

**Zhukovska O. A.**

*Cand. physics and mathematics, associate professor*  
ORCID ID: 0000-0003-1110-9696

**Manko Y. R.**

ORCID ID: 0000-0003-3828-5227

*National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"*

## **APPLICATION OF BAYESIAN STRATEGY OF COLLECTIVE DECISION-MAKING TO RESOLVE THE SOCIO-ECONOMIC PROBLEM OF KYIV CITY**

### **ЗАСТОСУВАННЯ БАЙЄСІВСЬКОЇ СТРАТЕГІЇ ПРИЙНЯТТЯ КОЛЕКТИВНОГО РІШЕННЯ ЩОДО ВИРІШЕННЯ СОЦІАЛЬНО-ЕКОНОМІЧНОЇ ПРОБЛЕМИ МІСТА КИЄВА**

*This article considers an implementation of a constructive scheme of collective decision-making, which is based on the Bayesian strategy, for the selection of investment projects to solve the socio-economic problem of Kyiv city. The relevance of this study is that in the absence of an objective and transparent system for selecting investment projects and with a limited regional budget, the government should accept only those investment projects that bring the greatest socio-economic benefits. The main ways of state investment in projects aimed at improving socio-economic problems are considered. Among them are the State Fund for Regional Development and the public-private partnership program. It is determined that a significant advantage of public-private partnership over the State Fund for Regional Development is the ability to attract both public funds and private investment. Three projects aimed at solving the problem were selected from the website of the Kyiv Investment Agency, which operates within the framework of a public-private partnership. The financial indicators of their profitability were calculated – NPV (net present value), IRR (internal rate of return) and PI (profitability index). They are based on the concept of incoming and outgoing payments during the period of project execution. It is determined that these indicators do not always give a consistent result, as well as their main drawback – the inability to assess the social component. According to the methodology of collective decision-making by a group of independent experts in terms of the minimum average probability of error, calculations were made to determine the most attractive project. It is noted that all experts make decisions separately and independently of each other. Recommendations were provided for the selection of a specific project. The study identifies the advantages of this method of project acceptance for investment: objectivity, consistency and transparency. In the future, it is planned to incorporate risks into the decision-making model. The main areas that need improvement were considered, and key ones were selected. The most problematic and urgent is the issue of waste recycling in Kyiv.*

**Keywords:** investment project; making collective decisions; expert evaluation; Bayesian strategy; optimal solution; public-private partnership.

*У статті на основі конструктивної схеми прийняття колективного рішення, яка ґрунтується на байєсівській стратегії, проведено дослідження щодо відбору інвестиційних проектів для вирішення соціально-економічної проблеми Києва. Актуальність даного дослідження полягає у тому, що за відсутності на даний час об'єктивної та прозорої системи відбору інвестиційних проектів та при обмеженому регіональному бюджеті влада має приймати лише ті інвестиційні проекти, які несуть в*

собі найбільшу соціально-економічну вигоду. Розглянуто основні способи державного інвестування у проекти, що спрямовані на покращення соціально-економічних проблем. Серед них виділено Державний фонд регіонального розвитку та програму державно-приватного партнерства. Визначено, що суттєвою перевагою державно-приватного партнерства над Державним фондом регіонального розвитку є можливість залучення як і державних коштів, так і приватних інвестицій. З сайту комунального підприємства «Київське інвестиційне агентство», що діє в рамках державно-приватного партнерства було обрано три проекти, спрямовані на вирішення обраної авторами проблеми. Проведено підрахунки фінансових показників їх прибутковості – NPV (чиста приведена вартість), IRR (внутрішня норма дохідності) та PI (індекс прибутковості), які ґрунтуються на понятті вхідних і вихідних платежів за період життя проекту. Визначено, що не завжди ці показники дають узгоджений результат, а також зазначено про неможливість оцінки на їх основі соціальної складової. За методологією прийняття колективного рішення групою незалежних експертів з точки зору мінімуму середньої ймовірності помилки проведено розрахунки для визначення найбільш привабливого проекту. Зазначено, що усі експерти приймають рішення окремо, незалежно один від одного. Надано рекомендації щодо обрання конкретного проекту. За результатами дослідження визначено переваги такого методу прийняття проекту для інвестування: об'єктивність, узгодженість та прозорість. Надалі планується інкорпорація ризиків до моделі прийняття рішення. Були розглянуті основні сфери, які потребують вдосконалення, серед них вибрано ключові. Найбільш проблематичним та нагальним є питання переробки відходів у столиці.

