Public-Private Partnership Models for the Russian Mineral Resource Complex

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Abstract. We propose a new approach to the development program for a raw-material base based on public-private partnership (PPP) mechanisms. This scheme is applied in production infrastructure development projects financed by the Investment Fund of Russia. This is a Russia-specific mechanism; thus, a special toolkit is designed for its assessment and formation. Our approach is based on synthesis of a simulation forecasting model and a planning model formulated as a bilevel Boolean programming problem. The technique applied in the proposed approach is presented using the examples of the PPP mechanisms practiced in Transbaikal.

Keywords: Production infrastructure development project, Raw-material base development program, Simulation forecasting model, Bilevel Boolean programming problem

Introduction

Public-private partnerships (PPPs) are widely used throughout the world and are an effective way to achieve a compromise of interests in various spheres of economy. World experience shows that PPPs can be a successful means, primarily, of creating new and maintaining the existing public sector infrastructure. In the mineral complex, PPPs help to considerably expand project financing and encourage subsoil users to develop new fields in remote areas.

How broadly is the PPP institution implemented in the mineral resources complex of Russia? It is quite often that the investor cannot implement an investment project due to a lack of the necessary infrastructure, and the state officials are unwilling to invest in infrastructure until they are sure it is used efficiently. What steps are taken to break this vicious circle? What economic and mathematical tools for designing an efficient PPP model can be used in the Russian context?

These questions are the focus of this paper. The author proposes the original approach based on synthesis of a simulation forecasting model and a planning model formulated as a bilevel Boolean programming problem. The corresponding decision support system, which has been tested in real-life conditions, would help to create an

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effective PPP arrangement and ensure long-term efficiency for the state as well as the private investor.

Section 2 gives an analysis for the current development level of the PPP institution around the world and in the mineral resource complex of Russia. Section 3 defines a technique of PPP mechanism assesment using simulation forecasting model. Section 4 gives the informal problem setting, introduces the main notation, and proceeds to a mathematical formulation of the planning model designed as a bilevel Boolean programming problem. In section 5 the received results are discussed and an area for further development of the prorposed tools is outlined.

1 Decision-Making Mechanisms

The original form of the PPP mechanism is traditionally termed BOT (Built, Own, Transfer) and is known worldwide as concession. This PPP mechanism was broadly used in Europe since the 19th century in the development of transport infrastructure [1].

The next step in the development of PPPs — the BOOT mechanism (Built, Own, Operate, Transfer) — was taken in Australia [2]. In this scheme, the private investor builds, finances, manages, and operates an infrastructure object. In this case, the ownership of the created object belongs to a private partner until the end of the contract, after which it passes to the state [3].

The next stage in the development of PPPs is associated with the DBFO (Design, Built, Finance, Operate) mechanism [4] and the adoption of a new strategy for government projects in the UK, i.e., the Private Finance Initiative [5]. In this scheme, the private investor sets up a management company for a long term (30–60 years) to build, finance, and manage the object and provide the services specified in the government contract [6].

This is a general outline of the two-centuries long evolution of the PPP institution in the world. The history of the PPP institution in Russia is much less eventful. There were attempts at using PPPs in Russia, but those were isolated instances of an experimental nature.

The situation has changed only in the last decades. Private capital began to flow to the infrastructure sector, but on a lower scale compared with developed nations. A particularly complex situation is observed in the mineral resource sector, which has traditionally been in focus of the state. Here the state is most interested in the development of PPP tools capable of attracting the resources of the various financial and credit institutions to the implementation of major investment programs.

PPP projects financed by the Investment Fund of Russia have been most widely used in the Russian mineral resources complex. This mechanism is based on international experience, but its original form has undergone serious change in the process of adaptation to the Russian conditions.

The production infrastructure projects financed by the Investment Fund use a non-classical PPP mechanism evolved due to the specific features of the Russian economy. What the Russian government calls a PPP is not considered PPP in Western literature.

Methodologically, investment projects become PPP projects only when a private company finances the construction and (or) operation of state-owned objects [7]. Within Russian projects, production infrastructure is built under the principle that each participant finances their own objects only.

The major infrastructure projects supported by the Investment Fund are implemented according to the above scheme. The federal investment project on the integrated development of the Lower Angara region includes infrastructure projects and the construction of the Boguchansk hydroelectric power plant (HPP), an aluminum smelter, and a pulp and paper plant. The support of the Investment Fund is to come in the form of co-financing of the investment project on negotiated terms through construction of the HPP and infrastructure facilities that will become the property of the Russian Federation.

