INSTRUMENTATION OF DYNAMIC PROGRAMMING IN OPTIMIZATION OF A REGIONAL TRANSPORT SYSTEM

Shramko, Alexander P., *Admiral Ushakov Maritime State University, Novorossiysk, Russia.*

ABSTRACT

Optimized approaches to modeling of a region's transport system based on the principles of dynamic programming are compared with correlation of the volumes of cargo flows with the transport system's capabilities and the definition of an optimal route of movement for transportation of goods. A methodological tool for modernizing the regional transport system is proposed.

Keywords: water transport, auto enterprises, railway, regional transport system, dynamic programming, modeling, international transit.

Background. *For efficient functioning of a transport system, a balanced transport and throughput capacity of the network with the needs of domestic and international transit is necessary. Transport is a servicing branch of material production, through which a constant cycle of productive capital and rhythmic functioning of industrial production take place.*

The uneven growth in traffic volumes should be compensated by the growth of infrastructure potential, the required number of rolling stock and cars.

Objective. *The objective of the author is to consider dynamic programming in optimization of a regional transport system.*

Methods. *The author uses general scientific and engineering methods, dynamic programming, mathematical calculation, evaluation approach.*

Results. *One of the effective methods for forecasting and designing transport systems is dynamic programming (DP), which is used for long-range forecasting and planning, for stage-by-stage modernization of a regional transport system.*

A cargo flow is characterized by a vector: point of departure, destination, class, kind of cargo, delivery time, departure time.

In turn, transportation of goods is associated with a scheme (cartogram) of a cargo flow, speed of movement, capacity (carrying capacity) of rolling stock (the higher is carrying capacity, the lower is cost of transportation, but more costs, due to downtime). At the heart of a sustainable cargo flow is organization of interaction of modes of transport, cargo handling capacity of terminals, optimal carrying capacity of a rolling stock unit (Pic. 1).

The transport complex is a dynamic system, therefore all variables appearing in the process are functions of time. Any finite carrying capacity W_k should be considered at some specific time t.

The input – cargo flow of a transport complex – also varies with time, therefore such system states are possible when the cargo flow values will differ significantly from carrying capacity of the complex, which can lead to failures. In these conditions, a particular interest is the established mode of operation, stability of the process throughout a range of changes in the cargo flow. For this, it is necessary to know the magnitude and regularities of the change in the cargo flow of the transport complex and its carrying potential.

The development of international relations has revealed a number of additional workloads in the form of differences in technical standards for rolling stock, transport routes, dimensions and weight of cargo, originality of national regulatory requirements, which creates great delays in transshipment of goods from one mode of transport to another crossing the borders, thereby increasing risks and costs.

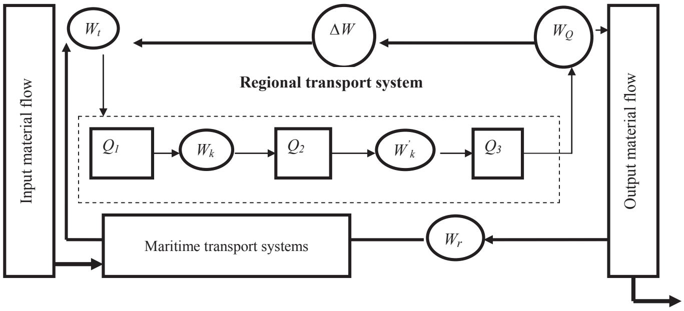
The transport complex of the Azov-Black Sea basin of the Russian Federation, characteristic of this point of view (Pic. 2), is a collection of various modes of transport operating in the region. Its development is due to the features of the economic complex, the sectoral and territorial structure of production, the place of the region in the post-Soviet division of labor, geographical location and a number of other conditions and factors [8].

The required carrying capacities of the transport complex are determined by the growth in the volume of transportation. This parameter can be either constant or variable. The transport demand function appears as:

$$Q(t) = Q_{(t-1)} + aA_t + a_1A_{t-1} + a_2A_{t-2}, \qquad (1)$$

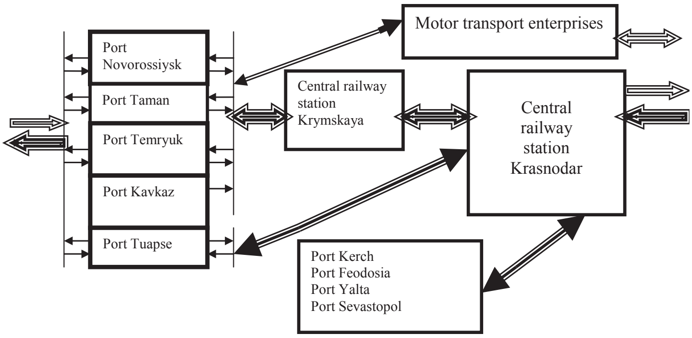
where Q(t) – forecasted transportation volume in period t; $Q_{(t-1)}$ – volume of transportation in the previous period; a, a_1, a_2 – constant coefficients affecting transit positively or negatively; A_t – number of vehicles (railway, road, sea) for the period t.

