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Sazonets O.

*Doctor of Economics, Professor,
University of Customs and Finance, Dnipro, Ukraine;
e-mail: onsazonets@gmail.com; ORCID ID: 0000-0001-6521-7815.*

Terebii A.

*Postgraduate student,
Classical Private University, Zaporizhia, Ukraine;
e-mail: aterebey@gmail.com; ORCID ID: 0000-0002-8549-7452*

ECOLOGICAL OPTIMIZATION OF CARGO TRANSPORTATION OF AN ENTERPRISE USING INFORMATION SYSTEMS

Abstract. The aim of the article is to systematize the existing ways to decrease the environmental load at the enterprise, in the country and in the world, to identify ways of greening the enterprise by using transportation means to transport goods from enterprises to customers using information systems and technologies. In the process of preparing the article we used the method of theoretical generalization (to determine the theoretical and logical substantiation of the method of transport at the enterprise), the method of systematization (to build algorithms for determining the optimal route of transport to specialized centers), graphical method (to build a histogram of emission costs for different kinds of transport in the world), mathematical modeling (to determine the optimal route for the transportation of goods by the enterprise, which goes into solving the transport problem and the travelling salesman problem). The means by which the recovery of the ecological situation is stimulated are determined, namely, ecological supply chains are considered as competitive advantages of the enterprise, methods of solving the problem of routing in the enterprise, energy saving in transport, possibility of automobile sharing by different companies, expediency of introduction of innovative types of transport, supply optimization of products from the enterprise to consumers. The latter is considered more carefully using a mathematical apparatus, namely, by solving the transport problem using the method of the smallest element in the column and the method of potentials, and solving the travelling salesman problem using the branch and bound method. The scientific novelty of the work is the systematization of methods of greening the environment, identifying the capabilities of information systems used to achieve this goal, and applying the method of the smallest element in the column and the method of potentials to solve the transport problem, and the branch and bound method to solve the travelling salesman problem to achieve the ecological effect. The practical significance of the study is that the studied methods are used by processing enterprises to green their activities in transport operations.

Keywords: greening, transport transportation, enterprise, transport task, salesman task, information systems

JEL Classification C8, E17, Q3, Q53

Formulas: 3; fig.: 2; tabl.: 3; bibl.: 21.

Сазонець О. М.

*доктор економічних наук, професор,
Університет митної справи та фінансів, Дніпро, Україна;
e-mail: onsazonets@gmail.com, ORCID: 0000-0001-6521-7815*

Теребій А. А.

*аспірант,
Класичний приватний університет, Запоріжжя, Україна;
email: aterebey@gmail.com; ORCID ID: 0000-0002-8549-7452*

ЕКОЛОГІЧНА ОПТИМІЗАЦІЯ ТРАНСПОРТУВАННЯ ВАНТАЖІВ ПІДПРИЄМСТВА З ВИКОРИСТАННЯМ ІНФОРМАЦІЙНИХ СИСТЕМ

Анотація. Метою статті є систематизація наявних шляхів зменшення екологічного навантаження на підприємстві у країні та світі, визначення шляхів екологізації підприємства шляхом використання транспортних засобів для транспортування товарів від підприємств до

клієнтів за допомогою інформаційних систем і технологій. Використано метод теоретичного узагальнення (для визначення теоретико-логічного обґрунтування методу транспорту на підприємстві), метод систематизації (для побудови алгоритмів визначення оптимального маршруту транспорту до спеціалізованих центрів), графічний метод (для побудови гістограми витрат на викиди для різних видів транспорту у світі), математичне моделювання (для визначення оптимального маршруту перевезення вантажів підприємством, що використовується для розв'язання транспортної проблеми і проблеми продавця). Визначаються засоби, за допомогою яких стимулюється відновлення екологічної ситуації, а саме: екологічні ланцюжки поставок розглядаються як конкурентні переваги підприємства, методи розв'язання проблеми маршрутизації на підприємстві, енергозбереження на транспорті, можливість спільного використання автомобілів різних компаній, доцільність упровадження інноваційних видів транспорту, оптимізація поставок продукції з підприємства споживачам. Останнє розглядається більш ретельно за допомогою математичного апарату, а саме шляхом вирішення транспортної задачі з використанням методу найменшого елемента у стовпці та методу потенціалів, а також розв'язання проблеми продавця за допомогою методу гілок і меж. Наукова новизна роботи — систематизація методів екологізації середовища, виявлення можливостей інформаційних систем, що використовуються для досягнення цієї мети, і застосування методу найменшого елемента в колонці та методу потенціалів для розв'язання транспортної проблеми, а також методу гілок і меж для розв'язання проблеми продавця для досягнення екологічного ефекту. Практична значущість дослідження полягає в тому, що досліджувані методи використовуються переробними підприємствами для озеленення своєї діяльності у транспортних операціях.