Another such project is the one to create the transport infrastructure for the development of mineral resources in the southeast of the Chita oblast. In this project, the government builds the Naryn-Lugokan railway line to provide access to a cluster of prospective fields to be developed by a private investor.

It is possible to say that the first experience of Russian PPPs in the production infrastructure sector with the support of the Investment Fund was not very successful already today. This result is due not only to the transition nature of the economy and the lack of the necessary market institutions. An important role was played by the absence of a comprehensive assessment procedure for the implementation of the PPP project and by the financing scheme that was used at the time of making the decision.

How to create an effective PPP arrangement?

An analysis of the feasibility studies submitted to the Investment Fund for the PPP projects in the Lower Angara region and Transbaikal reveals insufficient project preparation [8–10]. In these materials the main focus is on the subprojects implemented by private investors. There are independent economic assessments for these subprojects, but no comprehensive assessment for the entire project, which would take into account the contribution of the Investment Fund to the infrastructure development.

The available experience shows that designing an efficient PPP mechanism for the Russian mineral resource sector would require specialized economic and mathematical tools for the development, assessment, and support of PPP projects. It is only these tools that can provide a comprehensive socioeconomic and environmental assessment of a PPP project and its funding scheme.

The subsequent sections of this paper are devoted mainly to the description of one of the possible approaches to this problem. This approach, which has been tested in real-life conditions, may be useful for natural resource-based regions that consider the use of PPP mechanisms in designing a program for the development of their raw material base.

2 PPP Mechanism Assessment: Simulation Forecasting Model

Necessary tools are essentially a forecasting model used to assess the consequences of a regional development program based on a particular PPP model. The procedure for an assessment of a PPP model is as follows.

Considering a mineral resource base development program as a set of long-term investment projects, the state seeks to achieve a compromise between the interests of all the stakeholders.

The assessment of a field in terms of economic rent plays an important role in the selection of projects by the investor. It characterizes the project profitability and is based on the net present value NPV of the project:

$$NPV = \sum_{t=1}^{T} \frac{D_t - R_t}{(1+E)^t}, \tag{1}$$

where D_t and R_t are the sales revenues and the technological costs of the project (capital investment, operational costs, and labor remuneration) in comparable prices in year t; E is the discount rate; and T is the field development period. An internal rate of return IRR is the discount rate, turning NPV into zero.

The investor's tax payments are not included into the technological costs R_t, since they are considered as part of the project's positive cash flow. NPV reflects the general efficiency of the project and corresponds to the discounted cash flow of the state and the investor taken together whereby the state plays a passive role of resource owner and recipient of fiscal revenues according to a particular tax system.

A proactive position of the state, which is associated with the use of PPPs, has a profound effect on the situation. Being part of a PPP, the state is involved in the financing of capital investment by building a part of the infrastructure needed for the technological project and implementing a range of environmental activities.

In this case, a relationship similar to (1) may also be constructed for the state (NPV_{st}). It uses a longer time horizon TS and a discount rate E_{st} that is considerably smaller than that of the investor:

$$NPV_{st} = \sum_{t=1}^{TS} \frac{IBR_t - R_t^{st} + tax_t}{(1+E_{st})^t}. \tag{2}$$

Here the costs of the state R_t^{st} are the capital investments in the infrastructure and environmental activities; the state revenues include not only the tax payments tax_t arising from the project but also the non-project revenues IBR_t generated by the development of local infrastructure.

The key efficiency indicator for the investor is NPV_{inv}, an analog of (1), which is characterized by reduced capital costs due to the state participation and by additional costs, i.e., tax payments:

$$NPV_{inv} = \sum_{t=1}^{T} \frac{D_t - R_t + R_t^{st} - tax_t}{(1+E_{inv})^t}. \tag{3}$$

The investor is interested in a project if $NPV_{inv} \geq 0$.

