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Methodology of Research on the Demand for Development of Transport Infrastructure and Rolling Stock for Perishable Goods Transportation

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ABSTRACT

In the context of globalisation of economic relationships, intensification of transportation and technological solutions, the methodology of research and development of transport infrastructure requires improvement and adaptation to dynamically changing conditions of the transportation market.

The objective of the work is to formalise and to develop a methodology for studying transport infrastructure, including specialised isothermal rolling stock. The initial data on cargo turnover were processed by the methods of mathematical statistics, and the technical parameters of innovative isothermal rolling stock were substantiated using the methods of T. Saaty analytic hierarchy process, expert assessment, and update engineering design process.

The article provides an analysis of the cargo turnover of perishable goods transported by railway refrigerated transport in Russia in terms of volumes, types of rolling stock, and origin. The main origin-destination cargo flows are presented by types of transportation (domestic, transit, export, import transport operations). It has been determined that key factors in development of isothermal rolling stock for transportation of perishable goods in the transport system of the country refer to transportation of meat, fish, beer, soft drinks, juices in the segment of domestic transportation. The analysis shows that there are no structural and quantitative shifts in terms of types of transportation and types of cargo.

The strategy for development of vehicles for transportation of perishable goods and the methodology are presented in a block diagram, in sections: «statement of the research problem», «decision-making stages», «decision implementation methods and algorithms». It is shown that the problem includes not only development of stationary railway infrastructure and of stages in development of isothermal rolling stock, but also the need to solve organisational, technical, technological, regulatory, and legal problems, as well as tariff regulation.

The issues of methodology for designing an innovative isothermal rolling stock are considered referring to possible prospects for its development and areas of operation, as well as to a set of engineering and technological solutions. The study of linear dimensions and useful section of the loading space of various types of isothermal bodies shows the advantage of wagons and swap bodies in comparison with large-capacity refrigerated containers.

It is proposed to design a prototype of innovative isothermal rolling stock on the basis of a universal isothermal swap body, configured with various types of refrigerating equipment with specified technical parameters that best meet the requirements of the modern transportation market. The areas of possible use of various types of isothermal rolling stock are analysed considering long-term forecasts for development of agricultural, fishing and processing industries.

<u>Keywords:</u> *transport, transport infrastructure, perishable cargo, research methodology, transport system, isothermal rolling stock, large-capacity refrigerated container, swap body.*

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INTRODUCTION

The key feature of transport, as of a supporting sector of the economy, requires improvement of methodology of research and development of *transport infrastructure (TI)* in the context of globalisation of economic relations, intensification of transport and technological solutions, innovative nature of ongoing changes, transformation of cargo flows associated with changes in volume, as well as in specialisation of cargo traffic and its directions. Macroeconomic changes in the external environment affecting transport and technological solutions in the system of managing cargo flows can be divided into the following groups:

• Quantitative changes in the volume of freight traffic in the main directions.

• Changes in the technology of transportation management, шт requirements for delivery time, cargo safety, price parameters.

• Changes in the institutional environment regarding transport services, operators of the transport services market, vehicles, and technologies of the transportation process.

• Current conditions and development trends of TI by mode of transport, of vehicle fleet, and of their characteristics.

• Geopolitical and national factors influencing development of TI.

• Mutual competition (interdependence) of operations of modes of transport for resources (capacity) of infrastructure, and others.

Localisation of the problem of TI development for a specific group of goods with specific operations management conditions, requirements for a fleet of vehicles, for freight terminal complexes for servicing cargo flows and vehicles along their route transforms standard methodological approaches to the study of transport systems. Such goods in the *transport system (TS)* of a country refer to the cargo (products, goods) requiring temperature-controlled transportation, namely to *perishable goods (PG)*.

The need for a separate consideration of the methodology for development of PG TI in Russia is also associated with significant institutional shifts in domestic practices of PG transportation, with a decrease in investment activity for development of specialised isothermal rolling stock (IRS) and vehicles for PG transportation in recent decades. Besides, the study of the problem requires considering the impact of the transport infrastructure on ensuring the food security in view of the country's spatial dimensions.

