ECONTECHMOD. AN INTERNATIONAL QUARTERLY JOURNAL – 2017, Vol. 06, No. 1, 55–62

Optimization of the load scheme of heavy vehicle for a given flow of goods

M. Oliskevych

Department of automobile technique operation and repair,
Lviv Polytechnic National University,
Bandery Str., 32, Lviv, 79020, Ukraine,
e-mail: Myroslav@3G.ua

Received: April 09.2017; Accepted: April 27.2017

Summary. This research is devoted to the problem of improving the usage of heavy road trains by increasing their actual loading with cargo. The present paper proves that the extremely forced road train not always fits the permissible loading from its axles and vice versa. This contradiction is reinforced by the fact that flows of general cargoes consist of different transport options packages. They are required to be arranged into a rational scheme of loading vans. There were formulated and showed an example of solving the optimization problem of placing cargo units into five-axle road train. There were used static equations of the mechanical system, which is the tractor plus van plus the general goods. First, the piece goods are considered as reduced to the centre of mass of road train. It was showed the importance to comply with accuracy of the coordinates of the centre of gravity value and its influence on the load of vehicle. The dependence of reducing of permissible loading from the centre of gravity coordinate deviation of the estimated optimal was built. The task of optimization of loading schemes was solved in three stages. In the first stage, there was defined the centre of gravity of cargo. At the second stage, there were taken into account the weight and dimensional parameters of transport packages and made a concentrated mass distribution on the wagon platform. It was found that it is advisable to choose the weight of transport packages for optimal load circuit. Each optimal loading scheme should meet the current transport scheme process of cargo delivery. To this aim, it was formulated and solved the problem of the third stage which variables are the parameters of incoming and outgoing flows such as fronts of vehicles, size of groups of cargo in packets.

Key words: road train, loading, pieces cargo, center of gravity.

INTRODUCTION

One of the urgent problems of modern road freight carriers is under-exploitation of cargo capacity of vehicles. The reasons are variability of the nature of the cargo carrying, inadequate packing, imperfect of vehicle loading technologies, restrictions imposed on dimensional weight and overweight settings to the road trains. The last two reasons are interrelated since there are several restrictions of weight. At loading, not all of them are accounted complexly. It happens that loaders miss the sight of redistribution of weight on the axes when following criteria of total weight of a truck train. It is also important to provide the satisfactory stability and control of loaded vehicle options that are often not included. It is about that parameters are contradictory. This article deals with the issue of load optimization of auto-train after criterion of cargo capacity with restrictions of its maximal weight. The task is complicated by the fact that general cargoes are majority packed by a piece and containers. Transporting packages have fixed standardized parameters often. However the presence of the optimal dynamic model of road train does not mean that a given transport packets can be loaded in it after appropriate scheme. It is necessary to found the consistent set of transport packages from which one can create the scheme and sequence of loading and fastening close to the optimum.

THE ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

There are known methods that are based on the fact that at the axles loading calculation of the heavy truck it is considered as a static system “tractor-trailer”. This should make it balance equation relatively points of contact of autotrain wheels with a road (fig. 1-3) [1].

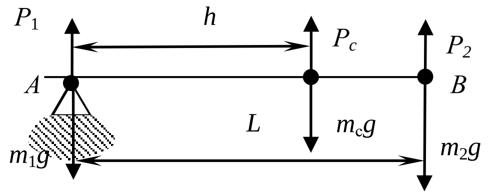

Fig. 1. Scheme of moments and forces relative to the front axle of the tractor: P_1, P_2, P_c − support reactions; h − the distance between the front axle and a truck saddle device; L − vehicle base; m_1g, m_2g, m_cg, m_3g – partial weights of tractor front, tractor rear, semitrailer saddle and semitrailer rear axes in accordance

