Modelling of the Transport–Technological Process of Delivery of Wood Raw Materials under the Conditions of Uncertainty

I M Enaleeva – Bandura¹, A V Nikonchuk¹, R A Chernykh¹

¹Reshetnev Siberian State University of Science and Technology, 31 Krasnoyarsky Rabochy Av. Krasnoyarsk, 660037, Russian Federation

E-mail: melnikov1978@inbox.ru

Abstract. This article considers the most well-known existing methods of modeling of the transportation process under the conditions of uncertainty, describes the analysis of specified methods of optimization of the transport–technological process. The modern stage of development of the market economy requires new approaches to the transportation of wood raw materials for the purpose of increasing the effectiveness of the transport–technological process. In this regard, the problems related to transport logistics appear to be particularly topical. The subject of transport logistics is a set of planning and management problems associated with the transportation of wood freights by different kinds and types of transport, namely: ensuring technical and technological connectivity between participants involved in the transport process, coordinating their economic interests; ensuring technological uniformity of transport and warehousing facilities; collaborative planning of manufacturing, transport and warehousing processes; selecting kinds of vehicles (Vs); selecting types of Vs; determining rational routes; selecting carriers and forwarding agents. This set of specified problems lies within the general scheme of transport logistics problems. A traditional transport problem may be stated in all cases when it is necessary to determine a scheme of transportation of some wood freight (freights) from one destination to another, to find the most reasonable way (route) of transportation, to select a type of vehicles and determine the time of performance of this operation, but each of the mentioned cases is associated with a certain statement of a transport problem. At the same time, we use the assumption that the cost of transportation of a wood product along any route is proportional to its volume. In practice, however, this assumption does not frequently come to fruition. A problem becomes more complicated if, when it is stated, it is necessary to consider that the cost of transportation depends not only on the pair "supplier–consumer", but also on the characteristics of a freight to be transported, a type of vehicles to be used, etc. It also should be noted that the practice of supply chains: rarely uses only one type of vehicles; as a rule, the transportation process involves two or more types of transport; in addition to dynamic factors, the transport-technological process is also affected by uncertainty factors. Thus, the search for new solutions by developing mathematical models suitable to realities on the basis of a logistic approach, with the uncertainty of input parameters taken into account, appears to be a topical scientific problem.

1. Introduction

The principles of distribution of finished products on the basis of minimization of total transport costs are relevant to the majority of problems of optimal planning of transportations under the conditions of uncertainty arising in the modern practices of organization of freight traffic flows. This means the
solution of production and transport problems and their different modifications. The analysis of works of many authors [1-15] showed that generally solve the problem of rational distribution of material (commodity) flows between - links of the wood transport system (for example, by means of distribution warehouse centers and consumer warehouses) under the conditions of wood raw materials yield and demand uncertainty and of identification of trade areas on the basis of classification of consumers and their attachment to production points with minimum transport costs, storage costs and the smallest losses from the short delivery of specified raw materials [16].

2. Research materials and methods

Let us consider the models that are best known in the scientific literature and take into account the uncertainty of input parameters. According to source [17], the objective functional will be defined as follows:

\[ L(X(Z)) = \sum_{j=1}^{n} R_1(Z_j) \int_{0}^{Z_j} \varphi_j(\theta) d\theta + R_2(Z_j) \int_{Z_j}^{\infty} \varphi_j(\theta) d\theta + \sum_{j=1}^{m} \sum_{i=1}^{n} C_j X_{ij}(Z) \]  

and satisfy the constraints:

\[ \sum_{j=1}^{n} X_{ij}(Z) \leq a_i, i = 1, 2, ..., n \]  

\[ \sum_{i=1}^{m} X_{ij}(Z) \leq Z_j, j = 1, 2, ..., m \]  

\[ \sum_{j=1}^{n} Z_j = \sum_{i=1}^{m} a_i = A \]  

\[ X_{ij} \geq 0, i = 1, 2, ..., m, j = 1, 2, ..., n \]  

where \( \theta \) - random demand value,
\( \varphi_j(\theta) \) - density of distribution of the random demand value for the commodity in the \( j \)-shop;
\( Z_j \) - volume of the commodity order for the \( j \)-shop,
\( a_i \) - payment for the storage of the commodity unit in the \( j \)-shop;
\( \beta_j \) - cost of the commodity unit in the \( j \)-shop while selling;
\( C_j \) - purchase cost of the commodity unit;
\( Z = (z_1, z_2, ..., z_n) \) - distribution of the commodity order volumes for the total of shops, \( j = 1, 2, ..., n \).

