Probabilistic assessment of investment projects for the development of titanium dioxide deposits

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Abstract. The paper substantiates the possibility and scope of the simulation method for the purpose of assessing the probability of the effectiveness of the implementation of a strategic project for the development of deposits and the production of titanium dioxide in Russia. The results of the work are based on the methods of complex economic analysis and economic and mathematical modeling. The main and additional effects of the implementation of a strategic investment project of combining several titanomagnetite ore deposits in the mining complex are identified, an economic–mathematical model for estimating the probability of the effectiveness of the project for the production of titanium dioxide is proposed, taking into account changes in environmental factors. According to the results, the investment project for the construction of an industrial complex for the titanium dioxide production from a set of titanomagnetite ore deposits - Kolvitsky, Afrikandsky and Pudozhgorsky will be successfully implemented. The results of the study can be used for a preliminary feasibility study assessment of titanomagnetite ores mining and further stages of project planning and implementation.

1. Introduction

Due to the need to develop advanced industries in Russia that consume titanium and its compounds, as well as taking into account the growing demand for synthetic and mineral raw materials for the construction and paint industries in the near future, there will be a greater shortage in provision of this raw material.

The world market of titanium dioxide pigment is characterized by a high degree of consolidation with several large producers located in the USA, Europe and in the countries of the Asia-Pacific region. The global production capacity of pigment TiO₂ averages about 6.6 million tons per year, 71% of which comes from China, the USA, Germany, the United Kingdom and Japan. Major producers of titanium dioxide pigment are Du Pont (the USA) - 22%, Millenium (the USA) - 13%, Tronox (the USA) - 12%, HunstmanTioxide (the UK) - 10% and Kronos (Germany) -10%. About 24% of titanium dioxide is produced in North America, 18.7% in Western Europe, 5% in Eastern Europe and the CIS, 35.2% in Asia, 4.3% in Australia, 1.2% in South America, 0.5% in Africa [1, 2, 4, 9].

Production of titanium dioxide pigment in the Russian Federation is currently characterized by low production, insufficient brand assortment and low quality. The production technology at existing domestic enterprises provides the possibility of producing limited titanium dioxide brand composition - no more than 3-4 brands, along with Kemira, DuPout, Bayer, Tioxide, which produce several dozen
brands. It does not sufficiently satisfy the needs of Russian industry. The quality of produced pigments lags behind the quality of imported pigment. Only 20% of white pigments correspond to the level of world standards [2, 9].

Analysis of the raw material base shows that Russia has large balance reserves of titanium dioxide, according to various sources, from 110 to 591.5 million tons. Off-balance reserves are 868.6 million tons. By the sum, the country ranks second in the world in terms of reserves after China [2, 3].

However, in Russia there is only associated mining of titanium raw materials in the Murmansk region at the apatite-nepheline deposits of the Khibiny group and at the Lovozero rare metal deposit, and in the Amur region at the Kuranakhilmenite-titanomagnetite deposit.

The perspective areas of titanium dioxide production in the Russian Federation include a number of modern projects: projects for the development of the Gremyakha-Vyrmes deposit (Murmansk region) and Tsentralnoje deposit (Tambov region by Norilsk Nickel), OJSC “VSMPO-Avisma Corporation”, Yarega deposit within the licensed area of OJSC “YaregaRuda”, JSC “Crimea Titan” transferred to the Russian LLC “Titanium Investments”. The restraining factors for the Russian deposits have so far been insufficiently studied open mined deposits, large deposits of rutile-containing, ilmenite and ilmenite-magnetite ore that are exploited and prepared for exploitation. More than 80% of titanium dioxide is concentrated in this deposits. After the collapse of the USSR these deposits turned out to be outside the Russian Federation. The quality of ore of Russian objects is much worse than in the developed primary deposits like: Lac Tio (32% TiO$_2$) in Canada and The Tellnes (18% TiO$_2$) in Norway, but comparable to the Chinese Panzhihua deposit (9.5% TiO$_2$) and ranges from 3.3% (Tulunskoye deposit) to 11, 5% (Podlysanskyay group). The lack of cost-effective technologies for the enrichment of ore with a low content of TiO$_2$ is also obvious [1, 3].

