Optimization of transport activity of industrial enterprises in the Arctic region based on logistics solutions

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Abstract. Functioning and development of industrial enterprises operating in the Arctic conditions depends largely on organized and well-coordinated work of all the links in the supply chain. The lack of the year-round transport infrastructure in the regions of the Arctic zone significantly increases the transport costs of the enterprise. When solving these problems, it is necessary to improve the accuracy of planning, analysis and assessment of the logistics processes of supply, storage and transportation of material flows of the enterprise. The application of logistic methods for solving problems allows developing rational schemes for the delivery of goods, which can have a positive impact on the economic results of the company’s transport activities. The authors consider a method for solving the Make-or-Buy problem (MOB - “to make or buy”), when in terms of logistics service purchase other options with intermediary vehicles are considered as alternatives in order to minimize costs.

1. Introduction
Cargo delivery to hard-to-reach settlements and places of extraction of natural resources of the Arctic zone of Russia is carried out using several types of transport. The search for innovative solutions for the purpose of ensuring the stability of supply chains and cost optimization excite high scientific interest in this area. Research on intermodal freight traffic has intensified with the development of logistics services. Scientific publications in this field of transport research have increased significantly and have become an important topic at conferences on transport and logistics. This topic has been the subject of several special issues of the journal such as Research in Transportation Business & Management [1]. They show that the majority of research in the field of intermodal transportations is focused on the modeling of intermodal systems, there are case studies at the macro and microeconomic level. Authors Flodén J, Bärthel F, Sorkina E. consider aspects that affect the decisions of buyers of transport services [2]. Analysis of the reasons for the choice of transport is important in intermodal transportations.

Most researchers consider business-models through the changing characteristics of the market; in recent years, many studies on various decision-making scenarios related to climate change have appeared [3]. It is noted that climate change can influence the functioning of transport networks, which can influence the choice of a route, the capacity of waterways [4]. Taking into consideration the fact that natural communications are used in the Arctic regions, this area of research is relevant.

Industrial enterprises in the Arctic zone of the Republic of Sakha (Yakutia) are mainly engaged in the extraction of mineral resources (gold, diamonds, etc.). The expansion of their extraction poses the problem of optimizing transport activities and the logistics of the enterprise. The peculiarity of the functioning of the enterprises in the Arctic territories of Yakutia consists in the need to ensure annual supply
of material, fuel and energy resources due to the lack of year-round transport communications. The harsh climate and the presence of permafrost greatly increase the cost of construction of the transport infrastructure: long-term periods of construction, a considerable distance of the effect obtained from the investment, predominant manifestation of the effect of transport construction in the non-transport field. In addition, high capital costs are accompanied by subsequent increased investments in the operation of transport facilities [5].

The main purpose of this research is to show the application of some logistics solutions to optimize the transport activities of the enterprises in the Arctic. The results of the simulation of total logistics expenses can improve the accuracy of planning, analysis and assessment of the logistics processes of supply, storage and transportation of material flows of the industrial enterprises in the Arctic.

2. Model Development

To optimize the transport activity of the enterprise for logistics, the multiple-option approach is used oriented to: use of the existing transport directions in different variations; use of the prospective transport direction associated with the railroad to Yakutsk city and further with various modes of transport. Prevaling use of water transport is one of the cheapest in terms of transportation component costs. The following methods were applied in the course of this study: mathematical modelling, comparative economic analysis of the effectiveness of different options, expert and predictive appraisals with regard to influence of business conditions and natural climatic conditions on the operation of transport [6, 7].

Production facilities of industrial enterprises in arctic areas of Yakutia are hard to access for transport due to their geographical location, although they are located not too far from human settlements. Natural transportation lines (rivers, Northern Sea Route) are available where the main supply depots for enterprises are and there are airports within the reach distance. However, the delivery of materials, equipment, machinery and other cargo is carried out by water, auto-truck and air transportation companies, which operate primarily on a seasonal basis and use long-distance and multiple-link patterns including from 3 to 5 stages (Table 1).

The choice of the optimal pattern for cargo delivery to the arctic areas covers a set of issues concerning the composition and characteristics of transport facilities, the specific operating conditions, as well as the engineering, economic and performance parameters of their operation. The optimality criterion for the chosen economic and mathematical model should adequately reflect the real situation; the choice of problem-solving methods is characterized with occurrence of many abnormal situations [8] and may be related to uncommon modes of cargo transportation. Therefore, the application of contingency management is one of the required conditions.

The objects to be considered in this study are consignee (N), transportation companies involved in cargo delivery (water, motor, air transport), points of departure, points of transshipment and points of destination, transport vehicles, cargo traffic volume and structure.

