Oil Tanker Transportation In The Russian Arctic

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Abstract: High hydrocarbon resource potential makes the Russian Arctic an attractive region for major oil and gas producing companies. Any investment decision is commonly based on an assessment stage which includes various types of technical and economical evaluations. Transportation cost in the Russian Arctic drastically influences overall project economics. Thus accurate method for transportation cost assessment becomes important from early stages of project definition. Infrastructure in the Russian Arctic is poorly developed so conventional estimation methods of hydrocarbon transportation tariff are ineffective. This paper describes a cost estimation method for tanker transportation of oil which considers key features of operations in the Russian Arctic.

Index Terms: icebreaking fleet, offshore engineering, oil tanker, oil&gas economics, the Russian Arctic, transportation tariff

1 INTRODUCTION

Territory of the Russian Arctic includes Barents sea, Kara sea, Laptev sea, East Siberian sea and Chukchi sea. According to the different estimations the amount of hydrocarbon resources in the Russian Arctic varies from 66 billion TOE (USGS estimates) to 160 billion TOE (Petrologica Ltd. estimates) and accepted mean value is about 100 billion TOE.

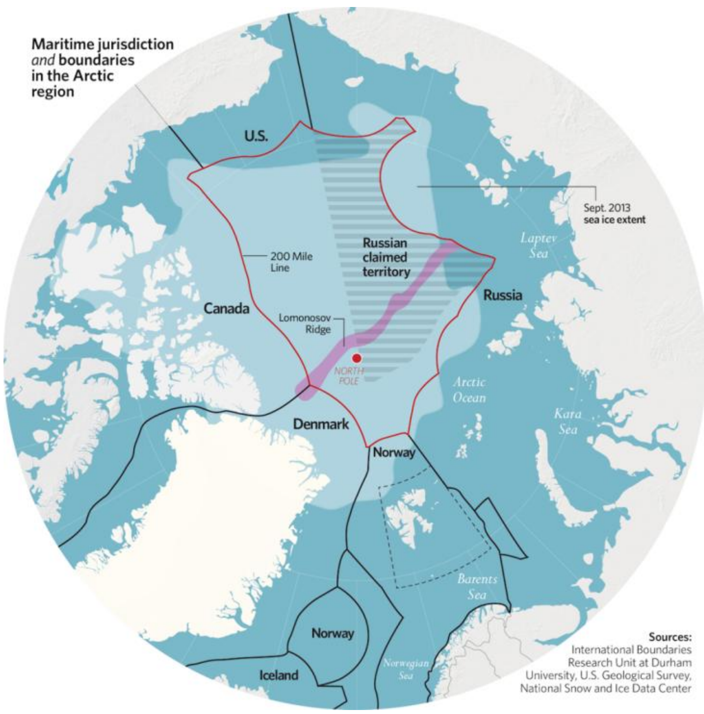

Fig. 1: Boundaries in the Arctic region

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Offshore oilfield development is related to three types of transportation: transportation of produced hydrocarbons, transportation of production facilities to installation point and offshore logistics with complex monitoring system. Production facilities transportation and development of logistic infrastructure should be classified as capital expenditures of investment project, oil transportation is at intersection of operation and capital expenditures. Further in this article we will put an emphasis on oil transportation. Common practice in evaluation of oil transportation expenditures is application of transportation tariff. Transportation market in the Russian Arctic is very limited. Oil production in the Russian Arctic requires construction of ice class shuttle tankers that will be applicable to severe environment. Specific ice and metocean conditions and corresponding technological constraints for transportation are widely discussed in many studies [1], [2], [3] and in several industrial standards. Peculiarities of Northern Sea Route navigation with application to transportation issue are reviewed in [4]. Iyerusalimskiy [5] proposes transportation concept for the Russian Arctic that can be applied to the particular project in Pechora sea. Econometric modeling of transportation cost is discussed in [6]. In most papers available to us transportation costs in the Arctic are not considered despite the fact that such data is crucial for prospect evaluations and feasibility studies of corresponding offshore investment projects. One of the few papers on transportation cost estimation is [7]. In that work authors analyzed key factors that determine external transport infrastructure cost in the Arctic projects. Moreover approach to construction and lifecycle cost estimation of external transport infrastructure is proposed. The present work expands an approach proposed in [7] to the level of resource cost model. The paper is organized as follows. General description of the Arctic tanker fleet is given in the section 2. Arctic transportation cost breakdown is shown in the section 3. The 4th section describes the cost model of hydrocarbons transportation. Results and conclusion are given in the section 5.