**Ключові слова:** інвестиційний проект; прийняття колективних рішень; експертна оцінка; байєсівська стратегія; оптимальне рішення; державно-приватне партнерство.

**Introduction.** A regional development is a key issue for stable economic growth in the country. Significant contribution to such development is made through public investment and regional projects. Unfortunately, there is currently no objective and transparent system for selecting such projects – the regulations available provide only a qualitative assessment. Today, one of the key issues of sustainable regional development of Ukraine is the introduction of an effective investment policy. One of the main tasks of the investment program of the region is a reasonable selection of those investment projects that would be most profitable for further development of the region [1].

Most often, such investment projects are implemented through the State Fund for Regional Development or public-private partnership (PPP) programs. Quite common in the city of Kyiv is the form of PPP, which provides for the implementation of a regional investment project through the partial attraction of public investment.

However, the PPP program in its legal framework does not provide a specific system of evaluation of such projects: usually the socio-economic effect is assessed “verbally”, without the use of any formalized modeling methods. After reviewing the passports of already implemented projects, the main drawback was identified: among the comprehensive evaluation of the project (financial costs, qualitative and quantitative results, etc.) there is no assessment of the impact of its implementation on regional development, socio-economic results and forecasting future effects from the implementation of such projects. Namely, this item is

important in the evaluation and selection of regional development projects, as well as ensures the transparency of such a procedure.

The importance of this issue is difficult to overestimate, and, therefore, the purpose of this article is to apply a constructive decision-making scheme, based on the Bayesian strategy [2,7] for the process of selecting an investment project by the group of independent experts. The article uses the work of Oglikh V. V., Yefanova T. I. [1], Blank I. A. [3], Vovchak O. D. [4] in the field of investment management and selection of profitable investment projects.

**Setting objectives.** Each city in the world faces its own special problems, and Kyiv is no exception. Today, one of the most significant problems for the capital (and for the whole of Ukraine as well) is the issue of solid waste recycling and garbage in general.

Annually, each Ukrainian generates about 330 kg of waste, while landfills accumulate about 11 million of household waste. The total area of such landfills or dumps is approximately 30,000 km<sup>2</sup>, which amounts 5% of the total territory of the state, or, alternatively, the size of Denmark. At the same time, there is only one waste incineration plant “Energiya” in Ukraine (it is located in the city of Kyiv in the Darnytskyi district), although previously there were four – in Kyiv, Kharkiv, Rivne and Sevastopol. Thus, for comparison, there are 126 such plants in France and 121 in Germany. However, the capacity of the domestic plant is not enough even to meet the needs of Kyiv alone. Thus, in Kyiv, on average, about 1.2 million tons of household waste are accumulated per year, and the “Energiya” plant is capable of burning 260-280 thousand tons. Thus, 77.5% of garbage remains unprocessed in the capital [5].

Most waste in Kyiv is generated from food - 30%, glass - 12.5%, polymers - 12.3%, paper and cardboard - 8.9%. The other 36.3% are formed by ferrous and non-ferrous metals, textiles, wood, bones, leather, rubber, hazardous waste, etc. According to research, based on the number of inhabitants and the average amount of waste produced by one person, the percentage of waste of various types, as well as the average capacity of waste processing enterprises, it is needed to build 2-3 sorting plants and 1-2 waste processing plants and composting plants in Kyiv [6]. Today there is no waste processing plant in Kyiv, most of the waste is buried in landfills.