Engineering, economic and performance parameters are determined for each section of the transport route with regard to the applicable standards for using transport facilities by load, speed, time and potential opportunity to enhance the operational efficiency of technical means. The operating term of the section depends on the start and end of work of its stages. Some moments, such as the periods when a section with a year-round motor road has season interruptions in work (ferry crossing), should also be considered. Among the variety of transport patterns, the particular difficulties arise in the arrangement of minor river navigation where the duration of section operation is 20 days while the navigation on the Lena River is up to 150 days, the navigation on the Vilyuy River is 40 to 60 days. Accordingly, the date of acceptance for carriage is determined for each pattern. The limited transport accessibility imposes the specific arrangement of activities and logistics of all enterprises of the region, which have to keep available higher stock levels (Table 2). This factor not only complicates the supply management but also requires the concurrence of delivery terms.
Table 1. Description of the cargo delivery patterns of industrial companies in the western part of the Arctic area of the Republic of Sakha (Yakutia).

| Mode of transport | Delivery route pattern | Distance | Transportation period | Nature of cargo |
|-------------------|------------------------|----------|-----------------------|-----------------|
| Railway transport | Destination-railway station Berkakit, Aldan, Tommot, N.Bestyakh (in the future) | Year round | Equipment, ITP, C&M. |
| Railway transport | Winter Road Yakutsk–Mayat | 20 December – 20 April*, 25 May – 20 October* | Equipment, ITP, C&M. |
| Automobile transportation | motor road Berkakit-Yakutsk | 840 km | Winter Road Yakutsk–Mayat | 10 January - 20 April* | Equipment, ITP, C&M, products, POL |
| Automobile transportation | Winter Road yakutsk–Mayat | 2574 km | Winter Road Urying Khaya – Mayat | 20 January – 30 April POL |
| Automobile transportation | motor road / winter road Lensk – Mayat | 1572 km | Winter Road Urying Khaya – Mayat | 1760 km | 1 February- 20 April* | equipment, ITP, C&M, products, POL. |
| Water transport | Ust-Kut – Urying Khaya | 4679 km | June-September | POL |
| Water transport | Yakutsk – Urying Khaya | 2700 km | July-September | building material, C&M |
| Water transport | Ust-Kut – Lensk | 952 km | June-October | ITP |
| Water transport | Yakutsk–Sytyakh – Molodo | 1274 km | June-October | equipment, ITP, C&M, products, POL. |
| Water transport | Arkhangelsk – Uiring Khaya | 5200 km | August-September | POL, C&M |
| Air transport | Yakutsk-Saskylakh-Mayat | 1285 km | May-September | repair parts, C&M, products |
| Air transport | Storage and processing of goods Base Yuryung-Haya | Year round | equipment, ITP, C&M, products, POL. |
| Air transport | Lens | Year round | POL |
| Air transport | | Year round | ITP |

* – dependence on open/close state of ice crossing or ferry crossing the Lena River; POL – petroleum, oil, lubricants; C&M – commodities and materials; ITP – industrial and technology products

Table 2. Review of the transport accessibility of the Arctic area of Yakutia.

| Area               | Point of delivery / bailment | Distance, km | Average term of navigation, days | Term of delivery, days | Min. time slack, days | Max. time slack, days |
|--------------------|------------------------------|--------------|----------------------------------|------------------------|----------------------|-----------------------|
| Abyisky            | Belaya Gora                  | 5223         | 123                              | 28                     | 129                  | 344                   |
| Allaikhovsky       | Chokurdah                    | 4809         | 101-123                          | 24                     | 217                  | 341                   |
| Anabarsky          | Saksylakh                    | 4767         | 47                               | 24                     | 133                  | 349                   |
| Bulunsky           | Tiksi                        | 3682         | 81-125                           | 22                     | 118                  | 308                   |
| Verkhneokolymsky   | Zyranka                      | 6262         | 120                              | 33                     | 136                  | 350                   |
| Verkhoyanskoy      | Batagai                      | 4765         | 100                              | 338                    | 338                  | 440                   |
| Nizhneokolymsky    | Chersky                       | 5394         | 52-123                           | 26                     | 136                  | 350                   |
| Oleneksky          | Taymylyr                     | 4422         | 47                               | 81                     | 274                  | 445                   |
| Sredneokolymsky    | S-Kolymsk                    | 5918         | 52-123                           | 30                     | 133                  | 345                   |
| Ust-Yanskiy        | Ust ' -Kuyga                 | 4380         | 107-114                          | 22                     | 125                  | 334                   |
| Eveno-Bytantayskiy | Verkhoyanskoy                | 4887         | 107                              | 533                    | 533                  | 635                   |
### 3. Model Formulation