Ключові слова: екологізація, транспортні перевезення, підприємство, транспортне завдання, завдання продавця, інформаційні системи.

Формул: 3; рис.: 2; табл.: 3; бібл.: 21.

Introduction. The problem of global warming caused by rising carbon levels in the atmosphere is constantly raised in the speeches of reputable figures and international organizations involved in the environment. Despite the fact that without the development and functioning of industry, the progress of mankind as a whole is impossible, the presence of large-scale pollution of the environment by industrial enterprises and vehicles is very acute.

In the field of transport, environmental thinking and environmental priorities are becoming more widespread. Therefore, the issue of greening in enterprises that actively use transport is very acute at this time. It is necessary to systematize ways to improve the environmental condition of roads. One of the ways to reduce the negative impact of transport on the environment is to reduce the routes of transport, which is achieved by calculating the most optimal of them. A mathematical apparatus should be used to minimize transport connections.

Analysis of research and problem statement. The study, conducted in [1], aimed to compare, from an environmental point of view, four different scenarios for the use of freight transport by the supplier to transport the product to the customer on the Italian route.

The study was conducted in order to find an environmentally sustainable solution, or at least a sustainable compromise, as well as the biggest environmental problems associated with the geographical dimension of transport in Italy. The publication [2] considers the identification of possible sources of competitiveness of companies in terms of international transportation and logistics with an emphasis on knowledge and ecology. In the article [3] industrial ecology is used as a basis for the analysis of production of various sources of energy for transport and consequences of this process.

Another way to reduce the burden on nature is energy saving in transport [4]. Much effort is currently being made to develop energy-saving technologies and improve the environmental safety of various modes of transport [5, 6]. Issues of optimization of intra-corporate transport are relevant. In order to reduce the environmental load inside the company, one can use the method of applying the optimization of transport, speeding up the processing of semi-finished products in warehouses

[7]. Article [8] assesses the potential of the truck sharing economy of various enterprises in Polish cities.

The article [9] notes the One Belt, One Road initiative proposed by China to launch cooperation between the respective countries in the field of energy and trade. The study highlights the relationship between industrial value-added cost per capita, freight transport and CO₂ emissions of partner countries of the One Belt, One Road initiative with the help of the Group of 33 economies in 1986—2017. The idea of greening in multimodal transport was proposed in [10]. Global aspects of greening in transport were considered in [11]. Also, the problems of greening in transport were studied in [12; 13].

Unsolved aspects of the problem. However, the means to improve the environmental situation in transport are not yet fully systematized. Reserves for reducing emissions into the atmosphere have not been studied. These reserves can be identified on the basis of route optimization in the transportation of goods.

The purpose of the article is to systematize the existing ways to improve the environmental situation both in Ukraine and in the world, to identify the means of greening in the enterprise under consideration, through the effective use of transportation means for the transportation of goods using information products.

Research results. European environmental policy aims to reduce greenhouse gas (GHG) emissions from transport operation by 90% by 2050 compared to 1990. Facilitating measures to move to the most economical kinds of transport can make an important contribution to achieving this goal. For passenger transport, the transition from air to railroad transport potentially has a key role to play. This is because the pollution of the environment from railway transport is the lowest (Fig. 1) [15; 16]. The biggest polluter is motor transport, which is ahead of air transport.