The analysis showed that the constraining factors for the development of the Russian titanium industry are insufficient knowledge of mineral deposits, the remoteness of most deposits from infrastructure facilities, transportation routes, significant capital costs in enrichment capacities, long design and construction of production facilities, high operating costs. This situation is also caused by the complex scheme of enrichment and low content of the useful component in the ore, the need for complex use of mined minerals, lack of qualified personnel, experience in implementing such projects and preferences for mining companies. Such companies operate low-profitable deposits and have insufficient support from the state.

Considering the high degree of uncertainty of the external and internal environment, it is expedient to estimate the cost of projects for the development of titanomagnetite deposits taking into account the assessment of the probability range of a positive NPV [5, 6, 8, 9].

2. Methods of the study
To estimate the probability index of a positive NPV, taking into account the influence of variable environmental factors, a stochastic estimation method should be applied. The essence of the method consists in the distribution of probabilities of the prevailing uncertainty on a given set (regression analysis) with the subsequent application of simulation modeling of possible particular scenarios.

As the most significant variable factors of external environment were selected: the volume of production, the cost of the finished product, the tax environment.

Using the corridor minimum and maximum values of external environment factors, by applying the density function of the normal distribution, an array of four key indicators of net discounted income was calculated.

According to the economic-mathematical method of simulation, the probability of a positive NPV, considering changes in the production volume factors, cost of finished products, tax environment in the selected ranges, is determined from the array of dynamic data calculated by the formula:

$$NPV_1 = -\sum_{i=1}^{\alpha} \frac{IC_i^T}{(1+r)^T} + \sum_{i=1}^{\alpha} \frac{C_i^T - CO_i^T}{(1+r)^T} = -\sum_{i=1}^{\alpha} \frac{C_i^T + CO_i^T}{(1+r)^T} + \sum_{i=1}^{\alpha} \frac{(VP_{plan} + \Delta VP_{plan}) - (C_i + \Delta C_i) - (C + \Delta C)}{(1+r)^T}$$
the coefficients i, j, k are the variable value of the corresponding indicator of the threshold value of the investment, cost of commercial products, the total value of the costs, respectively;
ICO - the value of the initial investment in period t;
CI - cash flow from the investment project in period t;
CO - cost in an investment project in the period t;
CVPF and ∆CVPF - the value of capital costs and the coefficient of capital costs changes under the influence of environmental factors, respectively;
VP_plan and ∆VP_plan - the volume of commodity products production and the coefficient of change in the volume of commodity products production under the influence of environmental factors, respectively;
Cc and ∆Cc - the price of titanium dioxide and the coefficient of price change under the influence of environmental factors, respectively;
C and ∆C - the value of operating costs and the coefficient of change in operating costs under the influence of environmental factors, respectively.

![Diagram](Image)

**Figure 1.** Conceptual scheme for calculating the criterion for the effectiveness of the investment project implementation

All possible options of variables according to the NPV project are written into the n / m matrix, where the scatter of all different values of variables is presented in the array with a frequency of the normal distribution, Figure 1. 

As initial conditions are the conditions of the titanomagnetite ore deposits of the Kolvitskoe, Afrikandskoe, Pudozhgorskoye located on the Kola Peninsula. The deposits are characterized by shallow layers and the possibility of mining by the open method; ore with a TiO2 content of less than 10% require mandatory pre-enrichment with the release of titanomagnetite concentrate.

The range of price changes for finished products of titanium dioxide varies considerably depending on the quality characteristics and is 50-150% of the average global price. For example, in 2017, the price of pigment in Russia ranged from 900 to 2,050 dollars per ton. The cost of DuPout titanium dioxide, depending on the brand assortment, is $3200-3800 per ton. [2, 9, 10].

