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International freight railway transport management: current state improvement in a multi-level structure

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ABSTRACT

This work the development of accelerated rail freight traffic will allow not only to compete with road transport, but also to introduce new (in terms of characteristics) services and logistics technologies to the transport services market. So far, there is no clear definition of the concept of *accelerated freight train*; therefore, the following original definition considers here a train that follows its route without re-composition with a high-speed route and providing transport of non-mass types of cargo. One of the most important reasons for the lack of competitiveness of the traditional railway operation is the low level of customer services. The organization of accelerated freight by rail is complex because it involves as main objects cargo (along with packaging/container), locomotive, train composition, wagons and terminals, as well as four main operational processes: reloading, warehousing, transport by rail and by road. In all processes, a wide range of equipment and technologies is in use, as well as various types of cargo are transported, including those shipped in containers.

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INTRODUCTION

The relevance of the research topic is depending on the need to improve the accelerated freight by rail to increase its competitiveness in the transport of non-bulk cargo and small shipments, which can be an additional source of income for rail transport.

Cargo transported by rail split into two categories:

- Bulk cargo such as coal, ore, oil;

- Non-mass cargo: industrial and food products (including perishable goods), semi-finished products, materials, automobiles, etc.

In contrast to the mass types of cargo, for non-mass cargo and small shipments, accelerated rail transport is on demand due to:

- High unit cost of non-bulk cargo;

- Limitations and variability in time of demand for a part of non-bulk goods (perishable, seasonal, etc.).

However, the general term of delivery of goods transported with the participation of rail transport, does not ensure its competitiveness with respect to road transport when transporting at medium and long distances (from 1,000 to 2,000 km or more). Thus, railway transport is losing significant volumes of high-yield freight transport in this potentially competitive sector of the freight transport market.

In addition to the duration of the total delivery of goods, there are other reasons for the departure of non-mass types of cargo and small shipments to road:

- Complexity and duration of the application and documents for the transport of goods by rail;

- Low flexibility of tariff policy in the rail transport system;

- Deficiencies in customer service systems.

This study is devoted to the improvement of accelerated freight traffic, providing for the transition to the implementation of pre-provided cargo spaces in trains of established composite, circulating on schedule between the basic cargo terminals of major transport hubs.

The improvement of accelerated freight traffic will also contribute to the solution of problems of stated importance: the improvement of the environmental situation associated with the reduction of harmful emissions into the atmosphere; reducing the load on the highways, allowing delaying and redistribute investments in expensive road infrastructure.

The purpose of the study is to develop new principles of organization for the process of accelerated freight transport by rail.

Objectives of the study are:

- Analysis of the principles for the organization of accelerated freight by rail in Italy and foreign countries;

- Development of the classification of accelerated freight trains;

- Development of transport with the traffic planning according to the schedule of accelerated freight trains of fixed composition and requirements for equipment necessary for the implementation;

- Development of methods for planning for the composition of accelerated freight trains;

- Building accelerated freight logistics by rail in large transport hubs;

- Determination of the economic efficiency of the proposed;

- Conceptual development of a new rack-type wagon.

The subject of the research is the transport of non-mass types of cargo and small shipments by rail and the related equipment ensuring the implementation of accelerated cargo transport.

The theoretical and practical significance of the thesis is to tackle for accelerated freight by rail, providing transport services through the free sale of pre-provided cargo packages in trains of established composition to be applied to the organization of freight traffic on conventional and high-speed lines;

The developed method allows calculating the plan for the composition scheme of accelerated freight trains and the calculations to show the high efficiency.

The new proposed rack wagon can be used both within the framework of the proposed transport and for the existing technologies for the transport of goods by rail.

The main provisions of the thesis are the theoretical basis for the further improvement of accelerated freight by rail, including the refinement of transport for specific forms and conditions of implementation.

Methodology and research methods aim to solve the problems by:

- Systematic, integrated approach to the development of new principles for the organization of accelerated freight traffic;

- Statistical methods for analyzing the market sector of non-bulk goods and small shipments;

- Economic and mathematical modeling for the transport of non-mass cargo;

- Optimization by linear programming of planning for the composition of accelerated freight trains.

The scientific novelty of the research consists in:

- Development of a classification of accelerated freight trains;

- Development of principles and methods of for the planning of accelerated freight traffic and requirements for the equipment necessary to its implementation;

- Development of methods for planning the composition of accelerated freight trains;

- Development of a methodology for determining the economic efficiency of options for implementing and an economic-mathematical model to determine the effectiveness of technological solutions for each potential link.

The structure of the thesis consists of the present introduction, three chapters, conclusion, references and appendix.

CHAPTER I: ORGANIZATION OF ACCELERATED RAIL FREIGHT TRANSPORT

1.1. Classification of increased speed freight trains for goods delivery and analysis transport services market

So far, there is no clear definition of the concept of *accelerated freight train*; therefore, the following original definition considers here a train that follows its route without re-composition with a high-speed route and providing transport of non-mass types of cargo.

The variety of possible technologies for accelerating rail freight traffic classify freight trains with a higher speed of cargo delivery. The classification assigns route speed ranges for high-speed freight trains based on the standards applied on domestic railways and foreign experience, taking into account the technical capabilities of rolling stock and infrastructure.

The term *accelerated* is qualifying freight trains covering 1300 km/day or more, while *high-speed* trains runs over 2500 km/day. For speeds over 1300 km/day, as a rule, rolling stock with improved running characteristics is required. In accordance with the proposed classification, a speed range is associated to the corresponding train itself. Possible options for the implementation to accelerate rail freight are in Figure 1.

The design of accelerated freight trains is for conventional railway lines, including cargo-intensive ones,[1] which can be in operation on modernized fast lines.

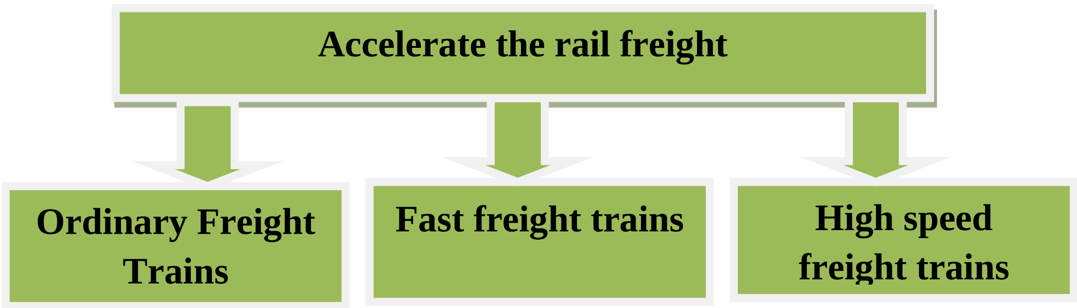

Figure 1. Options for commercial speed implementation to accelerate rail freight

Fast freight trains operate both on sections of normal lines with mixed traffic and main lines with prevailing passenger traffic, including lines modernized for high-speed traffic.

Fast freight trains should run in the framework of the proposed transport, which intensifies their terminal processing and improves interaction with other modes of transport; otherwise, the time gain from increasing train speed will have little effect on reducing the delivery time.

High-speed freight trains will provide particularly fast express freight delivery. The carriage of goods by high-speed freight trains at a higher cost of transport will provide a much shorter delivery

[1] Troche, G. High-speed rail freight. Report. Stockholm, KTH Royal Institute of Technology, 2005. 93 p.

time compared to the exclusive transport by road and can compete with air cargo; such trains will make up an insignificant share of the total accelerated freight traffic on the railway network.

The results of the analysis of possible technologies for the acceleration of rail transport made it possible to classify freight trains of higher speed cargo delivery (Table 1).

Table 1. Classification of high-speed freight trains

№	Types of high-speed freight trains / Characteristics and scope	Accelerated Freight Trains	Fast freight trains	High-speed freight trains
1	Characteristics of trains and rolling stock	Existing accelerated freight trains and trains operating of accelerated freight traffic	Freight trains composed by modernized or new specialized rolling stock	New specialized rolling stock
2	Travel speed [km/h]	≤ 90	91÷160	> 160
3	Trip speed [km/day]	≤ 1300	1301÷2500	> 2500
4	Lines and polygons of treatment	Normal and cargo-stressed lines; modernized fast lines while ensuring reduced impact of rolling stock on the track	Normal lines with mixed traffic and prevailing passenger traffic, including lines upgraded for fast traffic	Fast and high-speed highways, modernized and specialized

In the future, under the term *accelerated freight trains* will be included accelerated freight trains, turning on schedule.

The most important aspect ensuring the success of the implementation of the proposed is a qualitative analysis of the market of accelerated freight traffic.

The results of the research allowed developing the following methodology for the sequence of analysis of the transport services market:[2]

- Analysis of the activities of transport undertakings leading in a particular transport corridor (landfill) in the transport of non-bulk cargo and small shipments, with the determination of the competitive advantages of the proposals of leading companies;
- Analysis of the activities of other companies, with the determination of the reasons for their occupying secondary positions (e.g. methods of work, type of transport used, transport schemes);
- Retrospective analysis of accelerated freight traffic in a particular transport corridor, identifying the most original transport solutions;
- Survey of the main consumers of transport undertakings in a specific corridor, using statistical data, official reporting of enterprises (if available) and marketing survey data;

[2] Faiola, A. (October 28, 2013), Italy’s train wars show the bumpy ride into competition, The Washington Post

- Development of its own marketing strategy based on the analysis carried out with the widespread use of accelerated freight traffic;

- Adjustment of selected transport technologies implemented during operation for accelerated freight traffic.

For the North-South transport corridor, an analysis of the transport services market is as follow:[3]

1) The high-speed rail line in Italy consists of two lines connecting most of the largest cities in the country. The first line connects Turin with Salerno via Milan, Bologna, Florence, Rome and Naples, the second runs from Turin to Venice via Milan and is partially in operation.

