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Research Article

Methodology for calculating the criteria of economic efficiency of investments in nuclear icebreakers*

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Abstract

An economic and analytical model for evaluating the criteria of efficiency (profitability) of investments in the projects of innovative nuclear icebreakers of the Northern Sea Route is suggested. The model is based on the new analytical representation of the methodology for forecasting the investment project efficiency that is widely used in international practice. The mathematical expression for the net discounted income provides convenient formulas for calculating several investment efficiency criteria for nuclear icebreakers: internal rate of return, minimum annual revenues from icebreaker convoys, discounted payback period, and the volume of delivered cargo. The paper gives estimates of the criteria for the efficiency of investments in "*Leader*" class icebreakers that depend on the discount rate of cash flows, capital, and operating costs. It is shown that at high capital costs, typical for construction of "*Leader*" class nuclear icebreakers, the minimum required revenue of an icebreaker, representing a financial burden for ships transporting cargo along the NSR, rapidly increases with the growth of discount rate and the reduction of investment payback period. This means that the profitability of such icebreakers is only possible at low discount rates of 2–3% per year, which is an extremely low-interest credit. Even with low interest and impressive technical characteristics of the icebreaker (high speed of navigation, large number of ships in the caravan and their maximum capacity) the payback period would exceed 25 years.

Keywords

Northern Sea Route (NSR), nuclear icebreakers, capital and operating costs, revenues, investment efficiency criteria, ship escort tariffs

Introduction

In the 21st century interest is growing in the development of the Arctic zone by the state of Russian Federation (Frolov 2015, Kashka et al. 2016, Ruksha et al. 2016, Sarkisov et al. 2018, Kashka et al. 2021, Knyazevsky acces. Apr. 10, 2021). In particular, the task of developing the Northern Sea Route (NSR) and augmentation of its cargo traffic to 80 million tons per year is set in the Presidential Decree No. 204 dated May 7, 2018 "On the national objectives and strategic goals of the development of the Russian Federation for the period until 2024". The 5,600-km long Northern Sea Route begins in the Kara Strait and ends in the Providence Bay. "The plan of the development

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of the infrastructure of the Northern Sea Route for the period until 2035" prepared by the Rosatom State Atomic Energy Corporation enacted in December 2019 by the Government of Russia provides for the organization of year-round navigation along the NSR waterway and the development of competitive transborder and national transport corridor on the basis of the NSR. Beginning from 2019 the Rosatom State Corporation acts as the operator of the NSR infrastructure; some information pertaining to this new direction is summarized in Table 1 according to the data from (Frolov 2015, Frolov 2019, ROSATOM Key Results).

Table 1. Summary information about new products of the Rosatom SAEC for the period of 2015–2020

Indicators	2015	2016	2017	2018	2019	2020
Rosatom SAEC, earnings (total), billion rubles	821.2	878.1	967.4	1033.9	1151.9	1207.2
Earnings from new products, billion rubles	125	147.4	170.9	196.7	227.9	261.6
Fraction of new products in the Rosatom SAEC earnings, %	15.2	16.8	17.7	19.0	19.8	21.7
Portfolio of orders of new products for 10 ahead, billion rubles	583.5	1018.8	814.1	1082.6	1169.1	1602.1
FSUE Atomflot, earnings (total), billion rubles	6.073	6.364	6.622	6.806	9.476	н.д.
Fraction of new products in the FSUE Atomflot earnings, %	4.9	4.3	3.9	3.5	4.2	н.д.
Total tonnage of vessels convoyed along the NSR, million tons(number of vessels, units)	2.043 (195)	5.29 (400)	7.2 (492)	12.7 (331)	31.5 (510)	33.0 (497)

According to the data in the above table, relative fraction of the FSUE Atomflot earnings from new products (business areas) of the Rosatom SAEC amounts to slightly more than 4% of the total earnings from new products but, however, it does have a growth tendency. At the same time the planned volume of cargo traffic along the NSR was again overachieved in в 2020: 479 vessels with total tonnage of more than 32.4 million tons were escorted by nuclear icebreakers. Earnings of the FSUR Atomflot and earnings of the Rosatom SAEC from this business will be further bolstered by the recently adopted amendment of the Merchant Marine Code (Federal Law No. 94-FZ 2021).

