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CREATION OF MODERN DESIGNS OF HOPPER CARS FOR GRAIN TRANSPORTATION TAKING INTO ACCOUNT SAFETY REQUIREMENTS

Summary

The agricultural sector of Ukraine is a strategically important part of the economy, particularly the production and export of grain crops, which ensure food security and contribute significantly to the country's economic development. One of the main areas of development is the improvement of the logistics infrastructure, including storage systems, transport chains, and port facilities. Grain storage and transportation are critical stages in the export process, as most of the grain is exported through Ukraine's seaports. However, the growing volumes of grain production and increasing transportation demands necessitate the modernization of transport vehicles, particularly grain cars. The analysis shows that due to the aging fleet of grain cars in Ukraine and the increasing transportation needs, it is essential to improve the design of hopper cars, taking into account modern technical solutions and innovative machine-building technologies. The development of a new generation of grain cars is an urgent scientific and practical task for Ukraine's transport infrastructure and the global grain transportation market.

Keywords: agro-industrial complex, grain transportation, logistics, infrastructure, railway hopper cars

Introduction

The agricultural sector of the economy is a strategic and promising area of development of the national economy and many European countries. Cereal crops and products made from them have always been liquid, as the food supply and security of the state are based on them. The natural and climatic conditions of Ukraine and the developed agro-industrial complex of Great Britain ensure high productivity and promote the cultivation of all grain crops and make it possible to obtain high-quality food grain in volumes sufficient to meet domestic needs and build export potential[1].

Therefore, the grain sector is one of the most important branches of agriculture. In recent years, Ukraine has taken the leading positions in the production and export of grain crops among the countries of the world. Of course, the export of grain is not a simple procedure and it involves many related industries, one of which is the storage and transportation of grain, because it is collected in a fairly short period of time. In 2017, the total crop yield, according to[2], amounted to almost 62 million tons. Consequently, it is urgent to improve the infrastructure that would provide all logistics and sufficient volumes of transportation, most of which goes for export.

The logistics infrastructure that ensures the export of grain has three main segments: the storage system, transport chains and port facilities. The grain storage system in Ukraine is represented by grain warehouses of agricultural producers, linear and transfer harvesting and commercial elevators, terminal containers, and elevators of processing enterprises. It is worth inoting that over the past ten years, the grain storage system in Ukraine has undergone significant changes, primarily related to the privatization of the bread industry, the increase in the production of grain and oil crops, and the sharp increase in their export. Thus, while in 2001 the total volume of one-time storage of grain crops was 28 million tons, in the pre-war period the system of grain storage in Ukraine was represented by more than 870 grain warehouses with a total volume of one-time storage of more than 45 million tons.

More than 90% of Ukrainian grain exports go through sea ports. In Ukraine, transshipment of export and transit grain cargoes is carried out in

[1] APK-Inform, *Analysis of grain logistics in Ukraine and proposals for its modernization* (p. 88). APK-Inform Information Agency 2013.

[2] D. M. Baranovskyi, *The problem of aging and wear of freight wagons*. Vagonny Park, 7-8, 112-113, 2016.

the water areas of such sea trade ports as Illichivskyi, Odeskyi, Pivdennyi, Mykolaivskyi, Khersonskyi. Currently, in Ukraine a significant volume of grain transshipment is carried out through non-state terminals, among which the largest are Transinvestservis LLC, Nibulon LLC, etc. The unique position of Ukrainian ports and their proximity to mo st key markets (the Middle East, North Africa, Europe) significantly increase the competitiveness of these ports, despite the efforts of other countries to develop their own port capacities.

In general, in Ukraine, the system of storing grain and ensuring its transshipment in ports is entering the phase of development and orientation to market requirements. In this regard, commercial elevators and port containers are actively developing. The key figures in the grain storage development segment are agricultural holdings and multinational companies that have sufficient investment funds to support modernization and construction projects.

However, the most important component of the logistics infrastructure that ensures the export of grain is transportation. Grain is delivered to seaports by rail (about 61% of exports), road (about 36%) and water transport (about 3%). Thus, the main flows of grain to ports for export transshipment are provided by railway transport[3].

Despite the growth in grain production, the share of rail transport in grain transportation is decreasing. At the same time, the volume of grain transportation by road is increasing. One of the reasons for this situation is the shortage of hopper cars (grain cars). This problem is especially acute during periods of peak grain transportation (from September to December), when the daily load reaches up to 100,000 tons. It is worth mentioning that in the coming years, with the growth of grain production, the problem of shortage of grain cars will increase. This is due to significant moral and physical wear and tear of cars, which reaches more than 90%. Thus, the average age of grain cars in Ukrainian rolling stock is about 28 years (with a standard service life of 30 years)[4]. Therefore, the direction of research related to the improvement of rolling stock designs for the transportation of grain is a topical scientific and applied problem for railway transport and transport engineering.

[3] Center for Transport Strategies, *Agrologistics in Ukraine: Analytical research* (p. 56), Kyiv 2016.

[4] Delo.ua, *Russia destroyed more than 15% of grain storage facilities in Ukraine: how farmers will store the 2022 harvest*, 2022.

Grain transport market overview in Ukraine analysis of logistics on the grain market in Ukraine

Let's consider the infrastructural component of grain transportation in Ukraine. The capacity of certified grain warehouses (Figure 1) at the beginning of 2023 was 32 million tons, and about 10-12 million tons go to non-certified warehouses. The total number of certified warehouses is about 740, of which only 620 elevators have rail connections. And the growth of grain production reveals a deficit of storage capacities of about 18-20 million tons[5],[6],[7]. Unfortunately, it is currently difficult to determine the exact number due to a significant number of damaged and destroyed elevators as a result of hostilities by Russian troops. The US State Department, with reference to the research of the non-governmental organization Conflict Observatory, stated that due to the constant shelling of the Russian troops on the territory of Ukraine, more than 15% of granaries were lost or damaged. Thus, due to the military aggression of the Russian Federation in Ukraine, every sixth granary out of the total volume of grain enterprises was damaged, and 75 objects out of the 344 examined are damaged[8].



Figure 1. Modern grain elevator
Source: ooo-avg.ru.

[5] Elevatorist, *Main elevator site*.
[6] Elevatorist, *Map of elevators in Ukraine*.
[7] Elevatorist, *The working fleet of grain wagons in Ukraine is shrinking.*
[8] FAO., *Crop Prospects and Food Situation: Quarterly Global Report No. 1*. Rome 2023.

In addition to traditional elevator complexes, special sleeve bags are also used for temporary grain storage (Figure 2). This allows for temporary storage and preservation of grain in field conditions.



Figure 2. Temporary grain storage technology in the field
Source: liliani.ru.

The port component of the infrastructure is 44 million tons per year in the nominal capacity of the ports for grain transshipment, but if we do not take into account idle ports, the maximum volume of transshipment will be 39 million tons, with an average capacity utilization factor of 67%.Separate port loading ranges from 65% to 100%[9].