2 ARCTIC TANKER FLEET

According to the Russian Maritime Register of Shipping navigation across Russian Arctic territory should be carried out on ice class ships (at least Arc4 ice class on Russian classification). There are several recognized classification societies around the world; among them the best known are: American Bureau of Shipping (ABS), Bureau Veritas (BV), Det Norske Veritas and Germanischer Lloyd (DNV GL), Lloyd's Register (LR), Russian Maritime Register of Shipping (RS). Matching between several classifications is given in [8]. Correspondence of critical ice thickness to the Russian ice classes is given in the Table 1.

TABLE 1
MATCH OF CRITICAL ICE THICKNESS TO THE RUSSIAN ICE CLASSES FOR DIFFERENT NAVIGATION PERIODS (RUSSIAN MARITIME REGISTER OF SHIPPING 2014)

till 1995	till 2007	since 2007	W-Sp	S-A
	LU9	Arc9	MY	MY
	LU8	Arc8	MY up to 3,4m	MY
ULA	LU7	Arc7	FY thick up to 1,8m	SY up to 2,8m
	LU6	Arc6	FY medium up to 1,2m	FY thick up to 1,5m
UL	LU5	Arc5	FY medium up to 0,8m	FY medium up to 1,2m
L1	LU4	Arc4	FY thin up to 0,7m	FY medium up to 0,9m
L2	LU3	Ice3	Crushed ice up to 0,7m (Open pack ice)	
L3	LU2	Ice2	Crushed ice up to 0,5m	
L4	LU1	Ice1	Crushed ice up to 0,4m	

W-Sp: Winter-Spring navigation period; S-A: Summer-Autumn navigation period; FY – first-year; SY – second-year; MY – multi-year (>3 m ice thickness). The matching between several classifications is shown in the Appendix A.

3 COST OF OIL TRANSPORTATION

Transportation cost can be split into fixed costs and variable costs. Fixed costs are independent on the number of trips and include following items (Table 2).

TABLE 2
INPUT DATA

Cost item	Description
Administrative cost	Vessel administrative fees
Insurance	Hull and machinery insurance, P&I (Protection and Indemnity) insurance
Annual depreciation	If a vessel is fully owned then depreciation should be replaced by initial CAPEX

Variable costs depend on vessel operating time, number of trips and include following items (Table 3).

TABLE 3
INPUT DATA

Cost item	Description
Crew	Salary, holiday, food supply, education, pension payments, crew movement cost etc.
Consumables and supply	Supply of consumables, dye, cleaning consumables for deck, cabins engine room etc.
Vessel repair and maintenance	Docking and classification society survey.
Fuel	Fuel for main engine and machinery.
Harbor fees	Tonnage tax, pilotage, lighthouse, navigation, environmental fee, harbor icebreaking support, mooring and towing, agency services, providing of communication and transport services.
Engine oil	Consumables.
Icebreaking cost	Icebreaker support.

Therefore transportation tariff can be calculated as a ratio of annual expenditures on transportation to the quantity of oil transported within a year:

$$C_{tr\,unit} = \frac{C_{tr}}{V_y}\,, \qquad (1)$$

where C_{tr} - annual expenditures, US$, V_y - annual tanker capacity, tones.