Thus, the task of this article is to use a constructive scheme of collective decision-making [7], to decide on the choice of such a project on waste recycling, which would improve the socio-economic situation in the region. This situation is assessed through three main components: environmental factor (probable concentration of CO<sub>2</sub> in the air, increase in land suitable for farming), economic (budget revenues from the operation of enterprises, namely tax payments per year), social (new jobs, improvement in living standards of the population, reduce in the number of those living below the poverty line). Thus, each expert assesses how likely it is for each project to achieve these goals.

**Methodology.** To calculate the profitability of the project, three different dynamic methods of project evaluation will be used, namely:

– *NPV* (net present value)

$$NPV = \sum_{t=1}^n \frac{CF_t}{(1+r)^t} - CF_0; \quad (1)$$

– *IRR* (internal rate of return)

$$IRR = r, \text{ under } NPV = 0; \quad (2)$$

– *PI* (profitability index)

$$PI = \frac{NPV}{IC}. \quad (4)$$

Where  $CF_t$  – cash flow at a time  $t$ ;  $CF_0$  – cash flow given  $t = 0$  ( $CF_0 = IC$ );  $r$  – discount rate.

Note that according to [11]:

- the project is unprofitable if  $NPV < 0$ ;
- the project is attractive for investment if  $NPV > 0$ ;
- the project will provide break-even result if  $NPV = 0$ .

It is also known [11] that

- the project is not attractive if the  $IRR < r$ ;
- the project is attractive if  $IRR > r$ ;
- the project provides break-even if  $IRR = r$ .

If the condition  $PI < 1$  is met, the implementation of such a project will not cover the costs.

When  $PI > 1$  – the project provides an additional return on capital.

If  $PI = 1$ , the income will be equal to the discount rate.

It should be noted that this approach, like most [11], provides only a financial assessment of the project and does not reflect the social component of the project. Modeling of the social component does not belong to the class of tasks that can be formalized. Therefore, in order to take into account the social factors of the project, a collective decision-making scheme [7] shall be used in terms of the minimum average probability of error in many possible situations  $\Theta$  ( $\Theta = \{S_{m_1 \dots m_N} : (\delta_1 = m_1) \wedge \dots \wedge (\delta_N = m_N), m_1, \dots, m_N = \overline{1, M}\}$ , where  $\delta_i = m$  – the number of the current state of the object was adopted as a result of an independent personal decision of the expert  $A_i$ ,  $m = \overline{1, M}$ ,  $i = \overline{1, N}$ ), according to which in each specific observed situation  $S \in \Theta$  a collective decision is made according to the scheme

$$D_S^{opt} = \arg \max_{1 \leq k \leq M} P(V_k) \prod_{i \in J_k} [1 - P^{(i)}(E | V_k)] \prod_{i \notin J_k} P^{(i)}(E | V_k) \quad (4),$$

where  $J_k$  – a set of number of experts, that in a situation  $S \in \Theta$  have made a personal decision  $\delta_i = k$ ,  $k = \overline{1, 2}$ ,  $J_\mu \cap J_\nu = \emptyset \quad \forall \mu, \nu = \overline{1, M}$ ,  $J_1 \cup \dots \cup J_M = \{1, \dots, M\}$ ;

$P^{(i)}(E|V_k)$  – pre-estimated on the basis of previous experience distribution of conditional probabilities of erroneous decisions of each of the experts;  $P(V_k)$  – probability distribution of the state of the object,  $\sum_{k=1}^M P(V_k) = 1$ ,  $M \geq 2$ .

**Results of the research.** It is clear that any project can be successful or unsuccessful in terms of socio-economic benefits – class  $V_1$  and  $V_2$ . Accordingly, the probability  $P(V_1)$  is the probability that the project shall be successful,  $P(V_2)$  – vice versa. These data can be obtained based on the experience of previous years, when the commission (committee) made a decision on a project with similar input characteristics.

For decision-makers, it is possible to determine the frequency of cases in which experts have made “correct” or “incorrect” (erroneous) decisions. This shall be  $P(E|V_1)$  i  $P(E|V_2)$  for each expert.

Data from the website of the Kyiv Investment Agency, an executive body subordinated to the Kyiv City State Administration, was taken as input. This portal carries out the procedure of selection and finding of investors within the framework of public-private partnership with a help of a commission of 5 experts.