2) Milan - Salerno is a major north-south high-speed corridor network. In 2008, Milan-Bologna segment opened. Its construction cost was approximately 6.9 billion euros. The line runs parallel to the *Autostrada del Sole* (A1) crossing 7 provinces and 32 municipalities. There are eight links with historical lines. At the Reggio Emilia junction, a new station, designed by Valencian architect Santiago Calatrava, was open since 2013. Calatrava also designed the bridge, where the line crosses the A1 motorway. The line cross the multi-level station of Bologna (the main railway junction of Italy) developed by Japanese architect Arata Izozeki.

3) The Bologna-Florence segment opened in 2009, allowing a 37 minutes journey between the two cities. It was particularly difficult to build, mainly because about 93% of its runs through the tunnels under the Apennines. The line has nine tunnels with variable length from 600 up separated by short surface segments (less than 5 km in total). Florence will have the largest new multi-level high-speed station in Belfiore, designed by British architect Norman Foster.

4) The Florence-Rome segment consists of the older *Direttissima* line completed in the period 1977-1986. This segment is under upgrade to full High-Speed standards. When entering Rome, high-speed trains have the choice of stopping at either the new Tiburtina station, developed by the architects ABD Partner led by Paolo Desideri or at the Termini station.

5) The Rome-Naples segment runs south from the Italian capital. The High-speed segment began its operation in December 2005. This line runs through 61 municipalities in two regions (Lazio and Campania) and connects to the existing national railway network in Frosinone Nord, Cassino Sud and Caserta Nord. In 2009, the work was complete with the opening of the 18 km between Gricignano and Naples Centrale. In the Campania region, the line passes through Afragola, the largest new transit station, designed by an architect of Iraqi origin Zaha Hadid.

6) Turin to Trieste corridor. Turin to the Novara segment of Turin to the Trieste corridor runs 85 km and opened in February 2006. Novara to Milan segment opened in 2009, allowing a 59 minutes

[3] Bergantino, A., Capozza, C., & Capurso, M. (2015), The impact of open access on intra- and inter-modal rail competition. A national level analysis in Italy, Transport Policy, Vol. 39, pp. 77-86.

trip between Milan Central and Turin Porta Nuova (45 minutes from Milan Porta Garibaldi to Turin Porta Susa). These two segments are combined for a total of 125 km, 80% (98 km) of which are in the Piedmont region (Turin, Vercelli and Novara provinces) and 20% (27 km) in the Lombardy region (Milan province). To minimize its impact on the area, Turin to the Milan segment runs along the existing infrastructure corridor, next to the Turin-Milan A4 motorway.

7) Milan to the Venice line includes segments in service from Padua to Mestre (Venice) and Milan to Brescia.

1.2. Organization of work with potential shippers, procedure for receiving cargo for formation of an automated management system for accelerated cargo

One of the most important reasons for the lack of competitiveness of the traditional railway operation is the low level of customer services. Transport companies, such as Italian Railways Logistics, acted as intermediaries between the operators and the customers. Taking on the role of shipper and consignee, transport companies perform complex and durable operations for the customer to file applications, execute shipping documents and pay for transport. Thanks to this scheme, in recent years, the quality of work with clients has improved, but because intermediary services require payment, rail transport not only does not attract new customers but also continues to lose them.

Therefore, the most important task for accelerated freight traffic is to improve the quality of work with customers. The new technology is similar of transporting passengers, when there are coaches of various categories following a predetermined schedule. Work with consignors should be based on a similar principle: the sale of standard cargo packages (for containers, packaged cargo, piece cargo), depending on their presence in the train composition. The contract is upon payment of the carriage, delivery of the cargo to the station within a short time (one to several hours) before the train departs, upon both the client and the carrier (selected when signing the contract), additional storage services at an adequate market value, etc.

Shippers who already use railway services and load on access roads adjacent to the cargo will receive limited additional, primarily because they mostly send bulk cargoes for which the traditional rail is already optimal shipments. The main nomenclature of goods aiming includes packaged goods, containers, cars and cargo. The highest attractiveness of the new services will be for small shipments that is the most important factor in favor.

The results of the analysis of the work of transport and forwarding companies made it possible to determine the main requirements that met when organizing accelerated freight by rail and working with customers:[4]

[4] Estache, A., & de Rus, G. (2000), Privatization and Regulation of Transport Infrastructure, Guidelines for Policymakers and Regulators, World Bank, Washington, DC.

- The quality of work with clients should not be lower than that provided by road transport;
- The quality of services provided by rail should exceed that of freight forwarding companies operating in road transport;
- The cost of transport from the consignor to the consignee must be lower than (or comparable to) the cost of transport by road carriers;
- Additional storage services should integrate the system of work with clients in a complex and competitive logistic market in terms of quality and cost.

Acceptance of cargo for transport and work with consignors are according to two schemes basing on the principles below:[5]

- Long-term contracts with special conditions of carriage, shipping notices and mutual reimbursement of penalties;
- Contracts on the fact of availability of cargo spaces in the train.

To ensure the receipt of reference information, the sale of cargo packages, the execution of shipping documents and other services, it is to introduce a specialized automated management system (AMS) *Urgent Cargo*.

The introduction of the proposed of accelerated transport will allow any shipper to connect, via the Internet, to an information server and receive information about the timetable of accelerated freight trains, the availability of free cargo places along the route of interest and the type of packaging. Further, in the dialogue mode (also without the participation of the operator), the automated system will select the cargo packages convenient for the shipper, will help to choose the desired type of packaging and the necessary cargo securing scheme. The client will be able to choose the additional services that he wants to receive when transporting his cargo, pay the order by wire transfer, by specifying the bank details of the shipper. Customer service can also assist by telephone and other means of communication. After payment of the carriage, the contract specifying the time during which the goods are to delivery enters into force. Cargo delivery to the loading station can be both by the shipper's and by rail carriers. During the acceptance of cargo for transport, the check of compliance with the rules of transport (correct packaging, no threat of terrorist act, etc.).

Organizing a service of this level will significantly shorten the full delivery time of the cargo (i.e. the time from the moment the transport need arises from the consignor to receiving the cargo at the final destination by the consignee) and makes it easier for customers to receive it.

After accepting the cargo for transport, it is loaded at a specialized terminal into the wagons of a freight train of established consistency in accordance with the paid cargo packages.

[5] Lang, M., Laperrouza, M., Finger, M. (2011), Competition Effects in a Liberalized Railway Market, Journal of industry, Competition and Trade, Vol. 13, pp. 375-398.

If necessary, trains will stop at supporting stations for loading and unloading operations without uncoupling trains' wagons and cargo delivery from the destination station to the consignee can be by the consignee or by the rail carrier.

As noted above, for the implementation, a specialized system manages all technological processes of accelerated freight by rail:

- Reference and information services for shippers;
- Satisfaction of customer requests and the sale of packages;
- Operations related to paperwork for the carriage of goods;
- Acceptance operations;
- Delivery of goods to the terminal, the final delivery of goods by road to the consignee;
- Terminal warehouse service;
- Operation and repair of rolling stock;
- Additional forwarding and warehousing services.
- Economy and financial accounting for accelerated freight traffic, including settlements between member companies;
- Management of accelerated freight traffic on the whole network and separately in directions using a single automated control center.

The *Urgent Cargo* automated management system is analog to the current production system used by *Trans Container*, which is basing on the principles of automating business processes.[6] The system should ensure the implementation of several competitive advantages of the proposed of accelerated freight by rail:

- New level of organization of work with the client;
- Sale of cargo packages, including along the route of the train;
- Integrated provision of basic and additional services;
- Operational and strategic management of intermodal transport in the interaction of railway transport with other modes of transport: road and sea.

The implementation of the *Urgent Cargo* automated control system will increase the competitiveness and economic efficiency of accelerated freight by rail.

1.3.Requirements for scheduling and installation of accelerated freight trains

For accelerated freight traffic by rail, the following seven types of cargo packages are suitable:

- Large containers;
- Large-capacity refrigerated containers;

[6] Padovese, I. (October 11, 2015), Italo and Trenitalia: the two Italian railway company's stormy relationship, ROOSTERGNN.

- Packaged cargo;
- Packaged perishable goods;
- Dimensional express shipments, loaded into baggage carts;
- Oversized express shipments directly loaded into indoor rolling stock;
- Cars.

For standard technology of accelerated freight traffic, standardized packages are already in use for road, rail and sea transport.

Requirements for packages proposed for accelerated freight by rail are in Table 2.

Containers with side panels (walls), pallet wide, with dimensions reduced along the profile of corrugations, allow at placing two transport packages on standard pallets 1200 mm in size across the container. This solution improves the use of the internal volume of the container and increases the efficiency of loading and unloading operations with packaged cargo. To ensure the possibility of unloading the container without removing it from the rolling stock, are in operation containers with side doors.[7]

Table 2. Requirements for freight trains in the implementation of accelerated freight by rail transport

№	Type of package	Type of rolling stock	Note	Characteristics of one package				
				Maximum weight [kg]	Overall dimensions [mm]			Max. volume, [m^3]
					length	width	height	
1	Large containers	Fitting Platforms	10 ft	10000	2991	2438	2438 2591 2896	14,7
			20 ft	24000	5867			32,7
			30 ft	26000	8931			50
			40 ft	30500	12192			74,2
			45 ft	33000	13522			86,5
2	Reefer containers	Fitting platforms for refrigerated containers	20 ft	25000	5867	2438	2591 2896	28
			40 ft	32500	12192			68
3	Packaged Cargo	Covered wagons	1 or 2 tiers	550÷1100	1200	800	1300/ <2000	1.25 1.63
		Racked wagons of rack type	2 tiers	450÷550			<1300	1.25
4	Packaged Perishable Goods	Covered isothermal cars	1 tier	1100	1200	800	<1900	1.63
			2 tiers	450-550			<1300	1.25
5	Packaged cargoes loaded on trolleys	Baggage wagons	on carts, overall	400	1200	870	2000	1.87
	Packaged goods		oversized	2000				

[7] Abramov, A. A. Container traffic on rail transport. tutorial. M .: RGOTUPS, 2004. 332 p.