4 COST MODEL

Transportation cost (C_{tr}) may be represented as a sum of fixed (OC_{fixed}) part increased on a ship owner margin (r) and variable (OC_{var}) part:

$$C_{tr} = OC_{fixed}(1+r) + OC_{\text{var}}\,, \qquad (2)$$

The fixed component equals (see Table 2):

$$OC_{fixed} = C_{adm} + C_{ins} + C_{dep}\,, \qquad (3)$$

where C_{adm} – administrative cost, C_{ins} – insurance cost, C_{dep} – depreciation.

$$C_{ins} = r_{P\&I} \cdot GT + r_{hull} \cdot C_{\tan\ker}\,, \qquad (4)$$

where $r_{P\&I}$ – P&I insurance rate, US$/gt, GT – vessel gross tonnage, gt, r_{hull} – hull and machinery insurance rate, %, $C_{\tan\ker}$ – tanker cost, US$.

$$C_{dep} = \frac{C_{\tan\ker}}{T_{operation}}\,, \qquad (5)$$

where $T_{operation}$ – service life of the vessel (depreciation period), years. The variable component equals (see Table 3):

$$OC_{\text{var}} = C_{crew} + C_{\text{sup}} + C_{r\&m} + C_f + C_{eo} + C_{harb} + C_{ice}\,, \qquad (6)$$

where sum of crew maintenance cost, consumables and supply cost and vessel repair and maintenance cost ($C_{crew} + C_{\text{sup}} + C_{r\&m}$) depends on squared deadweight of the vessel, C_f – fuel cost, C_{eo} – engine oil cost that has a linear dependence on fuel cost, C_{harb} – harbor fee, C_{ice} – icebreaking cost.

$$C_f = c_f R_f + c_{df} R_{df}\,, \qquad (7)$$

where c_f – fuel price, US$/t, R_f – fuel consumption for an engine and support mechanisms, t, c_{df} – diesel fuel price, US$/t, R_{df} – diesel fuel consumption, t. Fuel consumption is determined by the equation:

$$R_f = r_{f\,m} T_m + r_{f\,st} T_{st}\,, \qquad (8)$$

where $r_{f\,m}$, $r_{f\,st}$ – daily fuel consumption at propulsion and at standstill respectively, t/day, – T_m, T_{st} – time at propulsion and at standstill respectively, days. Diesel fuel consumption is a fixed percentage of the fuel oil consumption and noted below as r_D.

4.1 Fuel consumption estimation

Fuel oil consumption at propulsion and at standstill is directly proportional to the propulsion system power of a tanker (P):

$$r_{f\,m} = C_{f\,m} \cdot P \quad , \tag{9}$$

$$r_{f\,st} = C_{f\,st} \cdot P \quad , \tag{10}$$

where $C_{f\,m}$, $C_{f\,st}$ – empirical coefficients. In present work we assume following values for the constants:

$$C_{f\,m} = 3{,}5\,(t/(day \cdot MW))$$
$$C_{f\,st} = 0{,}4 \cdot C_{f\,m}(t/(day \cdot MW))$$

4.2 Trip time

Trip time includes en route time for a two-way voyage, standstill time and loading, unloading and non operational time. In this study we assume that average standstill time for loading, unloading and non operating time is 3,5 days per voyage for a tanker with the deadweight up to 100 000 t Time en route is determined by the length of a lane and vessel effective velocity. The term “effective velocity” implies the fact that a vessel spends certain amount of time on waiting for improvement in weather, vessel ice scrabbling in heavy conditions etc. Both length of route and effective velocity depend on current ice conditions and weather that may differ from one trip to another. Methods of simulation modeling and statistical data are appropriative to estimate enroute time for a particular lane.

4.3 Tanker capacity estimation

Tanker tonnage equals deadweight minus weight of reserves of fuel, water, food multiplied by allowance factor. Reserves per one voyage (W_{res}) are calculated as follows (11):

$$W_{res} = \left[(1 + r_D)\left(r_{f\,m} \cdot T_m + r_{f\,st} \cdot T_{st}\right) + r_w (T_m + T_{st})\right] K_{cont}, \tag{11}$$

where r_w – fresh water consumption, t/day, K_{cont} – contingency. In equation (11) it is implied that weight of crew and crew supplies is negligible. Tanker tonnage is determined by the equation:

$$V_t = DWT - W_{res} \,. \tag{12}$$

Tanker capacity per year is determined by the equation:

$$V_y = V_t \cdot N_{trip}, \tag{13}$$

where N_{trip} – number of trips per year.