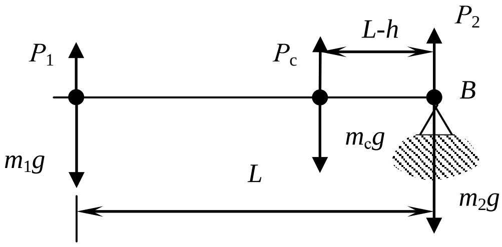

Fig. 2. Scheme of moments and forces relative to the axis of the tractor trolley

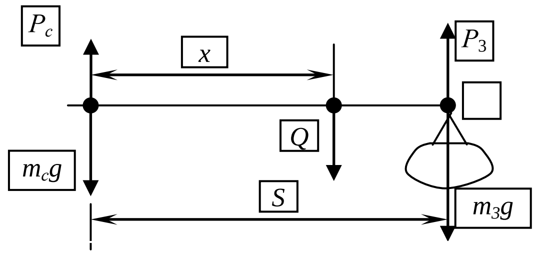

Fig. 3. Scheme of moments and forces relative to the axles of trailer bogie: Q – weight; P_3 − support reactions of trailer wheels; S – the distance between the seat to the axle bogie of the trailer; x − the distance from the saddle to the center of gravity of cargo; P_c – support reaction

As a result of solving the system of equations are the numerical values the reactions P_1, P_2, P_3, P_c with given m_1, m_2, m_3, Q.

$$P_1 = \frac{m_c g\left(L-h\right)}{L} - m_1 g , \quad (1)$$

$$P_2 = m_2 g + \frac{h}{L} m_c g , \quad (2)$$

$$P_c = \frac{Q\left(S-x\right)}{S} , \quad (3)$$

$$P_3 = -\left(P_1 + P_2 + P_c\right) . \quad (4)$$

However the coordinate of the centre of gravity x is very important in this case, which often is taken as geometric mean of a semitrailer [2]. In other cases the optimization of the location of the center of gravity of cargo are being used after expressions (1) - (4) by criteria $Q \to \max$. There are no methods which consider a cargo as a discrete material item that has a fixed location of its own center of mass and therefore continuous variables x in expressions below shall be replaced by discrete. That leads to errors in calculations of axle loads P_1, P_2, P_3, or underload of vehicle.

Some papers consider the factor of discreteness of size-weight parameters of transport packages as specified limit (it is believed that the number and weight of the package are given) [3, 5]. In order to avoid an overload of the tractor and trailer axles, one uses a combination of the location of cargo units in one or two rows. The divergence between the center of mass from its optimal location is significant, but the train weight parameters are within acceptable limits.

In works of Kravchenko A. [6] the importance of increasing of vehicles loading was given. However, this leads to accelerated wear of components and assemblies up to loss of its efficiency. He offers a few structural and technological measures to improve the properties of vehicle-based diagnostic information about their current technical state.

Some papers confirm the mismatch between a variety of design of two-section and three-section vehicles concerning their loading to which they are subjected during shipping. It was pointed on the prevalence of empirical calculation methods in this field. The author offers a method of grounding of road train depending on the operating conditions. But it is a task that is not always has practical meaning [7].

The cargo unit formation is one of the key parameters of through logistics process optimization including the transporting cargo process, goods handling and warehousing. The problem actuality of the loading unit choice is associated with increasing differentiation of cargo flows, with small parties of shipments formation. This is caused by the extensive use of logistics concepts as "just-in-time", lean manufacturing, etc. The problem of choice of the cargo unit is also necessary enough to the process of delivery of goods by different modes of transport. It is paid enough attention to the issue of formation of cargo units in the scientific literature on transport logistics, but the researchers took into account not matching the size and weight parameters a particular packet and vehicle. To develop methodic recommendations of freight units forming the carriage of goods there was taken into account only known practical examples of irrational formation of cargo units, but not it done feasibility study of relevant requirements [8].

The problem of efficient loading into a formal issue for piece and packing cargoes has been solved through a simple and effective heuristic an algorithm designed to solve the problem of packing the maximum number of rectangles of sizes (l, w) and (w, l) into a larger rectangle (L, W) without overlapping. This problem appears in the loading of identical boxes on pallets, namely the manufacturer's pallet loading (MPL), as well as in package design and truck or rail loading. However, in practice, there are problems associated with different sized packages and their weight parameters [9].