The specified features of cargo delivery dictate the need for concurrence, clear arrangement of all services (transportation, information, financial, etc.) within the short operating period of transportation networks [9]. Therefore, we have developed 26 cargo delivery patterns for the enterprise N with different modes of transport, including seasonal and year-round, with regard to the prospective directions, which are expected with the construction of a railroad to Yakutsk city, with construction of additional transport facilities. Solving the transportation problem concerning the choice of a cargo delivery pattern includes not only minimum transportation charges \( T \) for operating expenses for delivery \( C \), storage \( S \), loading/unloading \( L \), operating expenses for maintenance of the infrastructure \( I \) related to cargo delivery:

\[
T_i = \sum(C_{ij} + S_{ij} + L_{ij} + I_{ij}), \text{ roubles.}
\]

Expenses for immobilization of physical resources \( R_{im} \) for the period \( T_{co} \) when the cargo amount \( W \) is kept in circulation:

\[
R_{im} = \frac{(P \cdot W + C_i) \cdot d \cdot T_{co}}{360}, \text{ roubles,}
\]

where \( d \) – the interest rate on credit for shipped cargo and transportation; \( P \) – a wholesale price for 1 tonne of the shipped cargo, roubles.

Figures 1 and 2 clearly show the difference in the cargo amount \( W \) for seasonal modes of delivery and the involvement of the year-round section of the motor road, thus providing for substantial savings on operating assets and money-and-credit resources of the enterprise.

![Figure 1. Stock movement by the pattern: river harbor – winter road.](image1)

![Figure 2. Stock movement by the pattern: river harbor – motor road.](image2)
The assessment of variants \( (i) \) calculations is based on minimizing the logistics costs \( (C) \) to deliver 1 tonne of each cargo type \( (j) \); the economic model is presented as follows:

\[
C_i = \frac{RC_i}{W_j}, \text{ roubles/tonne}
\]

where \( RC \) — the reduced costs of delivery of the annual amount of cargo according to the \( i \)-th transport pattern, which take into account the sum of operating expenses \( (Op.) \), capital expenses \( (Cap.) \), immobilization expenses \( (Rim) \) per tonne of imported cargo.

\[
RC_i = Op_{i.t} + Rim_{i} + Cap_{i} \times q, \text{ roubles,}
\]

where \( q \) — the CBR refinancing rate.

It should be noted that in arctic conditions, almost all transport patterns under consideration require capital investments in certain infrastructure facilities, the type and geographical location of which is determined by the specific conditions of each option [10].

**Figure 3.** Dependence of unit logistics costs on the amount of imported cargo.

When choosing the optimal transport pattern of cargo delivery, it is necessary to take into account the change in costs while increasing the amount of imported cargo caused by the expansion of production [11]. Comparison of unit costs when investing in infrastructure facilities can give an effect related to the acceleration of return on capital expenses and significant savings on current expenses (Figure 3). It is not difficult to calculate the maximum amounts when investments in the construction of infrastructure facilities are inefficient. Thus, this procedure allows providing an economic assessment of each option of cargo delivery under the chosen transport pattern.

Industrial enterprises annually deliver petroleum products (POL), materials and equipment for their own needs, as well as commodities and materials for the needs of municipalities, while the annual tonnage factor of social cargo increases [12]. The winter road starts in the second decade of January and ends in the second decade of April with a difference of 5–10 days, depending on the weather (Table 3). Taking into account the significant deviation of the availability period of winter roads in last year’s (up to 11 days), as well as reducing navigation time, there is a need to revise the amount of reserve stocks and involve additional vehicles [13].

Annually, the enterprise N involves from 50 to 180 vehicles from outside companies, including individual entrepreneurs, for freight and cargo transportation in addition to the enterprise’s fleet of more than a hundred vehicles, including heavy vehicles (excavating machines, bulldozers, truck-mounted cranes). From the analysis of cargo turnover in previous years, the share of cargo transported by own transport is 40%. Raw materials and products are delivered to enterprise’s sites in two ways: centralized one or decentralized one. All deliveries are made on the basis of a supply contract, which plays an important role in the supply. Logistics system optimization is the search, assessment, selection, design
and implementation of improvements in logistics subsystems (procurement, transport, warehouses, planning, distribution, service), taking into account the chosen criteria (service, costs, time, etc.) according to the company’s logistics strategy. It is important for the company to manage logistics processes and minimize logistics risks [14,15].