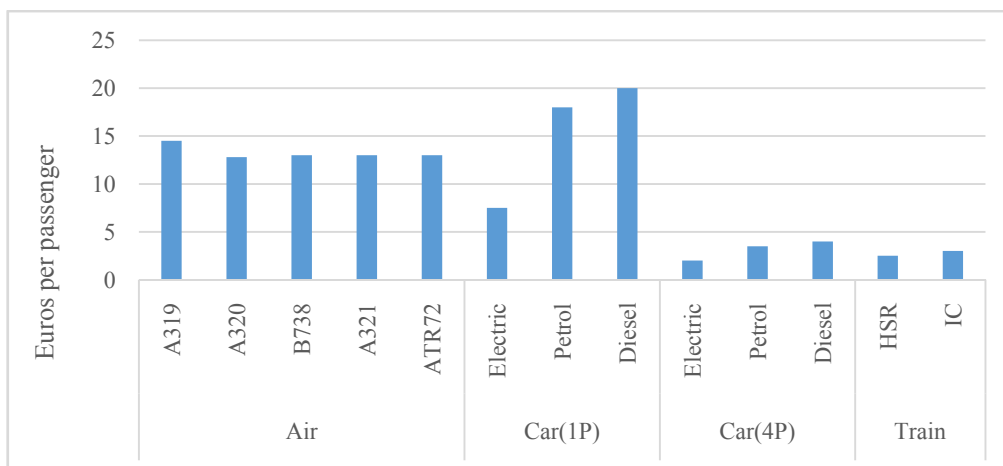


Fig. 1. Emission-related costs for different modes of transport (500 km)

The figure also shows the level of air transport emissions, which takes second place in this indicator after motor vehicles. In this case, the type of aircraft is also important. Approximately all types are contained in one position. At the same time, the Airbus A319 is slightly ahead of all other types. Traveling by electric car with four passengers and by high-speed train (HSR) is the most environmentally friendly.

The industrial environment is largely affected by the increase in energy efficiency of production systems, and this should be taken into account when analyzing product supply chains. A review of the current practice of transporting large quantities of products is necessary as a consequence of the requirements for improving the energy efficiency of industrial production systems.

The state of the environment in our country largely depends on energy saving in transport. Let's analyze the methods of energy saving in moto, railroad, water and air transport.

We will present key technologies for improving energy efficiency of motor transport.

1) Studies of vehicle manufacturers show that reducing the weight of cars and trucks due to the increasing use of polymeric materials can achieve a great economy. If earlier weight loss was achieved through the use of expensive magnesium and aluminum, now they have been replaced by composite materials, such as carbon fiber. Moreover, the use of composite materials does not affect safety.

2) Energy saving in vehicles is directly related to the type of fuel used, in particular — liquefied natural gas.

3) The use of «green» tires reduces rolling resistance, improves traction and saves up to 10% of fuel. Each car is exposed to friction and rolling resistance. To reduce rolling resistance, tire manufacturers are changing the carbohydrate for silicon. Silicon reduces rolling resistance by about 20% more compared to carbon. Thus, the car consumes less energy and, accordingly, consumes less fuel.

The leading role in increasing the pace of development of the enterprise is played by the optimization of transportation between its warehouses and distribution centers, which then supply products to their stores. Let's consider a specific task for the transportation of goods, the volume of which fluctuates during the week, but on average remains approximately the same. We will take this as a basis in our study.

There are two options for product delivery:

1. Transportation is carried out by separate trucks from each separate warehouse to the distribution center which are assigned beforehand while solving a transport problem.

2. Loading from all warehouses goes to one truck which then delivers production to all distribution centers in turn.

Let's analyze the first option.

In the task it is necessary to secure consumers of cargo in the form of products of the processing industry to suppliers.

In our case, to solve the transport problem for the processing industry, we have the distance between suppliers and consumers of products in the following form (*Table 1*).

Table 1

Distances between suppliers and consumers (km)

Suppliers	Consumers			
	B ₁	B ₂	B ₃	B ₄
	<i>Distance, km</i>			
A ₁	22	14	18	10
A ₂	10	26	14	16
A ₃	6	24	10	18

The amount of cargo leaving the warehouse A₁ — 300 kg, A₂ — 500 kg, A₃ — 800 kg. The amount of cargo that should be received by the distribution center B₁ — 200 kg, B₂ — 350 kg, B₃ — 650 kg, B₄ — 400 kg.