Loading of trucks in a plant is examination as a problem when different kinds of products are to be loaded on the same truck, but these goods are not ready. Therefore, the truck has to wait at the loading bay for an unbearably long time, blocking other trucks also in the process. In some papers, there were discussed a problem and presented several alternative strategies for drawing loading schedules in such situations, using information on status of products obtained with radiofrequency identification (RFID) technology, and compare their performance with traditional strategies, without RFID. The main technique of this research is simulation models under for comparisons with respect to three performance measures: average operating time in system, throughput of trucks and percentage of tardy performance trucks. Results demonstrate that these strategies have different performances with respect to different criteria but not effectives of truck loading [10].

Analysis of statistics for the last 10 years, received on weight control areas of roads I and III technical category on the territory of Kyiv and Chernihiv regions of Ukraine gives the following conclusions. First, the percentage of vehicles with a carrying capacity of more than 8 tonnes and freight trains in the composition of traffic has increased significantly up to 45%. Schemes of design of multi-axle trucks, three-axle trucks, two-axle tractor with three-axle semitrailer are most common. If one will select from the entire flow of vehicles the congestion then 54% of them are in five-axis road trains of different design schemes. Finally, analysis of load distribution between the axles of five-axle train composed of a tractor truck and trailer showed that the most loaded is second axle, which is often (in 16% of cases) loads over 100 kN. Three axis of a semi-trailer have an acceptable load (60 - 70 kN), but their journey leads to a complex pattern of deformation of asphalt pavement due to their close location (1,2 – 1,5 m) and mutual influence. So axle load distribution changes depending on changes in the total mass of many truck axes. Overload size of dual axles on Ukrainian carrier’s vehicles is much higher compared with foreign [11].

In the mentioned article, the analysis of the load on each vehicle axle of different schemes was given experimentally according to the weight and dimensional control on the roads of national value in the period of 2011-2013. Then the parameters and the distribution functions of loading of each axis of vehicles are matched.

Many authors, in addition, demonstrate the need to consider the parameters of vehicles and buses not only on the roadbed but also the in dynamics of traffic flow [12, 13]. Information and material flows the size and dynamics increase rapidly in few recent years. That also puts forward the need to consider options of loading units as a function parameter of logistic chain and of dynamics in which they move [16].

Traditional ways to acquire information on truck axle and gross weight are expensive and the subject to bias and this led to the development of weight-in-motion (WIM) techniques. Most of the existing WIM systems have been developed to measure only the static axle loads. However, dynamic axle loads are also important. Some systems use instrumented vehicles to measure dynamic axle loads, but are the subject to bias. All of this prompted the need to develop a system to measure the dynamic axle loads using an unbiased random sample of vehicles. Some papers aim to introduce the four methods in determining such dynamic axle loads from bridge responses. The four methods are interpretive method I, interpretive method II, time domain method, and frequency–time domain method. The examples and the experiments in laboratory show that all the four methods are feasible and the time domain method and frequency–time domain method give very good results even when 5% noise is added to the simulated input data [15].

There is known developed a heuristic for a problem motivated by the loading of an aircraft or etrucks: pack blocks into a bin so that their gravity center is as close as possible to the target point. It either produces good solutions or else signals that none is possible. It also works when loading no homogeneous blocks into a bin of nonzero and possibly no homogeneous mass [17].

The algorithm orientated literature on packing problems has concentrated on methods for achieving an efficient utilization of the transport or storage medium concerned. Many problems arising in a practice, however, also involve other objectives in addition to that of minimizing unused space. The stability of the load is a prime example. The paper [18] considers the stability objective in the context of pallet loading and examines approaches for generating stable stacking patterns that are also optimal from the viewpoint of space utilization. A statistical performance analysis of the methods described is presented and potentially fruitful directions for further research are discussed [19].

A method and apparatus for automatically loading a cargo compartment of a vehicle is disclosed that maximizes the utilization of available space within the vehicle by determining an optimum load configuration based on various parameters of the vehicle and the containers to be loaded. A self-propelled robot loader is used to load the cargo compartment based on the determined optimum load configuration. The robot loader automatically withdraws from the cargo compartment as the loading is completed [20].