4.4 Harbor fees

Nowadays harbor fees in the Russian Federation are established by the Federal tariff service (tonnage, lighthouse, navigation etc.) per 1 gross tonnage, and by harbors themselves for additional services like mooring, towing etc.

4.5 Icebreaking support

There are two ways of icebreaking cost estimation: by maximum rates of icebreaking for NSR routes that are determined by Federal tariff service and with the use of daily icebreaking rates. In this research we will use alternative model:

$$C_{ice} = K_I\left(c_p \cdot T_p + c_{st} \cdot T_{st}\right), \tag{14}$$

where K_I – average number of icebreakers supporting one tanker, c_p – daily rent rate of an icebreaker at propulsion, US$/day, c_{st} – daily rent rate of an icebreaker at standstill, US$/day, T_p – average icebreaker trip time per year, days, T_{st} – average icebreaker standstill time per year (waiting for a vessel to convoy), days. Equation (14) considers a possibility to unite tankers in caravan and to convoy them with one or several icebreakers.

4.6 Tanker cost

It is important that navigation across the Russian Arctic territory has to be provided with at least Arc4 ice class ships on Russian classification. There is still low number of such vessels on the market. Tanker cost depends on its power (P), that can be estimated using deadweight (DWT) and tanker ice class according Russian classification (Class 0, 1,…, 9).

$$C_{tanker} = a \cdot P^b, \tag{15}$$

where a, b – empirical coefficients, P – power of a tanker, MW. It is possible to divide power of an ice class tanker into two components:

- power of a non-ice class tanker with equivalent deadweight ($c \cdot DWT^d$);
- power that is necessary for propulsion in ice with h_{ice} thickness $\left(g_1 \cdot h_{ice}{}^{s_1} \cdot DWT^k\right)$.

$$P = c \cdot DWT^d + g_1 \cdot h_{ice}{}^{s_1} \cdot DWT^k, \tag{16}$$

where c, d, g_1, s_1, k – empirical coefficients. Moreover, terminative ice thickness for a vessel is related to tanker ice class (Table 1) and can be estimated as an exponent $h_{ice} = g_2 \cdot e^{s2 \cdot Class}$. Thus, equation (16) can be rewritten in the following form.

$$P = c \cdot DWT^d + g \cdot e^{s \cdot Class} \cdot DWT^k \tag{17}$$

where $g = g_1 \cdot g_2{}^{s1}$, $s = s_1 \cdot s_2$.

4.7. Modeling of vessel dimensions

The key dimensions of a tanker are: length (l), width (w), load draught (h_{load}), –can be determined as an exponent $a \cdot DWT^b$ where parameters a, b are chosen for each dimension of a tanker separately. Board height h can be estimated on the basis of tanker length. Known dimensions of a tanker allow to estimate its gross tonnage (GT):

$$GT = d \cdot (l \cdot w \cdot h), \tag{18}$$

where d – empirical coefficient. Thus, transportation cost of oil in Arctic conditions can be estimated on the basis of discussed cost items. Accuracy is affected by input data quality that depends on the stage of project definition. Replacement of unit tariff by fixed and variable components allows to determine the minimum acceptable transportation volume when profitability of a tanker becomes lower than its fixed operation costs.

4.8. Example

In order to clarify previous equations an example of transportation cost assessment in the Russian Arctic conditions is given. A unit cost of oil transportation is evaluated. Assessed case is transportation of oil from Kara sea to Murmansk with a long term freight of the 70 000 t DWT Arc 6 tanker.