6	Cars	Car carriers	little litter	1780	3400	2750	1800 1900	-
			medium litter	2500	4500			
			large litter	2700	6000			

For transport of packaged goods in covered (baggage) wagons, it is recommended to introduce transport wheeled carts with (or without) intermediate shelves to accommodate the cargo in them. When loading a wagon, cargo operations are by carts at the warehouse. Such a solution will make it possible to refuse to load the wagon with individual packaged unit loads without the use of packaging. The proposed size of transport carts is 1200 x 870 x 2000 mm.

Packaged cargoes can be in one tier (allowing high packages) or in two tiers (limited height of packages). The best conditions for bunk loading are by a new type of covered rolling stock (rack car). Its design eliminates the load from the upper packages to the lower ones, increasing the safety of the cargo.

Accelerated freight trains uses special technical points provided in large transport hubs, in which new transport technology operates.

The re-composition of a freight train is as the demand for the transport of certain types of goods changes.

The most important factor influencing the composition of accelerated freight trains is the structure of demand for freight traffic mastered by various types of transport.

It is necessary to take into account the volume and the structure of freight traffic generated by shippers who already use the services of rail transport of traditional technology. The new technology will have little effect on the market niche of shipments from industrial terminals. At the same time, transport of packaged goods (excluding cases of loading at industrial terminals), containers, cars and cargo luggage can use the new technology.

To determine the composition of accelerated freight trains, the following data is necessary:[8]

- Volume and structure of goods, which can be transferred to accelerated freight trains;
- Features of the transport network of railway junctions, availability of complex terminals and warehouses and their equipment.

The justification of the choice of the length of the train takes into account the following factors:

- Analysis of the lengths of platforms of existing freight yards, warehouses and terminals allows for the reorganization (or retrofitting) to ensure the processing of trains with a length of 400÷500 m without reshaping the composition (primary factor);

[8] Carron, N. Railways in the common transport policy of Switzerland. Railways of the world. 2004. № 1. p. 17-29.Parks, Tim (2013). Italian Ways: On and Off the Rails from Milan to Palermo. London: Harvill Secker.

- Outdated standard length of receiving and departure tracks (850 m):
- Reduced weight of train and volume of cargo required to load it;
- Possibility of skipping double length accelerated freight trains.

Considering the combination of these factors, the choice is for a unified train length of 425 m (including the locomotive) for the organization of accelerated freight traffic using the proposed technology. This indicator is depending on the conditions of the implementation of transport technology on a particular corridor or basin.

When scheduling accelerated freight trains, the following requirements are set:

1) The lowest coefficient of removal in relation to the type of train prevailing on the site while ensuring competitive route speed. Accelerated freight trains can follow in packages with passenger or regular freight trains to optimize the use of lines capacity, especially important when trains run on heavy traffic sections. A competitive level of speed without increasing the running speed is reachable thanks to the low downtime at technical stations. Accelerated freight trains are in combination with passenger traffic; therefore, depending on the technological capabilities of passing trains on the sections, priority could be in favor of accelerated freight trains in passenger train packages.

2) Accelerated freight trains operate on a precise schedule to ensure the production of loading and unloading operations at the terminal-warehouse and the smooth operation of vehicles. Analysis of world experience, market requirements and conditions of operation of vehicles in large cities suggests that accelerated freight trains should arrive at destinations at night to ensure fast delivery of cargo and efficient use of vehicles.

3) The new technology of accelerated freight traffic allows using rolling stock with very high efficiency and minimizing its unproductive downtime. More than half of the turnaround time of the wagon should be in motion, most of the remaining time under the execution of terminal loading and unloading operations. All other components of the rolling stock turnover should be the third, smallest part.

4) High reliability of compliance with the schedule of accelerated freight trains.

A clear timetable is a significant competitive advantage of accelerated freight traffic. With a high accuracy of compliance with the schedule, accelerated freight trains can provide for the transport of cargo on the main part of the route in the most diverse supply chains, well integrated into transport and logistics technologies of various transport organizations.

For accelerated freight trains, it is necessary to use the opportunity to increase its speed for scaling the schedule, given that upgraded or new specialized rolling stock technically provides a high running speed.

When implementing a new technology of accelerated freight traffic on routes with large freight traffic, it is possible to use the technology of organizing the passage of dual accelerated freight trains.

Nevertheless, with large traffic in North-South direction of the and a lack of capacity on this direction, it is possible to provide for the passage of doubled accelerated trains.[9]

Sending a double train from one terminal will require a corresponding increase in the volume of the cargo sent at a time, which, without changing the technical equipment of the terminal, will increase the rolling stock idle time. Should the cargo volumes at the terminal be insufficient for daily shipment, the frequency of the accelerated freight train will need to change, which may reduce the attractiveness for customers of this route. Therefore, a flexible transition to the technology of sending double trains (including the temporary limitation of throughput on the railway line) is associated with a number of additional costs and risks.

At the same time, two trains of standard length (425 m) can be formed at two terminals of one transport hub, which, being combined into one train, can follow the main part of the entire route.

The technology of organizing the traffic of dual accelerated freight trains, formed by two trains of standard length processed at different cargo terminals, can be in two ways:

1) Transfer of standard-length freight train from one terminal to another one (transfer or shunting locomotive), where it will be attached to the second train and sent with one train locomotive. To operate a double train, an electric EP20 or cargo series is required.

2) Departure of two accelerated freight trains from different terminals and combining them on the main routes of the haul or on a special route in one train.

The first technology is more difficult to implement, but it can give a significant reduction in the cost of transport due to the locomotive. The second technology requires special organization of connection and maintenance of double trains. The choice depends on many conditions determined by the economic efficiency of the organization of long accelerated freight trains.

At the destination, double freight train can run as follows:

a) The double train arrives at the cargo terminal, where half of it is unhooked and run to another cargo terminal of the hub;

b) Half of the double train is disengaged in the transport hub and follows the route, without cargo operations at the terminal in this transport hub;

c) The entire double composition at one terminal of the transport node.

To implement of passing double trains, freight terminals must have the necessary length of the track.

[9] Bespalov, R. S. Transport logistics. The latest technology to build an effective delivery system. M.: Vershina, 2008. 384 p.

1.4.Technical support of accelerated freight traffic

To organize the operation of accelerated freight trains, it is necessary to develop a set of requirements imposed by the new technology on rolling stock and loading and unloading equipment, on technical maintenance of rolling stock, machines and mechanisms.

Requirements for wagons of accelerated freight trains

For accelerated freight trains, typical technical characteristics are for cars of two categories:

- Wagons of existing models with axial load up to 23.5 t and operating speed up to 90 km/h;

- Modernized and new specialized wagons with axial loads up to 18 t and operational speeds of up to 120÷140 km/h;

The results of the analysis of requirements for non-pulling rolling stock and a comparison of the technical characteristics drawn up with the characteristics of commercially available rolling stock are in Table 3.[10] Most of the claimed proposed rolling stock technology are already on production by domestic companies.

[10] Fender, Marco Chiandoni and Keith. "ETR 1000 sets new Italian rail speed record". Retrieved 13 May 2017

Table 3. Typical characteristics of non-contracted rolling stock intended for accelerated freight traffic

Type of wagon	Wagon subclass	Tara [t]	Load capacity [t]	Gross [t]	Axial load [t/axle]	Body length inside [mm]	Body width inside [mm]	Height inside [mm]	Volume of cargo space	1st type of cargo space	Packages, pcs	Max weight of large places [t]	2nd type of cargo space	Packages [pcs]	Max weight of large places [t]	Trolleys	Construction speed [km /h]	Exploitation speed [km / h]	Equipment	Most appropriate serial model	Degree of compliance
Fitting platform	60 ft	25	47	72	18	18400	2870	-	-	10 ft container	6	8	-	-	-	KVZ-I2	140	**120**	fitting	13-2116	80%
			69	94	23,5							17,3					120	90			
Fitting platform	40 ft	24	48	72	18	13000	2870	-	-	40 ft container	1	48	20 ft container	2	24	KVZ-I2	140	**120**	fitting	13-1303	100 %
	80 ft	26,5	45,5	72	18	25000	3000				2	22,8		4	11,4	KVZ-I2	140	**120**		13-2118	80%
		22,5	71,5	94	23,5							35,8			17,9	18-100	120	90		13-7024	100 %
	2x45 ft	32,6	102	135	22,5	2x12025	2600				2	51,2		4	25,6	18-9771	120	90		13-9851	100 %
Covered	138 m3	31	41	72	18	15700	2740	2820	138	package on a pallet 1200x800 mm	76	0,54	-	-	-	KVZ-I2	140	**120**	four-door openings available	11-280, 11-1807	100 %
		27	67	94	23,5							0,88				18-100	120	90			80%
	158 m3	31	41	72	18	17680	2740	2820	158		84	0,49				KVZ-I2	140	**120**		11-1807-01	100 %
		27	67	94	23,5							0,80				18-100	120	90			80%
Shelving	St1	28,1	65,9	94	23,5	16400	2660	3300	144		76	0,87				18-100	120	90	sliding walls	11-280	40%
	St2	30,6	63,4	94	23,5	22400	2660	3300	197		104	0,61				18-100	120	90		missing	-
	St3	35	37	72	18	21600	2660	3300	190		100	0,37				KVX-I2M	140	**120**		missing	-
Luggage	176 m3	46	25	72	18	20000	2720	2800	176	t-pc loads	-	-	carts	60	0,42	KVZ-CNII	160	**140**	with / without brigade compartment	61-905	100 %
thermal	thermos	33	60	93	23,3	20240	2630	2400	126	t-pieces and packers.	100	0,60	-	-	-	18-100	120	90	thermal insulation	16-1807-04	80%
	refrigerator	40	50	90	22,5	17650	2600	2400	100/112		88	0,57	-	-	-	КВЗ-И2	120	100	thermal insulation, refrigeration units	отсутствует	-
Auto transporter	covered with side crate	36	16	52	13	24260	2840	1820 + 1850	~260	microliter car	14	1,14	medium liter. car	10	1,6	18-100	120	90	means for securing car	11-287, 11-1804	100 %
	covered with vent. hatches	45	25	70	17,5	25516	2820	1920 + 1840	~260		14-16	1,79		10	2,5	18-100	120	90		11-1291	100 %

To implement the technology of accelerated freight traffic, it is possible to use already existing models of wagons: covered, insulated and fitting platforms, baggage. This approach will require the lowest cost but does not provide the full benefits of the new technology. Creation of a new racking wagon for transport of packaged cargoes according to the proposed technology of accelerated freight traffic will eliminate many of the design flaws of conventional covered wagons.