Road transportation accounts for the major part of grain transportation, due to the initial collection for storage in the volume of the harvested crop. Road transport will also play a significant role in the grain transportation to the final consumer – more than 12 million tons. From the point of view of use profitability, the delivery of grain to seaports by motor vehicles is profitable at distances of up to 200 km, but in peak periods truck carriers are involved in longer distances. However, there are some issues when it comes to transporting grain by road, for example:

- high relative cost compared to the railway,
- poor condition of roads,
- high depreciation costs for trucks,
- accumulation of trucks in ports and their entrances during peak periods.

[9] Greenbrier Europe, *Product catalog: Hopper cars.*

In addition to the above-mentioned problems, since May 2016, the "State Transport Safety Service of Ukraine" has tightened weight control on the roads. Such measures increased the cost of delivery by 60-100%. As a result, part of the cargo was transferred to the railway. Therefore, the demand for hopper cars for grain transportation has increased significantly[10].

The railway component of the infrastructure currently allows for the export of up to 30 million tons of grain. The total fleet of hopper cars is 32,309 units, according to data as of 05/10/2023[11]. The possibilities of railway transportation are most often used when sending grain over long distances both within the country and abroad. Transportation by railway makes up 40% of the total amount of import deliveries of grain crops of Ukraine.

The method of grain delivery using railway facilities is characterized by a high degree of reliability, convenience, and speed. Almost all elevators, granaries and mills are located very close to railway junctions. The larger ones have their own sections of the track, which are used to move goods in cars[12].

However, there are significant limitations as well. For example, the working fleet of cars is already at the limit of its capabilities, and later the situation will intensify, taking into account the prospects of the further growth of grain cultivation, up to 90 million tons per year. Again, we should not forget about the aging of the rolling stock and its subsequent removal from the working fleet and decommissioning. In the previous few years, about 4,000 grain trucks were supposed to be decommissioned, but the introduction of amendments to the Procedure for extending the service life of freight cars made it possible to slightly change the overall picture of rolling stock for cargo transportation. Some of the cars received an extension of their service life. The term "useful life" is sometimes used to indicate the operation of a car after the service life appointed by the manufacturer. Most of the grain cars were put into operation

[10] A. V. Kupchenko, *Elevator capacities of Ukraine*. Grain Storage and Processing, (7), 33-37, 2014.

[11] S. S. Myamlin, *Creation and modernization of rolling stock for grain transportation by rail.* In 76th International Scientific and Practical Conference Problems and Prospects for the Development of Railway Transport (p. 44-45), Dnipro 2016.

[12] S. S. Myamlin, *Creation of technical means for grain transportation by rail*. In 77th International Scientific and Practical Conference Problems and Prospects for the Development of Railway Transport (p. 63-64), Dnipro 2017.

in a short period of time, about 30 years ago. The average age of the domestic fleet of hopper cars is 28 years, with a standard service life of 30 years[13, 14].

In addition, there are problems with the capacity of railway approaches to ports. In most cases, the infrastructure has not got any significant investment in the last thirty years. Therefore, port infrastructure is a restraining factor for increasing the transshipment capacity of ports. This is also a limiting factor in increasing the productivity of freight cars.

Moreover, due to difficulties with rolling stock, the railway cannot form warehouses with monoloads, which creates queues and significantly slows down the process of delivering cargo to ports. Due to untimely delivery, shippers suffer losses: vessels are idle, which is additional costs. Therefore, other technical and technological possibilities of railway transport should be considered in order to increase the volume of grain transportation. Next, we will consider the structure of the working fleet of hopper cars for grain transportation in Ukraine.

Analysis of logistics on the grain market in Ukraine

According to the statistical data, the working fleet of hopper cars on the railways of Ukraine includes 32,309 cars. The quantitative composition of the hopper cars by model is presented in Table 1.

Table 1. Information on the available models of hopper cars on the railways of Ukraine

Hopper car model	Number
Total	**32309**
11-739	1760
19-3054	382
19-4109-01	814
19-4146	2134
19-4146-01	694
19-4152	15

[13] S. S. Myamlin, *Development of modern freight wagon designs for trans-European transportation*. In 2nd International Scientific and Technical Conference "Advanced Technologies of Transport Means" (p. 72-74), Kharkiv 2014.

[14] S. S. Myamlin, *Mathematical modeling of spatial oscillations of railway rolling stock*. In International Scientific and Technical Conference "Information Technologies in Metallurgy and Mechanical Engineering" (p. 320-323), 2024.

Hopper car model	Number
19-6869	2311
19-6938	3
19-752	17157
19-7053-02	5765
19-970	350
19-970-01	300
19-9951	291
19-9950	130
19-9870-01	1
19-9945	65
19-923-07	9
19-9549	8
19-7053-03	120

Source: own study.

According to Table 1, 19-752 model prevails among the hopper cars used for grain transportation, which is 53% of their total number. This indicates the demand for this model among grain carriers.

The main operational indicators of hopper cars are shown in Table 2. It is worth mentioning that the shortage of hopper cars for grain transportation is 2,600 cars per day, which once again emphasizes the relevance of research related to the improvement of the designs of hopper cars for grain transportation.

Table 2. The main indicators of the operation of hopper cars as of 2023

№	The name of the indicator	Indicator
1	The average age of the cars	28 years old
2	A share in the rolling stock	11%
3	Stock shortage	2600 cars
4	The average time of circulation by Ukrzaliznytsia	13 days
5	Loading share	11%
6	Objective rental rate	UAH 3850 without VAT per day

Source: own study.

Undoubtedly, the deficit of the car fleet can be reduced by reducing the turnover time of cars, but this indicator cannot be significantly reduced without

improving the technical and economic indicators of the car and without significantly improving the technology of transportation on railways.

In recent years, the ratio of the number of cars by form of ownership has significantly changed in the direction of an increase in the number of cars owned by private operating companies compared to the fleet of hopper cars owned by the JSC Ukrainian railway (hereinafter UR). Figure 3 presents a diagram of the ratio of the fleet of hopper cars by ownership. According to the diagram in Figure 3 UR owns 11,658 hopper cars for grain transportation, which is 36%, and operator companies own 20,651, which is 64% of grain transportation hopper cars. The tendency to increase the fleet of hopper cars of private companies is increasing, both due to the purchase of new cars and the purchase of cars whose useful life has been extended.

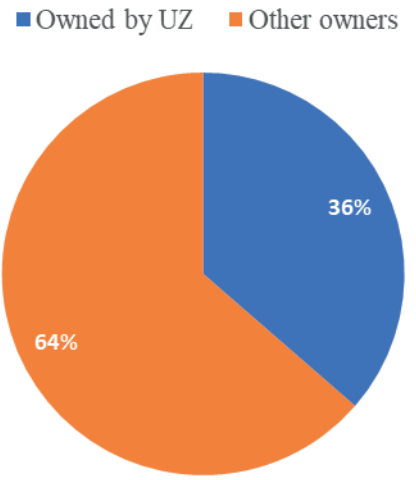


Figure 3. Comparison of the hopper cars number by ownership %
Source: own study.

