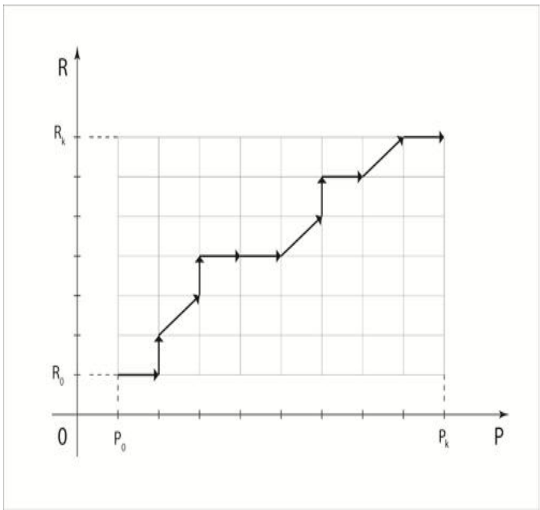

Fig. 2. Optimal trajectory of enterprise development

For each set of generated transition costs,

$$a_{i,j} = \alpha_{i,j} a^0_{i,j};\quad b_{i,j} = \beta_{i,j} b^0_{i,j};\quad c_{i,j} = \sigma_{i,j} c^0_{i,j};$$

according to the above procedure, its own optimal transition trajectory T from $(P_0,\ R_0)$ to $(P_k,\ R_k)$ is constructed and the minimal volume of investments Y is calculated.

The simulation model of the decision-making process on the investment volume and the optimal trajectory of enterprise`s development is being software implemented according to the following macroalgorithm:

Step 1. Determination and input of basic values

$$a^0_{i,j},\ b^0_{i,j},\ c^0_{i,j}, \alpha^1_{i,j},\ \alpha^2_{i,j}, \beta^1_{i,j},\ \beta^2_{i,j},\ \sigma^1_{i,j},\ \sigma^2_{i,j},$$

and the number of experiments (simulation model starts up) M .

Step 2. The generation of random variables $\alpha_{i,j}, \beta_{i,j}, \sigma_{i,j}$. If they are evenly distributed, then the generation can be performed according to the following formulas

$$\alpha_{i,j} = \left(\alpha^2_{i,j} - \alpha^1_{i,j}\right)\text{random} + \alpha^1_{i,j}$$

$$\beta_{i,j} = \left(\beta^2_{i,j} - \beta^1_{i,j}\right)\text{random} + \beta^1_{i,j}$$

$$\sigma_{i,j} = \left(\sigma^2_{i,j} - \sigma^1_{i,j}\right)\text{random} + \sigma^1_{i,j}$$

In the case of normal distribution, the following formulas for random number generation can be applied

$$\alpha_{i,j} = \sqrt{D\left(\alpha_{i,j}\right)}\left(\sum_{i=1}^{n} z_i - \frac{n}{2}\right)\Big/\sqrt{\frac{n}{12}} + M\left(\alpha_{i,j}\right),$$

$$\beta_{i,j} = \sqrt{D\left(\beta_{i,j}\right)}\left(\sum_{i=1}^{n} z_i - \frac{n}{2}\right)\Big/\sqrt{\frac{n}{12}} + M\left(\beta_{i,j}\right),$$

$$\sigma_{i,j} = \sqrt{D\left(\sigma_{i,j}\right)}\left(\sum_{i=1}^{n} z_i - \frac{n}{2}\right)\Big/\sqrt{\frac{n}{12}} + M\left(\sigma_{i,j}\right),$$

where $D(.),\ M(.)$ are dispersion and mathematical expectation of a random variable accordingly, $z_1, z_2, ..., z_n$ are uniformly distributed random variables from the interval $\left[0\ ,\ 1\right],\ k \geq 12$.

Step 3. The construction of the optimal transition trajectory T from $(P_0,\ R_0)$ to $(P_k,\ R_k)$ and the calculation of the minimal volume of investments Y for a given set of generated transition costs.

As noted in the work [8], if for a certain nodal point (see Fig. 2) there are several (two or three) sub-optimal decisions, then all of them are marked with arrows, and then any of them is selected. In these cases, the problem has several solutions if such nodal points belong to the optimal trajectory. In other words, the minimal volume of investments obtained for a given set of generated cost values can be spent using several transition trajectories T from $(P_0,\ R_0)$ to $(P_k,\ R_k)$.

Step 4. Repeating steps 2 and 3 M times and interval alignment of the obtained statistical material in the form of a table

Table 1

Results of computational experiments

Y	$(Y^1_s,\ Y^2_s),\ s = 1,...,m,$
Trajectory frequency T	$N_s,\ s = 1,...,m$

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Number $m-$ the number of intervals, which is determined by the Sturgess formula

$$m = 1 + 3.3 \cdot \lg M .$$

The length h of the interval $(Y_i^1,\ Y_i^2)$ is determined by the formula

$$h = \frac{Y_{\max} - Y_{\min}}{m},$$

where $Y_{\max}, Y_{\min} -$ are the maximum and minimum values of the parameter Y obtained as a result of experiments.

In Table 1 $N_s -$ the number of trajectories for which $Y \in (Y_s^1,\ Y_s^2)$.

Step 5. Average values calculation

$$\overline{Y} = \frac{\sum Y}{M}.$$

Obviously, at some value $s = s^* \in [1,\ m]$ $\overline{Y} \in (Y_{s^*}^1\ ,\ Y_{s^*}^2)$. several trajectories T of the enterprise development may correspond to the interval $(Y_{s^*}^1\ ,\ Y_{s^*}^2)$. The enterprise management can choose from them a specific, most convenient way of development from the implementation point of view.