Table 3. Analysis of the cargo turnover and involved motor vehicles.

|                      | 2015  | 2016  | 2017  | 2018  |
|----------------------|-------|-------|-------|-------|
| Actual amount (t)    | 25 410| 24 321| 15 898| 22 596|
| winter road start    | 12.01.15| 13.01.16| 13.01.17| 18.01.18|
| winter road end      | 20.04.15| 14.04.16| 10.04.17| 15.04.18|
| Duration, days       | 98    | 92    | 87    | 87    |
| number of trips      | 727   | 1079  | 603   | 768   |
| number of involved motor vehicles | 116   | 165   | 117   | 181   |

If the logistics processes within the company can be managed on the basis of the criteria and strategies chosen and described above, the presence of logistics intermediaries, who operate on their own criteria and based on their own strategies, poses significant risks that affect the results of the logistics process. Usually, companies use the services of logistics intermediaries who specialize in freight forwarding services [16]. For example, for many years the enterprise N has been cooperating with the company K (the general contractor for freight and cargo transportation) to carry out transportation, although the enterprise has its own fleet of vehicles and special equipment. The enterprise N does not use its own vehicles in foreign freight and cargo transportation; it is used only for domestic freight and cargo transportation between sites.

The method, which is based on the solution of the so-called Make-or-Buy problem in procurement logistics, has become widespread in the process of supply management. The solution of this problem requires argumentation of the answer to the question about the independent production of parts, services, etc., necessary for the enterprise or their purchase from external sources [17]. Therefore, in order to make a decision, it is necessary to compare the costs of own production of materials (services) with the costs of their purchase. An alternative to the services of a third-party (general) transporter may be to work based on a tender with small companies or individual entrepreneurs involved in freight and cargo transportation. The comparative analysis (Table 4) shows that the general transporter’s costs of transportation are significantly higher than the payment for hired drivers.

Table 4. Comparative analysis of the Make-or-Buy problem for C&M

| Contractor           | Route                  | Distance, km | price/t-km, excl. VAT | Plan for C&M, t | Costs of transportation (thous. roubles), excl. VAT |
|----------------------|------------------------|--------------|-----------------------|-----------------|---------------------------------------------------|
| General transporter  | Yakutsk – Mayat        | 2534         | 18,00                 | 3518            | 160 463                                           |
| General transporter  | Yuryung-Haya – Mayat   | 395          | 10,29                 | 9085            | 36 926                                            |
| With the general transporter | Total:               |              |                       | 12 603          | 197 389                                           |
| At the close of tender| Yakutsk – Mayat        | 2534         | 7,50                  | 3518            | 66 859                                            |
| At the close of tender| Yuryung-Haya – Mayat   | 395          | 5,15                  | 4585            | 9 327                                             |
| Hired fleet          | Yuryung-Haya – Mayat   | 395          | -                     | 4500            | 4 192                                             |
| Hired transport in the amount of 7 units with transporters at the end of the tender | Total: | 12 603 | 80 379 |
Costs under direct contracts consist of payment of one driver per month (130 thousand roubles) and expenses for petroleum, oil, lubricants and meals during 3 months of winter road operation. In total, for the availability period of winter roads, a fleet of 7 vehicles consumes an average of 20.9 thousand tons of petroleum, oil, lubricants worth 1,199.9 thousand roubles, one also needs 262 thousand roubles for meals and 2,730 thousand roubles for salary fund.

4. Discussion.
The logistics services market is complex and ambiguous. As in any market, there are many intermediaries therein [18]. The study showed that real transporters receive 40% of the contract price, while the rest of the funds are left for the general transporter. The examination of Federal Law No. 87 “On shipping and forwarding activities” of 06/30/2003 allows one to understand that the freight forwarder providing freight forwarding services, in fact, does not bear any responsibility for damage to or loss of cargo, or for failure to meet transportation deadlines or for other issues related to the quality of service. This practice has affected the emergence of a large number of non-professional companies trying to break into the logistics market through price dumping. Here are the risks [8], which should be discussed in more detail.

1) Time risks:
   - untimely delivery of vehicles for loading;
   - choosing a cheap, but slow route at all stages of transportation;
   - untimely agreement of documents with the sender;
   - delays in customs clearance due to an incomplete document package or incorrect codification in the packing list.

2) Economic risks:
   - mistakes in cargo insurance;
   - vehicle idle time, over-standard cargo storage increasing the company’s costs;
   - decrease in the company’s trade turnover due to time delays.

3) Legal risks:
   - mistakes of contractors in the preparation of primary accounting documents, hence the problems with audits and inspections;
   - declaration mistakes in the customs clearance of goods.

5. Conclusion
Thus, the enterprise can optimize its logistics system by maximizing the use of its own vehicles and refusing the services of the general transporter, putting up for tender the transportation services, while reducing the risks and overall logistics costs [19]. The logistics management process of this enterprise implies constant control over the structure of logistics costs. Systematic determination and analysis of the structure of logistics costs allows one to identify the main reserves for their reduction, to develop specific measures for their optimization.

The enterprise’s refusal of intermediate transporters in favor of the use of its own vehicle fleet results in the change and restructuring of business processes in planning and arrangement of the management of material and technical supply for production.

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