Works [1–5] address versatile approaches to development of concepts, models, and mechanisms of logistics management, of sectoral logistics transport systems as well as the issues of implementation of various innovative projects particularly regarding international transport corridors. The work [3] addresses dynamic territorial transport and logistics systems considered using the analysis of changes in the network elements and their subsequent management. The works [6; 7] show the growing significance of scenario forecasting of the need of large hubs in services of large systemically organised infrastructures and in interaction with sea transport. The efficiency and safety of the logistics transport system is considered in [8].

The *objective* of the study is to formalise and to develop a methodology for studying transport infrastructure, including specialised isothermal rolling stock. The initial data on cargo turnover were processed by the *methods* of mathematical statistics, and the technical parameters of innovative isothermal rolling stock were substantiated using the methods of T. Saaty analytic hierarchy process, expert assessment, and update engineering design process.

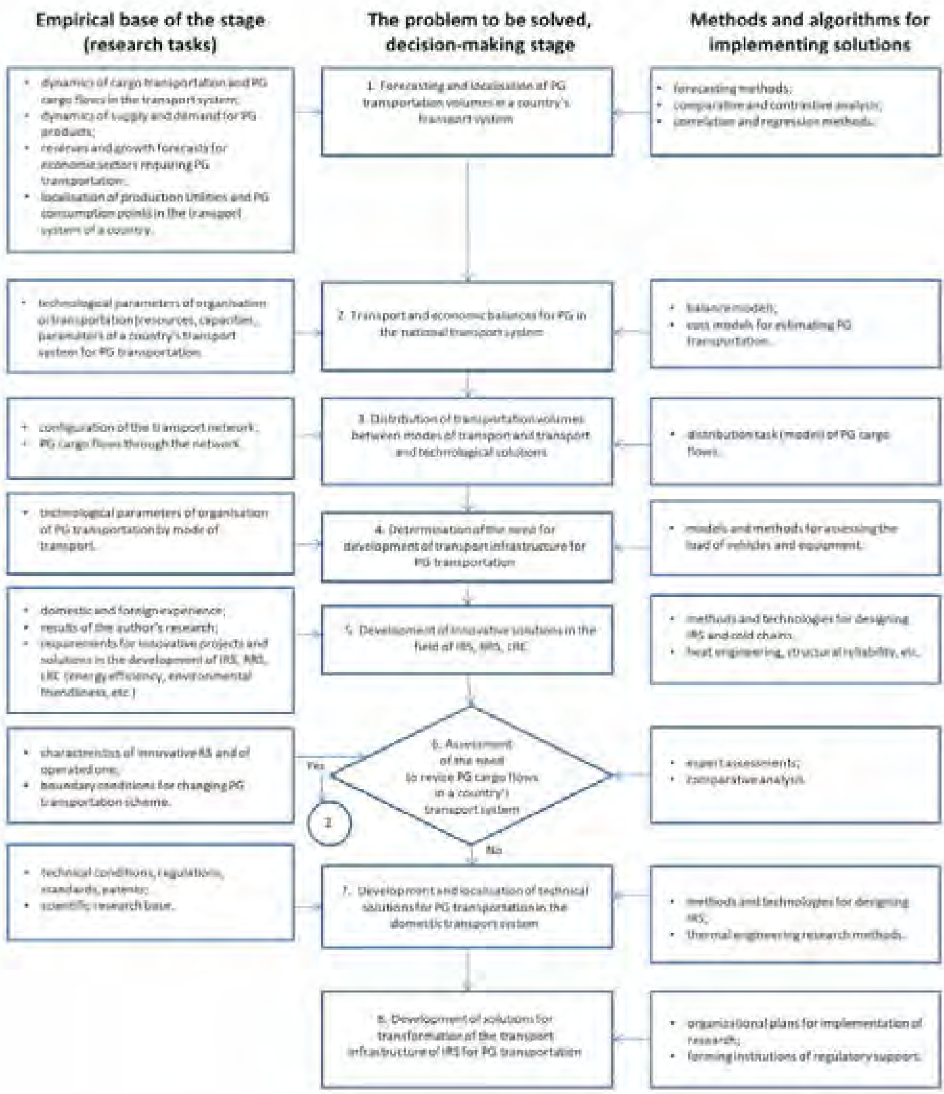
RESULTS

Methodological Scheme

The general methodological scheme for studying TI for PG transportation in a country's transport system is shown in Pic. 1. Forecasting and designing of transport and economic balances are key elements in development and implementation of such a strategic task.