The state implements the raw-material base development program as an integrated project consisting of a set of investment subprojects within a PPP mechanism. Within this project, the state builds infrastructure facilities and finances environmental activities. It receives tax revenues from all the investment subprojects and non-project revenues as a result of the development of local infrastructure. For such an integrated project, we can derive the state's integral NPV_{st}^{int} , which is defined by the selected PPP mechanism (cost-sharing arrangement) and is similar to (2). A compromise between the interests of all the stakeholders (the state and investors) is achieved if

$$\{\text{for each investor } NPV_{inv} \geq 0\} \text{ and } \{NPV_{st}^{int} \geq 0\}. \quad (4)$$

The above procedure for an assessment is according to the requirements of the Guidelines for the assessment of projects with state participation, which are officially accepted in Russia. However, the official methodology becomes absolutely useless if it isn't supported with the field development models adapted to the Russian conditions [12].

The key role in designing the tools to assess a raw-material base development program using a specific PPP mechanism is played by a model describing the implementation of an investment project. This model makes it possible to assess the profitability of a project and its implications for the region within a given scenario of external conditions, a part of which are determined by the chosen PPP mechanism and project financing scheme. The core idea is to use a computer model describing the operation of an enterprise created by the investor to implement the project. The model helps generate a forecast for the trajectory of the key economic indicators depending on a variety of factors. The formal scheme of the model is given by a system of recurrence equations:

$$X_t = F(X_{t-1}, P, E_t, PPPM), t = 1, ..., T, \quad (5)$$

where P is the original technological project; E_t is the forecast for the external operational conditions; and X_t is the vector describing the state of the enterprise at the end of year t. The components of X_t determine the production capacity and output, the mining of ore, oil, and gas, the results of their processing, the loans and interest paid under the chosen project financing scheme, tax payments by category, and financial and economic indicators showing the performance of the enterprise in year t.

The applied PPP mechanism $PPPM$ directly affects the project configuration because a part of the production infrastructure and necessary environmental projects are implemented by the state. The system's operator F is formalized as a set of simulation algorithms describing the functioning of individual units within the investor's enterprise. The model describes the interactions between the units and the decision-making routines to generate a forecast for the dynamics of the resulting material and financial flows of all kinds. An example showing the interactions for a typical mineral resource project such as the development of a polymetallic ore field can be found in [12].

Once a PPP mechanism $PPPM$ is chosen (exogenously) by an expert and the initial state of the investor's enterprise X_0 is described, the recurrence equations in model (5) are used to derive the enterprise development trajectory $\{X_t, t = 0, ..., T\}$ for each scenario $\{E_t, t = 1, ..., T\}$.

For field development projects that are most typical of the natural resource sector, model (5) allows the construction of annual charts of revenues and expenses for the state and the investor and the assessment of the economic rent from the field NPV and the corresponding NPV_{inv} and NPV_{st}. The rent sharing proportions between the participants are analyzed to determine the degree of compromise between their interests and evaluate of the chosen PPP mechanism.

The basic element of the assessment procedure is the investment project model (5) within a given PPP mechanism. For field development projects, one can use the original models for an oil-and-gas complex and a mining factory [11, 12].

The road, power line, HPP, etc. construction projects are standard infrastructure projects. An HPP is the most complex object in the group; it requires a special model with a dedicated environmental block describing the preparation, construction, and operation processes. In the general case [8], the environmental block contains a set of environmental project models to implement a range of compensatory actions such as resettlement from the flooding zone, protection from flash flooding, protective measures against ice weakening, etc. The road and power line models describe the construction and operation (maintenance and service) processes. They use the general investment project model (5) supplemented by a detailed project financing scheme.

The output of the assesment procedure is a forecast of the revenues and expenses of the private investor and the state during the implementation of the entire set of projects within the assessed cost-sharing arrangement. These data allow one to assess the efficiency of the selected PPP mechanism and the degree of compromise of interests provided by positive NPV and NPV_{inv}.

Thus, the core of the proposed PPP assessment technology is a forecasting model allowing the expert to evaluate the PPP mechanism and uncover its internal imbalances (negative NPV of some of the participants). A "manual" adjustment of the cost-sharing arrangement and repeated application of the model procedure make it possible to find a partnership mechanism ensuring a compromise of interests.

