DOI:10.54381/plmo2023.08

A delivery model for the optimal number of railcars for container flows in the process of interaction of sea and railway transport

Jumber CHOGOVADZE, Phridon GOGIASHVILI*, Gocha LEKVEISHVILI, Besik SIRBILADZE
Akaki Tsereteli State University, 59 Tamar Mepe, 4600, Kutaisi, Georgia
Irakli MIKELADZE
LLC "Amboli", 1 Leonidze Street, Batumi, Georgia
**Corresponding author*. E-mail: Pridon.gogiashvili@atsu.edu.ge

Abstract. The methodology developed in the article using the theory of inventory management, the optimal number of railcars to be delivered was determined, during which the overall cost of the process of interaction of sea and rail transport is minimal.

***Keywords*:** *transport; container; port; ship; railcar; mathematical model*

1. INTRODUCTION

Today, about 55% of cargo is transported by containers in the world. By 2025, the increase of this indicator is predicted within 70% of the current level. According to the forecast of the United Nations Economic and Social Commission, world container shipments will reach 577 million TEU in the shortest time.

In the report of the United Nations Economic Commission for Europe, it is noted that the total volume of containers imported and exported by sea and rail transport between China and EU countries is 62% and 7%, respectively (UNECE, 2018).

On the South Caucasus section of the New Silk Road, the Baku-Tbilisi-Kars railway through Akhalkalaki becomes a key section in the Transport Corridor Europe-Caucasus-Asia (TRACECA). This railway line is expected to transport 3 million tons of cargo at the beginning.

In order to ensure a continuous transport system in the logistics chain of cargo transportation, it is important not only to create an efficient transport system for each type of transport, but also the interaction of different types of transport. An important point in the process of transferring the container flows from one type of transport to another is ports and port stations.

In recent years, there has been a significant increase in the number of containers handled by the Georgian ports and transported by railway. Despite the growth in container shipping in recent years, there are problems in the field of interaction of different types of transport. During the delivery of the container flow, there are movements of the cars and vessels.

2. SUBJECT AND METHODS OF RESEARCH

Means of cargo transportation are characterized by constantly developing dynamics, which primarily means faster and more reliable services. Multimodal shipments are often used in the cargo delivery system, that is, shipments by various types of transport. In these logistics systems, the transfer of container flows from one type of transport to another is of paramount importance, the important points of which are ports and port stations.

The article [1, 2] provides a model that describes the movement of containers in the interaction of different types of vehicles and inside the terminal. Modeling results show that the transfer of containers from one mode of transport to another is significantly improved, by reducing the time spent on cargo arrival, departure and waiting.

With the proposed optimization model [3], it is possible to plan the movement of ships, trains and trucks in the terminals, as well as to determine the optimal time for the movement of containers and their delivery between the terminals.

In container terminals, containers are transshipped from one mode of transport to another [4]. Various devices necessary for the loading-unloading process are used in terminals for reloading cargo from ships to barges, trucks, train cars and vice versa. In the last decade, ships sizes have increased significantly and can carry several thousand TEU containers. For the efficient use of such large ships, it is necessary to shorten the time spending in the ports. This means that a large number of containers must be loaded, unloaded and reloaded in the shortest possible time, with minimal use of expensive handling equipment.

The article [5] shows the great importance of competition between land and sea mode transports within the framework of Eurasian integration. A spatial balance of sea and land transport is proposed. A proposed model for rail and sea container shipments in which transportation costs are equal.

Mathematical modeling of the process of interaction between railway and sea transport is carried out in the following stages: content description (descriptive model); parametric description (parametric model); symbolic abstract model; conduction of the calculation of models; optimization model (mathematical model); implementation of a mathematical model.

The so-called descriptive model of the transfer process of containers from sea to rail transport and vice versa involves the sequential execution of all necessary procedures and includes more than 20 operations of two-way movement of container flows.

A parametric model allows establishing relationships between parameters in the presence of their various components. Parametric description of ports and stations is the recording of parameters data that characterize these elements, systems or subsystems as a whole.

By constructing a parametric model, we find that the number of train cars delivered to the port area depends on the length and number of railways. Therefore, it is necessary to conduct a study to determine the optimal number of train cars required for delivery.

In particular, determination of the supply of the optimal number of train cars for mutually agreed operation of two objects (port + railway) is possible with the help of special methods used in the theory of inventory management [6, 7, 8].