Forecasting the volume of PG transportation, from the methodological standpoint of economic forecasting, should be based on a marketing analysis of the demand for PG from the point of view of their transportation. The segmentation of the market for each type of product, the complexity of considering this problem and obtaining adequate estimates are associated with the need to conduct marketing research for each type of product.

Form the point of view of transportation (of solving issues of TI development), it is allowed to aggregate commodity flows based on the homogeneity of transportation technologies. These criteria for aggregation of cargo flows include the requirement regarding rolling stock used at each specific mode of transport.



Pic.1. General outline of the strategy for development of vehicles for PG transportation (compiled by the author). (RRS is used for refrigerated vans, wagons, rolling stock; LRC for large-capacity refrigerated containers – Translator's note).

In railway transport, PG is transported by different types of generally homogeneous *isothermal rolling stock (IRS)*. So, the solution of problems (1)–(3) (see Pic. 1) can be reduced to a general analysis of the dynamics of PG cargo flows. It should also be noted that the demand for transport infrastructure can be also assessed considering localisation according to IRS typology.

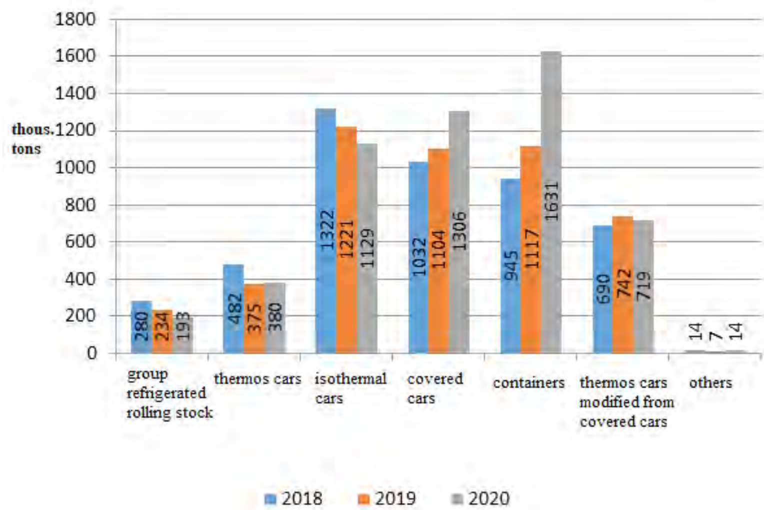
Analysis of the structure of PG transportation market by type of transportation and by type of rolling stock in Russia is shown in Pic. 2.

The analysis shows that there are no structural changes in the operated rolling stock regarding types of transportation. The geographic localisation of PG shipments by rail in 2018–2020 in Russia is presented in Table 1 and Pic. 4.

Pic. 4 shows structure and dynamics of PG transportation by rail across the territory of the Russian Federation (columns show volumes of PG forwarded respectively in 2018, 2019, 2020 through main railways).

The analysis shows that high proportion of shipments on Oktyabrskaya, Moscow, North-Caucasian, West-Siberian railways is explained by the level of product consumption in the PG segment or in economic sectors.

Pic. 2. Dynamics of PG railway transportation market by type of transportation (segments of the transport services market) (author's development based on ASORPS [Association of the organisations of food industry] data).