As can be seen from Table 3, the main technical and economic indicators of hopper cars used on the railways of Ukraine for the transportation of grain are given.

Table 3. Information on available models of hopper cars on Ukrainian railways

№	Model code	Load capacity, t	Minimum tare, t	Maximum tare, t	Length, over couplers, mm	Axle load, t	Volume, m3	Year		Standard term of service, years	Loading gauge
								Year of production start	End of production year		
1	11-739	65	21,3	22,7	14720	21,93	93	1975	1982	30	1-VM
2	19-3054	71	22,3	23	14720	23,5	94	1993	0	30	1-VM
3	19-4109-01	70	22,3	23,7	14720	23,43	94	2003	2010	30	1-VM
4	19-752	70	21,3	23	14720	23,25	94	1982	0	30	1-VM
5	19-752	70	21,3	23,5	14720	23,38	94	1975	1987	30	1-VM
6	19-7016	69,5	23	24,4	14720	23,48	108	2004	2004	30	1-T
7	19-7016	70,2	23,2	23,8	14720	23,5	108	2005	0	30	1-T
8	19-3116-01	70	22,6	24	13870	23,5	96,5	2007	0	30	1-T
9	19-7017-03	71	22	23	13720	23,5	91	2008	0	30	1-T
10	19-7017-04	71	22	23	13720	23,5	87	2008	0	30	1-T
11	19-3054-04	70,5	22,1	23,5	14720	23,5	112	2009	0	30	1-T
12	19-4109-01	70,3	22,3	23,7	14720	23,5	94	2010	2018	30	1-VM
13	19-9871	70,5	22,5	23,5	13920	23,5	96	2010	0	30	1-T
14	19-9814	70	23	24	14220	23,5	104	2010	0	30	1-T
15	19-7016-01	70,2	23,2	23,8	14720	23,5	108	2011	0	30	1-T
16	19-9882	70	23	24	14720	23,5	94	2011	0	30	1-VM
17	19-7053-01	70,5	22,5	23,5	14720	23,5	116	2011	0	30	1-T
18	19-7017-06	71	22	23	13720	23,5	96	2011	0	30	1-T
19	19-7053-02	70,5	22,5	23,5	14720	23,5	116	2011	0	30	1-T
20	19-9863	70	23	24	14720	23,5	94	2011	0	30	1-VM
21	19-4146	69,5	23,8	24,5	14720	23,5	116	2012	2020	30	1-T

№	Model code	Load capacity, t	Minimum tare, t	Maxi-mum tare, t	Length, over couplers, mm	Axle load, t	Volume, m3	Year		Standard term of service, years	Loading gauge
								Year of produc-tion start	End of produc-tion year		
22	19-970	70,8	21,8	23,2	14720	23,5	100	2012	0	30	1-T
23	19-970-01	70,5	22,1	23,5	14720	23,5	110	2012	0	30	1-T
24	19-1761-03	70,5	22,1	23,5	14720	23,5	112,5	2012	0	30	1-T
25	19-9951	70	23	24	14720	23,5	104	2013	0	30	1-T
26	19-9835-02	71	22,2	23	14720	23,5	101	2013	0	30	1-T
27	19-9835-03	71	22,2	23	14720	23,5	101	2013	0	32	1-T
28	19-9950	70,5	22,5	23,5	14720	23,5	105	2013	0	30	1-T
29	19-9858	70,3	23,2	23,7	14520	23,5	108	2013	0	30	1-T
30	19-9870-01	76,5	22,5	23,5	14720	25	101	2013	0	32	1-T
31	19-9945	70,5	22,5	23,5	14720	23,5	100	2014	0	30	1-T
32	19-923-07	70	22	23	13200	23,25	81	1979	0	26	1-T
33	19-6869	70,5	23	23,5	14720	23,5	120	2014	0	30	1-T
34	19-6870	76,2	23,3	23,8	14720	25	120	2015	2018	32	1-T
35	19-3058	70,5	22,5	23,5	14720	23,5	118	2015	0	30	1-T
36	19-9549	76	23	24	14720	25	120	2015	0	32	1-T
37	19-6870	76,2	23,3	23,8	14720	25	120	2015	2018	32	1-T
38	19-7053	76	23	24	14720	25	116	2015	0	30	1-T
39	19-6870	76,2	23,3	23,8	14720	25	120	2015	2018	32	1-T
40	19-6869	70,5	23	23,5	14720	23,5	120	2017	0	30	1-T
41	19-9549-02	77	22	23	14720	25	120	2017	0	30	1-T
42	19-4152	71,5	22,2	22,5	14720	23,5	133	2018	0	30	1-T

№	Model code	Load capacity, t	Minimum tare, t	Maximum tare, t	Length, over couplers, mm	Axle load, t	Volume, m3	Year		Standard term of service, years	Loading gauge
								Year of production start	End of production year		
43	19-9549-01	76	23	24	14720	25	126	2018	0	40	1-T
44	19-9549-04	76	23	24	14720	25	120	2018	0	32	1-T
45	19-6870	76	23,3	24	14720	25	120	2019	0	32	1-T
46	19-6870	76	23,3	24	14720	25	120	2019	0	32	1-T
47	19-6870	76	23,3	24	14720	25	120	2019	0	32	1-T
48	19-6938	70	23	24	14720	23,5	120	2019	0	30	1-T
49	19-7053-03	71	22	23	14720	23,5	124	2018	0	30	1-T
50	19-7053-04	76,5	22,5	23,5	14720	25	124	2018	0	32	1-T
51	19-1259	76	23	24	14720	25	127	2018	0	30	1-T
52	19-1259-01	76	23	24	14720	25	127	2018	0	30	1-T
53	19-6943	69,5	23,5	24,5	14720	23,5	120	2018	0	30	1-T
54	19-4109-01	70,3	22,3	23,7	14720	23,5	94	2019	0	30	1-VM
55	19-9567	71,5	21,8	22,5	14720	23,5	118	2018	0	30	1-T
56	19-1273-01	77	22	23	14220	25	107	2019	0	30	1-T
57	19-1274-01	71	22	23	14220	23,5	107	2019	0	30	1-T
58	19-6978	113,5	35,1	36,5	19380	25	160	2019	0	40	1-T
59	19-4146	69,5	23,8	24,5	14720	23,5	116	2020	0	30	1-T
60	19-4146-01	71,5	22	22,5	14720	23,5	126	2020	0	30	1-T
61	19-3058	70,5	22,5	23,5	14720	23,5	118	2020	0	30	1-T
62	19-641	69,5	23	24	14720	23,5	114	2020	0	30	1-T
63	19-3058	70,5	22,5	23,5	14720	23,5	118	2021	0	30	1-T

Source: own study.