The need of the region for transit and its carrying capacity: Q = F(A); $W_k = \phi(A)$. (2)



Pic. 1. Schematic diagram of functioning of a regional transport system as part of an international corridor: Wt – cargo flow of a transport complex; W_Q – transport products; W_r – needs of a consignee; W'_k – forecast carrying capacity of a transport complex; W_k – actual carrying capacity; Q_1 – operator of maritime transport; Q_3 – operator of railway transport; Q_3 – operator of motor transport; ∆W – increase (reduction) of a cargot flow.

Pic. 2. Schematic diagram of the regional transport system of the Azov-Black Sea basin [4].



Considering the transport system of the region from the point of view of dynamic programming, we carry out selection of an optimal plan for implementing multi-stage actions.

The transport process consists (organizationally and technologically) of m steps. At each step there is distribution and redistribution of resources, in order to improve a final result. These distributions in dynamic programming are called operation controls and are denoted by the letter u. The efficiency of the operation as a whole is estimated by the same indicator as the management effectiveness W(u). Moreover, W(u) depends on the whole set of controls at each step of the operation: $W = W(u) = W(u_1, u_2, ..., u_m)$. The control at which W exponent reaches a maximum becomes optimal.

Optimal control of multi-step process is a set of optimal controls at each stage: $u = (u_1, u_2, ..., u_m)$.

In most practical tasks, the efficiency indicator of operations is the sum of effectiveness of actions at all stages (steps), operations: $W=\sum_{t=1}^{m}\omega_i$ *where* ω_i *– efficiency of the operation at the i-th step. In this case, in case of optimal control of the system* $W=\max\sum_{i=1}^{m}\omega_i$.

The essence of solving dynamic programming problems is as follows [6]:

– optimization is made by a method of successive approximations (iterations) in two rounds; first from the last step of the operation to the first, and then, on the contrary, from the first to the last;

– on the first round, going from the next steps to the previous ones, a so-called optimal solution is found. It is chosen in such a way that all the previous steps give the maximum efficiency of the subsequent step. In other words, at each step such control is sought, which gives optimal continuation of operations. Accordingly, it is logical to consider the very principle of choosing control in this case as a principle of optimality;

– the second round of optimization begins with a step for which optimal control is known. Having for all steps after conditional optimal controls solution for each subsequent step is determined.

Dynamic model of the ratio of cargo flows and carrying capacity of the region's transport complex (Pic. 3).

The straight line $\phi(A)$ reflects the possibilities and needs for cargo transportation defined by F(A).

The actions of the dynamic model (Pic. 3) correspond to the indicated changes in the carrying capacity of $\phi(A)$ and the transportation demand determined by F(A). The equilibrium position is fixed by the point of intersection of Q and $\bar{W}_k$. In the initial period, the carrying potential is W_{k0} and Q_0 cargo volume is transported, corresponding to the point Q_0 on the line F(A). With insufficient carrying capacity of rolling stock providing transit, demand exceeds supply.

Taking this into account, in the second period the carrying capacity will be W_{k1} and Q_1 cargo will be transported. From point Q_1 on the line F(A), the motion will go horizontally to the intersection with the line $\phi(A)$. The vertical, lowered from the intersection point, will show the required carrying capacity of the next interval time, and on the ordinate axis – the volume of cargo transported in the next period. The relative carrying capacity and the volume of the cargo transported are, respectively, the coordinates of the points Q_1, Q_2, Q_3 on the curve that gravitate toward the point with the coordinates $\bar{Q}$, $\bar{W}_k$.