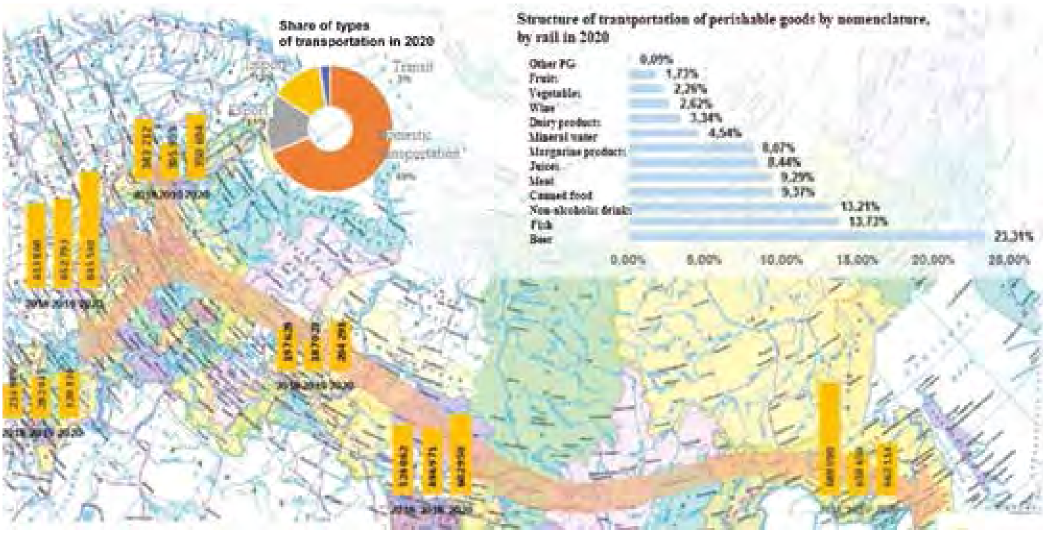
Pic. 3. Rolling stock used for PG transportation by railways (according to ASORPS data).

As per types of PG, the largest share falls on fish products and beer, Pic. 5.

Thus, key factors influencing the development of IRS for PG transportation in within Russian transport system are associated with transportation of fish, beer, soft drinks, juices, meat in the domestic transportation segment which accumulates a significant share of the total volume of PG transported. East–West direction is predominant for transportation of those type of PG within the territory of the country. The average distance of transportation is estimated to be about 4–5 thousand km. The feasible possibilities of PG transportation within transport corridors are considered in works [5; 9], while methodology presented in [10] can be used for a comparative assessment of efficiency criteria while planning a transport network.

From an environmental and economic standpoint, transportation over such distances requires an IRS of the refrigerated rolling stock (RRS) type, which provides a certain autonomy of transportation in relation to terminal service complex.

At the same time, the analysis of global practices of PG transportation over distances of up to 500–1000 km has shown the wide use of refrigerated containers with autonomous power supply. The current TI-related problems during transportation of fish were considered by the author in work [11].



Pic. 4. Structure, directions, and dynamics of PG transportation by rail across the territory of the Russian Federation (columns show volumes of PG forwarded respectively in 2018, 2019, 2020 through main railways).

Development of Functional Systems of Innovative IRS

Currently, there are serious problems in operation of the entire TI as part of a continuous cold chain. They relate to both stationary objects (maintenance and equipment points, cargo terminals, and backup refrigerators with feeder tracks) and a specialised IRS.

Still operated, refrigerated five wagon groups (thermos wagons) were designed for the planned economy with completely different transportation logistics. The presence and functioning of a powerful agricultural industry in Azerbaijan, Armenia, Belarus, Georgia, Moldova, Ukraine, huge volumes of contracts for supply of imported food made possible long-term forecasts and ensured a relatively stable load of refrigerated wagon groups (refrigerated wagon groups and refrigerated block trains with different number of wagons). The technical parameters of the currently operated IRS were developed precisely based on these conditions for operation of the *continuous cold* (or cooling) *chain (CCC)*. The peak of PG transportation was in 1988, when the volume of traffic exceeded 30 million tons. After that, a protracted decline began, primarily due to political reasons. Changed volumes, structure, regions of formation of cargo flows, reduction in the mass of shipment per wagon led to a serious transformation of routes and a systemic crisis of the transport services market [12].

In view of this, it is relevant to develop an innovative IRS, the technical features of which meet the demand in the current transport market of PG transportation. The properties of IRS should meet consumer appeal, expansion of the scope of its operation, technical features improvement thanks to new engineering solutions and technologies adopted for its design, will allow transport companies to take a worthy place on the PG transportation market [16].