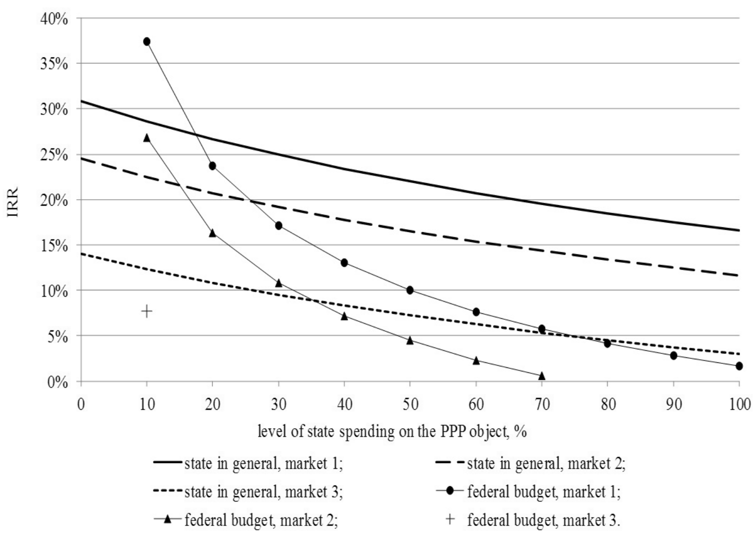

Fig. 1. State's internal rate of return for the PPP project

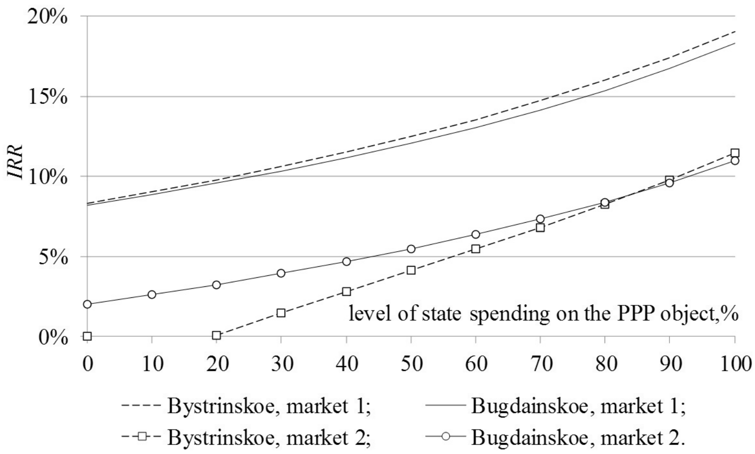

Fig. 2. Investor's internal rate of return for the Bystrinskoe and Bugdainskoe fields

The possibilities of the proposed approach are illustrated using the above described infrastructure projects implemented with the participation of the Investment Fund of Russia. Here, construction works are being completed on the Naryn-Lugokan railway line (up to the Gazimurovsky Zavod station) for a total cost of about 20 billion rubles; the project is financed by the Investment Fund of Russia. This opens up prospects for launching the first phase of the project to create the transport infrastructure for the development of mineral resources in the southeast of the Chita oblast and develop the Bystrinskoe and Bugdainskoe fields. The chosen PPP model allowed OAO Norilsk Nickel to build the key transport infrastructure element through the federal budget and create an economic background to launch the field development projects. How good was the choice of a PPP model for the Bugdainskoe and Bystrinskoe fields?

This question can be answered by applying the procedure for an assessment of a PPP model, which allows one to assess the two projects from the point of view of the investor as well as the regional and federal budgets under different PPP arrangements.

In the model experiments, the state's participates in the infrastructure project by sharing with the investor the construction costs of the railway line. The state's participation in these costs can range from 0 to 100%. The zero level corresponds to a situation whereby the investor independently finances the infrastructure project (the target object of the PPP). The 100% level means that the construction is financed from the federal budget. In the subsequent numerical experiments, we consider 11 levels of state participation with a step of 10%.

We consider three product price scenarios: optimistic (market 1), inertial (market 2), and pessimistic (market 3). The scenarios are based on a retrospective analysis and retain the general upward trends in the raw materials sector, which have been observed for the last decade. Our calculations show that the minimum number of process stages in the field development projects predetermines the maximum level of sensitivity of performance indicators to a change in the market conditions.

An analysis of Fig. 1 suggests that the internal rate of return for the federal budget financing of the railway construction falls sharply with the increase in the main PPP parameter, i.e., the state's share in the capital investments for this infrastructure. The state is in general much less sensitive; nevertheless, its internal rate of return becomes less than the modeled 5% discount for adverse market conditions if the state participation is more than 75%.