Originality and practical value

It is shown that, using the methods of optimal control theory and simulation modeling, it is possible to calculate the minimal value of capital investments to improve the selected economic indicators, which determine the efficiency of the enterprise at random costs for intermediate transitions by the development stages.

The technique proposed in the article is quite simple, but at the same time it allows, on the one hand, determining the priority directions of the enterprise`s investment activity. On the other hand, it increases the controllability and transparency of the enterprise's economic activity, increases the manager's confidence in the correctness of decisions made [8].

Conclusions

The proposed calculation method does not depend on the specific content of economic indicators. The result depends on the accuracy of determining the distribution laws of random variables $\alpha_{i,j}$, $\beta_{i,j}$, $\sigma_{i,j}$ using the methods of mathematical statistics. And this, in turn, depends on the quality of the statistical analysis of the specifics of the enterprise`s economic activity.

Let us note that the above calculation algorithm can be applied to any pair of economic performance indicators of any enterprise, including the enterprise connected with railway [1, 2, 8].

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МОДЕЛЮВАННЯ ПРОЦЕСУ ОПТИМІЗАЦІЇ ІНВЕСТИЦІЙ НА РОЗВИТОК ПІДПРИЄМСТВА З УРАХУВАННЯМ ВИПАДКОВИХ ВИТРАТ

Мета. Основною метою цього дослідження є обґрунтування методу визначення оптимального обсягу інвестицій на поліпшення обираних керівництвом підприємства основних економічних показників ефективності його роботи за випадкових витрат на кожному етапі розвитку. **Методика.** В основі запропонованої методики визначення оптимального обсягу інвестицій лежать методи імітаційного моделювання й теорії оптимального управління, зокрема процедура динамічного програмування, оскільки керований процес розвитку підприємства є багатоетапним. Використання поетапного планування з генерацією витрат на переходи і статистичної обробки результатів дає можливість отримати розв’язок задачі оптимізації, до якої не можна застосувати методи математичного аналізу. **Результати.** Розроблено алгоритм розрахунку мінімального обсягу капітальних вкладень на поліпшення обраних економічних показників. Побудовано оптимальну траєкторію розвитку підприємства від початкового економічного до кінцевого бажаного стану. При цьому враховані непередбачені проміжні витрати в процесі розвитку підприємства. **Наукова новизна**. Показано, що за допомогою методів теорії оптимального управління та імітаційного моделювання можна розрахувати мінімальний обсяг капітальних вкладень на поліпшення обраних економічних показників, які визначають ефективність роботи підприємства з урахуванням випадкових витрат на проміжні переходи за етапами розвитку. Причому такий розрахунок не залежить від конкретного змісту економічних показників. **Практична значимість**. Запропонована в статті методика розрахунку мінімального обсягу капітальних вкладень досить проста, але водночас дозволяє, з одного боку, визначити пріоритетні напрямки інвестиційної діяльності підприємства, а з другого – підвищує керованість і прозорість господарської діяльності підприємства, упевненість керівника в правильності прийнятих рішень.

Ключові слова: оптимальне управління; імітаційне моделювання; економічні показники; ефективність роботи; оптимальний обсяг інвестицій; оптимізація; конкурентоспроможність; керованість; динамічне програмування; оптимальна траєкторія; випадкові витрати

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МОДЕЛИРОВАНИЕ ПРОЦЕССА ОПТИМИЗАЦИИ ИНВЕСТИЦИЙ НА РАЗВИТИЕ ПРЕДПРИЯТИЯ С УЧЕТОМ СЛУЧАЙНЫХ ЗАТРАТ

Цель. Основной целью данного исследования является обоснование метода определения оптимального объема инвестиций на улучшение выбираемых руководством предприятия основных экономических показателей эффективности его работы при случайных расходах на каждом этапе развития. **Методика.** В основе предлагаемой методики определения оптимального объема инвестиций лежат методы имитационного моделирования и теории оптимального управления, в частности процедура динамического программирования, так как управляемый процесс развития предприятия является многоэтапным. Использование поэтапного планирования с генерацией затрат на переходы и статистической обработки результатов дает возможность получить решение задачи оптимизации, к которой нельзя применить методы математического анализа. **Результаты.** Разработан алгоритм расчета минимального объема капитальных вложений на улучшение выбранных экономических показателей. Построена оптимальная траектория развития предрияния от начального экономического до конечного желаемого состояния. При этом учтены непредвиденные промежуточные расходы в процессе развития предприятия. **Научная новизна.** Показано, что с помощью методов теории оптимального управления и имитационного моделирования можно произвести расчет минимального объема капитальных вложений на улучшение выбранных экономических показателей, которые определяют эффективность работы предприятия с учетом случайных затрат на промежуточные переходы по этапам развития. Причём такой расчет не зависит от конкретного содержания экономических показателей. **Практическая значимость.** Предлагаемая в статье методика расчета минимального объема капитальных вложений довольно проста, но в то же время позволяет, с одной стороны, определить приоритетные направления инвестиционной деятельности предприятия, а с другой – повышает управляемость и прозрачность хозяйственной деятельности предприятия, уверенность руководителя в правильности принимаемых решений.

Ключевые слова: оптимальное управление; имитационное моделирование; экономические показатели; эффективность работы; оптимальный объем инвестиций; оптимизация; конкурентоспособность; управляемость; динамическое программирование; оптимальная траектория; случайные затраты

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