To substantiate technical parameters of innovative IRS, the author has previously [13; 14] used the T. Saaty analytic hierarchy process, the method of expert assessments, and the method of updating engineering design process. Possible options for development of various types of IRS, *large-capacity refrigerated containers (LRC)*, container delivery vehicles for PG transportation, analysis of their technical and economic characteristics were presented in [13; 14; 16; 17]. The nature of the relationship between the links of CCC with consumer, organisational and technical parameters, the main directions, and prospects for improving the functional subsystems of IRS are considered in [13].

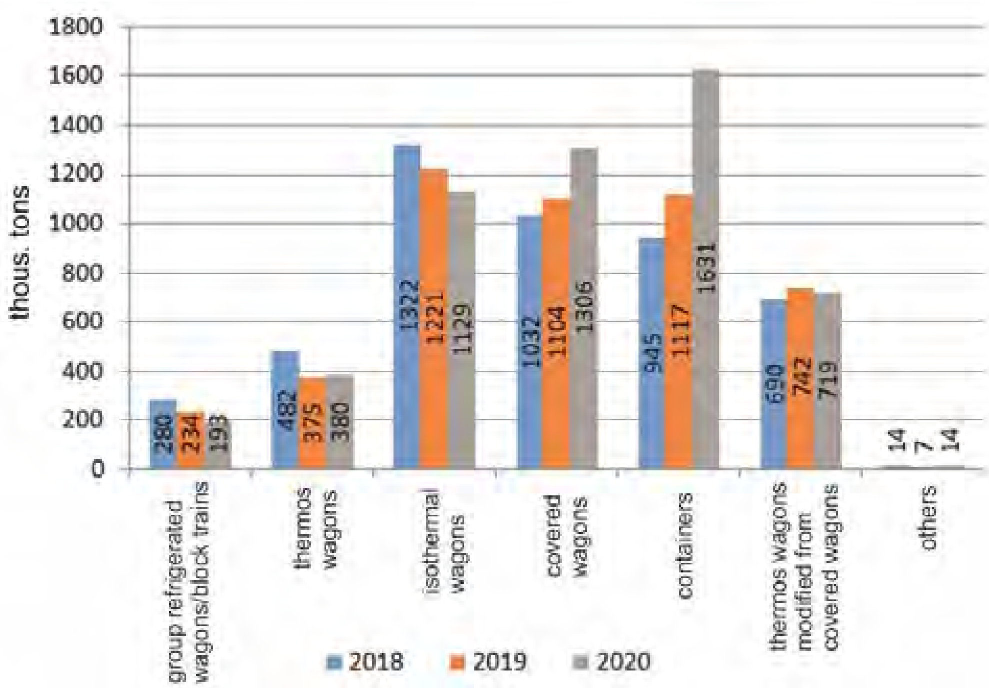
In accordance with the definition [15], innovative products include products, technological characteristics (functional features, design, capacity to carry out additional operations, as well as the composition of the materials and components used for their manufacturing), or intended use of which, are fundamentally new or significantly different as compared to similar previously manufactured products.

Table 1

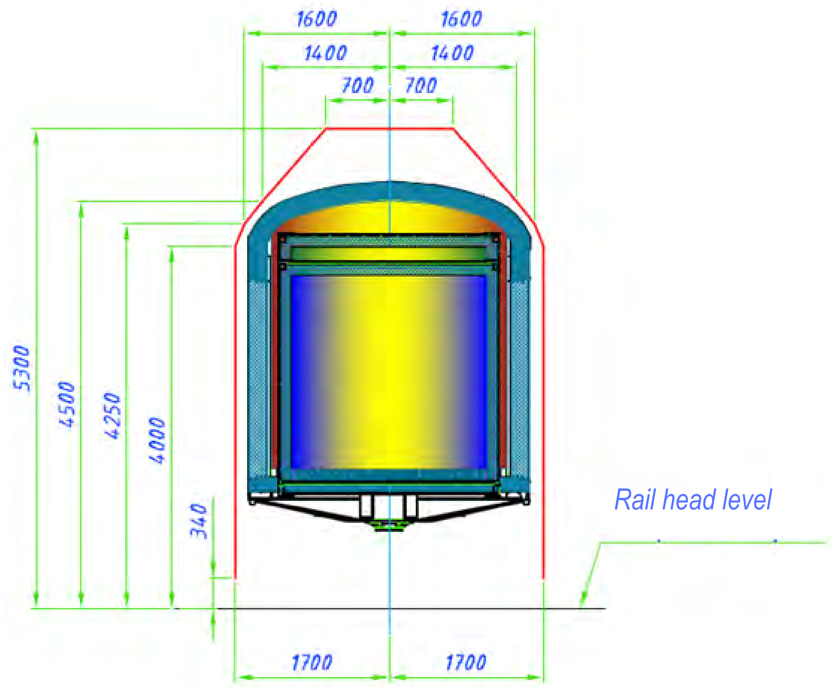
PG forwarding, domestic transportation, per origin railways* (based on ASORPS data)