In order to ensure the growing volume of container cargo transportation, it is necessary to investigate the process of interaction between sea and rail transport, which affects the efficiency increase of the South Caucasus section of the Eurasian transport corridor.

3. DETERMINING THE NUMBER OF ROLLING STOCK DELIVERED ON APPROACHES TO THE SEAPORT

The marine terminal when moving the cargo flows from sea transport to rail transport (and vice versa), is considered as a link in the logistics chain. The capacity of the marine terminal is determined by the combination of transshipment complexes and port railway station capacities. The throughput capacity of the cargo transshipment complex is determined by the chain of the system "sea cargo front-warehouse-railway cargo front". Direct transshipment of cargo, "ship-railcars, railcars-ship" is efficient in the case where there is no room for waiting for loading/unloading of ships and railcars.

In practice, the simultaneous delivery of ship and rail cars to sea and rail cargo fronts is difficult to implement. Thus, the biggest role in the interaction between the sea and rail transport is given to the port terminal.

When transferring a container from a ship to a rail transport with a direct option (cargo flow 1), high productivity of berth loading equipment is achieved. Moreover, this transshipment operation must be connected with the delivery of railway cars and the simultaneous processing of the customs documents.

A study was conducted using the theory of inventory management to determine the optimal number of railcars for container flows in a marine terminal and to maintain a portside railyard.

The cost of delivering a batch of railway cars to the port does not depend on the number of cars delivered. Let us assume that this constant part of the costs is C_1. With the non-productive cost (C_c) caused by the waiting for the car on the access track to the port in the unit of time and the stock of cars in the station in the time interval θ (N), the number of cars *n* per delivery should be determined, during which the total cost is minimal. The number of cars per delivery will be limited, on the one hand if the number of cars is equal to *n*=0. On the other hand, *n* is limited by the capacity of the approach road or the maneuverability of the locomotive, so let us accept 1≤n≤60. The level of stock replenishment in period *T*, which is equal to *n*/2, should also be determined.

In the time interval *T*, storage costs are equal to $\frac{1}{2}\mathrm{n}\cdot \mathrm{c}_{\wp}\cdot \mathrm{T}$, i.e. the cost per delivery is

$$\mathrm{C}_{\partial}=\mathrm{c}_1+\frac{1}{2}\mathrm{n}\cdot \mathrm{c}_{\wp}\cdot \mathrm{T}$$

The number of railcars delivered on approach to the port will be

$$\mathrm{r}=\frac{\mathrm{N}}{\mathrm{n}}=\frac{\theta}{\mathrm{T}} \qquad (1)$$

Then the total cost in the time interval θ will be

$$\mathrm{G}=\left(\mathrm{c}_1+\frac{1}{2}\mathrm{n}\cdot \mathrm{c}_{\wp}\cdot \mathrm{T}\right)\mathrm{r}=\left(\mathrm{c}_1+\frac{1}{2}\mathrm{n}\cdot \mathrm{c}_{\wp}\cdot \mathrm{T}\right)\frac{\mathrm{N}}{\mathrm{n}}=\mathrm{c}_1\frac{\mathrm{N}}{\mathrm{n}}+\frac{\mathrm{N}\cdot \mathrm{T}}{2}\mathrm{c}_{\wp}=\frac{\mathrm{N}\cdot \mathrm{c}_1}{\mathrm{n}}+\frac{\theta\cdot \mathrm{c}_{\wp}}{2}\mathrm{n}$$

Thus, *G* is a function of variable *n* with known parameters $\mathrm{N},\theta,\mathrm{c}_{\wp},\mathrm{c}_1$

$$\mathrm{G}(\mathrm{n})=\frac{\mathrm{N}\cdot \mathrm{c}_1}{\mathrm{n}}+\frac{\theta\cdot \mathrm{c}_{\wp}}{2}\mathrm{n}$$

Let us introduce designations:

- Total cost on delivery

$$G_1=\frac{\mathrm{N}\cdot \mathrm{c}_1}{\mathrm{n}}$$

- Total cost on downtime

$$G_{\wp}=\frac{\theta\cdot \mathrm{c}_{\wp}}{2}\mathrm{n}$$

As we can see, G_1 is inversely proportional to *n*, while $\mathrm{G}_{\wp}$ is directly proportional to *n* (Fig. 3.6). In this connection, the sum $G(\mathrm{n})=G_1+G_{\wp}$ must have a minimum at any value of *n*.