As can be seen from the data in Table 3, the developers offer 63 models of hopper cars for grain transportation, of which 19 are operated on the territory of Ukraine. The rest of the hopper car models are designed as concept models and can potentially be purchased by operating companies for the transportation of grain, but at the moment exist in the form of prototypes that have passed the necessary set of acceptance tests and are ready for serial production in case of receiving orders from businesses. The analysis of the main technical characteristics of hoppers developed in Ukraine for transporting grain shows that the carrying capacity is in the range of 65-77 tons, the weight of the tare varies from 22 to 24.4, almost all models have a length along the coupling axes of 14720 mm, which is related to the parameters terminals for loading and unloading cars. The body volume of models developed before the 2000s does not exceed 94 m^3. Car models developed after 2000 generally have a body volume exceeding 100 m^3, and in recent years they are trying to make the body volume in the range of 116-126 m^3. The axle load is generally in the range of 23.5-25 tons. Separately, the car model 19-6978 should be singled out, which has a carrying capacity of 113.5 tons, a slightly increased tare weight of 35.1-36.5 tons, while the distance along the coupling axes is 19380 mm, the axle load is 25 tons, the body volume is 160 m^3. The standard service life for almost all cars is generally 30 years, although for some models it is 32 years, and for models 19-9549-01 and 19-6978 it is 40 years.

In this way, the main technical features of the models of hopper cars, which are developed and used on the railways of Ukraine and can be proposed for use on the railways of other countries, have been considered. Taking into account the analysis of the technical characteristics of the models that were developed at the car-building enterprises of Ukraine and are in demand among cargo transportation operators, it is possible to form the technical requirements for a promising hopper model for grain transportation. Next, we will carefully consider the main technical characteristics of a promising model of a hopper car for further development.

Technical requirements for the design of a hopper car for the transportation of grain of a prospective design

A prospective design of a hopper car for grain transportation should take into account the advantages and disadvantages of existing models and be more

reliable. Taking into account the analysis of the design features of the main models of hopper cars, 19-7016, which has the following characteristics listed in Table 4, can be chosen as an analogue.

Table 4. Technical characteristics of the prototype and perspective car

TECHNICAL CHARACTERISTICS		
	19-7016	**Perspective car**
Cargo capacity, t	70,2	71
Body volume, m^3	108	
Tare weight, t	23,8	
Calculated load from wheelset on rail, kN (tf)	230,5 (23,5)	
Car base, mm	10 500	
Car length as per coupling axles, mm	14 720	
Loading gauge	1-T	
Quantity of hatches: - loading - unloading	 4(5) 3	
Design speed, km/h	120	
Inter-repair mileage, km	210 000	500 000
Term of service, years	30	32

Source: own study.

At the same time, it should be taken into account that the main design solutions must be original and not repeat the design of the analog car, despite the fact that the technical characteristics of these cars are similar. In order to determine patent purity, the authors separately performed patent studies to determine the absence of constructive plagiarism and proposed the registration of copyright and protection documents for intellectual property objects related to the main structural solutions of the hopper car for transporting grain, which is being developed in this study. With the participation of the author, original innovative designs of hopper cars for grain transportation were

developed[15,16,17,18,19,20], and research was also carried out on the strength and dynamic qualities of hopper cars for grain transportation and platform wagons for container transportation, including grain containers, taking into account traffic safety requirements[21,22,23,24,25].

Analysis of alternative options of grain transportation by rail transport

The deficit of the hopper car fleet is the second largest among all other types of freight cars and, depending on the season, can range from 1 to 2.4 thousand cars per day during the year. Challenges for railway transport from the business side are also related to the lack of freight cars owned by Ukrainian railway, which carry out export transportation. Therefore, in order to

[15] A. O. Lovska, V. P. Nerubatskyi, S. S. Myamlin, A. O. Plakhtiy, *Situational adaptation of 13-7024 flat wagon model for transportation of strategic goods.* Eastern-European Journal of Enterprise Technologies, 2(7), 38-46, 2024.

[16] A. O. Lovska, V. P. Nerubatskyi, S. S. Myamlin, A. O. Plakhtiy, *Determining the effect of sandwich-type components on the stress state of the universal gondola hatch cover*. Eastern-European Journal of Enterprise Technologies, 1(7), 6-13, 2024.

[17] Perevozki-Kiev, *Grain transportation in Ukraine*. http://перевозки-киев.com/perevozka-zerna-po-ukraine.html

[18] S. V. Panchenko, A. O. Lovska, S. S. Myamlin, A. V. Rybin, M. V. Pavlyuchenkov, *Hopper car with corrugated beams in the load-bearing structure*. Utility Model Patent of Ukraine, 156986, 2024.

[19] S. V. Panchenko, A. O. Lovska, S. S. Myamlin, A. V. Rybin, M. V. Pavlyuchenkov, *Covered hopper car for grain transportation*. Utility Model Patent of Ukraine, 156985, 2024.

[20] S. V. Panchenko, A. O. Lovska, S. S. Myamlin, A. V. Rybin, M. V. Pavlyuchenkov, *Hopper car for grain transportation*. Utility Model Patent of Ukraine, 156984, 2024.

[21] S. V. Panchenko, A. O. Lovska, S. S. Myamlin, A. V. Rybin, M. V. Pavlyuchenkov, *Hopper car with corrugated beams in the load-bearing structure*. Utility Model Patent of Ukraine, 156986, 2024.

[22] S. V. Panchenko, G. L. Vatulia, A. O. Lovska, V. G. Ravlyuk, S. S. Myamlin, *Modernized brake lever transmission of the bogie as a way to ensure the safety of freight trains*. Rail Transport of Ukraine, (4), 10-26, 2024.

[23] R. Sh. Rustamov, *Assessment of prospects for the development of grain logistics in Ukraine*. Colected Scientific Papers of the Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, (8), 127-133, 2014.

[24] D. Salin, *Ukraine Grain Transportation*. U.S. Department of Agriculture, Agricultural Marketing Service, 2020.

[25] I. Samoylenko, O. Sterniy, V. Nabok, *Wagons, routes. But there's nothing to carry the grain*. Zerno, 2012.

compensate for the shortage of hopper cars, carriers are looking for alternative options for grain transportation by rail. Let us consider some of them[26,27].

An alternative to the production of new hopper cars is the introduction of the latest solutions, for example, the use of containers of standard sizes with certain design changes that would allow grain crops to be transported in them. The production technology of such a container is much simpler than the production of a car, and it can be multi-purposeful. In addition, the unloading of such containers in ports can be performed much faster than the unloading of grain cars, which will contribute to reducing the turnover time of the cars that transport the containers, and the turnover time of the containers themselves. The platforms have sliding fittings, which allows them to be used for transporting both 20-foot and 40-foot containers. The main advantage of containers for grain transportation is the possibility of their transportation not only by railway platforms, but also by road and sea transport, which can significantly improve the entire grain transportation infrastructure as a whole.