Railway of origin	2018		2019		2020	
	Tons	Share, %	Tons	Share, %	Tons	Share, %
Moscow (MSC)	613 860	18,20	652 793	19,77	845 540	22,86
Far-Eastern (DVS)	688 090	20,40	658 650	19,95	662 114	17,90
West-Siberian (ZSB)	524 062	15,54	496 971	15,05	602 950	16,30
Oktyabrskaya [October[(OCT)	343 212	10,18	305 993	9,27	350 694	9,48
North-Caucasian (SKV)	234 989	6,97	282 445	8,55	320 334	8,66
Kuibyshev (KBSh)	197 629	5,86	187 023	5,66	204 291	5,52
Volga (PRV)	129 133	3,83	135 837	4,11	144 583	3,91
South-Eastern (YuVS)	131 692	3,90	117 710	3,57	125 060	3,38
Sverdlovsk (SVR)	104 285	3,09	87 714	2,66	95 554	2,58
Northern (SEV)	118 129	3,50	84 042	2,55	87 654	2,37
Krasnoyarsk (KRS)	86 992	2,58	82 997	2,51	86 243	2,33
East-Siberian (VSB)	55 305	1,64	58 533	1,77	61 630	1,67
Gorky (GOR)	50 833	1,51	63 296	1,92	54 191	1,46
Kaliningrad (KLG)	78 154	2,32	70 879	2,15	42 640	1,15
South Urals (YuUR)	13 232	0,39	13 372	0,40	13 059	0,35
Transbaikal (ZAB)	3 154	0,09	3 542	0,11	3 024	0,08
Railways of Yakutia (ZhDYa)	157	0,00		0,00	5	0,00
Total	3 372 908	100,00	3 301 797	100,00	3 699 566	100,00

*The listed railways are subsidiaries of JSC Russian Railways, except for Railways of Yakutia Stock Company which is JSC. – *Translator's note.*



Pic. 5. Distribution of transported cargo by types of PG (according to ASORPS data).



Pic. 6. Scale image of IW and LRC bodies of 1AA and 1AAA types and the clearances regarding the 1-T loading gauge (compiled by the author).

For manufactured wagons, this concept is divided into two categories regarding technical operation, maintenance, and reliability, as well as the technical characteristics of a wagon. The first (mandatory) category of innovation features [in Russia] includes an increase by twice the mileage between overhauls, and absence of restraints on the length of guaranteed haul distances [to be run be wagons without maintenance works]. The second (additional) category includes technical parameters such as load capacity, tare mass, axle load, and body volume.

Improvement of the technical and economic characteristics of IRS (an increase in carrying capacity and in travel speeds, efficiency and environmental friendliness) indicates that the new IRS should meet the criteria of innovation, and is associated with the ultimate ambitious task to return the positions of railway refrigerated transport previously list in the competition with road carriers.

In this regard, it is advisable to consider the following categories of innovative rolling stock:

• Single wagons with axle load of 23,5 or 25 tons for speeds of up to 120 km/h.

• Flat container wagons for transporting LRC with an axial load of 20 tons for higher speeds of up to 140 km/h.