However, it is known that the minimum of the sum of two variable quantities will be reached when their derivative is constant, when these quantities are equal to each other.

In a given model

$$G_1\cdot G_{\wp}=\frac{1}{2}\mathrm{N}\cdot\theta\cdot \mathrm{c}_1.\mathrm{c}_{\wp}=\mathrm{const}$$

Accordingly, $G_1+G_{\wp}$ minimum is reached (Fig. 1), when $G_1=G_{\wp}$, that is

$$\frac{\mathrm{N}\cdot \mathrm{c}_1}{\mathrm{n}}=\frac{\theta\cdot \mathrm{c}_{\wp}}{2}\mathrm{n}\ (2)$$

Therefore, the optimal number of railcars in delivery will be equal to

$$\mathrm{n}=n_0=\sqrt{2\frac{\mathrm{N}\cdot \mathrm{c}_1}{\theta\cdot \mathrm{c}_{\wp}}}$$

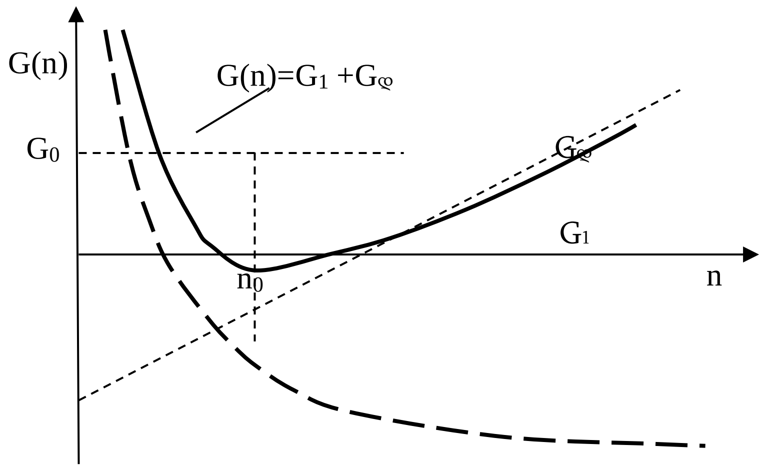

Fig. 1. Cost function

If we insert (2) into the formula (1), we get:

$$T = T_0 = \sqrt{2\frac{\theta \cdot c_1}{N \cdot c_{ლ}}} = \frac{\theta}{N} n_0$$

and

$$G_0 = G(n_0) = \sqrt{2N \cdot \theta \cdot c_1 \cdot c_{ლ}}$$

Now let us find the relative variation of $G(n)$ if n varies from $n_0 = -10\%$ to $n_0 = +10\%$. The infinitesimal increment of the function $P(n)$ is represented by differentials

$$\partial G = G\partial n = \frac{1}{2}\theta \cdot c_{ლ} - \frac{N \cdot c_1}{n^2}$$

This expression shows that the sensitivity of the function $P(n)$ increases linearly with an increase in $c_{ლ}$ and decreases linearly with an increase in c_1, then

$$\partial G = \frac{1}{2}[G(0{,}9n_0) + G(1{,}1n_0) - 2G(n_0)],$$

from which

$$\frac{\partial G}{G_0} = \frac{1}{2}\left(\frac{G(0{,}9n_0) + G(1{,}1n_0)}{PG_0}\right) - 1$$

The specific number of railway cars during delivery is calculated with the help of the quantities $N, \theta, c_{ლ}, c_1$, where N is the number of cars or its stock in the station.

According to statistical data, the use of railways in container shipments is minimal, and every year on average 10%-15% of the total number of containers handled in Georgian ports are transported by railways, which is a very low figure.

According to the statistical data of EU countries, 45-50% of port-to-port shipments are carried out by rail because of its safety and, most importantly, its cheapness.

In the time interval θ, the total cost *G* is a variable function with respect to *n* and in the case of known parameters $N, \theta, c_{ლ}, c_1$ is determined by the formula:

$$G(n) = \frac{N \cdot c_1}{n} + \frac{\theta \cdot c_{\wp}}{2} n$$

Depending on the number of delivered railcars, we calculate the total cost *G(n)* using the software package Mathcad.