A grain container must have a hatch in the roof for its loading and a device for unloading at the lowest point of the floor. At the same time, the shape of the container, in which grain is supposed to be transported, should be rounded to prevent the appearance of cargo residues.

Technical characteristics of the container are given in Table 5.

[26] A. O. Lovska, V. P. Nerubatskyi, S. S. Myamlin, A. O. Plakhtiy, *Situational adaptation of 13-7024 flat wagon model for transportation of strategic goods*. Eastern-European Journal of Enterprise Technologies, 2(7), 38-46, 2024.

[27] A. O. Lovska, V. P. Nerubatskyi, S. S. Myamlin, A. O. Plakhtiy, *Determining the effect of sandwich-type components on the stress state of the universal gondola hatch cover*. Eastern-European Journal of Enterprise Technologies, 1(7), 6-13, 2024.

Table 5. Technical characteristics of a 20-foot container for grain transportation

Characteristics	Data
1. Tank capacity, litre	28300
2. Weight of empty container (tare), kg	4200
3. Filling volume (with a coefficient of 0.8), litre	22640
4. Useful weight, kg (with a unit weight of 0.8 kg/m3)	22600
5. Maximum gross weight, kg	26800
6. Dimensions in accordance with ISO668:1195 1CC	
Length, mm	6058±6
Width, mm	2438±5
Height, mm	1591±5
The distance between the centers of fitting holes	
lengthwise, mm	5853±3
widthwise, mm	2259±3
7. Operating temperature range, ºC	-40…+50
8. Corner fittings in accordance with the requirements	ISO 1161:1984
9. The size of the hatch located on top, mm	1188 x 600
10. The hatch for unloading located at the bottom on the side, mm	500
11. Service ladders, number	4
12. Stairs	outside and inside
13. Vent hole	available

Source: own study.

The main disadvantage of the container presented in Table 5 is an underutilization of the useful volume according to the dimensions of the container. This negative factor can be avoided by extending the side walls of the grain container to the upper strapping of the container.

The design of the container allows increasing the usable volume of the grain container from 20,000 litres to 28,300 by raising the side and end walls for a standard 20-foot container.

To exploit all the useful volume of the container, it is possible to use end doors in its design for the possibility of unloading. Roof hatches can be provided for loading such containers or the entire roof can be completely sliding, which will significantly speed up the process of loading grain crops into the container.

The are capable of increasing the useful volume up to 34,500 litres for the dimensions of a standard 20-foot container. Another advantage of this type of grain container is that, in addition to grain, they can transport artificial

cargo, which can significantly reduce the empty mileage of the container and the fitting platform for its transportation. Thus, it is possible to transport grain from the elevator to the port, and artificial cargo brought to the port in the reverse direction.

Also, grain in containers can be transported in bulk using a hard wall, a transport liner (LINER-BAG) or using soft container-bags (BIG-BAG). By the way, container-bags can also be transported by semi-cars.

Also the method of transporting grain by semi-cars with external attachment of the shelter is used. However, this is a forced measure and it is supposed to be abandoned in the future.

There are several reasons for this, namely: this way of placing the cargo or securing the shelter caused traffic safety threats, and the transportation of grain in an open mobile warehouse poses many risks, including grain spoilage, theft, increased time for technological operations, safety risks etc.

All of the above-mentioned alternative methods of transporting grain by rail transport are promising, but there are some issues. The main thing is how well-preserved the grain transported will be. Moreover, attention should be paid to how long it is stored in a closed container, whether it is ventilated, etc. In addition, the entire basic infrastructure is adapted specifically to hopper cars. Therefore, it is suggested to consider solving the problems of grain transportation by rail precisely by improving the hopper car design.

Analysis of the worldwide agriculture market

Before proceeding to consider the global market for hopper cars, it makes sense to first analyze the volume of the agricultural market. Agricultural season 2022–2023 is coming to an end, and Food and Agriculture Organization of the United Nation (FAO)[28] estimates that global cereal production fell by 1.0 percent year-on-year in 2022, mainly as a result of a decline in maize production and, to a lesser extent, growth in sorghum. Cereal consumption is expected to decline by 0.9 percent between 2022 and 2023, driven primarily by lower consumption of coarse grains and rice, as well as unhealthy and unhealthy consumption of other staple grains; at the same time, there is an increase in consumption for food purposes. Forecasts for age, cereal production as a result of

[28] State Statistics Service of Ukraine.

exceeding consumption, and, as received, cereal stocks at the end of the 2023 season are significant (0.2 percent), exceeding those of the beginning of the season: the increase in stocks of wheat and barley is likely to more than offset the incidence of stocks corn, rice and sorghum. Trading volume in 2022-2023 season may fall by 2.3 percent from growth in 2021-2022, with this high trade volume expected to affect all major cereals except wheat.

For the 2023-2024 season, according to preliminary forecasts, grain production in 2023 could range from 1.0 percent to 2,813 million tons (including rice in flour equivalent). In the case of the main cereal crops, the main increase is provided by an increase in the volume of corn, as well as the production, in part, of rice and sorghum. At the same time, the volume of wheat and barley production may decrease compared to 2022, partially offsetting the above-mentioned growth.

According to the first forecast of world cereal consumption volumes for the 2023-2024 season, the annual volume is about 2,803 million tons, which is 0.9 percent higher than the results of the 2022-2023 season, with this increase almost in full volume will be provided due to the predicted growth in the consumption of feed grains. Expected growth in consumption both for food purposes, primarily corn, and for food products, mainly wheat and rice. In the industrial sector, there is also a foreign economic service.

Coverage from FAO's initial projections of global grain production in 2023 and consumption in the 2023-2024 range, global cereal stocks stand at 1.7 percent, reaching a record 873 million tonnes. As expected, among the main grain crops, an increase in stocks will be demonstrated by rice and barley. At the same time, stocks of wheat and sorghum are probably described below the level of the beginning of the season. Based on current projections of relative consumption and stock levels, the World Cereal Stocks-to-Consumption estimate is slightly down from 30.6 percent in the 2022-23 season to 30.4 percent in the 2023-24 season.

According to expectations, the volume of grain trade in the world will remain at the level of the 2022-2023 season and will amount to 472 million tons. Projected growth in global trade in coarse grains and rice will be partly offset by a decline in global trade in wheat. In May 2023, the FAO Cereal Price Index averaged 129.7 points, down 43.9 points (25.3 percent) from last year; such a high sharp decline in international prices for wheat and coarse grains on the increase in growth rates compared to their past values. While the FAO

Cereal Price Index is below the May 2022 high in May 2023, it is still 8.8 points (7.1 percent) higher than the average for the same month over the past five years (Table 6).