Correct removal of cargo units from the cargo space of a cargo delivery vehicle uses RFID tags on the cargo units too. A RFID transceiver is in the cargo space in that case. A sensor responds to closure of a door to the cargo space to initiate operation of the transceiver to interrogate the RFID tags and to create an inventory of the cargo units then in the space. An inventory created upon door closure at each delivery location. Provisional application of the vehicle is compared to the last prior inventory and differences identified by the RFID. This invention pertains to equipment and procedures for management of cargo movement into and out of the cargo space of a cargo transport vehicle. More, particularly, it pertains to equipment and procedures for accurately handling, and monitoring and recording the handling, of cargo units each of which carries a RFID tag by its units are individually identified [21].

When transporting container vehicles also established that, the normalized length of road train consisting of a trailer container is not used in full. In addition, the transportation of light cargo is not being providing efficiently and allowed full weight-train is not properly used. The author of publications offered design to change trains to transport containers and load schema of the vehicles [22].

OBJECTIVES

The aim of this research was to develop a method of loading cargo trains arriving at a given cargo terminal, which would allow to achieve a maximum cargo capacity of each subject to permissible load on the axle trailers and tractors. It was assumed that parameters of loading units must meet the standards, but the weight of packets is variable, which is subject to the rhythm of cargo, on the one hand, and the optimum load circuit, on the other.

THE MAIN RESULTS OF THE RESEARCH

It was formulated the following optimization problem. The weight and dimensional parameters of a road train (see Fig. 1): m_1g, m_2g, m_3g, m_cg, L_a, h, S was given. There is also a known standard size of transport packages that can be downloaded in one team sending lorry convoy $B_i \times W_i$, where i – number of the type of transport pallet. The weight of one package q_i can be within $q_{\min} \dots q_{\max}$. Transportation packages q_i arrive to download with the flow which tact is τ_i. Arrival tact of automobiles under load is τ_j. The front of vehicles that are ready to be loaded is f_j. It is necessary to develop such schemes of trains loading arriving at cargo terminal/cargo stations that would ensure a maximum use of the permitted total weight of G_a and loading Q_n taking into account weight limits for road vehicles operating in Ukraine or abroad. The problem is solved after three stages.

At the first phase, it was considered individual schema of loading to specific road train with a set of size and weight parameters. The criterion for the solution of the problem is cargo weight Q, which should be maximized.

The variables in this problem are two values:

x − the location of the consolidated centre of cargo gravity relatively the axle of semi-trailer of the tractor-trailer coupling saddle item;

G_a − a total weight of the auto-train, $G_c < G_a < [G_a]$.

The variable x is included in the expression (1) - (4), the results of which impose the restrictions:

$$P_1 \le [P_1], \tag{5}$$

$$P_2 \le [P_2], \tag{6}$$

$$P_3 \le [P_3], \tag{7}$$

where: the value of the right side of irregularities is a limitation on the load, respectively, front and rear driving axles and the axles of tractor of the semitrailer [1].

G_a variable defines the criteria:

$$G_c + Q = G_a\,. \tag{8}$$

For solving, it was used gradient method for solving nonlinear equations of mathematical programming. The resulting calculated value gives the coordinates of the center of mass is guaranteed to the restrictions on the axial load and the maximum load of the vehicle. The fig. 4 shows that the coordinate x is quite an important factor that determines the load of road train. The deviation from its optimal value (at fig. 4 - 4.93 m) at 1 m in any direction leads to underloading ΔQ more than 4 tons of cargo.