TABLE 4
INPUT DATA

Parameter	Value
Route	Kara sea – Murmansk
Length of route, miles	1 550
Deadweight DWT, t	70 000
Time at propulsion per year T_p, days	273
Time at standstill per year T_{st}, days	64
Tanker tonnage V_t, t	68 600
Tanker capacity V_y, kt/year	1 474
Tanker ice class (RS: ice - Arc)	6
Service life of the vessel $T_{operation}$, years	25
Average fuel consumption at propulsion $r_{f\ m}$, t/day	69
Average fuel consumption at standstill $r_{f\ st}$, t/day	31
Fuel price c_f, US$/t	500
Diesel fuel price c_{df}, US$/t	700
Tanker cost C_{tanker}, million US$	258
Icebreaker rate c_{icebr} ,US$/day	87 500
Average number of icebreakers per one tanker K_I	0,7
Icebreaker involvement T_{icebr}, days/year	239
Cumulative annual harbor fee by FTS c_{FTS} per 1 gross tonnage, US$/gt	11,66
Cumulative annual harbor fee by harbor administration c_{ha} per 1 gross tonnage, US$/gt	11,66
Administration cost C_{adm}, thousands US$	280
Ship-owner margin r, %	15
Annual P&I insurance rate $r_{P\&I}$, US$/gt	4,87
Annual hull and machinery insurance rate r_{hull}, %	0,1542
Annual cost of oil transportation, thousands US$	42 764
Unit transportation cost, US$/t	29,01

The general overview of a cost breakdown structure is important for variety of estimations (Fig. 2).

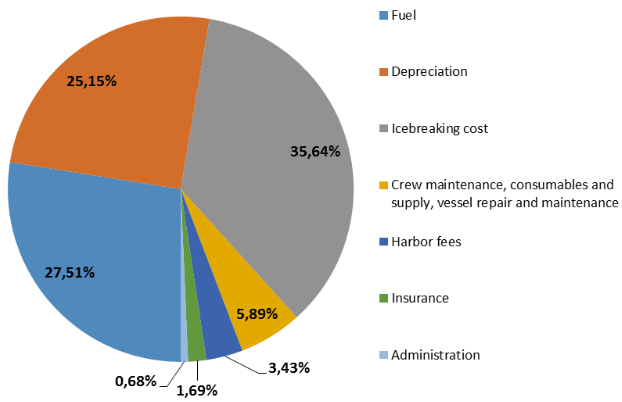

Fig. 2. Fixed and variable costs

As shown in the example transportation cost is mostly based on three main items: icebreaking cost, fuel cost and depreciation. Prospective growth of a cargo traffic on the Northern Sea Route will allow to reduce icebreaking cost, however, in that case, expansion of icebreaking fleet would be necessary.

5 CONCLUSION

Proposed cost estimation method for economic assessment of oil transportation in the Russian Arctic can be efficiently used in oil and gas companies for technical and economical evaluations. It is shown that tanker transportation cost can be easily divided into fixed and variable components instead of using a formal transportation tariff. Direct calculation of cost items with empirically determined dependences on technical parameters of tankers is considered to be an appropriate assessment technique for projects in the Russian Arctic.

6 Appendices

Appendix A.