Traction calculations show that passenger locomotives of all series, currently operated on domestic railways, provide guidance for trains weighing 1,350 t, most locomotives weighing 1600 t and many weighing 2100 t. The driving trains of double weight and length provide electric EP20 (is a type of 6 axle electric passenger locomotive) and cargo locomotives series. The second option is the use of technology of double trains, when each locomotive conducts its own train of usual length; in this case, locomotives correspond to the weight classes of the train.

Moreover, to improve the efficiency of transport of perishable goods by rail, the locomotive should distribute power supply for refrigerated containers from the locomotive.

Container forklifts and reach stackers must provide for the rearrangement of a full-fledged container (not less than 30.5 tons) through the train to the road transport[11] (Figure 2). With this technology, loading and unloading operations are more effective and the supply of vehicles is simplified.

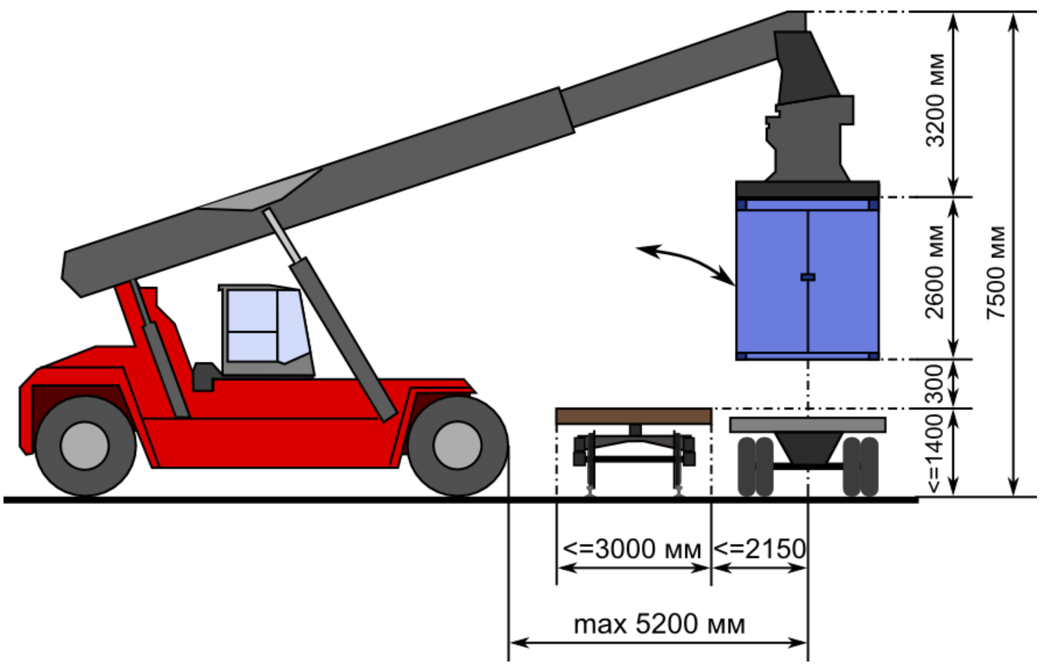

Figure 2. Direct transfer of containers between 2 transport systems

Electric forklift trucks, intended for loading and unloading operations with packages on pallets, can work with telescopic forks to handle the second row of packages in rack cars from one side of the road. There are no other specific requirements for forklift trucks to use in the new technology of accelerated freight traffic.

[11] European Communities (2008), Modern Rail modern Europe, Office for Official Publications of the European Communities, Luxembourg.

The concept above allowed forming a list of principles for the implementation of the new technology of accelerated freight traffic:[12]

1) Already implemented on domestic railways:

- operation of trains on schedule without re-composition along the route,

- Complexity of transport services, which may include, in addition to rail transport, the final delivery to customers by road and terminal and warehouse services of various types and levels,

- Use of an automated control system to ensure the management of all components of the transport process; implementation of transport services using an electronic online system;

2) Implemented in incomplete measure in individual projects of some transport companies:

- Information on train routes, timetables, layouts and vacancies available to all interested parties,

- Cargo operations carried out without reshaping trains because the length of cargo fronts corresponds to the length of trains;

3) Not implemented in domestic practice:

- Train destinations, schedule and composition dynamically determined by the carrier in accordance with changes in demand for cargo transport,

- Organization of the sale of pre-rendered cargo places in trains of variable (depending on the demand for transport) composition;

- Delivery of the train to the cargo front of the terminal warehouse carried out by a train locomotive, a train can also operate through the terminal warehouse, which ensures loading and unloading operations at the terminal along the train routes.

The combination of the presented principles allows implementing an integrated approach to the management of transport processes and multimodal transport involving various types of transport.

[12] Cantos, P., & Campos, J. (2005), Recent changes in the global rail industry: facing the challenge of increased flexibility, European Transport, Vol. 29, pp. 1-21.

CHAPTER II: LOGISTICS AND ECONOMIC EFFICIENCY OF ACCELERATED RAIL FREIGHT TRANSPORT IN ITALY

2.1. Terminal service of accelerated freight trains and general transport logistics issues

One of the competitive advantages of the new technology is the ability to perform loading and unloading operations without uncoupling wagons from the train, both at the initial and final stations, as well as in the intermediate stations along the route. In order to operate this service, a new technology provides for a single standardized container in accordance with packages and unified means of mechanization.

The analysis of the types of cargo packaging and rolling stock, storage areas, type of cargo front and mechanization of loading and unloading operations allowed formulating the principles of the organization with accelerated cargo trains.

Table 4 presents loading and unloading facilities, selected depending on the type of cargo, rolling stock and cargo front. Most of the presented technical and technological solutions provide high economic efficiency and short operational time.

Table 4. Organization of loading and unloading operations with accelerated freight trains

Tare type	Type of rolling stock	Type of cargo front	Storage area	Type of mechanization	Unmechanized labor
Large containers (40, 20, 10 ft)	Fitting platforms	Container site	Container site	Reach stacker (container forklift)	-
Reefer containers (40, 20 ft)	Fitting platforms for ref. containers	Container site	Platform for refrigerated containers	Reach stacker (container forklift)	electrician (maintains ref. containers)
Packages on pallets (1200x800)	Covered	High platform (on one or both sides)	Covered warehouse with pallet racks	Electric forklifts	-
	Covered (rack wagons)			Electric forklifts with telescopic forks	-
Packaged goods loaded on trolleys	Covered (baggage wagons)	High platform (special height)	Covered	Electric trolley with load trolleys	Loader (to move wagons with cargo)
Packaged goods		High platform (special height)	Covered with shelving		Loader (for handling the load itself)

Manual cargo operations with baggage wagons is not viable for widespread use under the new technology due to their high cost, low productivity, and problems with ensuring the safety of cargo. However, for individual bulky goods, not loaded into baggage carts, this method of cargo operations is still necessary.

Mechanization of cargo operations with baggage wagons by electric wagons with low-floor trucks (2-3 pieces), with level coinciding with the level of the floor of the wagon (special platform height), will ensure efficient overload of baggage carts and large-sized piece cargoes.

Depending on the technological task, a loaded electric trolley can move from the wagons to a covered warehouse for unloading or passing through a warehouse for reloading cargo onto vehicles; a high platform (normal height) ensures reloading of luggage carriages directly to vehicles. For bulky goods, low-floor hand trolleys is to use.

The calculations showed that the technical time for terminal operation should be about 6.5 hours for full unloading and loading of the train. The schedule of terminal processing of accelerated freight traffic is in Figure 3. Should the train be taken to a terminal with a train locomotive and does not require technical inspection of the rolling stock and change of locomotive, the processing time can be reduced to 5.3 hours. Nevertheless, the time required for processing the train at intermediate terminals along the route largely depends on the volume of loading and unloading operations and, therefore, is standard for each terminal.

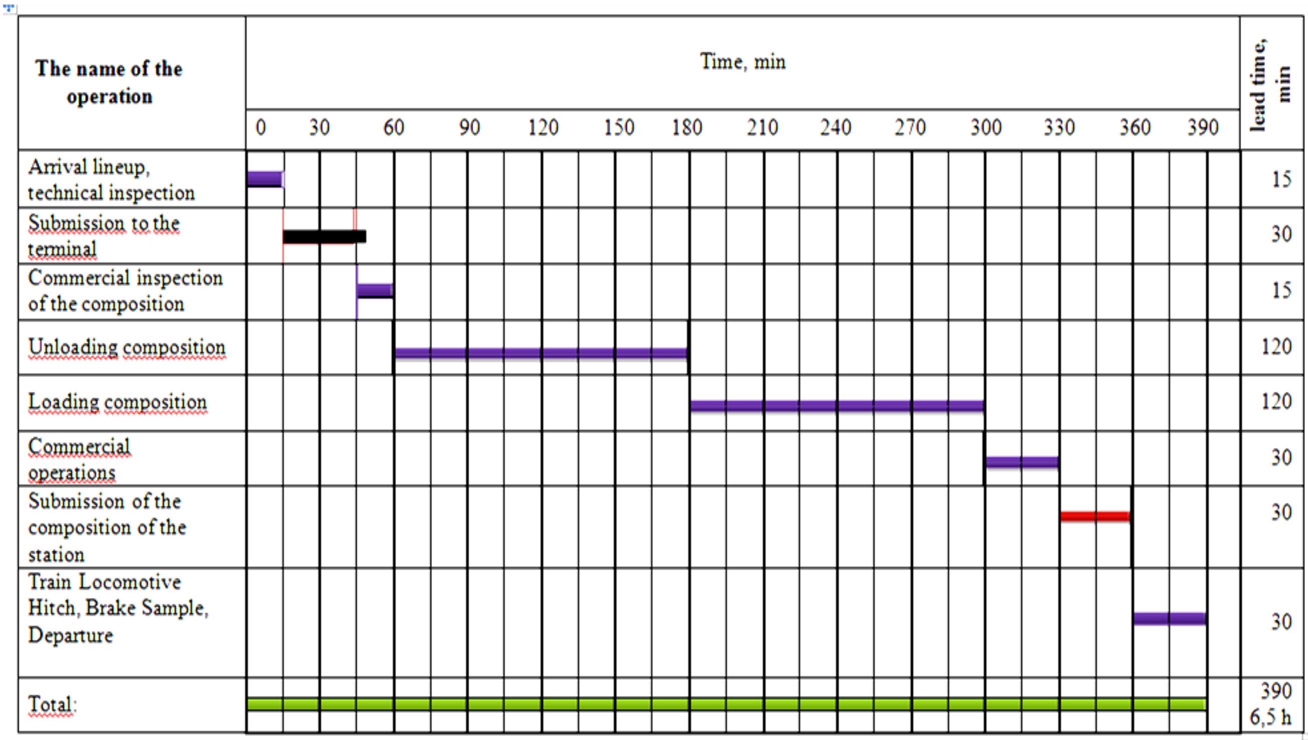

Figure 3. Technological schedule of terminal service for the accelerated freight train