The indicator of the volume of production, in terms of the implementation of the mining project for the extraction of titanium raw materials, depends on the volume of the Russian market and is 80 thousand tons. Considering the dynamics of growth in domestic demand for titanium dioxide and the conditions of a highly concentrated global market (6.6 million tons / year - 71% in China, the USA, Germany, the United Kingdom and Japan), the range of output should be taken at a rate of 50% from
the mean of 2017. Statistics show that the production of titanium dioxide pigment increases annually by 1.5-1.8%, while the price for it also increases by an average of 2% [2, 7, 8].

The tax environment factor takes into account preferences for deposits in the Arctic zone, in the form of preferential taxation, reduction of tariffs for products and services of natural monopolies, as well as the use of subsoil use rights as government guarantees zone against commercial risks for financing the areas of the Arctic.

3. Results & discussion

As a result of the calculations, 390,625 variations of the NPV values of the investment project were obtained using a computer program written by the author. All results were included in one of 4 groups according to key thresholds:

1) In case the project will not be released on a positive financial flow with the given indicators;
2) If the project comes to a positive financial flow, but does not reach a payback throughout the life cycle;
3) If the project comes to self-sufficiency during the life cycle, but does not receive a profitability indicator above 0.5% - 10%;
4) In case the project will reach a high rate of profitability and bring significant profits.

According to the obtained results, the investment project for the formation of an industrial complex for the production of titanium dioxide will be successfully implemented in 47.87% of cases in key NPV indicators changings influenced by factors such as volume, price, and tax environment, Figure 2.

At the same time, the range of final indicators of the project will vary from 16.9 billion rubles (with the most likely development scenario) to 50.26 billion rubles - the most positive option. According to the main indicators of economic efficiency analysis - the project can be accepted for implementation.

For further work it is necessary to develop detailed investment and technical projects for the organization of investment financing. On the basis of the results obtained, it is advisable to recommend a draft for consideration by the state commission on Arctic issues to include a preliminary list of the pool of investment projects as part of the program to create the Kola support zone.

![Figure 2. Indicators of the probability of the investment project successful implementation](image)

The overall probability that the project will pay off is 47.87%

42,1% NPV=50 262,56 mln. RUB
5,77% NPV= 16 969,85 mln. RUB
38,8% NPV= 14 990,88 mln. RUB
13,3% NPV= -118,96 mln. RUB

Analysis of the titanium dioxide resource base shows that not every field with a high content of useful component (for example, Yarega ore, the Komi Republic) is possible to develop now due to the many limitations of projects implementation. We mean high threshold values of investments in
construction assets on mining and processing of minerals, additional capital expenditures in geological exploration, complex enrichment technologies, high environmental requirements for the production and quality of mineral raw materials, high operating costs for the enrichment of titanomagnetite raw materials, price volatility and competition from global producers of raw materials [10, 11, 12]. Based on these conditions, to increase the efficiency of implementation of projects for mining titanomagnetite deposits, one should use the levers of state support and the capabilities of a developed base of old industrial regions.

The Murmansk region as part of Northwestern Federal District can act as a perspective platform for the implementation of a project to build an industrial complex due to the presence of a developed infrastructure, human resources, a developed industrial structure, research centers and related development programs [13, 14, 15].

Implementing projects to create titanium dioxide industry, one should take into account the effects generated by the economic and geographical position of the complex, which are manifested in capital infrastructure costs savings, the use of budget financing through state programs for the development of the region, support zones and increased industrial competitiveness.

The main advantages of the implementation of titanium dioxide mining projects in the Murmansk region are: the presence of several deposits of titanium-magnetite ore with similar mining and geological conditions and economically reasonable indicators of mining; favorable geographical location near the ice-free port and ports of the EU, the presence of a developed infrastructure in the form of roads and railways, the presence of energy facilities; human resources, scientific centers for the development of the mining industry, the implementation of the program for the development of the Arctic zone, where projects for the development of titanium dioxide deposits are included in the list of investment projects [12, 16, 17].