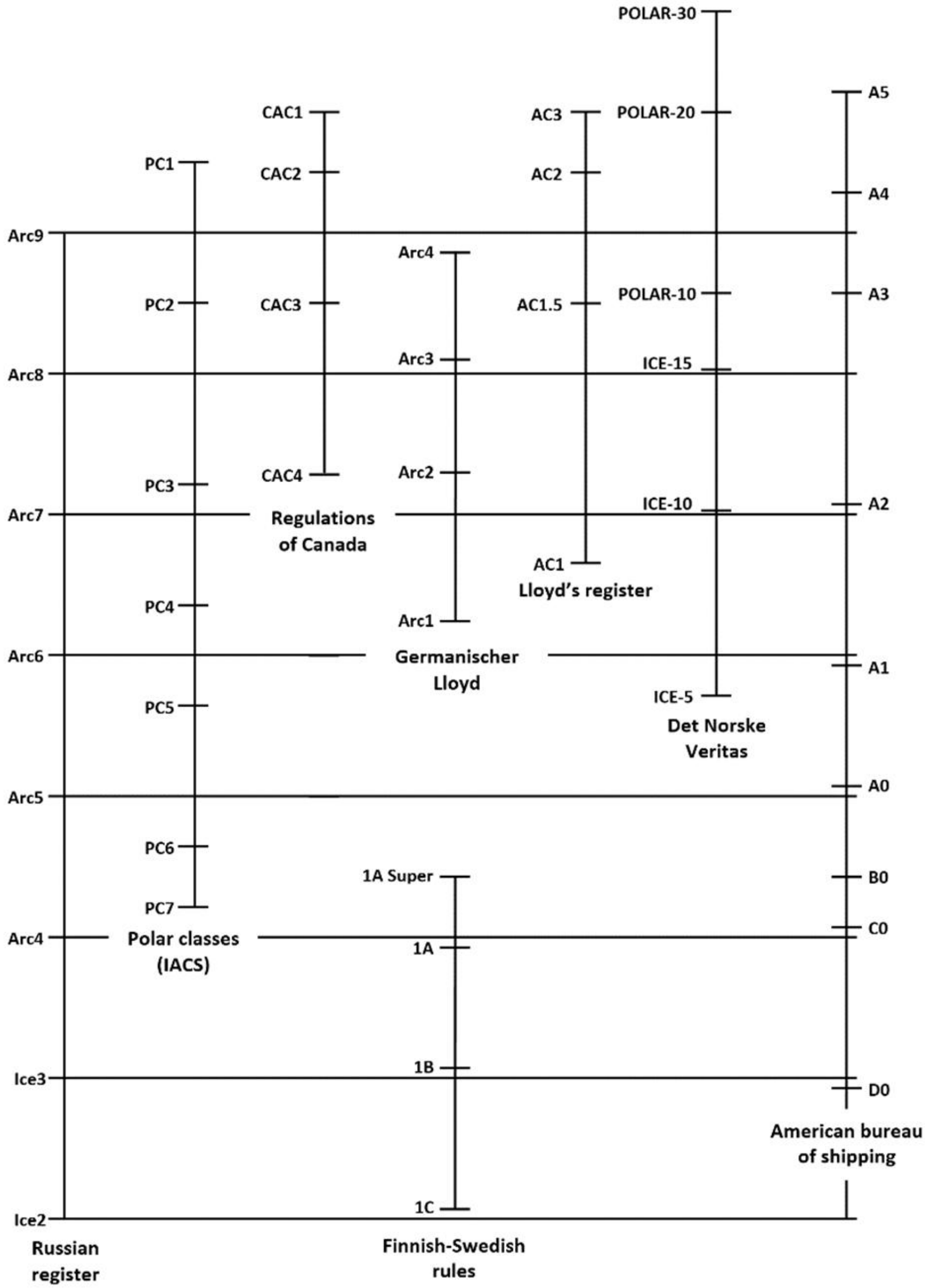

Fig. 3. Correspondence of ice classifications

APPENDIX B

This section contains detailed estimation for the example in section 4.8. First of all dimensions and cost of the tanker should be estimated.

$$C_{tanker} = 15{,}81 \cdot P^{0{,}83} \quad (19)$$

$$P = 0{,}028 \cdot DWT^{0{,}53} + 0{,}014 \cdot e^{0{,}47 \cdot Class} \cdot DWT^{0{,}33} \quad (20)$$

$$l = 5{,}44 \cdot DWT^{\frac{1}{3}} \quad (21)$$

$$w = 0{,}92 \cdot DWT^{\frac{1}{3}} \quad (22)$$

$$h = \frac{l}{11{,}03} \quad (23)$$

$$\mathrm{GT} = 0{,}35 \cdot (\mathrm{l} \cdot \mathrm{w} \cdot \mathrm{h}) \quad (24)$$