At the same time, if the random demand value \( \theta \) is less than an ordered commodity volume \( Z_j \), then there is a necessity of storing unsold commodities. If the demand \( \theta \) exceeds the order, then there are losses associated with a deficiency in these commodities. Then, it is evident that average values of storage costs and of losses from the short delivery will be defined by the following expressions:

\[ R_1(Z_j) = a_j \int_{0}^{Z_j} (Z_j - \theta) \varphi_j(\theta) d\theta \]  - average costs of the storage of unsold commodities in the \( j \)-shop,

\[ R_2(Z_j) = (\beta_j - C_j) \int_{Z_j}^{\infty} (\theta - Z_j) \varphi_j(\theta) d\theta \]  - average losses due to a deficiency in commodities in the \( j \)-shop.

Here:
\[ \varphi_j(\theta) = \frac{\varphi_j(\theta)}{\int_{0}^{Z_j} \varphi_j(\theta) d\theta} \]  - mentioned densities of the demand distribution in case of a surplus and a shortage of commodities.

In our opinion, the above method of modeling of the transportation process under the conditions of uncertainty is too unhandy for the transfer of its elements to linear dependence. Let us consider different nonlinear model [18] that suggests the two-level system of choice and making of managerial decisions in integrated wood enterprises under the conditions of uncertainty caused by risk factors.
where the first level solves traditional problems of planning of a wood enterprise’s main technical and economic indicators and the second one includes the estimation of a risk profile through expert methods in order to define a total effect of choice of an economic activity strategy. As an optimality criterion this model suggests total income indicator \((GM)\) corrected for the influence of uncertainty and risk factors specified by experts. An intermediate indicator in the course of making of managerial decisions is gross margin \((EM)\) that represents a value of revenues through selling a batch of wood raw materials:

\[
EM_i = V_i \cdot (P_j \cdot EC_i - S_j - TC_i + \Delta T_i - GC_i)
\]

(6)

where \(V_i\) - volume of a planned batch of commodities in m³;
\(P_j \cdot EC_i\) - planned revenues from selling 1 m³ of forest products in national currency (price of 1 m³ of forest products in foreign currency, \(EC_i\) - average weighted monthly exchange rate);
\(S_j\) - production cost (transfer price) of 1 m³ of forest products in national currency;
\(TC_i\) - transport and customs costs of 1 m³ of forest products in national currency;
\(\Delta T_i\) - difference between taxes paid to the budget and those compensated from the budget from 1 m³ of forest products in national currency;
\(GC_i\) - general business and commercial expenses attributable to 1 m³ of forest products in national currency.

A final indicator of the two-level system of choice and making of managerial decisions is gross income corrected for the influence of uncertainty and risk factors defined in an expert way. The formula that expresses this dependence is as follows:

\[
GM_i = (W_i + B_i + M_i + G_i) \cdot (V_i \cdot (P_j \cdot EC_i - S_j - TC_i + \Delta T_i - GC_i))
\]

(7)

The degree of influence of each of the factors on the functional reflects a weight coefficient \(g\) determined by a group of experts. According to the influence of the factors on the indicator and the value of the indicator of economic margin, \((EM)\) we calculate a total indicator of gross revenues \((GM)\) in respect of each of the product batches and choose the implementation of that economic solution where gross revenues corrected for the influence of uncertainty and risk factors take on maximum value [18]. We deem it promising to develop a dynamic model of the transport–technological process of delivery of wood raw materials corrected for uncertainty factors.

The works by I.A. Borodinova and L.A. Saraev [19] show that the solution of a similar problem is reduced to the determination of supply and demand probability coefficients in every production and consumption point; in our opinion, the introduction of the specified consumption and production coefficients under the uncertainty of input parameters into the mathematical model of the transport–technological process of delivery of wood raw materials is an integral part of this modeling.

3. Research results

The carried-out analysis of known results as per the methods for solving real wood transport logistics problems reveals a number of problems. The first reason for these problems is associated with a necessity of considering the uncertainty arising from the estimation of parameters of mathematical models of transport logistics problems. Another group of problems arises due to the possible inadequacy of linear transport logistics models. Therefore, the logistics-mathematical model developed by us includes only main factors that influence the process of delivery of wood raw materials according to the risk profile prepared by us. The developed model is of dynamic nature. The choice of an optimal traffic flow structure is defined as a problem of minimizing the \(F_{cm}\) functional:

\[
F_{cm} = F(t) + \mathcal{E}(t) \rightarrow \min
\]

(8)

where \(F(t)\) – final functional at time point \(t\);
\(\mathcal{E}(t)\) – effect of financial losses (risk profile) at time point \(t\).
\[
\mathcal{L}(t) = B(t) + G(t) + W(t)
\]

where \( B(t) \) - shadowy economic relations in the wood industry and inflation that influences a production cost of (shipped) manufactured products at time point \( t \);

\( G(t) \) - activities of legislative and monopolistic organizations at time point \( t \);

\( W(t) \) - resource factor at time point \( t \).