Projects realization for the development of titanium dioxide deposits in Northwestern region allows to reduce capital and operating costs due to economic and geographical conditions, expressed in the developed infrastructure; human resource capacity of the industrialized region, the concentration of extractive industries and research centers, the favorable location of the non-freezing port, close transportation to EU ports, the implementation of programs for the long-term socio-economic development of the region and the Kola support zone.

References

[1] Fedoseev S V 2016 Analysis and classification of resource-saving technologies of the mineral resource basereproduction in the titanium industry: Papers of the Mining Institute. Saint-Petersburg Mining University 221 p 756
[2] Fedoseev S V 2016 The prospects of creation and use of modern resource-saving technologies in the mining sector of the Russian economy (with titanium industry as an example): International Journal of Applied Engineering Research 11 (16) p 9014
[3] Nikolaeva O A 2012 Prospects for the development of production of titanium raw materials deposits of the Kola Peninsula: National interests: priorities and security 47 (188) p 31
[4] Arkhipova J A 2010 The current state of the titanium ore base of the Far East of Russia and its development: Regional economy. National interests: priorities and security 32 (167) p 36
[5] Marinina O A and Nevskaya M A 2017 Cost management of mining project life cycle: International Multidisciplinary Scientific Geo Conference Surveying Geology and Mining Ecology Management SGEM 17 V 17 (13) p 175
[6] Marinin M and Marinina O 2017 Improvement of project decisions efficiency and cost optimization at the mine engineering stage of reclamation in the context of open pit ore mining: 17th International Multidisciplinary Scientific Geo Conference SGEM 2017 17 (13) p 423 DOI: 10.5593/sgem2017/13/S03.054
[7] Ponomarenko T V et al 2018 Complex use of mineral resources as a factor of the competitiveness of mining companies under the conditions of the global economy: International Journal of Mechanical Engineering and Technology (IJMET) 9 (12) p 1215 ID: IJMET_09_12_123
[8] Kamala Kanta Sahu et al 2006 An overview on the production of pigment grade titanium from titanium-rich slag: Waste Management & Research 24 c 74
[9] Manuel Jesús Gázquez et al 2014 Review of the Production Cycle of Titanium Dioxide Pigment: Materials Sciences and Applications 5 c 441 Available from: http://file.scirp.org/pdf/MSA_2014052916520642.pdf [Accessed 20th December 2019]
[10] Mihail M et al 2018 Drilling and blasting influence on the process of dust particles formation: International Journal of Mechanical Engineering and Technology 9 (97-103) p 97
[11] Sidorov D V et al 2018 Economic justification of innovative solutions on loss reduction in the aluminium sector of Russia: Gorny Zhurnal № 6 p 65
[12] Didenko N et al 2018 Innovative and technological potential of the region and its impact on the social sector development International Conference on Information Networking 2018-January p 611
[13] Didenko N I et al 2018 System of econometric equations of the world market of natural gas: International Conference on Information Networking 19 p 217
[14] Didenko N et al 2018 A country competitiveness analysis. Adl-model involved: International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM V 18 (5) p 3
[15] Tsvetkova A and Katysheva E 2017 Ecological and Economic Efficiency Evaluation of Sustainable Use of Mineral Raw Materials in Modern Condition: 17th International multidisciplinary scientific geoconference SGEM 2017 17(13) p 259
[16] Nevskaya M et al 2016 The analysis of the problems of mining waste products in the mineral resources sector of the Russian Federation: International Journal of Applied Engineering Research 11(16) p 9018
[17] Vasilev Y and Vasileva P 2017 Improving efficiency of coal provision of TPS in the Russian federation: 17th International multidisciplinary scientific geoconference SGEM 2017 17(13) p 479