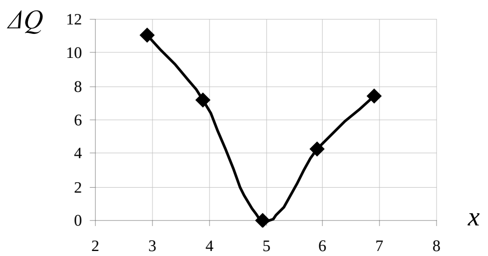

Fig. 4. The dependence of underloading of autotrain on the location of the center of gravity

The second stage of problem solution made sense in order to find the optimal weight distribution of cargo space within a semi-trailer. For this cargo the set of elementary parallelepipeds was considered. They are the same size ($b \times w$) and weight q_i. The task of organizing of parallelepipeds in enclosed space is known and its solution mentioned above. That is why the maximum number of transport packets in the semi-trailer is established in advance, regardless of the size of packages:

$$K_{\max} = \frac{B_a}{b} \times \frac{L_p}{w} \times H_t \,, \tag{9}$$

where: B_a – the internal width of the semi-trailer; L_p – the inner length of the semi-trailer; H_t – the allowable height of packages stacking (1, 2, 3 ...).

For the distribution of the total mass of the cargo Q on partial q_i it was applied the principle of the mass center:

$$x = \frac{\sum x_i q_i}{Q} \,. \tag{10}$$

It was involved an extra integer non-negative variables ν_i in the task such that $0 \le \nu_i \le H_t$. Other words, variable ν_i take an integer value that indicates the number of packages that can be placed in i row of space measured from its front to the rear side. The criterion of optimization of this phase of the general problem is a minimum of deviation of previously calculated cargo weight Q in the first phase of the problem from the one that is the sum of variables:

$$\frac{Q}{q_i} - \sum_i \nu_i \to \min \,.$$

The restriction:

$$\sum_{i=1}^{K_{\max}} q_i x_i \nu_i = Q \cdot x \,. \tag{8}$$

Additional restrictions on permissible stacking height for transport packages can also be imposed.

The problem in this form has the sense of integer programming. If we assume that packets are basic cubes, the solution of the problem gives us an idea of the perfect distribution of the weight loading along and across the platform of a semitrailer (Fig. 5). Here x' is the distance from the front board of a semitrailer's center of gravity of an elementary package. Fig. 6 shows a similar relationship, but the conditions in which the center of gravity of all cargo is at a the distance of 7,6 m from the axis of the saddle-coupling device.

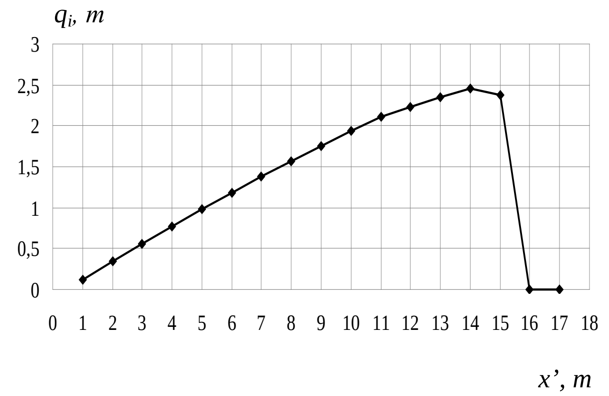

Fig. 5. Average weight of the cargo along the platform of a semitrailer provided optimal load distribution and load on the axle autotrain at x = 4,93 m

If the simulation goes $\nu_i = 0$, it packages must be empty if $\nu_i = 1$, the goods are placed in one row across the width of the platform symmetrically of the board. If $\nu_i = 2$, the number of rows across the width of the platform are two high – one. If $\nu_i = 3$ or more, it is assumed stacked packages.

However, general cargo is packaged by the piece, which have to be a fixed standard sizes. Therefore it is necessary to make a discretization of dependencies of mass distribution, as shown in Fig. 7.

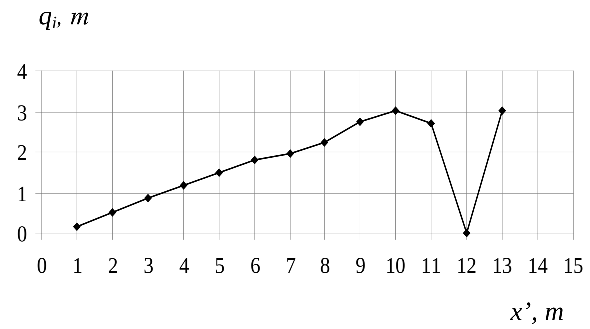

Fig. 6. Average weight of the cargo along the platform of a semitrailer provided optimal load distribution and load on autotrain axles x = 7,6 m

It brings additional deviations in the optimal scheme of loading, which, after all, is possible to compensate by the various weight of transport package. Fig.7 shows the optimal scheme of loading of semitrailer Shmitz SDK by transport packages with pallets sized 800 × 1200 mm. The maximum number of the packages that can fit in the semi-trailers in a stack is 34.