The organization of direct supply of the train to the terminal by the train locomotive is preferable. If an electric traction is used, the access section must be electric and the section of the network located above the cargo front must be isolated from adjacent sections and be able to switch off for the time of the cargo operations. In order to provide the necessary size for the production of loading and unloading operations, the suspension height of the contact wire above the rail level can reach the maximum allowed RTO (Rules of technical operation) of 6.8 m.[13]

Whenever necessary, special devices should switch off the contact network.

Terminals for accelerated freight trains must ensure end-to-end passing through of freight trains, which will eliminate time-consuming shunting operation, especially in intermediate terminals along the train route.

The new technology is firstly focusing the large volumes; however, it is usable also for small volumes of cargo handling, mainly packaged and packaged unit.

In order to emphasize the advantages of the proposed technology of accelerated cargo transport by rail, we will consider some issues for improving its logistics.

Operation of terminals for supply and distribution of large containers

As part of the technology of accelerated rail freight transport, it will be necessary for vehicles to participate twice: carrying the container and reloading it from the road to railway transport and back.

When returning the empty container, the operations is in the reverse order. When unloading cargo from a container at the end not *off the wheels*, an additional flight will be required to pick up the empty container.

The technology of accelerated freight transport by rail provides for improved interaction with maritime transport and seaports. This is a mutually beneficial interaction. It is by an active interaction with rail transport that port terminals achieve the best performance in the transport of containers.[14] With the full realization of the technological solutions, when the accelerated freight train load/unload directly at the berth, additional vehicles are not necessary and the port will increase its capacity.

Transport of small shipments

Since 2013, the termination of cargo transport in medium-tonnage containers on the Italian Railways network further aggravated the problem of transporting small shipments by rail.

It is necessary to intensify the transport of goods in 10-foot 1DD (type of container) containers, which, due to their characteristics, will be able to replace 5 t medium-tonnage containers. 10-foot containers are equipped with lower and upper fittings, which ensures their fastening on the railway platform and allows organizing loading and unloading operations using a reach stacker with a spreader of the appropriate size.

[13] Di Porto, Fabiana (1 January 2008). La disciplina delle reti nel diritto dell'economia [The regulation of networks in economic law] (in Italian). Rome: CEDAM. p. 103.

[14] Parks, Tim (2013). Italian Ways: On and Off the Rails from Milan to Palermo. London: Harvill Secker.

Transport of perishable goods

In the proposed technology for the accelerated transport of goods by rail, the preference for the carriage of perishable goods is for refrigerated containers. It is necessary to create a proprietary fleet of such containers and work with consignors and consignees to increase the use of this type of packaging. Loading and unloading of refrigerated containers is at the railway terminals and bilateral terminals are particularly convenient for this. Upon arrival at the railway terminal, the refrigerator container is either temporarily stored with connection to the grid (which prevents damage to the cargo) or is immediately transferred for to a covered warehouse for intermediate or long-term storage. The shipper must provide the cargo for transport, taking into account the possibility of loading it into a refrigerated container. Such technology will provide high performance of loading and unloading operations, but cargo operations are required to load/ unload cargo into containers.

2.2. Economic model of accelerated freight traffic

The organization of accelerated freight by rail is complex because it involves as main objects cargo (along with packaging/container), locomotive, train composition, wagons and terminals, as well as four main operational processes: reloading, warehousing, transport by rail and by road. In all processes, a wide range of equipment and technologies is in use, as well as various types of cargo are transported, including those shipped in containers.

The process of accelerated freight transport in the form of a flowchart (Figure 4), in which, by conditional blocks, we will display possible options for moving the cargo from the sender to the recipient.

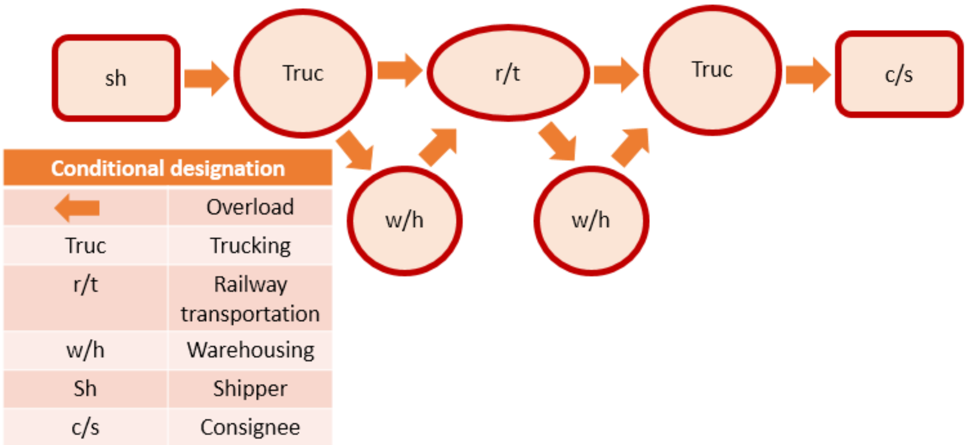

Figure 4. Model of technology accelerated freight traffic in the form of a flowchart

Using the simulation method allows you using a series of experiments to study objects (systems), the study of which is directly or completely impossible, time-consuming, or requires a significant investment of material, financial and other resources.[15]

For transport systems - as one of the varieties of socio-economic systems - it is effective to use economic and mathematical modeling, which describes systems sign mathematical tools. For the task of determining the effectiveness of accelerated freight traffic, it is proposed to apply the financial planning method.

The experience on economic-mathematical models shows that simple models are often more effective for practical use than complex models. Therefore, a relatively simple financial planning model was in charge for the task.

The developed economic model describes the operation of the new concept in terms of links: transport by rail, final delivery of goods by road, terminal and warehouse services. To implement the economic and mathematical model, it is necessary to determine the revenues and costs in the above-mentioned types of transport activities, as well as the amount of investment in rolling stock, in the creation (if necessary) of wagon for transporting vehicles, terminal warehouse systems and an automated control system.

For the economic-mathematical model[16], the criterion of optimality for all kinds of transport activities in the *organization of accelerated freight traffic:*

$$F = \sum P_i \rightarrow max$$

Where P_i is the profit from the i-th kind of transport activity:

P_1 - profit from rail transport;

P_2 - profit from cargo delivery from the railway terminal to customers (and vice versa) using motor transport;

P_3 - profit from attendant transport of terminal warehouse operations;

$P4$ - profit from additional logistic (primarily warehouse) services.

With the following restrictions:

$$C_{eft} \leq C_{hw}$$

$$C_{dev} \leq C_{dev.comp}$$

$$C_{wh} \leq C_{wh.comp}$$

$$C_{add} \leq C_{add.comp}$$

[15] Gadzhinsky, A.M. Modern warehouse. Organization, technology, management and logistics. ucheb. -practical guide. M.: TK Velbi, Prospect Publishing House, 2005. 176 p.

[16] Kvizda, M. (2011), Definition of Relevant Market in the Railway Industry, Horizons of Railway Transport, Vol. 2, pp. 86-95.

$$R_{dem} \leq k_{stk} * R_{cash}$$

- C_{eft} = total cost of transport of goods on accelerated freight;

- C_{hw} = cost of direct trunk freight in large-capacity wagons;

- C_{dev}, C_{wh}, C_{add} = tariffs, respectively, for the delivery of cargo from the railway terminal to the recipient, for the main terminal and warehouse services (transshipment and short-term storage), for additional logistic services;

- $C_{dev.comp}$, $C_{wh.comp}$, $C_{add.comp}$ = tariffs of competing organizations, respectively, for the delivery of cargo from the railway terminal to the recipient, for the basic terminal and warehouse services, for additional logistics services;

- R_{dem}, R_{cash} = required and available railway carrying capacity;

- k_{stk} = ratio of the permissible filling capacity of the railway; is assumed to be 0.91 for double-track lines and 0.85 for single-track ones.[17]

Thus, the optimum of function F consists of maximizing profits on the accelerated transport, subject to lower tariffs for transport services compared to competing organizations and the absence of restrictions on the throughput capacity of railways.

The total cost of services for the accelerated transport of cargo C_{eft} in general consists of the cost of transport by rail C_{wag}, the cost of delivering cargo to/from the terminal by truck C_{dev} and the cost of terminal and warehouse service C_{wh}:

$$C_{eft} = C_{wag} + C_{dev.} + C_{wh}$$

C_{eft} is according to three transport schemes: *terminal-to-terminal, terminal-to-door* and *door-to-door*.

Profit P_n is the difference of income and expenses for the relevant activity:

$$P_n = I_n - C_n$$

Where I_n is the income from the relevant activity and C_n is the cost of the relevant activity.

For convenience of calculations, the value added tax is not included in the income and, therefore, not deducted when calculating the profit.