Table 6. World food situation summary tables

WORLD CEREAL MARKET							
	Production	**Supply**	**Utilization**	**Trade**	**Ending stocks**	**World stock-to-use ratio**	**Major exporters' stock-to-disappearance ratio**
	million tonnes					**percent**	
2014/15	2 608,0	3 277,8	2 508,1	375,9	767,7	30,1	19,4
2015/16	2 584,9	3 352,6	2 552,8	392,9	790,4	30,1	17,0
2016/17	2 665,2	3 455,6	2 630,2	406,6	826,3	31,1	17,8
2017/18	2 693,2	3 519,5	2 657,6	423,0	858,1	31,9	18,1
2018/19	2 645,8	3 503,9	2 686,1	411,7	836,0	30,8	18,8
2019/20	2 714,9	3 550,9	2 711,4	439,7	832,5	30,2	18,6
2020/21	2 776,6	3 609,1	2 760,4	480,7	839,7	30,0	18,4
2021/22	2 813,4	3 653,1	2 801,7	482,8	856,8	30,8	19,2
2022/23	2 786,5	3 643,3	2 777,6	471,6	858,2	30,6	20,5
2023/24	2 813,1	3 671,3	2 803,8	471,6	873,0	30,4	20,9
WORLD WHEAT MARKET							
	Production	**Supply**	**Utilization**	**Trade**	**Ending stocks**	**World stock-to-use ratio**	**Major exporters' stock-to-disappearance ratio**
	million tonnes					**percent**	
2014/15	735,6	935,1	708,7	156,4	228,1	31,8	18,8
2015/16	737,3	965,4	717,4	167,5	242,3	32,9	18,0
2016/17	763,5	1 005,8	737,2	177,2	266,6	36,1	19,9
2017/18	761,5	1 028,1	738,5	177,9	289,1	38,6	21,0
2018/19	731,4	1 020,6	749,2	169,1	274,7	36,8	18,1
2019/20	759,3	1 034,0	746,3	183,8	286,1	37,6	15,6
2020/21	775,3	1 061,4	761,6	189,4	294,6	38,0	15,2
2021/22	777,7	1 072,3	774,6	195,9	295,1	37,8	16,0
2022/23	800,9	1 095,9	779,7	199,6	310,7	39,8	19,1
2023/24	776,7	1 087,4	780,3	193,7	308,5	38,9	17,7

WORLD COARSE GRAIN MARKET							
	Production	**Supply**	**Utilization**	**Trade**	**Ending stocks**	**World stock-to-use ratio**	**Major exporters' stock-to-disappearance ratio**
	million tonnes					**percent**	
2014/15	1 381,9	1 679,3	1 312,9	174,5	363,9	27,1	14,7
2015/16	1 358,7	1 722,6	1 344,5	184,1	374,6	26,8	13,4
2016/17	1 404,7	1 779,2	1 397,9	181,0	385,5	27,1	14,6
2017/18	1 431,8	1 817,4	1 421,2	196,6	391,7	27,3	15,3
2018/19	1 406,3	1 797,9	1 435,9	198,3	374,3	25,6	15,6
2019/20	1 452,0	1 826,3	1 464,0	210,1	358,6	24,1	14,0
2020/21	1 483,4	1 842,0	1 489,0	239,2	350,1	23,3	11,5
2021/22	1 509,7	1 859,8	1 504,4	230,9	364,8	24,7	13,1
2022/23	1 468,8	1 833,5	1 478,2	218,4	352,6	23,5	13,0
2023/24	1 513,0	1 865,6	1 503,3	221,4	366,2	23,6	14,5
WORLD RICE MARKET							
	Production	**Supply**	**Utilization**	**Trade**	**Ending stocks**	**World stock-to-use ratio**	**Major exporters' stock-to-disappearance ratio**
	million tonnes					**percent**	
2014/15	490,4	663,5	486,5	45,0	175,6	35,8	24,6
2015/16	489,0	664,6	490,9	41,3	173,6	35,1	19,7
2016/17	497,1	670,6	495,1	48,4	174,2	35,0	18,8
2017/18	499,9	674,1	497,9	48,5	177,3	35,4	18,1
2018/19	508,1	685,4	501,0	44,3	187,0	37,3	22,6
2019/20	503,6	690,5	501,1	45,8	187,8	36,8	26,1
2020/21	518,0	705,8	509,8	52,1	195,0	37,3	28,5
2021/22	526,0	720,9	522,7	56,0	197,0	37,9	28,7
2022/23	516,9	713,8	519,8	53,6	194,8	37,5	29,5
2023/24	523,5	718,3	520,1	56,6	198,3	37,8	30,6

Source: own study.

Ukraine is a strong player in the global wheat market. Black Sea wheat successfully competes on the basis of lower prices, favorable exchange rates, and the region's advantageous location (FAS, Grain: World Market and Trade). Ports on the Black Sea have easy access to the growing rapidly markets in the Middle East and North Africa where wheat and feed demand has grown. The U.S. share of the global wheat market has been declining as the European

Union (EU) have risen in prominence. Globally, wheat is mainly used for human consumption. But Ukraine exports wheat both for milling and feed[29].

In the corn market, the United States is still the leading exporter, but faces strong competition from Brazil,

Argentina, and Ukraine. U.S. corn prices are still competitive, but Black Sea prices are declining and production is increasing (FAS, Grain Market and Trade February 2019). The U.S. Department of Agriculture forecasts that Ukraine is expected to grow as a major corn exporter, reaching shipments of 31.2 million metric tons (mmt) in 2029. Corn is mainly used for feed in the Middle East and North Africa. Because of challenges obtaining specific data from the full Black Sea region, Ukraine is being used as a proxy for the entire region. To assess the relevance of the development of hopper cars, let's consider what part they occupy in the share of agricultural products transportation. It is proposed to consider the example of Ukraine and the USA. Most Ukrainian grain is transported by rail (68 percent), followed by truck (23 percent) and river (9 percent) (Figure 4). At the same time, in the United States, the rail traffic figure is not as high at 37 percent, but it is still a significant percentage of total traffic.

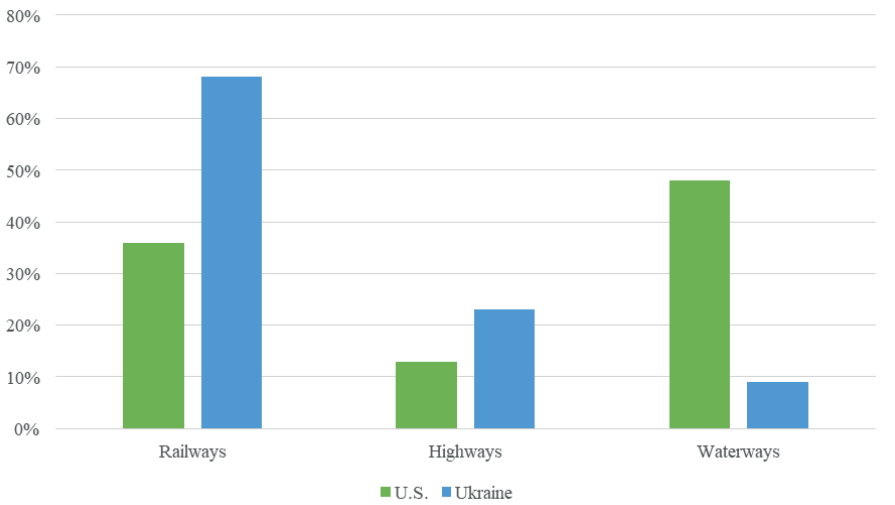


Figure 4. U.S. and Ukrainian grain and oilseeds exports by mode
Source: own study.