The calculations show that even under the most favorable price conditions, at least 80% state participation is required for an investor with a discount of 15 % to invest in the Bystrinskoe and Bugdainskoe fields. Any other market situation pushes the investor into the domain of smaller IRR and negative NPV (Fig. 2).

Thus, the evaluated fragment of the Transbaikal mineral resource base development program using a PPP whereby the state builds the Naryn-Gazimurovsky Zavod railway line ensures a positive return for the state in a wide range of market conditions. Within the initial technological projects for the development of the Bystrinskoe and Bugdainskoe fields, the chosen PPP gives a sufficient return for the investor under favorable market conditions only. To achieve greater price stability for the field development projects, they should plan a greater number of technological process stages.

3 PPP Mechanism Formation: Bilevel Boolean Programming Problem

In the above example, a special forecasting tool allowed the expert to reasonably split the infrastructure projects between the investor and the state. Such a cost-sharing arrangement for a small fragment of the raw-material base development program helps design a specific PPP mechanism to achieve a compromise between the interests of the investor and the state. In real life, a similar problem would comprise hundreds of fields and require a special planning model. This model complements the forecasting model and allows one to optimize the designing of a PPP mechanism within a development program for a natural resource-based region.

The planning model is formulated as a bilevel Boolean programming problem where the state's objective function is maximized at the upper level and the investor's NPV is maximized at the lower level.

We introduce the following notations:

NP,NI,NE — number of investment, infrastructural and ecological projects, T — planning horizon, $i = 1, ..., NP,\ j = 1, ..., NI,\ k = 1, ..., NE,\ t = 1, ..., T$:

- CF_{it} is the cash flow of the production project i in year t.
- EL_{it} is the cost estimate for the environmental losses in project i.
- BR_{it} is the budget revenues from project i in year t.
- WP_{it} is the wages paid during the implementation of project i.
- CI_{jt} is the cost schedule for the infrastructure project j in year t.
- ELI_{jt} is the cost estimate for the environmental losses in project j.
- IBR_{jt} is the non-project (indirect) budget revenues from the implementation of project j, which are associated with the overall economic development of the region.
- WI_{jt} is the wages paid during the implementation of project j in year t.

- CE_{kt} is the cost schedule for the environmental project k in year t.
- ER_{kt} is the cost estimate for the environmental revenue from project k.
- WE_{kt} is the wages paid during the implementation of project k in year t.
- μ_{ij} is a coherence indicator for the production and infrastructure projects: we assume that $\mu_{ij} = 1$ if the production project i cannot be implemented unless the infrastructure project j is implemented, and $\mu_{ij} = 0$ otherwise.
- ν_{ik} is a coherence indicator for the production and environmental projects: we assume that $\nu_{ik} = 1$ if the production project i cannot be implemented unless the environmental project k is implemented, $\nu_{ik} = 0$ otherwise.
- Θ and θ are the discounts of the state and investor, respectively, B_t and b_t are the budget constraints of the state and investor, respectively.

The Booleans variables:

- $z_i = 1$ if the investor runs the production project i; and $z_i = 0$ otherwise.
- $x_j = 1$ if the state runs the infrastructure project j; and $x_j = 0$ otherwise.
- $y_k = 1$ if the state runs the environmental project k; and $y_k = 0$ otherwise.
- $u_k = 1$ if the investor runs the environmental project k; and $u_k = 0$ otherwise.
- $\overline{y}_k = 1$ if the state declares readiness to undertake the environmental project k; and $\overline{y}_k = 0$ otherwise.

State's Problem
The state's goal is to maximize the discounted cash flow of the region:

$$\sum_{t=1}^{T}\Big(\sum_{i=1}^{NP}(BR_{it} + WP_{it} - EL_{it})z_i + \sum_{j=1}^{NI}(IBR_{jt} + WI_{jt} - ELI_{jt} - CI_{jt})x_j +$$

$$+\sum_{k=1}^{NE}(ER_{kt} + WE_{kt} - CE_{kt})y_k + \sum_{k=1}^{NE}(ER_{kt} + WE_{kt})u_k\Big)/(1+\Theta)^t \to \max_{x,\overline{y},y,z,u} \quad (6)$$

subject to

$$\sum_{j=1}^{NI} CI_{jt}x_j + \sum_{k=1}^{NE} CE_{kt}\overline{y}_k \leq B_t; t = 1, ..., T; \quad (7)$$

$$(y, z, u) \in \mathcal{F}^*(x, \overline{y}); \quad (8)$$

$$x_j, \overline{y}_k \in \{0, 1\}; j = 1, ..., NI, k = 1, ..., NE. \quad (9)$$

where $\mathcal{F}^*(x, \overline{y})$ is the set of the optimal solutions of the investor's problem:

Investor's Problem
The investor maximizes its total net present value:

$$\sum_{t=1}^{T}\Big(\sum_{i=1}^{NP} CF_{it}z_i - \sum_{k=1}^{NE} CE_{kt}u_k\Big)/(1+\theta)^t \to \max_{z,u} \quad (10)$$

subject to

$$x_j \geq \mu_{ij} z_i;\ \ i = 1, ..., NP, j = 1, ..., NI; \tag{11}$$

$$y_k + u_k \leq 1;\ \ k = 1, ..., NE; \tag{12}$$

$$y_k + u_k \geq \nu_{ik} z_i;\ \ i = 1, ..., NP, k = 1, ..., NE; \tag{13}$$

$$z_i \geq \nu_{ik}(y_k + u_k);\ \ i = 1, ..., NP, k = 1, ..., NE; \tag{14}$$

$$y_k \leq \overline{y}_k;\ \ k = 1, ..., NE; \tag{15}$$

$$\sum_{k=1}^{NE} CE_{kt} u_k - \sum_{i=1}^{NP} CF_{it} z_i \leq b_t;\ \ t = 1, ..., T; \tag{16}$$

$$\sum_{t=1}^{T} \Big(\sum_{i=1}^{NP} (WP_{it} - EL_{it}) z_i + \sum_{j=1}^{NI} (WI_{jt} - ELI_{jt}) x_j + $$

$$+ \sum_{k=1}^{NE} (ER_{kt} + WE_{kt})(y_k + u_k) \Big) / (1 + \Theta)^t \geq 0; \tag{17}$$

$$y_k, z_i, u_k \in \{0, 1\};\ \ i = 1, ..., NP, k = 1, ..., NE. \tag{18}$$

In the upper-level problem, the state maximizes an analogue of NPV_{st}^{int} (6) of the entire development program. The objective function is constructed so as to take into account the interests of the population and includes the economic benefits of new jobs and the accompanying environmental losses. The budget constraint (7) determines the limit for the state spending on environmental projects and infrastructure development.

In the lower-level problem, the investor maximizes its NPV (10), which takes into account the costs of the investor's environmental projects. Constraints (11)–(15) show the relationship of the production, environmental, and infrastructure projects. The form of objective function and the budget constraints (16) guarantee that the cost-sharing arrangement for the infrastructure and environmental projects between the state and the investor ensures a normal profit for the investor. Constraint (17) shows a long-term positive balance between the costs and benefits of the population from the entire array of the projects. This is a way to protect the rights of the local people, who are the first to feel the consequences of environmental pollution and who are interested in new jobs and green technologies.

The input of the planning model (6)–(18) is the full range of projects planned by the state and the private investor. The state forms a list of infrastructure projects on the basis of the efficiency estimates considering the long-term regional development prospects. The investor's choice defines a necessary set of environmental projects and depends on what the state offers in terms of infrastructure construction.

The output of the model is a set of vectors $\{z_i; x_j; y_k; u_k\}$, which determines the raw-material base development program and the cost-sharing arrangement underlying the PPP mechanism.

It is fundamentally important that the input data of the planning model be formed using the forecasting model database and individual assessment procedure. Although model (6)–(18) is formulated in comparable prices, some of its input parameters cannot