To implement the objectives of this article, the following three investment projects were selected: project A – “Reclamation of a landfill №5” [8]; B – “Construction of a waste sorting complex on Collectorna street, 44 in Darnytskyi district” [9]; C – “Modernization of the waste incineration plant “Energiya”” [10].

According to the data provided in [8–10], the following calculations of financial efficiency indicators were given (table 1):

Table 1 – The results of investment evaluation of projects

Indicator	Project A	Project B	Project C
<i>NPV</i>	2.5 mln UAH	5.8 mln UAH	121.9 mln UAH
<i>IRR</i>	0,03	0,06	1,01
<i>PI</i>	35%	45%	15%

One may see that project C has a significant advantage over projects A and B. This is obvious, because the modernization of the waste processing plant is much more financially advantageous compared to landfill recultivation and construction of a waste sorting center. However, such conclusions reflect only the financial content of the project, i.e. its profitability and payback, and in the case of public investment projects one should consider the social component. As the concept of socio-economic benefits is difficult to formalize, it is proposed to use a method in which a group of experts assesses the social attractiveness of the project, and each expert decides individually to accept or reject the project. Therefore, it is worth referring to the methodology proposed by the authors.

According to the statistics of the investment fund for the previous ten-year period, 75.6% of the funded projects were successful, i.e.  $P(V_1) = 0,69$ , and, accordingly,  $P(V_2) = 0,31$ .

To make a decision on the possibility of financing the current project, an expert group of 5 people was involved. Error probabilities estimates of these experts for previous decisions are summarized in table 2.

Table 2 – Distribution of conditional probabilities of erroneous decisions

Expert	Erroneous decision probability	
	$P^{(i)}(E V_1)$	$P^{(i)}(E V_2)$
1	0,059	0,068
2	0,012	0,059
3	0,048	0,087
4	0,01	0,031
5	0,063	0,053

Subsequently, for each project, the experts have made independent decisions on whether to accept or reject the project.

As a result of the decision of each of the experts for project A, the following situation is observed

$$S_{12121} : (\delta_1 = 1) \wedge (\delta_2 = 2) \wedge (\delta_3 = 1) \wedge (\delta_4 = 2) \wedge (\delta_5 = 1).$$

We see that in this case the personal decisions of the experts are inconsistent: the experts  $A_1, A_3, A_5$  have defined project A as successful, and experts  $A_2, A_4$  – as unsuccessful. To make a final collective decision, one must firstly define the sets of experts, who in this given  $S_{12121}$  have provided of agreed decision:  $J_1 = \{1,3,5\}$ ,  $J_2 = \{2,4\}$ .

According to scheme (4) for making the optimal collective decision we shall calculate the following values for project A:

$$\begin{aligned}
& P(V_1) \prod_{i \in J_1} [1 - P^{(i)}(E|V_1)] \prod_{i \notin J_1} P^{(i)}(E|V_1) = \\
& P(V_1) [1 - P^{(1)}(E|V_1)] P^{(2)}(E|V_1) [1 - P^{(3)}(E|V_1)] P^{(4)}(E|V_1) [1 - P^{(5)}(E|V_1)] = \\
& = 0,69 \cdot (1 - 0,059) \cdot 0,012 \cdot (1 - 0,048) \cdot 0,01 \cdot (1 - 0,063) = 6,95 \cdot 10^{-5}, \\
& P(V_2) \prod_{i \in J_1} [1 - P^{(i)}(E|V_2)] \prod_{i \notin J_1} P^{(i)}(E|V_2) = 8,86 \cdot 10^{-5}. \\
& D_S^{opt} = \arg \max_{1 \leq k \leq 2} P(V_k) \prod_{i \in J_k} [1 - P^{(i)}(E|V_k)] \prod_{i \notin J_k} P^{(i)}(E|V_k) = 2,
\end{aligned}$$

that is, we make the final decision in favor of the class  $V_2$ , that is, project A is considered to be unsuccessful.

Similarly, it was determined that project B could also be low-performing, and project C has every chance of being successful.