[29] O. Zaruba, *The biggest problem in grain transportation is the lack of responsible planning*. Ukrainian Grain Association 2023.

And in general, in countries where there is a network of railways, a similar situation is observed. Somewhere more, and somewhere less, but often rail transportation in such countries takes, if not a key, then quite a significant share in the total transportation of grain in the country. And the annual growth of the market, and with it the need for transportation, once again confirms the relevance of developments in the field of car building, namely hopper cars for transporting grain.

Analysis of the worldwide trends in global hopper car market

According to Zion[30], the global hopper car market size was worth around USD 2.1 Billion in 2022 and is further expected to grow to around USD 3.3 Billion by 2030 with a compound annual growth rate (CAGR) of approximately 5.25 percent over the forecast period (Figure 5).

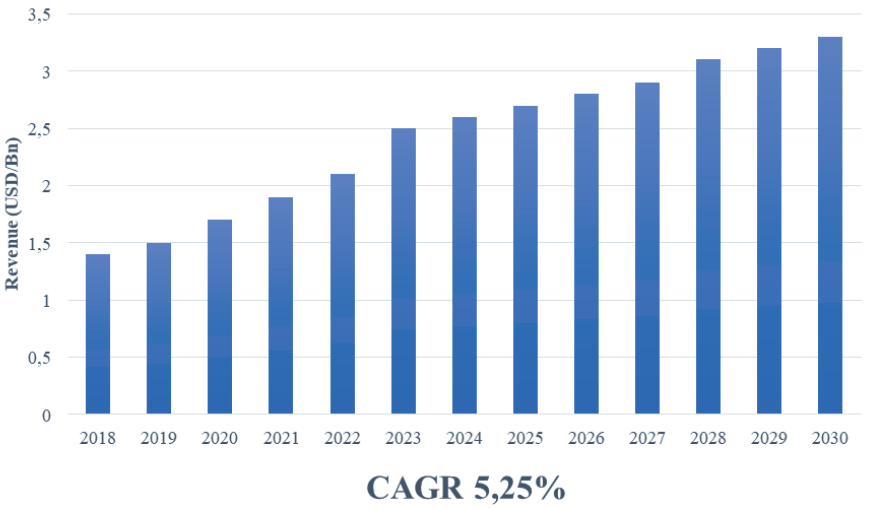


Figure 5. Global Hopper car market size (2018-2030)
Source: own study.

Demand in the global hopper car market is expected to grow exponentially due to a significant increase in demand for bulk cargo transported by rail. The cost-effectiveness of rail transportation of bulk cargo compared to

[30] Zerno Ukrainy, *Grain of Ukraine 2015*, Kyiv 2011.

road transportation and the increased focus on sustainable transportation due to minimal carbon emissions and reduced road congestion, especially in densely populated regions, are expected to contribute to the growth of the global hopper car market.

In addition, the introduction of technological advances such as digitalization, automation and the Internet of Things in the rail industry has greatly helped to streamline operations, minimize overall costs and improve operational efficiency. These factors are expected to create strong growth opportunities for the hopper car industry during the forecast period. However, the need for high capital costs for the production and rental of hopper cars, along with the costs of their maintenance and regular repairs, may hinder the growth of the hopper car market in the forecast period.

The global hopper car market is dominated by players such as:

- Novatec,
- PIOVAN S.p.A.,
- Summit Systems,
- UK Plastics Machinery Limited,
- Maguire Products Inc.,
- National Steel Car,
- TrinityRail,
- The Greenbrier Companies,
- American Rail Car Industries,
- FreightCar America,
- Vertex Railcar Corporation,
- ARI Fleet Management. Jenco Controls & Export Limited,
- SIMAR GmbH,
- Budzar Industries, Inc.,
- Movacolor,
- Advanced Auxiliary Equipment, Inc.

Next, consider a few examples of products from the previously mentioned manufacturers in the hopper car market. For example, consider the model range of cars from the The Greenbrier Companies. This 4-axled hopper cars[31] is used for the transportation of grain like corn, wheat, barley, rice corn,

[31] Zion Market Research, *Hopper Car Market by Type, Application, and Region – Global and Regiona Forecasts 2023-2030*, 2023.

rape, sunflower, rye, oat, or soy. The main characteristics of these cars are given in the Table 7.

Table 7. Technical characteristics of grain hopper cars manufactured by The Greenbrier Company

Model name General parameters	Tagnoos 898 90 m^3 4-axle hopper car	Tagnpps 95 m^3 4-axle grain hopper	Tagnpps 102 m^3 4-axle grain hopper car	Tagnpps 130 m^3 4-axle grain hopper car
Axle load	22.5 t / axle	22.5 t / axle	22.5 t / axle	22.5 t / axle
Track gauge	1,435 mm	1,435 mm	1,435 mm	1,435 mm
Loading gauge	G1-TSI	G1-TSI	G1-TSI	G1-TSI
Max. speed at 90.0 t	100 km/h	100 km/h	100 km/h	100 km/h
Max. speed (unloaded)	120 km/h	120 km/h	120 km/h	120 km/h
Climate condition	T1	T1	T1	T1
Length over buffers	17,180 mm	14,800 mm	15,400 mm	20,000 mm
Tare weight	~ 24.0 t	20.0 t ± 2 % t	~ 20.8 t	~ 22.0 t
Box volume	90.0 m^3 ± 1%	95.0 m^3 ± 1%	102.0 m^3 ± 1%	130.0 m^3 ± 1%
Loading opening	12,934 x 1200 mm	12,400 x 800 mm	13,400 x 800 mm	18,000 x 800 mm
Material of box	Carbon steel	Carbon steel	Carbon steel	Carbon steel
Operations	Manually	Manually	Manually	Manually

Source: own study.

Thus, general trends in the market for the production of hopper cars were considered, the largest manufacturers of hopper cars were given, and an example of hopper products for grain transportation from one of the largest representatives in the market for the production of hopper cars for grain transportation was presented.

Conclusions

The volumes of grain transportation in Ukraine and the share of grain transportation accounted for by rail transport were considered. Every year there is an increase in the transportation of grain, and, taking into account the prospect of growth of grain cultivation to 90 million tons per year, it is necessary to increase the share of transportation by railway transport.