The location of the points Q_1, Q_2, Q_3 depends on the nature of the dependencies $\phi(A)$ and F(A). Oscillations can be fading, explosive and regular. If the functions F(A) and $\phi(A)$ are given by equations

$F(A) = Q_0 + aA_t$; $\phi(A) = W_{k0} + bA_t$. (3)

(where a and b – constant coefficients; W_{k0} – carrying capacities of the transport complex in the previous period), then the compliance of the carrying capacity to the volume of transportation will be expressed by equations

$$\bar{Q} = Q_0 + a\bar{A}_t = W_{k0} + b\vec{A}_t\,; \quad (4)$$

$$\bar{A}_t = \frac{Q_0 - W_{k0}}{b-a}\,. \quad (5)$$

In the event that the carrying capacity of rolling stock lags behind the need for transportation, the equation takes a form:

$Q_1 = Q_0 + aA_{t-1} = W_{k0} + bA_t$. (6)

Subtracting equation (6) from equation (5), we obtain

$$\Delta A_t = A_t - \bar{A} \quad (7)$$

and as a result $a\Delta A_{t-1} = bA_t$.

The equation describes deviations from the equilibrium level. If we denote C = a/b and put it in this equation, we get $\Delta A_t = C\Delta A_{t-1}$. If the value of A_0 is known at time t_0, then $\Delta A = A_0C^t$, ... $A = A + (A_0 - A)C_t$; $\Delta A = A_0C^t$.

In this case $C=\frac{(+a)}{(-b)}$; *$\Delta A_t = A_0(-1)^tC^t$ and is therefore equal to the values A_0C;...A_0C^2;... A_0C^3, so that ΔA_t acquires alternately a positive or a negative value.*

The analysis shows that the following cases are possible:

1) $a > |-b|$, angle of inclination of F(A) to the axis OA is greater than the angle of inclination of $\phi(A)$. In case $C > 1$ and a series of successive values ΔA_t are infinitely increasing in absolute value $\Delta \to \infty$, explosive oscillations take place;*

2) $a = |-b|$, i.e. angles of inclination of F(A) and $\phi(A)$ are equal. In this case $C = 1$ and a series of values ΔA_t will consist of alternations $(A - \Delta A_t)$ and $(A + \Delta A_t)$, i.e. ΔA_t will be either greater, or less than W_k by the same amount;

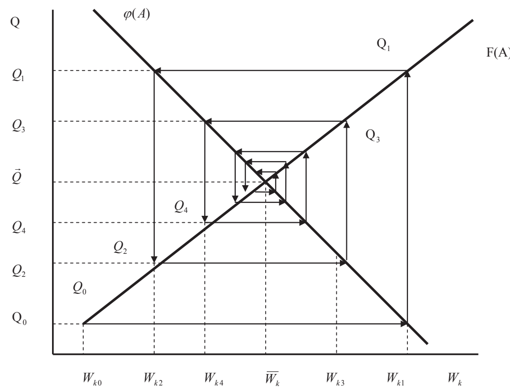
3) $a < |-b|$, i.e. angle of inclination of $\phi(A)$ is greater than of F(A). In this case $C < 1$ and successive ΔA_t decrease by absolute value. The oscillations are damped, tending to a level of equilibrium. The greater is β with respect to α, i.e. the steeper is $\phi(A)$ as compared to F(A), the faster the unevenness in the arrival of goods into the system will be attenuated.

The problems that lead to network transport models can be solved by dynamic programming.

Conclusion. The toolkit for dynamic programming remains in demand, despite the fact that the proposed models are a fairly general mapping of the transport process, which takes into account the main interrelationships between the main components: the transport network, freight flows and vehicle flows, as well as the volume of cargoes at terminals in the port and approaches to it.

Methods of dynamic programming are focused on increasing efficiency in solving transport problems by splitting them into relatively small and, therefore, easily solvable subtasks. At the same time, the optimality principle is the basis for step-by-step nature of actions, but it does not contain information on how to solve subtasks arising at each stage. For this reason, the optimality principle is sometimes regarded as too general to be useful in practical research. The situations can arise when decomposition of tasks is carried out properly, but the numerical result cannot be obtained due to the great complexity of optimization subtasks associated with each stage. Nevertheless, it should be noted that, despite these shortcomings, the method of dynamic programming makes it much easier to solve a number of practical tasks [6].

The formulated problem belongs to the class of problems of optimization of interconnected flows on the network: the primary one, representing the flow of vehicles through the transport network, and the secondary one – the flow of transported goods



Pic. 3. Dynamic model of the ratio of cargo flows and carrying capacity of the region's transport complex.

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Information about the author:
Shramko, Alexander P. – Ph.D. (Economics), associate professor at the department of System analysis and process management on water transport of Admiral Ushakov Maritime State University, Novorossiysk, Russia, ocenka-shramko@mail.ru.

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