In accordance with given documents the FSUE Atomflot would conduct construction at the "Baltiysky Zavod" JSC of five new generation nuclear icebreakers from the "Project 22220" equipped with coupled innovative RITM-200 nuclear reactors generating propulsive power of the icebreaker (propeller power) reaching 60 MW (Table 2) (Knyazevsky et al. 2014, Kashka et al. 2016, Ruksha et al. 2016, Resolution of the Government 2020, RITM 2020, Zverev et al. 2020, Kashka et al. 2021, Knyazevsky acces. Apr. 10, 2021).

Cost of icebreaker amounts to 37–52 billion rubles. Construction of three nuclear icebreakers of Leader type under Project 10510 equipped with a pair of innovative RITM-400 nuclear reactors generating 120-MW(th) icebreaker propulsive power (See Table 2) is organized at the Zvezda LLC Shipbuilding Complex for ensuring year-round navigation in the eastern part of the NSR waterway and maintaining commercially efficient cruising speed. 127.6 billion rubles are allocated from the budget for the period of 2020–2027 for building the lead Project 10510 icebreaker (Resolution of the Government 2020).

Table 2. Engineering and financial characteristics of new icebreakers

Characteristic	Project 22220, "Arktika" type icebreaker	Project 10510, "Leader" type icebreaker
Principal region of operations	**Western part of Arctica – year-round, Eastern region – summer-autumn**	**All Arctica regions, year-round**
Length, m	173	209
Width, m	34	47
Water draft, m	10,5	13
Propeller power, MW	60	120
Speed on ice-free water, knots	22	20
Icebreaking capability (ice thickness penetrable at a speed of 1.5–2 knots), meters	2.9	4.3
Crew complement, persons	53	60
Capital investment, billion rubles	37–52*	127
Operating costs, million rubles/day	3–4*	4–5*
Nuclear propulsion plant	RITM-200	RITM-400
Thermal power, MW	2×175	2×315
Duty factor (reactor design SOW requirement)	0.65	0.65
Uninterrupted operation time, hours	26 000	26 000
Required reactor core power generating capacity, TW·hour	4.5–7.0	6.0
Fuel enrichment, %**	17.5–19.7	17.5–19.7
Fuel burnup, MW·day/kg (g ^{235}U/MW·day)	77 (2.3)	77* (2.3)*
Time period between fuel reloading, years	4.5–7	6–10
Preset lifespan, years	40	40
Construction period, years	6*	8*

* Indicative figures. ** Average mass fraction of ^{235}U in uranium 46.7% (RITM-200) and 53.8% (RITM-400) is indicated in (Frolov 2019).

Commercial use of the Arctic presupposes that Arctic cargo transport along the NSR must be competitive against cargo transport across South Seas circumventing Eurasia. The costs of icebreaker escort are the additional financial burden in the conduct of cargo transport operations (Executive order of the Federal Tariff Service 2014, Annex to the Executive 2014, Zagorodnikov 2017a, Mu Aril'd 2020). At present time the tariffs for icebreaker assistance for vessels are differentiated considering the ice reinforcement class and the gross registered tonnage of the escorted vessel, the distance and zonality of the vessel escort, season of navigation (summer-autumn or winter-spring) (Annex to the Executive 2014, Executive order of the Federal Tariff Service 2014, Zagorodnikov 2017a). However, as it was noted in (Mu Aril'd 2020), "no coherent analysis of costs and benefits from year-round operation of the sea route has been published so far". Attempt was made in (Mu Aril'd 2020) to estimate the volume of cargo transport and the level of tariffs for covering operation and capital expenditures for the icebreaker fleet as a whole.