This problem is formulated as a transport one and is solved by the method of the smallest element in the column.

While solving it transport work will be the following:

$$200 \cdot 6 + 300 \cdot 14 + 50 \cdot 24 + 100 \cdot 14 + 550 \cdot 10 + 400 \cdot 16 = 19\,900 \text{ (kg} \cdot \text{km)}. \quad (1)$$

Next, we check for optimality by the method of potentials.

As a result of the test, a square with a negative potential was obtained. This indicates that the plan is suboptimal, and then the reassignment of suppliers to consumers takes place. After reassignment of the cargo, all unfilled squares have positive potentials, and the potentials of filled squares are zero. This means that the resulting plan is optimal.

Thus, the optimal plan was found, according to which a load of 300 kg will be transported from the A₁ warehouse to the B₂ distribution center. From the warehouse A₂ goods in the amount of 50 kg will be transported to the distribution centers B₂ and B₃, as well as the amount of 400 kg of goods to the distribution center B₄. From the A₃ warehouse 200 kg of products will be transported to the B₁ center and 600 kg — to the B₃ center.

Thus, as a result of optimal assignment of distribution centers to warehouses-suppliers of products, the volume of transport work will be:

$$200 \cdot 6 + 300 \cdot 14 + 50 \cdot 26 + 50 \cdot 14 + 400 \cdot 16 + 200 \cdot 6 + 600 \cdot 10 = 19800 \text{ (kg} \cdot \text{km)}. \quad (2)$$

The problem can be solved with the help of Excel tools using the functions SUMM, SUMMPROYZV, the command «Search for a solution» on the tab «Data» and the software product C++.

Let's look at the second loading option. In our case, the distances between the distribution centers of the enterprise are given in *Table 2*.

Table 2

Distances between distribution centers (km)				
	B₁	B₂	B₃	B₄
B₁	M	10	6	15
B₂	11	M	9	3
B₃	6	8	M	7
B₄	12	3	8	M

This option requires solving the travelling salesman problem, which we will solve by the branch and bound method.

The solution of the problem (*Table 3*) will be presented as follows. Let's take as an arbitrary route:

$$X_0 = (1,2); (2,3); (3,4); (4,1). \\ F(x_0) = 10 + 9 + 7 + 12 = 38.$$

Table 3

Emissions into the atmosphere in different ways of constructing the route of delivery of goods of the enterprise

Emissions from different methods of delivery of goods	Numeric value (d)
Emissions from the traditional method of delivery of goods	26 534
Emissions from the delivery of goods based on the calculation of routes using the method of optimization by solving the transport problem	18 124
Emissions when optimizing routes using the branch and bound method when solving the travelling salesman problem	7 790

Gradually determining the lower limits by means of a reduction operation, performing branching and checking for the minimum, we will eventually arrive at the final matrix (2 · 2).

As a result Hamiltonian cycle forms the edges on the tree branches: (B₁,B₃), (B₃,B₂), (B₂,B₄), (B₄,B₁).

The length of the route is $F(Mk) = 30$.

In this case, the total workload will be 48,000 kg · km, which is much more than in the first option. Relevant calculations are performed using information systems Excel and C++. We see that the use of the first option of optimization is more appropriate in terms of saving enterprise resources.

Let's define an ecological component of the results of these calculations. This study is due to the feasibility of implementing in Ukraine a new law of the European Union, according to which emissions for freight cars at present should be reduced by 19% compared to 2012. For trucks, starting in 2020, annual emission reductions of 3% must be ensured [18—20].

The company under study uses long-distance trucks and light commercial vehicles (vans) to transport its products - for transportation inside the city brands MAN, SCANIA, FORD are used. All vans of the enterprise have an average weight of 2610 kg and carry no more than 3.5 tons of cargo. They emit CO₂ in accordance with the standards calculated by the formula [21]:

$$CO_2 = 130 + a(M - M_0) \left(\frac{g}{km} \right), \quad (3)$$

where M is the curb weight in kilograms,

$$M_0 = 1\,372 \text{ kg},$$

$$a = 0,0457.$$

The calculations lead us to the emission values presented in *Table 3* for the first and second methods of traffic optimization.