The calculation of income from the type of activity in general can be determined:

$$I_n = C_n N_{wag} c_{uti}$$

Where:

- C_n is the tariff for the corresponding transport services: C_{wag}, C_{dev} and C_{wh}.

[17] Vakulenko, S.P. New technology of accelerated freight by rail. M: "T-PRESS". 2014. № 2 (51). Pp. 47-49.

- N_{wag} is the total number of wagons in accelerated freight trains on the considered landfill in both directions for a given period of time;

- c_{uti} is the utilization of the capacity of the rolling stock.

$$N_{wag} = n_{wag} (2\ n_t)\ T$$

Where:

- n_{wag} is the number of wagons in the composition;

- n_t is the number of trains per day (in pairs);

- T is the number of days for the reference period (month, year).

Incomes of I_4 can be preliminarily determined as a part of the income of I_3 and calculated using the coefficient c_{add}:

$$I_4 = I_3\ c_{add} = C_{wh}\ N_{wag}\ c_{uti}\ c_{add}$$

I_3 – *3st* income from the relevant activity

I_4 – 4rd income from the relevant activity

Based on the expert assessment, it is proposed to set $c_{add} = 0.4$.[18]

In general, revenues from the organization of accelerated freight traffic is:

$$I = (C_{eft} + C_{wh}\ c_{add})\ N_{wag}\ c_{uti}$$

The cost of rail carriage C_1 can be determined in three steps. As follows:

$$C_1 = C_{hau} + C_{inf}$$

Where:

- C_{hau} is the cost of traction trains;

- C_{inf} is the infrastructure charge for the freight train.

$$C_{hau} = C_{ld} + C_{lbh} + C_{fe}$$

Where:

- C_{ld} are the costs associated with the time of locomotive;

- C_{lbh} are the costs associated with the time of locomotive personnel;

- C_{fe} is the cost of fuel and electricity.

$$C_{inf} = (I_1 + I_2\ n_{wag})\ 2\ n_t\ T$$

Where:

- I_1 = costs associated with the process of composing, monitoring and de-composing the train, etc., depending on the distance of train only;

[18] Kirillova A. G. - Economic and mathematical models of optimization of container and piggyback transport based on innovative technologies. Tutorial M: UOC GI MIIT, 2014, pp.96

- I_2 = costs associated with the maintenance of wagons along the line (technical inspection without repair and equipment, depending on the number of wagons in the train and the distance run by each wagon;

The cost of the baggage component is missing in the proposed accelerated freight trains concept.

The cost C_2 related to the delivery of goods from/to the terminal to the consignee using road transport is:

$$C_2 = C_{fs} + C_{run} + C_{pre}$$

Where:

- C_{fs} is the cost of the salary of employees;

- C_{run} is the running costs, which include the cost of fuel lubricants, depreciation, repair and maintenance of the fleet;

- C_{pre} is the cost of maintaining the industrial premises (garage) and the office of dispatchers.

The cost C_3 for the main terminal warehouse services is:

$$C_3 = C_{op} + C_{st}$$

- C_{op} = costs of loading and unloading operations;

- C_{st} (storage costs) = $C_{rent} + C_{fse} + C_{util}$

Where:

- C_{rent} is the cost of rent or tax deductions for its own storage facilities;

- C_{fse} is payroll fund of employees;

- C_{util} is the cost of utilities.

Costs C_4 are tentatively determined as 40% of the costs C_3 (coefficient $c_{add} = 0.4$):

$$C_4 = C_3\ c_{add}$$

Therefore, the general objective function is:

$$F = \{(C_{wag} + C_{dev} + C_{wh} + C_{wh} * c_{add}) * N_{wag} * c_{uti}\} - \{(C_{hau} + C_{inf}) + (C_{fs} + C_{run} + C_{pre}) + (C_{op} + C_{st}) + (C_{op} + C_{st}) * c_{add}\} \rightarrow max$$

2.3. Calculation of operational costs for a pair of accelerated freight trains

The calculation of operating costs for the introduction of a pair of accelerated freight trains can be made by the following methods:

- Unit expenditure rates;
- Postal-luggage trains.

Unit expenditure rates method

The method of unit expenditure rates can be applied to determine the cost of accelerated freight traffic with different types of traction, different composition of trains, different speeds, as well as depending on other technical characteristics of transport.

The form for calculating the cost of electricity and fuel is given in Table 5. The form for calculating the operating costs of accelerated freight trains (a pair of trains per year) is given in Table 6. As an example, the calculation is carried out both for electric and diesel traction. The forms allow determining the operating costs of an accelerated freight train along a desired route.

The method of unit expenditure rates is characterized by simplicity of calculation and can be used without additional research when calculating the cost of accelerated freight transport for the entire railway network.[19] Its disadvantages are the imperfection of determining the size of expenditure rates and their similarity for different conditions and sections.

Table 5. Calculation of the cost of electricity and fuel for the traction of accelerated freight trains

Indicators	**Milan Naples**	**Naples Turin**
Locomotive series	**2TE116U (1 section)**	**2ES4K**
Thrust Index	843	10,000
Type of wagons	average	average
Average gross weight of freight train [tons]	2000	2000
Nominal efficiency of the locomotive	0.31	0.92
Nominal power of a locomotive [kW]	2040	5920
Travel speed [km/h]	80	90
Relative idle energy consumption [kW]	0.02	0.02
Power utilization rate of auxiliary consumers of the idle locomotive	0.75	0.75
The coefficient of the technical state of a locomotive, which is the ratio of the actual and passport hourly expenses of the energy carrier in the rated power mode, is determined empirically mode	1.03	1.03
Coupling weight of the locomotive [tons]	**138**	**192**
Specific main resistance to train movement [kg/t]	2.58	2.92
Weighted average bias in preferred direction (Milan-Turin) [‰]	0.50	0.50
Length of the calculated area (Milan-Turin) [km]	673	282
Sizes of freight traffic [steam/day]	1	1
Annual energy consumption [kWh/kg]	2484490	4842623
Cost of diesel fuel [US dollars/kg] and electricity [US dollars/kWh]	43.00	3.70
Cost of fuel and electricity [US dollars x 1000]	106833	17918
Calculation of the main specific motion resistance		
Proportion of the continuous path (Milan-Turin)	100	100
Load on freight wagon axle [tons]	20.00	20.00
The rate of electricity consumption (kWh) or fuel (kg) per 10,000 tkm gross	24	107

Postal-luggage trains method

[19] Wheat, P., & Nash C. (2006), Policy Effectiveness of Rail, EU policy and Impact on the rail system, European Commission

According to this calculation method, the determination of expenditures for using the infrastructure used for accelerated freight train is performed as for a postal-luggage train.[20]

The advantage of the method is the use for the calculation of the established form intended for postal baggage trains for the new accelerated trains.

Table 6. Calculation of operating costs for accelerated freight trains according to the method of unit expenditure rates (a couple of trains/year)

Indicators	**Milan Naples**	**Naples Turin**
Number of main paths	1	2
Average gross weight of freight train [t]	2000	2000
Average number of cars in the composition	25	25
Travel speed [km/h]	80	90
Ratio of speed to running speed (km/h)	0.60	0.66
Local speed [km/h]	48	59
Standard idle time of trains at stations [h]	0	0
Extra time for locomotive crews, including acceptance operations [h]	1	1
Train downtime at technical stations [h]	0	0
Length of the calculated area [km] (Milan-Turin)	673	282
Train running time [h]	14.02	4.75
Size of the movement of the Unified Hydraulic Transmission (UHT) [pairs/day]	1	1
Operational distance of locomotives [km/year]	491290	205860
Expenditure rate of locomotives [US dollars/km]	**19.90**	**19.90**
Costs associated to locomotives operational distance [US dollars x 1000]	9778	4097
Operational time of locomotives [h/year]	10235	3466
Expenditure rate of locomotives [US dollars/h]	**643**	**643**
Costs associated to locomotives operational time [US dollars x 1000]	6577	2227
Operational time of locomotive personnel [h/year]	10965	4196
Expenditure rate of locomotive personnel [US dollars/h]	**952**	**952**
Costs associated to locomotive personnel operational time [US dollars x 1000]	10443	3996
Operational distance of wagons [km/year]	12282250	5146500
Expenditure rate of wagons [US dollars/km]	**4.73**	**4.73**
Costs associated to wagons operational distance [US dollars x 1000]	58034	24317
Operational time of wagons [h/year]	255880	86641
Expenditure rate of wagons [US dollars/h]	**38**	**38**
Costs associated to wagons operational time [US dollars x 1000]	9672	3275
Traffic [gross t x km x 1000000]	1050	451
Expenditure rate of traffic [US dollars / t x km x 1000000]	**16065**	**16065**
Costs associated to traffic [US dollars x 1000 / t x km]	16874	7249
Cost of fuel and electricity [US dollars x 1000]	106833	17918
Total operating costs for the operational sites [US dollars x 1000000]	218	63
Share conditionally - fixed costs in total expenses [%]	37	50
Conventional constant operating costs [US dollars x 1000000]	128	63
Total operating costs [US dollars x 1000000]	**346**	**126**
Total operating costs [US dollars x 1000000]	**473**	

[20] Salento, Angelo; Pesare, Giuseppe (4 July 2015). "From Liberalisation to Appropriation: The Trajectory of Italian Railways". London: Society for the Advancement of Socio-Economics. Retrieved 31 July 2015.

Table 7 shows the form for calculating the costs by this method and an example for an electrified line. The cost of the luggage component I_3 is absent. The form of calculating the cost of electricity (fuel) is identical to that used in the method of unit expenditure rates.

2.4. Determination of the economic efficiency of new accelerated freight traffic

For the model calculation of economic efficiency according to the developed economic model, it is selected the distance of 660 km from Milan to Naples.