The functional \( F \) is defined by a total value of subfunctionals \( F_1, F_2 \) and \( F_3 \) representing costs related to the delivery of wood raw materials.

\[
F_1 = \sum_{i=1}^{m} \sum_{j=1}^{n} \left[ C_i(t) \cdot (1 \pm g_b(t)) + C_{ij}^{TP}(t) \cdot (1 \pm g_c(t)) \right] \cdot X_{ij}(t) \times (1 - g_w(t))
\]

where \( C_i(t) \) - selling price of 1 m³ forest product at the supplier, rub., at time point \( t \);

\( C_{ij}^{TP} \) - transportation costs per product unit, rub., at time point \( t \);

\( i \) - production point, \( i = 1, 2, ..., m \);

\( j \) - consumption point (dealer, wholesale intermediate seller, \( j = 1, 2, ..., n \);

\( X_{ij}(t) \) - scope of delivery by the \( i \)-supplier to the \( j \)-consumer, m³ at time point \( t \);

\( g_b(t) \) - coefficient of assessment of the influence of the resource factor on the volume of (shipped) manufactured products and the influence of a risk of short delivery or of delivery of low-quality products at time point \( t \);

\( g_c(t) \) - coefficient of assessment of the influence of the factor of shadowy economic relations and the influence of inflation on a production cost of (shipped) manufactured products at time point \( t \);

\( g_w(t) \) - coefficient of assessment of the influence of the legislative and monopolistic factor on transportation costs at time point \( t \).

Coefficients \( g(t) \) specified in expression (10) are defined by the method of expert assessment of forestry specialists; these coefficients show the degree of influence of this or that uncertainty factor on the size of total costs while delivering wood raw materials from the manufacturer to the end user [18].

\[
F_2 = \sum_{i=1}^{m} \sum_{j=1}^{n} C_i^s(t) \cdot (1 \pm g_b(t)) \cdot U_j(t) \cdot (1 - g_w(t))
\]

where \( C_i^s(t) \) - storage costs per product unit at the \( i \)-supplier, rub., at time point \( t \);

\( U_j(t) \) - volume of the supplier's stock, m³, at time point \( t \).

\[
F_3 = \sum_{i=1}^{m} \sum_{j=1}^{n} C_j^s \cdot X_j(t) \cdot (1 - g_w(t))
\]

where \( C_j^s \) - short delivery losses per product unit, rub., at time point \( t \);

\( X_j(t) \) - short-delivered quantity, m³, at time point \( t \).

With the constraints of:

(1) The static balance of the supplier and the consumer's volumes:

\[
\sum_{i=1}^{m} a_i(t) \cdot K_{np}^u = \sum_{j=1}^{n} b_j(t) \cdot K_{cp}^u
\]

where \( a_i(t) \) - scope of supply, m³, at time point \( t \);

\( K_{np}^u \) - coefficient of the supply unbalance, %;

\( K_{cp}^u \) - coefficient of the demand unbalance, %;

\( b_j(t) \) - size of consumption, m³, at time point \( t \).

\[
K_{cp}^u = \frac{Q_{cp}}{Q_{np}} \cdot 100\%
\]
where $K_{\text{спр}}^n$ - coefficient of the demand unbalance in the $j$-consumption point; 
$Q_{ф}$ - average actual size of consumption in the $j$-point for several periods; 
$Q_{пл}$ - average planned size of consumption in the $j$-point for several periods.

$$K_{\text{спр}}^n = \frac{Q_{ф}}{Q_{пл}} \cdot 100\%$$

where $K_{\text{спр}}^i$ - coefficient of the supply unbalance in the $i$-production point; 
$Q_{ф}$ - average actual volume of production in the $i$-point for several periods; 
$Q_{пл}$ - average planned volume of production in the $i$-point for several periods.