As we can see, carbon emissions in the formation of the route, taking into account the travelling salesman problem and the transport problem, are much lower than in the old way of transporting goods. The reduction of emissions when transporting goods using the method of optimization by solving the transport problem is 8 kg 410 g, reducing emissions by optimizing the route of the van using the branch and bound method when solving the travelling salesman problem is 18 kg 744 g, which are significant figures. At the same time, we see that the second method is much more effective in terms of greening the environment, so we will recommend the company to increase the level of environmental responsibility to use the branch and bound method in solving the travelling salesman problem. This method of transporting the products of this enterprise significantly reduces emissions into the atmosphere, which significantly improves the ecological state of the environment.

Thus, we have obtained several basic, in our opinion, ways of greening the use of transportation means and information systems. Their systematization is shown in *Fig. 2*.

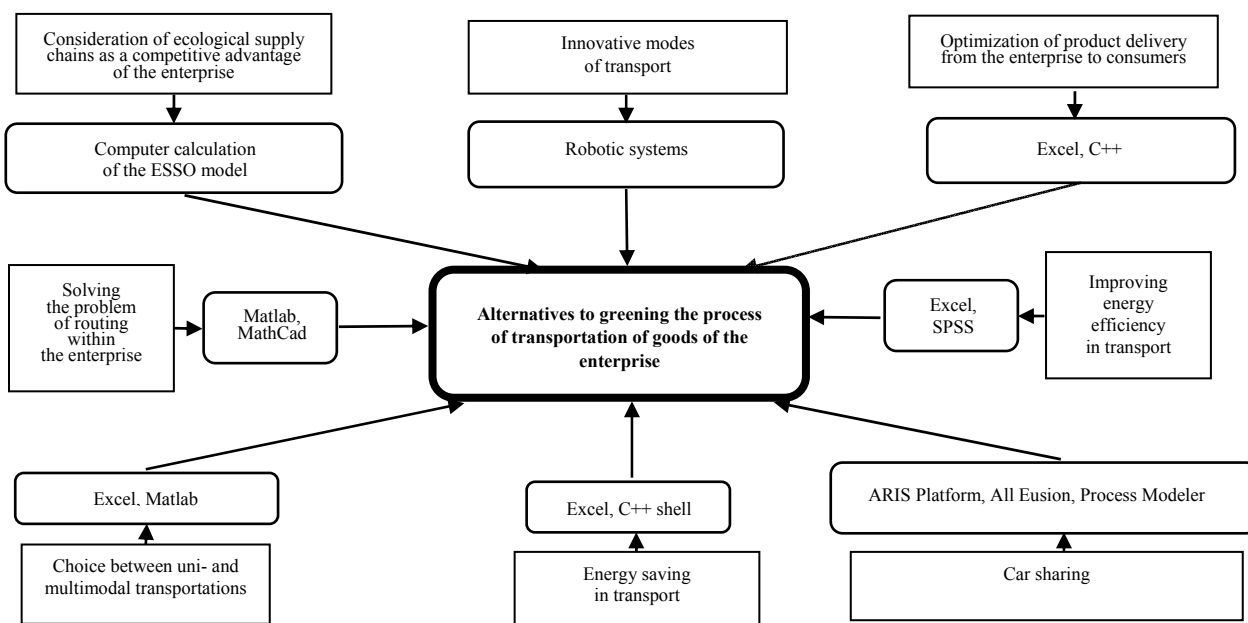


Fig. 2. Information interpretation of ecologically optimal transportation of goods

Conclusions. Based on the analysis, the article identifies the main methods of greening the environment both in Ukraine and in the world when using transport systems, namely, reducing harmful emissions into the atmosphere. These methods include consideration of environmental supply chains as a competitive advantage of the enterprise, solving the problem of routing within the enterprise, energy saving in transport, car sharing by different companies, introduction of innovative kinds of transport, energy efficiency in transport, calculation of optimal air routes in the world, optimization of the transportation of goods from the enterprise to consumers. The latter is considered more carefully with the coverage of the mathematical apparatus, namely, with the solution of the transport problem using the method of the smallest element in the column and the method of potentials and the travelling salesman problem using the branch and bound method. The presented mechanism of route optimization can be used at any enterprise engaged in transportation of goods.

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