Thus, a group of experts decided to finance project C – “Modernization of the waste incineration plant “Energiya””. In this case, this project proved to be the most profitable both financially and socially. However, there is a possibility of inconsistency between these two criteria. In such a way, it is worth either rejecting such a project or conducting a more in-depth study.

**Conclusions.** This article presents a practical way to apply the methodology of collective decision-making based on the Bayesian strategy for the selection of a regional investment project, which aims to solve a specific socio-economic problem of the city of Kyiv city. This method of collective decision-making allows for clear and formalized, and most importantly – effective and transparent selection of social projects, if the financial criteria give non-homogeneous results. Within the framework of the presented method, a group of experts performs the assessment of the project feasibility to achieve socio-economic criteria that will improve the situation in the region.

This technique was applied to real data obtained from three projects that are planned to be implemented within the framework of public-private partnership in the city of Kyiv. In the future, to maximize the realism of the obtained results, it is planned to add to the calculations the impact of possible risks during the project implementation in the future.

#### References:

1. Ohlikh V. V., Yefanova T. I. Optyimizatsiia investytsiinoi prohramy rozvytku rehionu // *Biznesinform*, 2013. № 4. pp. 166-171
2. Manko Y.R., Zhukovska O.A. Methodology of selecting an investment project in the event of experts decisions inconsistency // “Actual problems of economics and management”, *Journal of Management and Marketing Faculty of National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”*, 2020. № 14. URL: <http://ape.fmm.kpi.ua/article/view/205839/205746>
3. Blank Y. A. *Upravlenye ynvestytsiyamy predpriyatiya*. K.: Nyka-Tsentr, 2003. 480 p.
4. Vovchak O. D. *Investuvannia : navch. posibn.* Lviv : Vyd-vo «Novyi Svit-2000», 2007. 544 p.
5. Kohda y kak budet reshena problema utylyzatsyy musora v Ukrainy. *finance.ua* [elektronnyi portal novyn] [Elektronnyi resurs]. – URL: <https://news.finance.ua/ru/news/-/419120/musornoe-budushhee-kogda-i-kak-budet-reshena-problema-utilizatsii-musora-v-ukraine>.
6. Kapustianska M. O. Pryntsypy formuvannia merezhi smittiepererobnykh kompleksiv na terytorii Ukrainy [Elektronnyi resurs]. – URL: [https://promusor.com/info/articles/stati/nauchnye/sciencearticle\\_1/](https://promusor.com/info/articles/stati/nauchnye/sciencearticle_1/)
7. Zhukovska O. A., Fajnzilberg L. S. *Matematichni modeli kolektivnih rishen: monografiya*. Kyiv: Osvita Ukraini, 2018. 160 p. URL: <http://ela.kpi.ua/handle/123456789/23456>
8. Proektni dani proektu «Rekultyvatsiia smittievoho polihonu №5». Website Kyivskoho investytsiinoho ahentstva [Elektronnyi resurs]. – URL: <https://investinkyiv.gov.ua/ua/projects/rekultivaciya-smittyevih-poligoniv>
9. Proektni dani proektu «Budivnytstvo smittiesortuvalnogo kompleksu po vul. Kolektornii, 44 v Darnytskomu raioni». Website Kyivskoho investytsiinoho ahentstva [Elektronnyi resurs]. – URL: <https://investinkyiv.gov.ua/ua/projects/budivnictvo-smittyesortuvalnogo-kompleksu-po-vul-kolektornij-44-v-darnickomu-rajoni>
10. Proektni dani proektu «Modernizatsiia smittiespaliuvalnogo zavodu «Enerhiia»» / Website Kyivskoho investytsiinoho ahentstva [Elektronnyi resurs]. – URL: <https://investinkyiv.gov.ua/ua/projects/modernizaciya-smittyespalyuvalnogo-zavodu-energiya>
11. Measures of Profitability. Website AnalystPrep [Elektronnyi resurs]. – URL: <https://analystprep.com/cfa-level-1-exam/corporate-finance/measures-profitability-npv-irr-aar-pi/>