As an example of the implementation of a mathematical model of the optimal number of railway cars, the sea port of Batumi, located on the Black Sea coast of Georgia, was selected, with the parameters as follows: 1. c_c=2.02 GEL/hour; c_1=150 GEL; N=200 cars; 2. c_c'=10.1 GEL/hour; c_1=150 GEL; N=200 cars, θ=24 hours; For the initial data, the number of railcars *n* per delivery, during which the total cost is minimal, was determined.

According to the values obtained by calculation, we build a curve of the total costs function *G(n)* (Fig. 2, 3) depending on the number of delivered railcars *n*, when the numerical values of the parameters $N, \theta, c_{1,} c_c$ are known.

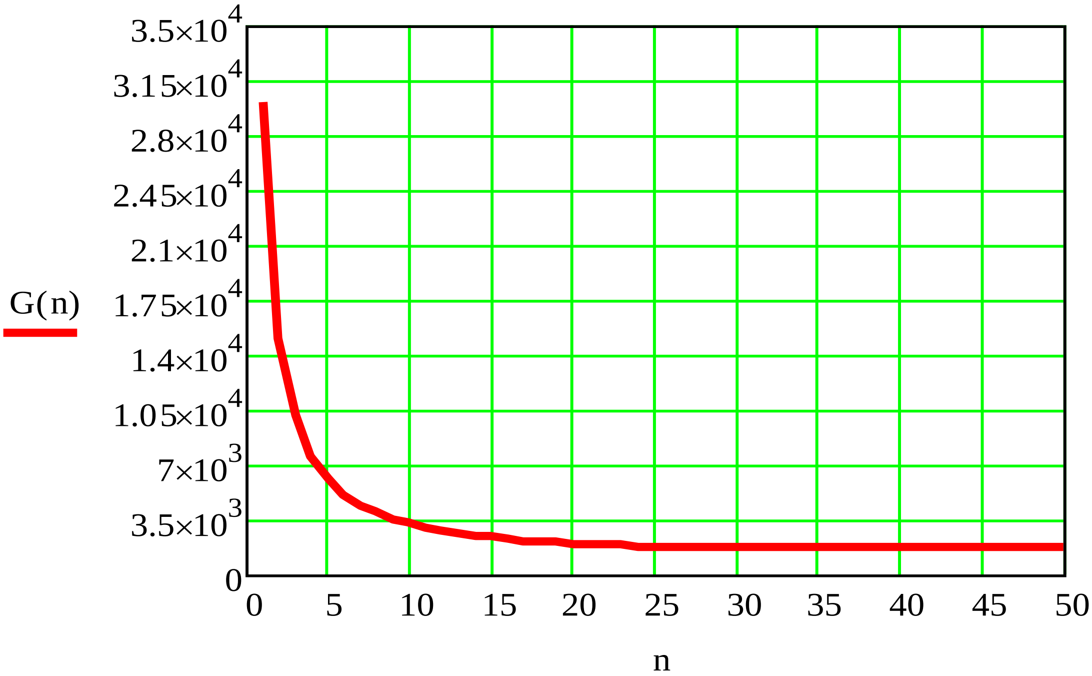

Fig. 2. Variability of costs for delivery of railcars ($c_{\wp} = 2{,}02\ GEL/hr$; c_1=150 GEL; $N = 200$ cars)