Table 7. Calculation of operating costs for accelerated freight trains (a couple of trains per year)

Indicators	2ES4K	2ES4K	2ES4K	2ES4K	2ES4K	EP2K	2ES4K	EP20	EP2K	EP2K
Wagon type	covered 140 m^3	covered 140 m^3	covered 140 m^3	ST1	ST1	ST2	40ft	40ft	80ft	ST3
Average gross weight of freight train [t]	2070	3300	4400	2070	4320	1500	1950	1950	1410	1225
Average number of wagons in the composition	22	35	47	22	46	16	27	27	15	17
Travel speed [km/h]	90	90	90	90	90	90	90	120	90	120
Ratio of speed to running speed (km/h)	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Local speed [km/h]	59	59	59	59	59	59	59	79	59	79
Standard idle time of trains at stations [h]	0	0	0	0	0	0	0	0	0	0
Extra time for locomotive crews, including acceptance operations [h]	1	1	1	1	1	1	1	1	1	1
Train downtime at technical stations [h]	0	0	0	0	0	0	0	0	0	0
Length of the calculated area [km]	660	660	660	660	660	660	660	660	660	660
Train running time [h]	11.11	11.11	11.11	11.11	11.11	11.11	11.11	8.33	11.11	8.33
Size of the movement of the Unified Hydraulic Transmission (UHT) [pairs/day]	1	1	1	1	1	1	1	1	1	1
Operational distance of locomotives [km/year]	481800	481800	481800	481800	481800	481800	481800	481800	481800	481800
Expenditure rate of locomotives [US dollars/day]	**52458**	**52458**	**52458**	**49578**	**52458**	**35718**	**52458**	**49578**	**35718**	**35718**
Operational time of locomotives [days/year]	338	338	338	338	338	338	338	253	338	253
Costs associated to locomotives operational time [US dollars x 1000]	17729	17729	17729	16756	17729	12071	17729	12567	12071	9054
Expenditure rate of locomotive personnel [US dollars/h]	**2721**	**2721**	**2721**	**2721**	**2721**	**2721**	**2721**	**2721**	**2721**	**2721**
Operational time of locomotive personnel [h/year]	8841	8841	8841	8841	8841	8841	8841	6813	8841	6813
Costs associated to locomotives operational distance [US dollars x 1000]	24057	24057	24057	24057	24057	24057	24057	18539	24057	18539
Cost of fuel and electricity [US dollars x 1000]	39995	59515	76973	40201	76134	29025	43924	54563	27588	36295
Total charge for train traction, including VAT [US dollars x 1000000]	97	120	140	96	139	77	101	101	75	75
Expense rate I_1 [US dollars / train]	194964	194964	194964	194964	194964	194964	194964	194964	194964	194964

Expense rate I_2 [US dollars / wagon]	1164	1164	1164	1164	1164	1164	1164	1164	1164	1280
Total (I_1 + I_2) [US dollars x 1000000]	161	172	182	161	181	156	165	165	155	158
Total cost, including VAT [US dollars x 1000000]	**258**	**292**	**322**	**257**	**321**	**233**	**266**	**266**	**230**	**234**

The shipping packages are pallets and 40 ft containers and the estimated daily freight traffic is 5600 t to Milan and 5000 t to Naples.

The estimated dimensions of traffic is 10 pairs of trains per day (the total size varies according to the financial plan options).

The rolling stock includes the locomotive of series EP2K, EP20 and 2ES4K for compositions of appropriate weight, the wagons with a capacity of 140 m^3, rack cars of models St1, St2 and St3, platforms with a frame length of 40 and 80 ft.

The utilization factor is 0.70 for covered wagons and 0.75 for platforms, taking into account the return of empty containers.

The number of wagons in the composition is between 15 and 47.

The development of terminal and warehouse infrastructures includes additional equipment, upgraded and new specialized.

The travel speed is 90 km/h for covered wagons (St1 and St2 with 40 and 80 ft platforms) and 120 km/h with wagons St3 and 40 ft platforms.

The amount of income depends on the tariffs defined in §2.4 according to *terminal to door* scheme and *door to door* scheme for the FP5 plan for the transport of express cargo.

The investments include the cost of the acquisition of rolling stock, the establishment of the transport undertaking, the development of terminals and warehouse infrastructures and management systems.

For long trains compositions (>425 m), additional time expenditures for uncoupling trains, shunting operations and loading and unloading of increased cargo volume at the point of arrival are taken into account.

The costs of loading and unloading operations and the costs of other warehousing operations, including storage, can be short-term (average duration of 1.5 days) or long-term (average duration of 8 days).

When calculating the income for accelerated freight trains composed by traditional covered wagons, a lower loading height is considered. Smaller loading height may exclude the possibility of loading packaged cargo in two tiers; therefore, in the variants of financial plans with covered wagons, the income level is reduced 28%. In the calculations, an increment factor of 30% ensure the size of the carriage identical to the wagons St1/St2.

The calculation of the profit and profitability of accelerated freight traffic and the technical and economic characteristics of the links for the options are in Table 8.

The results of calculations showed that the profitability of rail transport of packaged cargo at a tariff of 570 US dollars/cargo (excluding VAT) according to the *terminal-to-door* scheme (section 2.4).

Table 8. Calculation of profit and profitability of accelerated freight traffic

№	locomotive series	wagon type	Max speed [km/h]	distance [km]	Wagons in composition	Utilization factor	Railway tariff Cwag dollar/wag. according to the transport scheme:			associated costs under the scheme *from terminal to door* C_{dev} + *Chw* [dollars]	For a couple of trains according to the from terminal to door scheme, [US dollars x 1000000 / year]			Profitability of railway under the transport scheme		
							from *door to door*	from *terminal to door*	from *terminal to terminal*		costs	income	profit	from *door to door*	From *terminal to door*	from *terminal to terminal*
1	2ES4K	covered	90	660	22	0,70	20714	43290	65867	22576	**258**	380	122	**-0,29**	**0,47**	**1,24**
1.2	2ES4K	covered	90	660	35	0,70	20714	43290	65867	22576	**292**	605	313	**-0,01**	**1,07**	**2,15**
1.3	2ES4K	covered	90	660	47	0,70	20714	43290	65867	22576	**322**	812	490	**0,21**	**1,52**	**2,84**
2	2ES4K	St1	90	660	22	0,70	20714	43290	65867	22576	**257**	487	230	**-0,09**	**0,89**	**1,88**
3	2ES4K	St1	90	660	46	0,70	20714	43290	65867	22576	**321**	1018	697	**0,52**	**2,17**	**3,82**
4	EP2K	St2	90	660	16	0,70	28346	59239	90133	30894	**233**	484	251	**-0,01**	**1,08**	**2,16**
2K40	EP20	square 40 ft	120	660	27	0,75	3700	12250	20800	8550	**266**	181	-85	**-0,79**	**-0,32**	**0,16**
2.2K40	EP20	square 40 ft	120	660	27	0,75	17220	25770	34320	8550	**266**	381	115	**-0,04**	**0,43**	**0,91**
2.3K40	2ES4K	square 40 ft	90	660	27	0,75	17220	25770	34320	8550	**266**	381	115	**-0,04**	**0,43**	**0,91**
2K80	EP2K	square 80 ft	90	660	15	0,75	34440	51540	68640	17100	**230**	423	193	**0,23**	**0,84**	**1,45**
5	EP2K	CT3	120	660	17	0,70	41421	130786	220150	89364	**234**	1136	902	**0,54**	**3,86**	**7,17**

Note: for covered wagons, calculations take into account the coefficient of decreasing revenues, due to the likelihood of the impossibility of ensuring the transport of packed cargo in two tiers.

The handling of 22 wagons accelerated freight trains from boxed wagons with a capacity of 140 m^3 is 47% and 89% for the composition of wagons' rack of the model St1 in the same conditions.

The profitability of rail transport of large containers at a rate of 17,220 dollars for cargo space for a loaded 40 ft door-to-door container when handling 15 wagons accelerated freight train from 80-ft-long fitting platforms is 23%.

In table 8, the transport of cargo according to the *door-to-door* scheme for many railway transport options has a low or negative profitability. The cost of shipping containers for option 2K40 is sufficient only for the scheme *from terminal to terminal*, therefore, in further calculations; this option is not under consideration.

The following factors are under accounting in order to ensure a positive profitability under the *door-to-door* scheme:

- Length of the train; when using longer compositions (Table 1, options 1.2, 1.3) the profitability of transport is much higher;
- Utilization rate of rolling stock (adopted 0.70 and 0.75), potentially increased by the innovative operational scheme;
- Tariffs for transport services to be potentially increased: now 12% lower than for road transport;
- Profitability increased by the length of the route: 35% for Milan - Naples - Turin (length: 1099 km).

According to the options for implementing the proposed, financial plans used the principles set out in[21]. The balance of cash expenditures and receipts generated is in the form of a cash flow model with discounting of expenditures and receipts in order to bring them to the time of investment.

The reduction of costs and benefits to actuality uses the discount factor *a*t, determined by the formula:

$$\alpha_t = \frac{1}{(1+E)^t}$$

Where:

- t is the number of the calculation step (t = 0, 1, 2, ..., T);
- E is the discount rate.

The applied constant discount rate is 0.077 and the value of Net Present Value (NPV) G is [95]:

[21] Kalla-Bishop, P.M. (1971). Italian Railways. Newton Abbot, England: David & Charles.

$$G = \sum_{T=0}^{T}(D_t - Z_t - I_t)\frac{1}{(1+E)^t} = \sum_{T=0}^{T}\frac{P_t}{(1+E)^t}$$

Where:

- D_t, Z_t and I_t are, respectively, total income, expenses and investments made at the *t*-th calculation step;

- $P_t = (D_t - Z_t - I_t)$ is the effect achieved at the t-th step;

- *T* is the calculation horizon.

The greater the NPV, the more effective the project.[22]

Table 9 shows the results of the NPV calculation for the new scheme. For financial plans FP2 (St), FP22 and FP23, the profit is calculated identical to FP2 plan.

The calculations take into account the effect of individual parameters and technological solutions on the financial results of the transport process.

Carriage of packaged cargo in rack wagons are under comparison with the transport of containerized cargoes; moreover, it includes:

- Use of compounds of increased (50%) and double length;
- Organization of intermediate or long-term storage.

Tables 10÷13 show the options for financial plans comparing various criteria. The results of the calculations and the dynamics of changes in NPV according to calculation period (charts of figures 4÷7).