The purpose of the present study is the development of the economic analysis model for evaluating microeconomic criteria of efficiency (profitability) of investments in the projects of nuclear icebreakers for the NSR on the basis of the methodology previously developed at the NRNU MEPhI (Kharitonov 2014, Kharitonov et al. 2018) including the determination of the revenues and the icebreaker payback period, the internal rate of return, minimum permissible tariffs and volumes of cargo transport depending on the capital and operating costs for the icebreaker.

Criteria of efficiency of investments in the nuclear icebreaker

The main microeconomic criterion of efficiency of the investment project characterizing its profitability is the net present value *NPV*, i.e., essentially, the net discounted income accumulated during the period of the project's lifecycle including building and operation of the icebreaker reduced to a certain time moment T_c (Kharitonov 2014, Kharitonov et al. 2018). The task for the investor is to define engineering and financial parameters of the project (icebreaker) determining annual costs and revenues for which the net present value has the largest positive value. When $NPV < 0$ the project is unprofitable. A new illustrative working formula for *NPV* calculation with constant discount rate *r* was derived in (Kharitonov et al. 2018) in the following form by summing up the costs and revenues (earnings) with consideration for their non-simultaneity:

$$NPV = -\sum_{t=1}^{T_c} \frac{K_t}{(1+r)^{t-T_c}} + \sum_{t=T_c+1}^{T_c+T_o} \frac{R_t - Y_t}{(1+r)^{t-T_c}} = -K\varphi_c + \frac{R-Y}{r}\varphi_o, \quad K = \sum_{t=1}^{T_c} K_t \quad (1)$$

where *K* are the net capital costs (rubles) aggregated over the whole period of icebreaker operation T_c, years; R_t and *R* are the operating and the yearly average (over the whole period of operation) revenues, RUB/year; Y_t and *Y* are the current and the yearly average operating costs, RUB/year. Dimensionless reduction factors φ_c and φ_o take into account the period of construction T_c and the period of operation T_o of the icebreaker, respectively, and are described by the formulas derived from the definition of the weighted average value:

$$\varphi_c = \frac{1}{K}\sum_{t=1}^{T_c} \frac{K_t}{(1+r)^{t-T_c}} \approx \frac{(1+r)^{T_c-1}}{rT_c} \quad (2)$$

$$\varphi_o = \frac{r}{R-Y}\sum_{t=T_c+1}^{T_c+T_o} \frac{R_t - Y_t}{(1+r)^{t-T_c}} \approx 1-(1+r)^{-T_o} \quad (3)$$

Right sides of expressions (2) and (3) correspond to the base case scenario with constant annual costs and revenues. Reduction factors correspond to the tying of the moment of reduction of cashflows to the beginning of operation of the icebreaker and indicate the difference between the real project from the "ideal" one for which $\varphi_c = \varphi_o = 1$. For instance, for 8-year period of construction of the icebreaker, 40-year operation and discount rate equal to 5%/year the reduction factors calculated from expressions (2) and (3) are equal to $\varphi_c = 1.19$ and $\varphi_o = 0.86$.

The following three auxiliary but, nevertheless, popular and important in the analysis criteria of competitiveness stem out from the mathematical definition of the NPV: internal rate of return *IRR*, reduced (minimal) revenues of the icebreaker *LR* (Levelized Revenue) and the discounted payback period Θ counted from the beginning moment of the icebreaker operation. The *IRR* value serves as the upper limit of the discount rate (profitability of the project $r < IRR$) and, correspondingly, of the interest rate for the attracted financial resources (loans) and is determined from the condition $NPV(r = IRR) = 0$ by the following expressions:

$$IRR \times \varphi_c(r = IRR)/\varphi_o(r = IRR) = IRR_0;\ IRR_0 = (R - Y)/K. \quad (4)$$

Here, IRR_0 (1/year or %/year) is the internal rate of return for the "ideal" project (with $\varphi_c = \varphi_o = 1$) equal to the ratio of the yearly average revenues to the capital costs, where $IRR<IRR_0$. For example, for $IRR_0 = 12.8$%/year, $T_c = 8$ years and $T_o = 40$ years we obtain $IRR = 9$%/year. The higher is the *IRR* value the more sustainable is the project and the wider are the possibilities to look and find the required loan offers on the market. As follows from (4), internal rate of return is the higher the larger is the yearly average revenues $R - Y$ and the smaller are the capital costs *K*.