2. Initial data: $c_{\wp}' = 10{,}1\ GEL/hr$; c_1=150 GEL; $N = 200$ cars, $\theta = 24\ hr$.

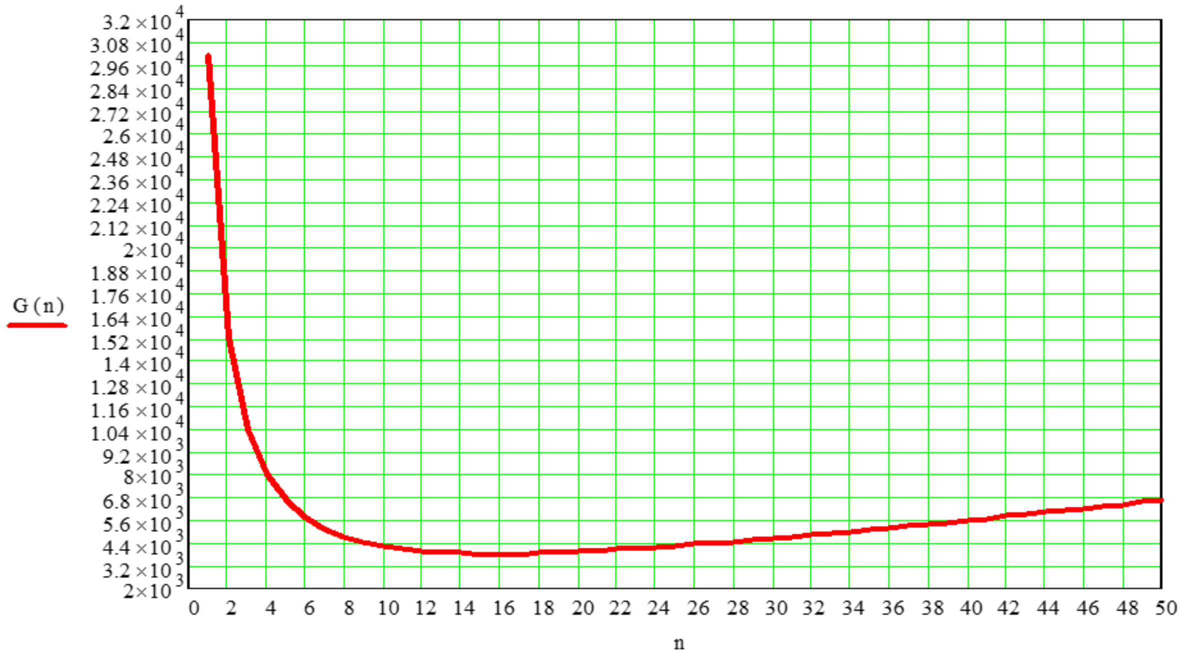

Fig.3. Variability of costs for delivery of railcars ($c'_{\wp} = 10{,}1\ GEL/hr$; c_1=150 GEL; $N = 200$ cars, $\theta = 24\ hr$.)

Thus, according to the calculation data of the first case, the optimal number of railcars should vary between 31 and 39 (Fig. 2), and in the second case – between 14-18 railcars (Fig. 3). The results of this theoretical research will be used in building the mathematical model of the work of the sea port and the railway station in front of the port.

The obtained value, in the case of a 10 percent deviation of costs from the value n to value n_0 (that is, when the number of railcars on delivery decreases or increases), causes a change in the total cost by about 0.6%.

In the time interval θ, the total costs G in relation to n and $c_{\wp}$, in the case of a variable function and known parameters $N, \theta, c_{\wp}, c_1$ is determined by the formula:

$$G(n, c_{\wp}) = \frac{N \cdot c_1}{n} + \frac{\theta \cdot c_{\wp}}{2} n$$

Initial data: c_1=150 GEL; $N = 200$ cars, $\theta = 24\ hr$.