With the use of input data from the Table 4 (19)-(24) result in:

$$C_{tanker} = 15{,}81 \cdot 19{,}68^{0{,}83} = 258{,}2\,(US\$\,MM),$$

$$P = 0{,}028 \cdot 70000^{0{,}53} + 0{,}014 \cdot e^{0{,}47 \cdot 6} \cdot 70000^{0{,}33} = 19{,}68\,(MW),$$

$$l = 5{,}44 \cdot 70000^{\frac{1}{3}} = 224\,(m),$$

$$w = 0{,}92 \cdot 70000^{\frac{1}{3}} = 37{,}9\,(m),$$

$$h = \frac{252{,}50}{11{,}03} = 20{,}3\,(m),$$

$$GT = 0{,}35 \cdot (224 \cdot 37{,}9 \cdot 20{,}3) = 60318\,(gt).$$

Fixed component of transportation cost (OC_{fixed}) can be estimated with equations (4) and (5). Administrative cost doesn't depend on oil transportation, thus it is considered as input parameter ($C_{adm} = US\$280K/year$).

$$C_{ins} = 4{,}87\frac{US\$}{gt \cdot year} \cdot 60318gt + 0{,}1542\frac{\%}{year} \cdot US\$258{,}2 \cdot 10^6$$
$$= US\$692{,}7\,K/year$$

$$C_{dep} = \frac{US\$258{,}2 \cdot 10^3\,K}{25\,years} = US\$10329{,}5\;K/year$$

Fixed component equals:

$$OC_{fixed} = US\$280K/year + US\$692{,}7\;K/year$$
$$+ US\$10329{,}5\;K/year = US\$11302{,}2\;K/year$$

Variable component of transportation cost (OC_{var}) will be estimated with equations (25)-(27).

$$C_{crew} + C_{sup} + C_{r\&m} = 1827{,}41 + 1{,}205 \cdot 10^{-7} \cdot DWT^2 \quad (25)$$

$$R_{df} = 0{,}05 \cdot R_f \quad (26)$$

$$C_{eo} = 0{,}017 \cdot C_f \quad (27)$$

With the input data from Table 4 results are as follows.

$$C_{crew} + C_{sup} + C_{r\&m} = 1827{,}41 + 1{,}205 \cdot 10^{-7} \cdot 70000^2$$
$$= 2\,417{,}86\,(US\$\,K/year)$$

$$R_f = 69\frac{t}{day} \cdot 273\frac{days}{year} + 25\frac{t}{day} \cdot 64\frac{days}{year} = 20437\frac{t}{year}$$

$$R_{df} = 0{,}05 \cdot 20437\frac{t}{year} = 1021{,}85\frac{t}{year}$$

$$C_f = 500\frac{US\$}{t} \cdot 20437\frac{t}{year} + 700\frac{US\$}{t} \cdot 1021{,}85\frac{t}{year}$$
$$= US\$10933{,}8\,K/year$$

$$C_{eo} = 0{,}017 \cdot 10933{,}8\frac{US\$\,K}{year} = US\$185{,}9\,K/year$$

$$C_{harb} = 11{,}66\frac{US\$}{gt \cdot year} \cdot 60318gt + 11{,}66\frac{US\$}{gt \cdot year} \cdot 60318gt =$$
$$= US\$1439059/year = US\$1406{,}6\;K/year$$

$$C_{ice} = 0{,}7 \cdot 87500\frac{US\$}{day} \cdot 239\,days = US\$14638{,}8\,K/year$$

The variable component equals:

$$OC_{var} = US\$2\,417{,}86\,K/year + US\$10933{,}8\,K/year$$
$$+ US\$185{,}9\,K/year + US\$1406{,}6\,K/year$$
$$+ US\$14638{,}8\,K/year = US\$27966\,K/year.$$

With the ship-owner margin annual cost of oil transportation is:

$$C_{tr} = (1 + 0{,}15) \cdot US\$11302{,}2\,K/year + US\$29766\,K/year$$
$$= US\$42763{,}6\,K/year$$

Annual tanker capacity is calculated assuming that one-way trip taxes approximately six days, which corresponds to the route from southern part of Kara Sea to Murmansk.

Finally the unit cost per transported ton of oil is:

$$C_{trunit} = \frac{US\$42763{,}6 \cdot 10^3/year}{1474 \cdot 10^3\,t/year} = US\$29{,}01/t.$$

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