The minimal possible yearly average revenues of the icebreaker *LR* (RUB/year) for which the project does not cause losses and $NPV = 0$ is determined from (1) in the following form:

$$LR = AK + Y;\ A = r\varphi_c/\varphi_o, \quad (5)$$

where *A* is the effective norm of depreciation of capital costs, $A > r$. The value $AK + Y$ is called the reduced yearly costs consisting of the capital *AK* and the operating *Y* components. Correspondingly, the value of the minimal yearly average revenues from the icebreaker is equal to the present value. With such revenues the costs associated with the icebreaker are compensated by the end of its lifecycle, i.e., after $T_o \approx 40$ years after the beginning of its operation.

If the lender requires the return of investments after $\Theta < T_o$ years after the beginning of operation of the icebreaker, then the value of revenues during the time period Θ must exceed the value (5) in accordance with Formula (Kharitonov et al. 2018)

$$LR_\Theta = \begin{cases} A_\Theta K + Y, & T_c \le t \le T_c + \Theta; \\ Y, & t > T_c + \Theta. \end{cases} \quad (6)$$

Here the effective norm of depreciation of capital costs during the period Θ of return of investments $A_{\Theta} = r\varphi_c/\varphi_{\Theta}$, where $\varphi_{\Theta} = \varphi_o(\Theta) = 1 - (1 + r)^{-\Theta}$, exceeds the value A in (5) because $\varphi_{\Theta} < \varphi_o$ with all remaining conditions being equal. For instance, for Θ = 15 years, r = 5%/year, T_c = 8 years and T_o = 40 years we obtain φ_{Θ} = 0,519 and A_{Θ} = 11.5%/year > A = 6.9%/year, i.e., the capital component of the present value is increased by almost two times. After settling accounts with the lender ($t > T_c + \Theta$) the icebreaker is operated without generating profit, with earnings equal to the operating costs, which is required by the definition of LR corresponding to $NPV = 0$. It follows from the comparison of espressions (4) and (5) that for achieving profitability of the project internal rate of return IRR_0 must exceed the depreciation rate A.

Discounted payback period of investments in the icebreaker is determined in the general case by the sequential calculation of NPV as a function of time of implementation of the project. From the right side of (1) with reduction factors (2) and (3) we obtain the analytical expression for estimating the payback period Θ (after the beginning of operation of the icebreaker) as follows:

$$\Theta = -\ln(1 - r\varphi_c/IRR_0)/\ln(1 + r). \quad (7)$$

For instance, with IRR_0 = 15%/year the payback period for the icebreaker Θ will amount to 10 years when the discount rate does not exceed 5%/year. It is clear that the conditions of profitability of the project require low discount rates and, correspondingly, low-interest credits.

Thus, using expressions (1) – (7) it is possible to analytically estimate the main profitability criteria for icebreaker projects. Requirements imposed on key factors influencing profitability of icebreaker projects (high positive values of NPV and the internal rate of return IRR, minimal earnings LR and payback period Θ) are the following: reduction of capital and operating costs and duration of icebreaker construction, as well as facilitation of access to cheap borrowing (low discount rate).