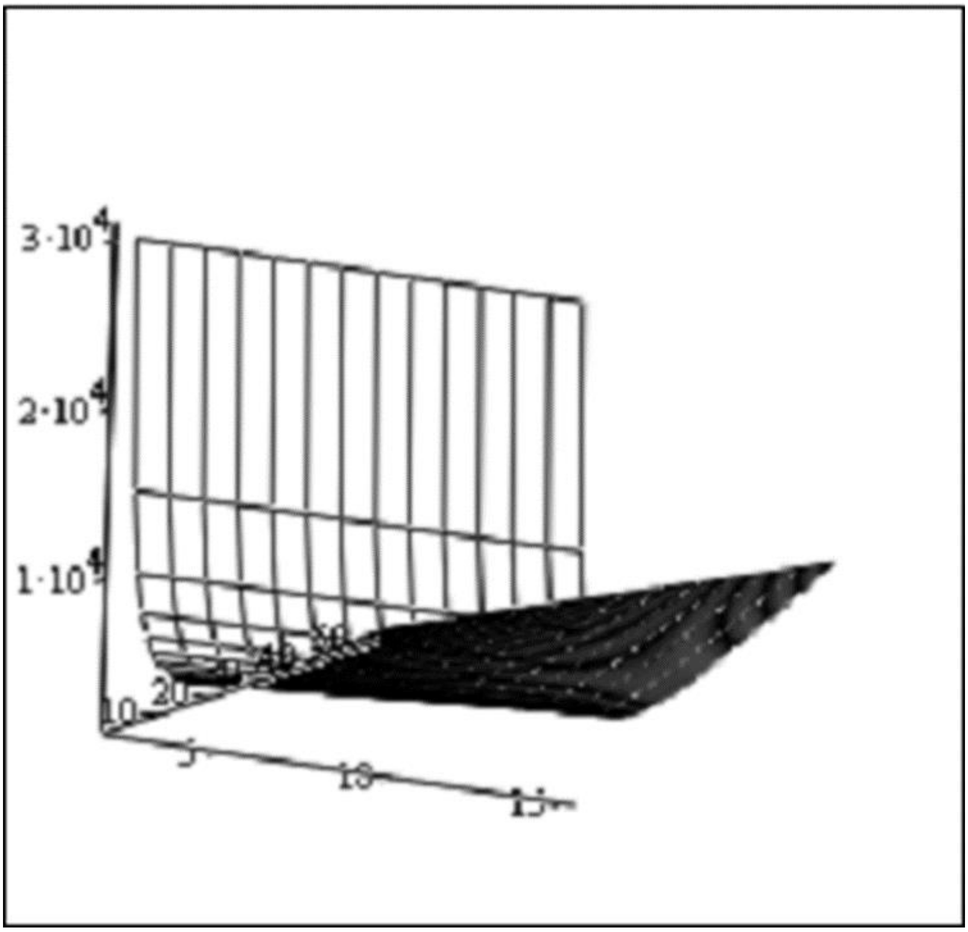

Fig.4. Graph of cost variation of $G(n, c_{\varphi})$

According to the values obtained by calculation, we build a curve of the function $G(n, c_{\varphi})$ of the total costs (Fig. 4) depending on the number of delivered railcars (*n*) and the cost of 1 hour of downtime (c_{φ}), when numerical values of the parameters N, θ, c_1, are known. In this case, the maximum value of the total costs is obtained when *n*=1 wagon and (c_{φ}) = 4.01 GEL and it is G(1; 4,01)=3,005X10^4 GEL.

4. CONCLUSIONS

Using the theory of inventory management, it was found that the total cost $G(n)$ in the time interval θ during the process of interaction of sea and rail transport depends on the number of delivered railcars *n*. The optimal number of delivered railcars determined by the developed model ensures the overall minimum cost of executing the process of interaction of sea and rail transport, reducing the number of railcars and ships during container flow delivery.

References

1. Qu Hu[1], Bart Wiegmans[1,2], Francesco Corman[3], Gabriel Lodewijks[4]. Integration of inter-terminal transport and hinterland rail transport. *Flexible Services and Manufacturing Journal* (2019) 31:807–831. https://doi.org/10.1007/s10696-019-09345-8

2. Negenborn RR, Lodewijks G (2017a) Planning inland vessel operations in large seaports using a two-phase approach. *Computers and Industrial Engineering*, vol. 106, pp. 41-57
3. Schepler X, Balev S, Michel S, Sanlaville E (2017) Global planning in a multi-terminal and multi-modal maritime container port. *Transp Res Part E-Logist Transp Rev* 100:38–62
4. Vis IF, De Koster R (2003) Transshipment of containers at a container terminal: an overview. */ European Journal of Operational Research 147* (*2003*) *1–16*
5. Mengqiu Lu1, Yu Chen2*, Robin Morphet[3], Yuqi Lu[2] & Enkang Li[2]. *The spatial competition between containerized rail and sea transport in Eurasia.* 2019
6. Кузнецов Б.Т. Математические методы и модели исследования операций. Издательство ЮНИТИ-ДАНА- 2005Б с.390. Kuznetsov B.T. Mathematical methods and models of operation research. UNITI-DANA publishers, 2005, 390 p.
7. Рихтер К.Ю. *Транспортная эконометрия*. - М.: Транспорт, 1982.-317 с. Rikhter K.Yu. *Transport econometrics.* M.: Transport, 1982 – 317 p.
8. Стерлигова А.Н. *IУправление запасами в цепях поставок.* Учебник. -М.: ИНФРА-М, 2008. - 430 с. Sterligova A.N. *Inventory management in terms of the supply chain.* Textbook. – M.: INFRA publishers. – M, 2008. – 430 p.