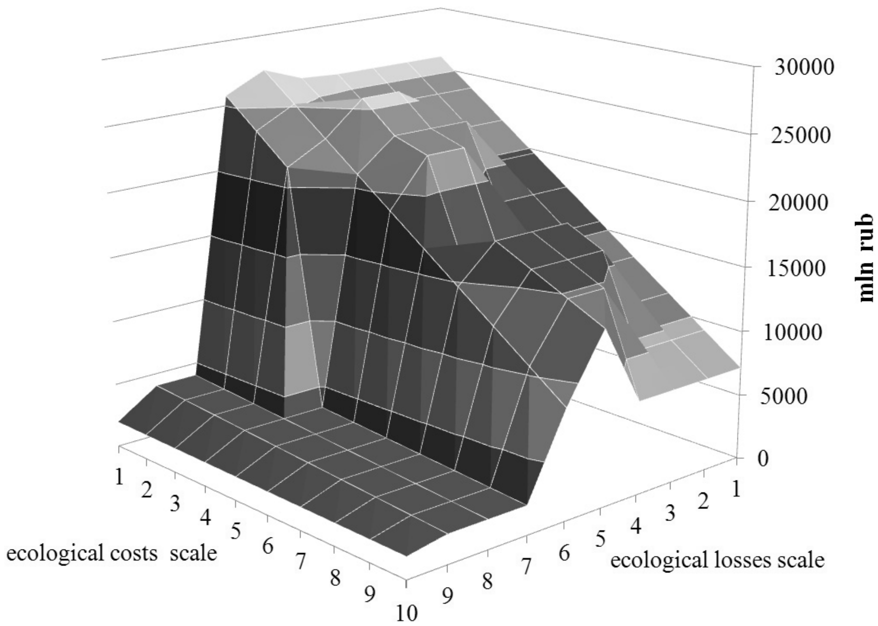

Fig. 3. Objective function of the investor

be obtained by expert assessment. Thus, the cash flow of the production projects and the budget revenues depend on the starting time of the projects and market conditions. This circumstance defines the source of these data for the planning model — they are generated in the field model by varying the project start year.

Thus, the planning model is a bilevel integer programming problem, the solving of which is, generally speaking, a serious challenge [13–18]. In [19], we have shown that the problem is NPO-hard, and the investor's problem is NPO-complete. A local search algorithm with alternating heuristics is proposed for solving this problem [19]. The algorithm gives good results for the real-life cases ($T = 20, NP = NE = 100, NI = 20$). Figs. 3–4 show some of the impirical results for the mineral resources base development program of the Zabaikalsky krai (51 fields of polymetallic ores).

The figures show change in the PPP performance depending on a ratio of ecological costs and losses. For the investor used "green" technologies with small ecological losses, value of objective function decreases monotonously when ecological costs increase. A linear nature of this dependence is broken when ecological losses increase. Then the state begins to help an investor for implementation of ecological projects. However, the state closes up an infrastructure program and stops the help an investor if pollution reaches some critical level. It leads to strong decrease of investor's NPV.

The planning model (6)–(18) is fine-tuned to the Russian PPP production infrastructure projects whereby private companies build private objects and the state builds state-owned ones. Together with the forecasting model, the planning model provides

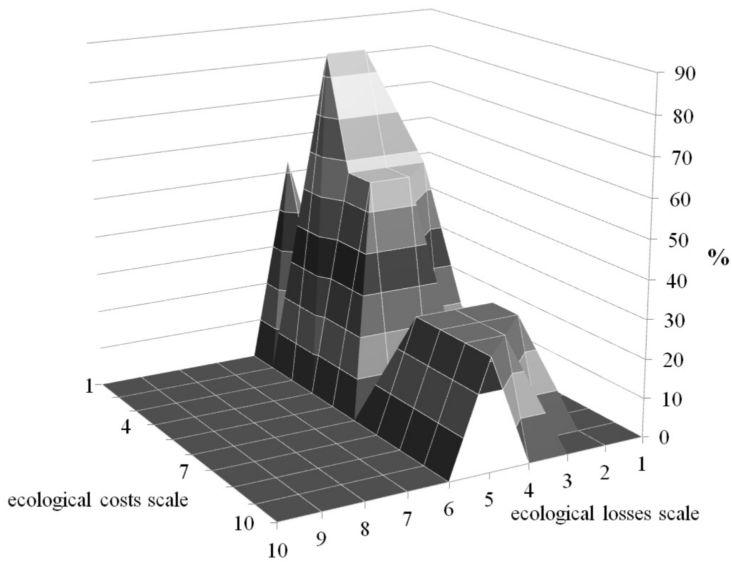

Fig. 4. Share of the state in ecological costs

a special modeling toolkit for decision-making in the development, assessment, and support of this type of PPP projects.

4 Conclusions

From the retrospective analysis of the development of the PPP institution in modern Russia we conclude that it is far from the western analogs. Although the government pays much attention to the development of the mineral resources complex, its attempts to stimulate the use of the various PPP models are not reinforced by economically sound administrative decisions. The political losses due to the failure of the PPP projects financed by the Investment Fund of Russia are big enough for the government to become seriously concerned about decision-making in this sphere.