Estimation of criteria of efficiency of investments in leader-type icebreakers

In accordance with (Resolution of the Government 2020) K = 127 BRUB (BRUB = 1×10^9 rubles) are allocated from the budget for the eight-year cycle of icebreaker building (T_c = 8 years),it must be noted that Leader-type icebreakers are the most expensive civilian vessels in Russia. Yearly average capital costs are accepted here at the level of $K_t = K/T_c \approx$ 15.9 BRUB/year. Capital costs increase, as a rule, with increased duration of icebreaker building. For the sake of argument let us assume $K = 15{,}9T_C$. There is no publicly available reference to icebreaker operating costs in the references. Estimations of daily nuclear icebreaker rent equal to 3–5 MRUB/day (MRUB = 1×10^6 rubles) are provided in (Mu Aril'd 2020). Annual operating costs for Leader-type icebreakers amount to 2.9 BRUB/year (≈ 7.94 MRUB/day) and are presented in (Zagorodnikov 2017a). Strictly speaking both fixed and variable operating costs (expenses) must be differentiated; however, no such information is available in accessible references. Since the icebreaker requires year-round maintenance, we assume yearly average operating costs to be equal to $Y = 4\times365 \approx$ 1.5 BRUB/year including costs of reactor fuel reloading that needs to be done every 6–10 years. In pursuance with regulatory document "RD 31.21.86-82." Time rates for reloading nuclear reactor cores" updated on 01.01.2021, reactor reloading takes no more than 35 days (RD 31.21.86-82).Substituting the acquired data lets us estimate using Formulas (5) and (6) the minimal revenues required for breakeven operation of the icebreaker. As follows from Fig. 1, minimal revenues rapidly increase with increased capital costs, duration of the icebreaker building period and discount rates, as well as with decreased investment (loan) return rates. Thus, for discount rate equal to 2–3%/year, icebreaker cost equals to 111 BRUB,

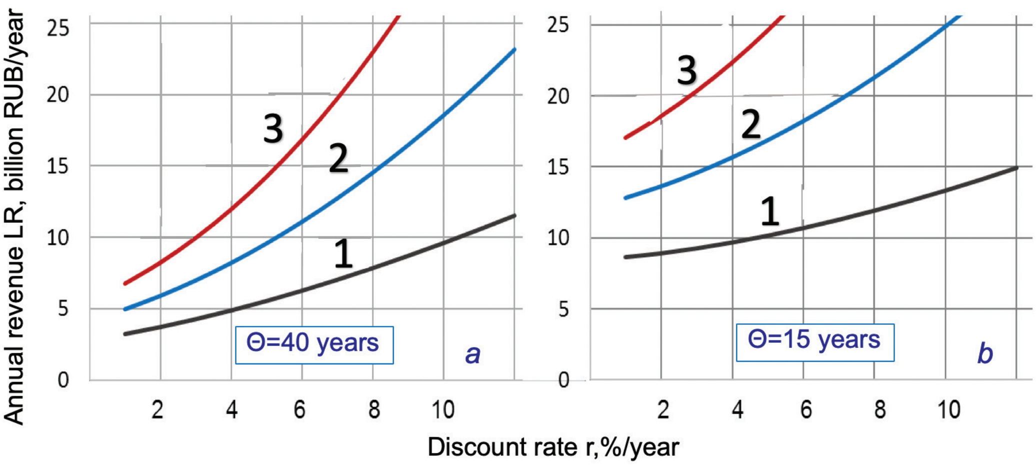

Figure 1. Minimal required annual revenues for Leader-type icebreakers depending on the duration of construction T_c = 4–10 years, capital costs K = 64–159 Billion RUB, discount rate r = 1–11%/year and the investment return period Θ = 40 years (a) and 15 years (b) with yearly average capital costs K/T_c = 15.9 Billion RUB/year and operating costs Y = 1.5 Billion RUB/year. Calculation performed using Formulas (5) and (6). **1** – T_c = 4 years, K = 64 Billion RUB; **2** – T_c = 7 years, K = 111 64 Billion RUB; **3** – T_c = 10 years, K = 64 Billion RUB.

duration of icebreaker building period of seven years and the investment return period of 15 years (middle curve in Fig. 1b) the icebreaker project will be profitable if annual revenues exceed 13.5–14.5 BRUB/year. Such low discount rates demonstrate the impossibility of borrowing from commercial banking sector to cover the icebreaker capital costs. Overrun of duration and increased cost of icebreaker building significantly negatively affect the potential of return of investments.