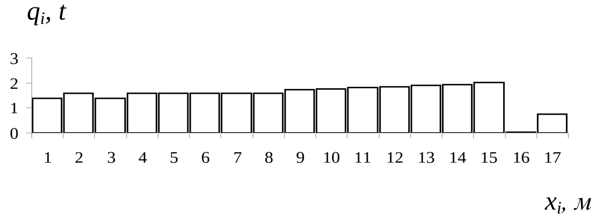

Fig. 7. The optimum layout of the transport package 800 × 1200 mm in a semi-trailer

Due to the variable weight parameters of package the minimal loading deviation from the nominal value was achieved. This means that in real terms the transport process requires a differentiated approach to the formation of transport packages.

The third phase of the choice of load scheme was carried out by the described in the latest research method [23, 24, 25]. Thus an incoming cargo flows at the transport station are considered, such as a distribution terminal. It is necessary to evaluate the settings of incoming flows such as tact, front and size of loads group. Modelling a work of station as a distribution node, where incoming cargo flows merge first, and then divided by the size of transport packets q_i, we can provide any scheme of truck loading with a needing weight and size of packages. So, to provide the scheme of Fig. 7 we need transport packages on pallets sized 800 × 1200 mm, which can not be in two layers stack of weights, respectively: 0.4 0.7 0.9; 1.0 tons, or in other combinations. According to Fig. 7 these packages should be formed in such a way (Table 1).

A capacity of distributed flows depends on the required parameters of joint outgoing flows of loaded vehicles and cargoes.

Table 1. The scheme of distribution of various weight of transport packages

№ row	1	2	3	4	5	6	7	8
packet weight, ton	0,7	0,4	0,7	0,4	0,4	0,4	0,4	0,4
number of packets	2	4	2	4	4	4	4	4

Table 1. (continuation)

№ row	9	10	11	12	13	14	15	16	17
packet weight, ton	0,9	0,9	0,9	0,9	0,9	1,0	1,0	0	0,4
number of packets	2	2	2	2	2	2	2	0	2

CONCLUSIONS

1. The formulated and solved task gives the ability to increase the vehicles workload by optimization of packets ordering scheme, under which the most important is the location of the gravity center of cargo.
2. To provide an optimal loading scheme of an auto train it needs to use a different weight of transport packages.
3. The physical effect of loading the train for optimum scheme may reach 50% of the rated load auto-train provided by the restrictions of loading on its axles.