The proposed approach to the development of economic and mathematical tools to design and evaluate PPP models may address a substantial part of these issues. The forecasting model takes into account all the features of the mineral resources complex and project financing details when evaluating a particular PPP arrangement. Having been tested in real-life contexts, the model can be used already at the decision-making stage to predict situations involving the risk of partnership termination and project suspension.

The planning model (6)–(18) is configured to address the issues faced by natural resource-based regions and to design an effective raw-material base development program. Solving (6)–(18) generates both the program and a cost-sharing arrangement between the state and the private investor, which fits into the current model of the majority of Russian PPPs. However, the development of effective methods to solve (6)–(18) for real-life cases with hundreds of projects is still a challenge. This is an area for further development of the proposed tools. Here, it might be useful to apply the approaches to solving bilevel integer programming problems [16, 17, 19].

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References

1. **Reznichenko, N. V.**: Public-private partnership models. Bulletin of St. Petersburg Univ., Series 8: Management. 4, 58–83 (2010) (in Russian).
2. **Quiggin, J.**: Risk, PPPs and the public sector comparator. Australian accounting review 14(33), 51–61 (2004).
3. **Grimsey, D., Levis, M. K.**: Public Private Partnerships: The worldwide revolution in infrastructure provision and project finance. Edward Elgar, Cheltenham (2004).
4. **Mayston, D. J.**: The Private Finance Initiative in the national health service: An unhealthy development in new public management. Financial accounting and management 15(3), 249–274 (1999).
5. **Groute, P. A.**: The economics of the Private Finance Initiative. Oxford review of economic policy 13(4), 53–66 (1997).
6. **Broadbent, J., Laughlin, R.**: Public Private Partnerships: An introduction. Accounting, Auditing and Accountability Journal 16(3), 332–341 (2003).
7. **Varnavsky, V. G.**: Public-Private Partnership. Institute of World Economy and International Relations, Moscow (2009) (in Russian).
8. **Lavlinskii, S. M.**: Public-private partnership in a natural resource region: ecological problems, models, and prospects. Studies on Russian Economic Development 21(1), 71–79 (2010).
9. **Glazyrina, I. P., Kalgina, I. S., Lavlinskii, S. M.**: Problems in the Development of the Mineral and Raw Material Base of Russia's Far East and Prospects for the Modernization of the Region's Economy in the Framework of Russian-Chinese Cooperation. Regional Research of Russia 3(4), 21–29 (2013).
10. **Glazyrina, I. P., Lavlinskii, S. M., Kalgina, I. S.**: Public-private partnership in the mineral resources complex of Zabaikalskii krai: Problems and prospects. Geography and Natural Resources 35(4), 359–364 (2014).
11. **Lavlinskii, S. M.**: Techniques of developing the economic clauses of a production sharing agreement for oil and gas projects. Studies on Russian Economic Development 18(1), 68-74 (2007).
12. **Lavlinskii, S. M.**: Models for Indicative Planning of the Social and Economic Development of a Mineral Resource Region. Siberian Branch, Russian Academy of Sciences, Novosibirsk (2008) (in Russian).
13. **Dempe S. J.**: Foundations of bilevel programming. Kluwer Academ. Publishers, Dordrecht (2002).
14. **Davydov, I., Kochetov, Yu., Plyasunov, A.**: On the complexity of the (r|p)-centroid problem in the plane. TOP 22(2), 614–623, (2014).
15. **Plyasunov, A. V., Panin, A. A.**: The pricing problem, Part I: Exact and approximate algorithms. Journal of Applied and Industrial Mathematics 7(2), 1–14 (2013).

16. **Plyasunov, A. V., Panin, A. A.**: The pricing problem, Part II: Computational complexity. Journal of Applied and Industrial Mathematics 7(3), 1–13 (2013).
17. **Kononov, A. V., Kochetov, Yu. A., Plyasunov, A. V.**: Competitive facility location models. Computational Mathematics and Mathematical Physics 49(6), 994–1009 (2009).
18. **Davydov, I., Kochetov, Y., Carrizosa, E.**: A local search heuristic for the (r|p)-centroid problem in the plane. Computers and Operations Research 52(B), 334–340 (2014).
19. **Lavlinskii, S., Panin, A., Pliasunov, A.**: A two-level planning model for Public-Private Partnership. Automation and remote control 11, 89–103 (2015).