(2) The natural non-negativeness of freight flows and stocks:

$$X_j(t) \geq 0, \quad i = 1, 2, \ldots, m; \quad j = 1, 2, \ldots, n$$

$$U_j(t) \geq 0, \quad j = 1, \ldots, n$$

(3) The dynamic link of suppliers and consumers:

$$X_j(t) = X_j(t+1) \cdot (1-g_w), \quad i = 1, 2, \ldots, m; \quad j = 1, 2, \ldots, n; \quad t = 0, 1, \ldots, T$$

where $X_j(t)$ - delivered quantity, at time point $t$, m$^3$; 
$X_j(t)$ - arrived quantity, at time point $(t+t_y)$, m$^3$; 
t$y$ - standard time of delivery, days.

(4) The movement of consumers and suppliers' stocks:

$$U_j(t+1) \cdot (1-g_w) = U_j(t) \cdot (1-g_w) + \sum_{i=1}^{m} X_i(t) \cdot (1-g_w) - b_j(t) \cdot (1-g_w)$$

where $X_i(t)$ - volume of raw materials arrived to the supplier's warehouse, m$^3$, at time point $t$; 
a$w_i(t)$ - total of the supplier's volume, production capacity, at time point $t$; 
$U_j(t)$ - volume of raw materials arrived to the supplier's warehouse, i.e. accumulation at time point $t$.

(5) The dynamic balance of production and consumption:

$$\sum_{i=1}^{m} \sum_{j=1}^{n} a_i(t) \cdot (1-g_w) = \sum_{t=1}^{t_y} \sum_{j=1}^{n} b_j(t) \cdot (1-g_w)$$

where $t_y$ - standard time of delivery.

4. Conclusion

The suggested setting of a stochastic transportation problem in the dynamic setting ((8) - (20)) gives priority to the distribution of deliveries to less expensive destination points (transportation costs taken into account) and only then to points with lower storage costs, which ensures the main principles of a logistic approach and effective functioning of the wood transport system.

5. References

[1] Bavbel' E I and Lyshchik P A 2009 Forestry Journal vol 4 82–88
[2] Borisov G A and Kukin V D 2009 Forestry Journal vol 1 60–65
[3] Bolotov O V, El'deshteyn Yu M, Bolotova A S, Mokhirev A P and Goryaeva E V 2005 Basics of calculating and planning sustainable forest management [Krasnoyarsk: SibGTU] 183
[4] Gromov I A and Tyurin N A 2017News of the Saint Petersburg State Forest Technical Academy vol 219 133-143
[5] Elderstein Yu M 2003 *Modeling and optimization of production processes in the forest and woodworking industry* (Krasnoyarsk: SibGTU) 104

[6] Kovalev R N and Gurov S V 1996 *Planning of transport systems of forest enterprises in a multi-purpose forest management* (Ekaterinburg: Ural. State Forestry Academy) 250

[7] Kovyazin V F and Romanchikov A Yu 2018 *Notes of the Mining Institute* (St Petersburg) vol 229 98-104

[8] Kovyazin V F and Romanchikov A Yu 2015 *Notes of the Mining Institute* (St Petersburg) vol 216 232-237

[9] Livitin A V 2006 *Introduction to The Design and Analysis of Algorithms* (Moscow: Vi'yams) 349-353

[10] Sokolov V A 2014 *Siberian Forest Journal* (Krasnoyarsk) 14-24

[11] Chernykh R A 2011 *Conifers of the boreal area* (Krasnoyarsk: SibGTU) ed Pavlov N I 130-133

[12] Chernykh R A and Bolotov O V 2009 *Water resources of the region, their protection and rational use* (Krasnoyarsk: SibGTU) ed Bolotov O V 67-68

[13] Thomas H Cormen 2009 *Introduction to Algorithms* 3rd ed. MIT Press 1292

[14] Abdi E, Majnounian B, Darwishsefat A, Mashayekhi Z, Sessions J 2009 *Journal of Forest Science* 55(4) 171-176

[15] Newnham R M 1995 *Journal of Forest Engineering* 6(2) 17-26

[16] Gnedash M A 2006 *Thesis by Candidate of Technical Sciences* (Lipetsk) 275

[17] Seraya O V and Dunaevskaya O I 2011 *The Technology of Solution of Undefined Nonlinear Multiindex Transport Problems Information technologies: science, technique, technologies, education, health: Int. Sc.-Pract. Conf.* vol 19 (Khrakov) 364

[18] Kobalinsky M V 2006 *Thesis by Candidate of Economic Sciences* (Krasnoyarsk) 42

[19] Saraev L A and Borodinova I A 2010 *A Stochastic Transportation Problem* (Saratov: Vestnik SGU) 7 81