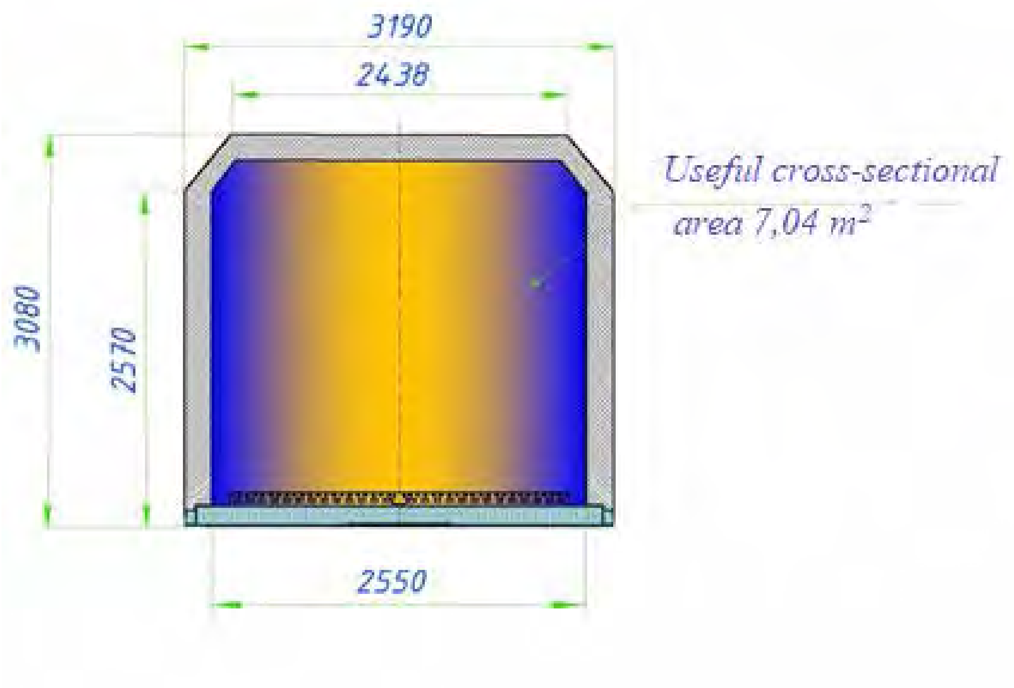
• Articulated wagons.

• Swap bodies.

However, selection of an unconditional priority in the structure of development prospects and of a choice of a specific type of IRS is now problematic.

The works [13; 14] present a new refrigerated wagon in the form of interconnected functional subsystems: body, running gear, draw-and-buffer devices (couplers), thermal stabilisation system (cooling and heating) [13], power supply unit, equipment to create special environmental parameters in the loading space, control systems with remote monitoring functions.

Since specialised railway infrastructure is lacking, such a complex of engineering and technological solutions makes it possible to create, based on an universal isothermal body, a wagon of a required configuration with specified technical parameters of each module of the subsystem, which ensure together maximum conformity of wagon's properties with consumer appeal in the transport services market. Interrelated engineering solutions are offered for each subsystem, while the final set of engineering solutions is developed individually for each modification of a wagon considering logistics needs of an operator [12; 13; 16–18].



Pic. 7. Cross-section of an isothermal swap body with a thermal insulation thickness of 200 mm (compiled by the author).

Features of design of rolling stock for multimodal transportation (large-capacity containers and swap bodies) are considered in works [19–21]. Since they relate to the usual non-refrigerated rolling stock, they can only be considered in the distant future.

When comparing the technical and economic parameters of innovative rolling stock (wagons, swap bodies, and large-capacity containers), one should consider their place within the general transport and technological system of railway transportation and CCC, and that was previously considered in [12].

The main technical characteristics for IRS are carrying capacity and the useful volume of loading space (LS). The carrying capacity is determined by the value of the axle load and the tare mass of the wagon. An increase in the useful volume is possible with an increase in the body length and in the permissible loading height of loading space since the body height itself is limited by the dimensions of rolling stock. If their priority in terms of carrying capacity and useful volume is not in doubt, then for specialised cooling equipment these indicators may be different.

When considering these parameters for an *isothermal wagon (IW)* and a container considering the flat wagon, we introduce the indicator of the specific useful volume of the loading space per the linear length. In our case, we take an isothermal wagon with a standard body length of 21 m (along the coupling axes it will be 22,15 m) flat wagons with a length of, respectively, 14,5, 19,6 and 25,5 m along the coupling axes [13]:

$V_{spec} = V_u/L_{wag}$,

where V_{spec} – specific useful volume along the linear length the wagon;

V_u – useful volume of the loading space of the wagon or of the container, m^3;

L_{wag} – length of IW or of the flat wagon along the axes of the automatic coupler, m.