If the discounted payback period Θ (years) in (7) is assumed to be preset, then it is possible to determine the dependence of the minimal permissible internal rate of return IRR_0 on the values of Θ and the discount rate (Fig. 2a), and to estimate using the determined IRR_0 value from Formula (4) the dependence of the minimal permissible yearly average revenues $R = IRR_0\mathrm{K} + Y$ on Θ and r (Fig. 2b). As it is evident, minimal permissible revenues for the icebreaker rapidly increase with increasing discount rate and reducing investment payback period. As in the previous case, with low discount rates of 2–3%/year, icebreaker cost of 127 BRUB, icebreaker building period of eight years and the payback period of less than 20 years the icebreaker project will be profitable if the annual revenue value will exceed 10–11 BRUB/year (Fig. 2b). Since earnings for the icebreaker represent financial load for the escorted vessels transporting cargo along the NSR, then for the purpose of enhancement of competitiveness revenues of icebreakers must be minimized, however remaining sufficiently high for ensuring cost efficient operation of the icebreaker.

Estimation of cargo transport volumes and tariffs

Annual revenues of the icebreaker depend on the mass of transported cargo and tariffs for icebreaker supported pilotage of vessels. Leader-type icebreakers will be capable to pass through ice with thickness over four meters forming navigable channel with width up to 50 meters, which allows escorting vessels with high carrying capacity and cargo mass up to 175 kilotons or container vessels with carrying capacity up to 14 TEU (TEU – Twenty-foot Equivalent Unit – standard measurement unit of carrying capacity of container vessels based on the volume of 20-ft container with load of about 14.5 tons which can be transported using different means of transportation) or tankers with liquefied natural gas with capacity in excess of 100 kilotons.

Leader-type icebreaker is capable of escorting vessels through 2-meter-thick ice with the above cargo carrying capacity and ice reinforcement class no less than Arc7 at a speed of up to 12 knots (1 knot = 1.852 km/hour). Maximum speed of vessels during summer-autumn navigation period (from July 1 until November 30) can reach up to 17–19 knots. However, during winter-spring period (from December 1 until June 30) the speed may be reduced to six knots or less. The number of vessels in the caravan and its speed are affected by the consolidation of ice measured by: 0 corresponds to ice-free water, 10 – compact ice. Consolidation of ice characterizes the degree of coverage of water surface with ice (from 0 to 100%). The higher is the ice consolidation, the smaller is the number of vessels in the caravan. Normally, caravan consists of no more than 10 vessels.

The volume of cargo transported along the NSR affects the duration of operation during calendar year. According to some estimations each icebreaker is on the average used during 9.5 months a year (289 days). With duty factor for RITM-400 reactor equal to 65% (Duty factor in Table 2) the icebreaker can be operated on full power during not more than 237 days a year. According to the data in (Zagorodnikov 2017) annual effective fund of icebreaker operation amounts to 315 days, because duration of maintenance and repair period including, in particular, annual survey for classification with docking (vessel dockage) for surveying the submerged part of the vessel, amounts to about 50 days. Progressive deterioration of icebreaking capability of icebreakers associated with increasing roughness of external ship shell plating caused by intensive corrosion and erosion wear is noted in ref-