An analysis of the working fleet of freight cars was carried out, with the number of hopper cars for grain transportation being singled out, which make up 11% of the total fleet of freight cars. The ratio of the state and private sector of grain transportation by rail is also shown. Thus, the relevance of carrying out research on the improvement of hopper cars for the transportation of grain is substantiated. The main stages of grain transportation logistics, as well as the advantages and disadvantages of grain transportation by road and rail transport, are considered. The composition of the working fleet of hopper cars for grain transportation of Ukrainian Railways, which is 32,309 units, most of which are morally and physically worn out, was analyzed. The average age of these cars is 28 years with a standard service life of 30 years.

The main model range of hopper cars for the transportation of grain is considered. Their main structural features are determined. Alternative options for transporting grain by rail were considered. The expediency of improving the design of the hopper car for the transportation of grain, taking into account modern technical solutions and innovative machine-building technologies, has been confirmed.

The grain transportation market in Ukraine and the world is analyzed. The orientation of the main directions of transportation of grain for export has been determined.

A general overview of the world market of hopper car manufacturers was also presented, and a brief overview of the model range of hoppers for grain transportation was presented.

Based on the results of the analysis of the above information, the following conclusions can be drawn:

- the overall world grain market is growing;
- there is an acute shortage of vehicles in the grain transportation market in Ukraine and in the world, and the situation is especially acute with hopper cars;
- Significant growth is predicted in the market of hopper cars manufacturers.

Therefore, we can conclude that the development of a promising hopper cars for the transportation of grain taking into account traffic safety requirements is an urgent scientific and applied task.

Literature

1. APK-Inform, *Analysis of grain logistics in Ukraine and proposals for its modernization* (p. 88). APK-Inform Information Agency 2013.
2. Baranovskyi, D. M., *The problem of aging and wear of freight wagons*. Vagonny Park, 7-8, 112-113, 2016.
3. Center for Transport Strategies, *Agrologistics in Ukraine: Analytical research* (p. 56), Kyiv 2016.
4. Delo.ua., *Russia destroyed more than 15% of grain storage facilities in Ukraine: how farmers will store the 2022 harvest*, 2022. https://delo.ua/ru/agro/rf-unictozila-v-ukraine-bolee-15-zernoxranilishh-kak-fermery-budut-xranit-zerno-urozaya-2022-goda-404298/
5. Elevatorist, *Main elevator site*. https://elevatorist.com/kompanii/
6. Elevatorist, *Map of elevators in Ukraine*. http://elevatorist.com/karta-elevatorov-ukrainy
7. Elevatorist, *The working fleet of grain wagons in Ukraine is shrinking*. https://elevatorist.com/novosti/13015-v-ukraine-sokraschaetsya-rabochiy-park-zernovozov
8. FAO, *Crop Prospects and Food Situation: Quarterly Global Report No. 1*. Rome 2023.
9. Greenbrier Europe, *Product catalog: Hopper cars*. https://www.greenbrier-europe.com/product-catalog/hopper-cars/
10. Kupchenko, A. V., *Elevator capacities of Ukraine*. Grain Storage and Processing, (7), 33-37, 2014.
11. Myamlin, S. S., *Creation and modernization of rolling stock for grain transportation by rail.* In 76th International Scientific and Practical Conference Problems and Prospects for the Development of Railway Transport (p. 44-45), Dnipro 2016.
12. Myamlin, S. S., *Creation of technical means for grain transportation by rail*. In 77th International Scientific and Practical Conference Problems and Prospects for the Development of Railway Transport (p. 63-64), Dnipro 2017.
13. Myamlin, S. S., *Development of modern freight wagon designs for trans-European transportation*. In 2nd International Scientific and Technical Conference Advanced Technologies of Transport Means (p. 72-74), Kharkiv 2014.
14. Myamlin, S. S., *Mathematical modeling of spatial oscillations of railway rolling stock*. In International Scientific and Technical Conference Information Technologies in Metallurgy and Mechanical Engineering (p. 320-323), 2024.
15. Lovska, A. O., Nerubatskyi, V. P., Myamlin, S. S., Plakhtiy, O. A., *Situational adaptation of 13-7024 flat wagon model for transportation of strategic goods*. Eastern-European Journal of Enterprise Technologies, 2(7), 38-46, 2024.
16. Lovska, A. O., Nerubatskyi, V. P., Myamlin, S. S., Plakhtiy, O. A., *Determining the effect of sandwich-type components on the stress state of the universal gondola hatch cover*. Eastern-European Journal of Enterprise Technologies, 1(7), 6-13, 2024.
17. Perevozki-Kyiv, *Grain transportation in Ukraine*. http://перевозки-киев.com/perevozka-zerna-po-ukraine.html

18. Panchenko, S. V., Lovska, A. O., Myamlin, S. S., Rybin, A. V., Pavlyuchenkov, M. V., *Hopper car for grain transportation*. Utility Model Patent of Ukraine, 156818, 2024.
19. Panchenko, S. V., Lovska, A. O., Myamlin, S. S., Rybin, A. V., Pavlyuchenkov, M. V., *Covered hopper car for grain transportation*. Utility Model Patent of Ukraine, 156985, 2024.
20. Panchenko, S. V., Lovska, A. O., Myamlin, S. S., Rybin, A. V., Pavlyuchenkov, M. V., *Hopper car for grain transportation*. Utility Model Patent of Ukraine, 156984, 2024.
21. Panchenko, S. V., Lovska, A. O., Myamlin, S. S., Rybin, A. V., Pavlyuchenkov, M. V., *Hopper car with corrugated beams in the load-bearing structure*. Utility Model Patent of Ukraine, 156986, 2024.
22. Panchenko, S. V., Vatulia, G. L., Lovska, A. O., Ravlyuk, V. G., & Myamlin, S. S., *Modernized brake lever transmission of the bogie as a way to ensure the safety of freight trains*. Rail Transport of Ukraine, (4), 10-26, 2024.
23. Rustamov, R. Sh., *Assessment of prospects for the development of grain logistics in Ukraine*. Colected Scientific Papers of the Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, (8), 127-133, 2014.
24. Salin, D., *Ukraine Grain Transportation*. U.S. Department of Agriculture, Agricultural Marketing Service, 2020.
25. Samoylenko, I., Sterniy, O., Nabok, V., *Wagons, routes. But there's nothing to carry the grain*. Zerno, 2012.
26. State Statistics Service of Ukraine. http://www.ukrstat.gov.ua.
27. Zaruba, O*., The biggest problem in grain transportation is the lack of responsible planning*. Ukrainian Grain Association 2023.
28. Zerno Ukrainy, *Grain of Ukraine 2015*, Kyiv 2011.
29. Zion Market Research, *Hopper Car Market by Type, Application, and Region – Global and Regiona Forecasts 2023-2030*, 2023.