For IW, $V_{spec} = 136/22{,}15 = 6{,}14$ m^3/l.m.

For a forty-foot LRC (1AAA according to the international ISO classification), considering two containers fitted on a longer 25,5 m flat wagon, the specific useful volume will be $V_{spec} = (2•68)/25{,}5 = 5{,}33$ m^3/l.m.

When using other standard sizes of containers and models of flat wagons, different loading schemes will be used, and the values of this parameter will turn out to be even less, e.g., 4,67 and 3,47 m^3/l.m., respectively.

Comparison of useful cross-sectional areas of the loading space of IW and LRC (Pic. 6)

Table 2

Calculated linear dimensions of bodies of various types of isothermal rolling stock (developed by the author)

Rolling stock type	Outer width, m	Useful width, m	Useful section, m^2	Possible length, m	Useful height, m
Wagon	3,105	2,6	7,454	21,0	2,96
Swap body	3,19	2,55	7,04	13,71	2,62
Large-capacity 1AA container	2,438	2,154	5,232	12,192	2,212
Large-capacity 1 AAA container	2,438	2,154	4,575	12,192	2,429

shows that for a 1AA container this area is of 61,4 %, and for a standard 1AAA container it is of 70,2 % of the useful section of IW. This indicates that the specific linear useful volume of IW will be 6,14 m^3/l.m. against 5,33 for LRC. With an average length of a cargo train of 1000 m, the difference in useful volumes per different types of rolling stock in this case can attain about 810 m^3, which indicates a more efficient use of carrying capacity of the railway transit capacity when using IW [13].

Pic. 6 shows a scale image of the IW and LRC bodies of 1AA and 1AAA types and the clearances regarding 1-T loading gauge. Pic. 7 shows a scaled cross-section of a swap body with a thermal insulation thickness of 200 mm. Calculated linear dimensions of isothermal bodies are presented in Table 2.

Considering the linear dimensions and useful section of the loading space of various types of isothermal bodies, the advantage of wagons and swap bodies can be seen. However, the use of the useful length of rolling stock is different for them. Undoubtedly, the full use of the length is possible only for wagons. When considering swap bodies and large-capacity containers, it is necessary to consider the length and type of «carriers» which are flat wagons of various models. Besides, the allowed schemes of loading and the use of two standard sizes of LRC (20- and 40-feet containers) at the points of assembly of container trains lead to a deterioration in the use of the useful length of the train.

CONCLUSIONS

The proposed strategy and methodology for development of vehicles for PG transportation comprise research tasks, decision-making stages, as well as methods and algorithms for implementing decisions. It follows from the analysis that the problem includes not only the development of stationary railway infrastructure and of stages of development of IRS, but also the solution of organizational, engineering, technological and regulatory problems along with the issues of tariff regulation.

The previously considered indicators of the volume of PG traffic in Russia by type of transportation (domestic, transit, export and import transport of goods), for the purposes of development forecasts, should be analysed considering the routes where studied rolling stock is operated.

Isothermal wagons will prevail in domestic traffic and in transit through the territories of the CIS countries that have the same track gauge. Large-capacity containers will be used for international transcontinental transit and export-import multimodal transportation. Swap bodies are at the initial stage of their adoption, and despite good design engineering and economic characteristics, they will not be able to take immediately a significant position in the domestic and foreign markets. The first cause is associated with only partial availability of the existing infrastructure for using them in domestic traffic. Then, the significantly larger body width (3,19 m versus 2,438 m for large-capacity container) will not allow their use in multimodal transportation, while technical parameters of the flat wagons and fitting issues have not yet been fully resolved. In any case, the final decision on the structure and type of IRS should be made based on long-term forecasting of development of agricultural, fishing and processing industries, and considering the requirements of modern technical regulations and specifications.

The proposed methodology, once it is duly adapted, seems to be applicable to a large extent in other countries.

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