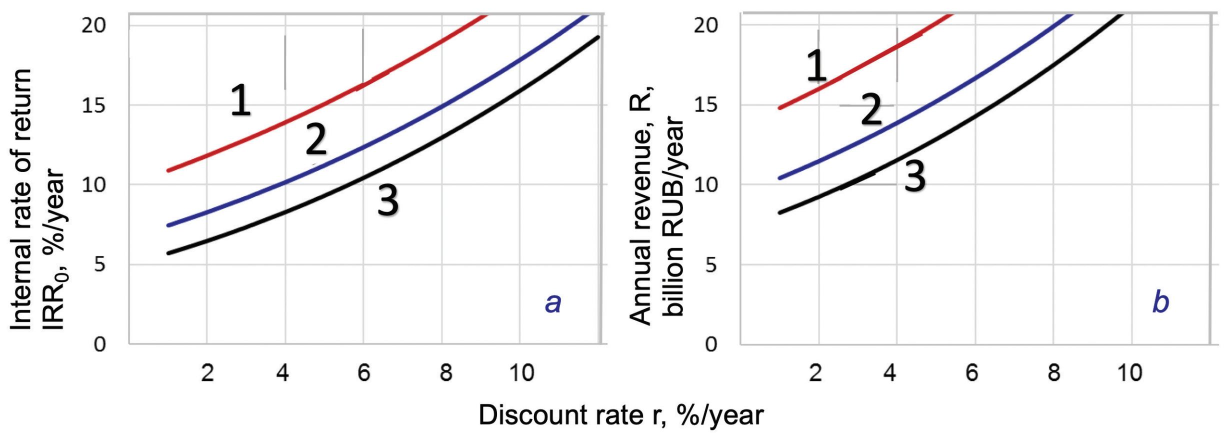

Figure 2. Dependence of internal rate of return IRR_0 (a) and annual revenues R (b) for the icebreaker as function of discounted payback period Θ and discount rate r for K = 127 Billion RUB, Y = 1.5 Billion RUB /year T_c = 8 years, T_o = 40 years and NPV = 0. Calculation performed using Formulas (7) and (4). **1** – Θ = 10 years; **2** – Θ = 15 years; **3** – Θ = 20 years; **4** – Θ = 40 years.

erences (Tsoy et al. acces. Apr. 10, 2021, Nesterov acces. Apr. 10, 2021).

Tariffs for escorting vessels by icebreakers are applied depending on the carrying capacity and the ice reinforcement class of the vessel, distance along which the vessel is escorted, period of navigation and the section of the NSR waterway (Annex to the Executive 2014, Executive order of the Federal Tariff Service 2014). NSR waterway is divided into seven zones (Bazhenov and Vetrova acces. Apr. 10, 2021). Two most difficult zones (sixth and seventh) with perpetual ice are located in the eastern part of the NSR. Depending on the vessel ice reinforcement class, period of navigation and weather conditions icebreaker escort may be required either on separate sections or along the whole passage. According to acting rules of application of the tariffs for icebreaker supported pilotage of vessels along the NSR waterway (Annex to the Executive 2014) the tariff for vessels of Arc6 – Arc9 ice class with cargo carrying capacity in excess of 100 register tons increases from 263 RUB/register ton for escorting during summer-autumn period across all seven zones to 657 RUB/register ton during winter-spring period, which means it increases by 2.5 times.

Forecasting revenues of the icebreaker from escorting vessels along the NSR is a multiparameter problem requiring large volume of specific information not available in references. For performing analytical estimations of revenues of the icebreaker we will apply optimistic set of data presented in Table 3. We assume the number of days of icebreaker operation to be equal to 315 per year, from which 133 days correspond to summer-autumn period (20 days less than the calendar period) and 182 days during winter-spring period (30 days less than the calendar period).

Correspondingly, for average speed of pilotage equal to 14 and 8 knots, number of vessels in the caravan equal to 10 and 5, average tariffs equal to 265 RUB/register ton and 665 RUB/register ton for icebreaker supported escort of vessels of Arc6 – Arc9 ice reinforcement class with gross cargo carrying capacity of 100 register ton the annual revenues of the icebreaker will amount to 10.3 BRUB/year assuming that the vessels are loaded to full capacity during both forward and return voyages along the NSR. It is of great interest is that earnings during the most difficult winter-spring period are practically the same as those for the summer-autumn period despite significant difference between the numbers of trips (seven and five, respectively). This is related to higher tariffs and longer duration of this navigation period.