REFERENCES

1. **Farobin Y. E. Ovcharov V. A. and Kravtseva V.A. 1981.** Theory of movement of specialized rolling stock. Voronezh: Publishing house of the Voronezh State University, 160. (in Russian).
2. **Qu T. Luo H. Cao N. Fang J. Zhong R. Pang A. Qiu X. and Huang G. 2012**. RFIDenabled justintime logistics management system for 'SHIP' supply Hub in industrial park The 42nd International Conference on Computers and Industrial Engineering (CIE42), Cape Town, South Africa, In CIE42 Proceedings, v. 1. 263126319.
3. **Yatskivskyy L. Y. Kunda N. T. and Shejko K. V. 2004.** The problems of international cargo shipments small. Proceedings of the National Transport University. Issue 9. 162-165. (in Ukrainian).
4. **Enhlezi I. P. 2011.** Analysis technical development of vehicles for transportation grouped packaged unit loads in order to increase their use. Bulletin of Donetsk Academy of road transport. №1. 30-34. (in Ukrainian).
5. **On measures to preserve public roads.** Cabinet of Ministers of Ukraine. Kyiv. 2007. Nr. 879. (in Ukrainian) Available online of http://zakon3.rada.gov.ua/laws/show/879-2007-%D0%BF.
6. **Kravchenko A. P. 2004.** Methods of problems solution of operation efficiency increase of trains, Technical service of agriculture, engineering and technology in agricultural engineering Bulletin of Kharkiv State Technical University of Agriculture. (HDTUSH). Vol. 23, 274-277. (in Russian).
7. **Glinchuk V. M. 2009.** The choice and justification of trailer types and parts of a three-tier trains. Manuscript. The thesis for the degree of candidate of technical sciences. National Transport University. Kyiv, 23. (in Ukrainian).
8. **Habrielova T. Yu. and Litvinenko S. L. 2011.** Methodology and practice of loading units during transportation by air transport. Current economic problems. №6 (120), 60-66. (in Ukrainian).
9. **Morabito R. and Morales S. 1998.** A simple and effective recursive procedure for the manufacturer's pallet loading problem. Journal of the Operational Research Society. Vol. 49. Issue 8, 819-828.
10. **Wei J. Leung S. 2011.** A simulation modeling and analysis for RFIDenabled mixed product loading strategy for outbound logistics: A case study. Computers & Industrial Engineering. Vol. 61. Issue 1, 209-215.
11. **Hamelyak I. P. and Raykovskyy V. F. 2014.** Experimental determination of axle load vehicles.

Scientific and industrial magazine. Nr 3 (239), 25-29. (in Ukrainian).

12. **Fornalchyk Ye. Mohyla I. and Hilevych V. 2015.** The Influence of Dynamic Characteristics of Vehicles on the Passenger Car Equivalent and Traffic Delay ECONTECHMOD. An international quarterly journal. Vol. 04. Nr 2, 45-51.
13. **Oliskevych M. 2015.** Optimization of information flows of logistic supply chain ECONTECHMOD. An international quarterly journal. Vol. 4. No. 4, 71-76.
14. **Axle Load Calculation and Load Planning Software (Truck, Trailer, Container & Railcar)**. Available online of http://www.loadxpert.com/index.htm
15. **Chan T. H. T. Yu L. Law S. S. and Yung T. H. 2001.** Moving force identification studies, I: Theory. Journal of Sound and Vibration. Vol. 247. Issue 1, 59-76.
16. **Oliskevych M. S. 2013.** Optimization of transport cycles depending on the amount of projected cargo. Bulletin of East Ukrainian National University after Volodymyr Dahl. № 5 (194). Part 1. 140-145. (in Ukrainian).
17. **Amiouny V. S., Bartholdi J. J. III, Vande Vate J. H. and Zhang J. 1992.** Balanced Loading. Operations Research, Vol. 40. Issue 2, 238246.
18. **Eberhard E. 1991.** Stability aspects of pallet loading Operations-Research-Spektrum. Vol. 13. Issue 4, 189-197.
19. **Truck Loader.** Available online of http://www.TLrun.com.
20. **Automated cargo loading system.** 1991. United States Patent 5.015.145. Available online of https://www.google.com/patents/US5015145.
21. **Wilde E. D-De. 2004.** Truck cargo management RFID tags and interrogators. United States Patent Application Publication Pub. Nr.: US 2004/0069850 A1. Available online of https://www.google.com/patents/US20040069850.
22. **Marchuk R. N. 2011.** Definition of load on the axle-train container. Herald NTU. Proceedings of the NTU, Vol. 24 (1). №29, 115-118. (in Ukrainian).
23. **Vilkovskyy J. K. Oliskevych M. S. and Dorosh V. N. 2006.** Method of determining the required number of vehicles on the pendulum routes. Bulletin NTU. Nr 13. Part 2, 68-72. (in Ukrainian).
24. **Zhivitskaya H. 2014.** Topological properties and methodology of research of complex logistic systems efficiency ECONTECHMOD. An International Quarterly Journal On Economics In Technology, New Technologies And Modeling Processes. Vol. 3. No. 3, 23-33.
25. **Yuskiv V. M. 2015**. The car-service company internal potential analysis in terms of logistical concept. The bulletin of transport and industry economics. Nr 52. 84-94. (in Ukrainian).