Comparing the estimated earnings in Table 3 with minimal earnings required for ensuring profitability of the icebreaker presented in Fig. 2b, a conclusion can be made that even with optimistic enough performance characteristics of the Leader-type icebreaker taken from this table the icebreaker payback period is close to the duration of the period of its operation for very low discount rates. One icebreaker takes part in escorting 19 million registered tons a year when escorted vessels are loaded to full capacity either way during the return trip. Three

Table 3. Estimation of performance characteristics of Leader-type icebreaker for one calendar year of operation on the NSR

Period of navigation	**Summer-autumn (July 1 – November 30), 153 days**	**Winter-spring (December 1 – June 30), 212 days**
Number of days of icebreaker operation	133	182
Average speed of escort, knots	14	8
Travelling time (one way) *, days	9	16
Number of two-way voyages (round trips) during one year	7	5
Number of vessels in the caravan	10	5
Average gross cargo carrying capacity of the vessel**, register ton	100 000	100 000
Volume of cargo transported during one year (round trips) ***, million register ton/year.	14	5
Average tariff for icebreaker supported pilotage of vessels, RUB/register ton	265	665
Annual revenues, BRUB/year	3,7	3,3
Aggregate annual revenues, BRUB/year	**7**	

* NSR length from Kara Strait to Providence Bay is about 5,600 km (3,024 miles). ** Cargo carrying capacity of the vessel is measured in registered tons – measurement unit of volume of compartments included in the measurement, 1 register ton = 2.83 m^3. *** For equal load of vessels during forward and backward voyages.

icebreakers can ensure escorting 57 million registered tons a year. If the vessels travel empty on the return trip the volume of transported cargo is reduced twofold which makes the project unprofitable (the rules for application of tariffs deal with cargo carrying capacity of the vessels and not their factual load). The costs for each vessel associated with vessel escort along the NSR (one way) amount to more than 26 MRUB/trip during the summer-autumn period and to 66 MRUB/trip during winter-spring navigation period. By varying parameters in Table 3 it is possible to estimate for the given tariffs the volume and cost and revenues of the icebreaker escort or to shape the icebreaker escort tariff for the given volume of cargo transport.

Conclusions

Economic analysis model is suggested for estimation of microeconomic efficiency criteria (profitability) for investments in the projects of innovative nuclear icebreakers for the Northern Sea Route. The model is based on the analytical representation of the methodology for forecasting efficiency of investment projects widely used in the international practices. Easy to use formulas for calculating such icebreaker investment efficiency criteria as the net present value, minimal annual revenues from escorting vessels and discounted icebreaker payback period are derived from the mathematical expression for discounted net income.

It is demonstrated that for high capital costs typical for building of the Leader-type nuclear icebreakers, the minimal permissible revenues for the icebreaker, which represent the financial burden for escorted vessels transporting cargo along the NSR, rapidly increases with growing discount rates and decrease of the investment payback period. This means that profitability of icebreakers is possible for low discount rates equal to 2–3%/year which is an extremely cheap credit. Even for such low-cost credit and exceptional performance of the icebreaker (high vessel transport speed, large number of vessels in the convoy and their cargo loading capacity) the payback period would exceed 25 years.

Continued research implies that the increase of complexity in presented economic analysis model aimed at the more accurate accounting for the risks of increased icebreaker payback period due to the development, inflation in Russian economy including those due to the increased volatility of the Russian currency, as well as due to the overrun of time needed to build serial sea vessels caused, in particular, by the increase of Russian ruble exchange rate volatility, as well as by the overrun of schedules of production of serial vessels for the NSR caused by the low pace of production and technological restructuring of Russian ship-building industry.

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