The analysis of changes in the NPV (Net Present Value) schedules for the financial plan for various implementation options FP1, FP2, FP3, FP4 and FP5 (Figure 4) allowed the following conclusions: the investments for option FP22 are bigger than for FP1, but the payback period for option FP22 is less. Option FP4 pays off faster due to the use of more capacious wagons of type St2 with lower operational costs; this option can be only for packaged cargo up to 610 kg.

Analysis of calculations of various options for financial plans showed that when transporting express cargo FP5 under the *door-to-door* scheme, even with large amounts of investments and costs for transporting cargo by road and terminal services, the project pays off in 5 years of its implementation. This indicates a high yield of the accelerated freight traffic when transporting small shipments of express cargo. However, there is currently no express cargo flow in the transport corridor under consideration ensuring the traffic dimensions corresponding to 10 pairs of accelerated trains per day.

[22] Lang, M., Laperrouza, M., Finger, M. (2011), Competition Effects in a Liberalized Railway Market, Journal of industry, Competition and Trade, Vol. 13, pp. 375-398.

Table 9. Results of the calculation of Net Present Value by year for accelerated freight services

Version of the financial plan	Locomotive series	Wagon type	Running speed [km / h]	Number of wagons in the composition	Type of terminals and warehouses	Delivery organization	Storage type	Net present value by implementation year [US dollars x 1000000]							Investments over 5 years [US dollars x 1000000]
								1	2	3	4	5	6	7	
FP1	2ES4K	covered	90	22	retrofit	own	intermediate	-1605	-1564	-1279	-1338	-254	739	3510	5633
FP12	2ES4K	covered	90	35	retrofit	own	intermediate	-1593	-1167	-341	309	2419	4637	8990	5594
FP13	2ES4K	covered	90	47	retrofit	own	intermediate	-1525	-910	171	1170	3743	6533	11559	5374
FP 2	2ES4K	St1	90	22	retrofit	own	intermediate	-1530	-1228	-581	-146	1608	3425	7190	5392
FP2(xp)	2ES4K	St1	90	22	retrofit	own	long-term	-1581	-1272	-607	-137	1688	3658	7621	5710
FP22	2ES4K	St1	90	22	modernized	own	intermediate	-1571	-1364	-815	-454	1193	3071	6836	7358
FP23	2ES4K	St1	90	22	special	own	intermediate	-1723	-1810	-1568	-1452	-136	1902	5668	7461
FP3	2ES4K	St1	90	46	modernized	own	intermediate	-1653	-1060	34	1080	3783	6887	12333	6152
FP4	EP2K	St2	90	16	modernized	own	intermediate	-1423	-1089	-381	227	2130	4364	8437	5404
FP2.2K40	EP20	Platform 40ft	120	27	retrofit	own	intermediate	-1323	-1427	-1368	-1639	-1060	-567	1258	4716
FP2.3K40	2ES4K	Platform 40ft	90	27	retrofit	own	intermediate	-1155	-1201	-1082	-1228	-583	45	1871	4171
FP2K80	EP2K	Platform 80ft	90	15	retrofit	own	intermediate	-907	-588	9	552	2026	3727	6685	3363
FP5	EP2K	St3	120	17	special	own	intermediate	-1878	-1670	-998	-473	1701	4817	10001	8098

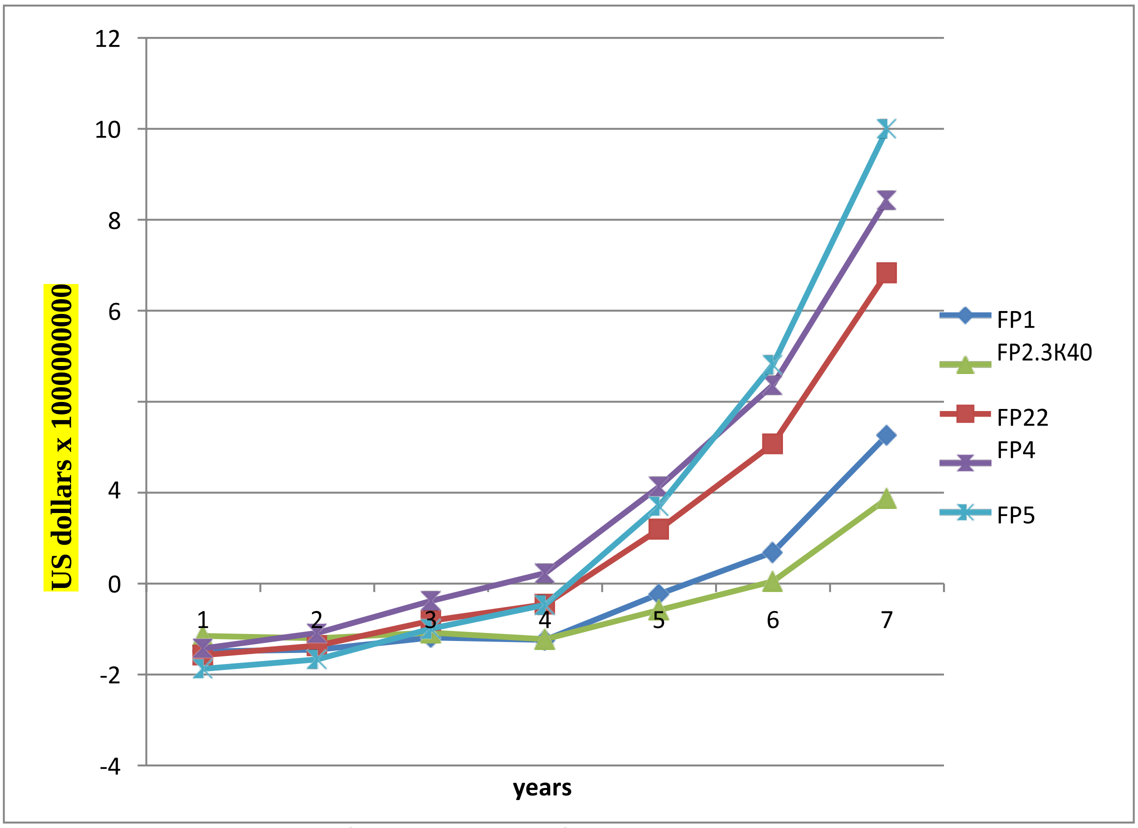

Figure 4. NPV for the selected financial plan options (Table 10)

Table 10. Selected financial plan options

Version of financial plan	Type of packing	Locomotive series	Type of wagons	Number of wagons in the composition	Autotransport	Type of terminals and warehouses	Storage time
FP1	Packages	2ES4K	Covered	22	Own	Retrofit	Interim storage (1.5 days)
FP2.3K40	Container 40 ft	2ES4K	40 ft. Platform 90 km/h	27		Retrofit	Interim storage (1.5 days)
FP22	Packages	2ES4K	St1*	22		Modernized	Interim storage (1.5 days)
FP4	Packages	EP2K	St2*	16		Modernized	Interim storage (1.5 days)
FP5	Packages	EP2K	St3*	17		Specialized	Interim storage (1.5 days)

Note: *Variants of models of the new wagon rack type

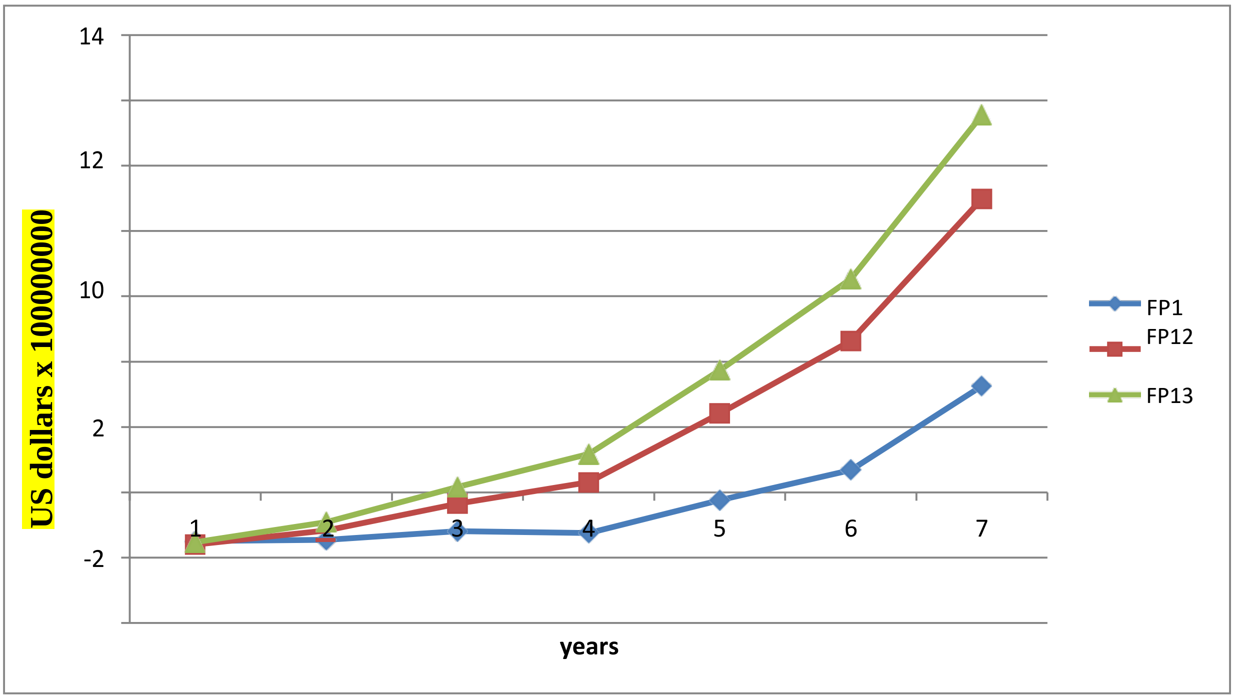

Figure 5. NPV for financial plans depending on the number of wagons in the composition (traditional box wagons) (Table 10)

Table 11. Variants of the financial plans depending on the number of wagons in the composition (traditional covered wagons)

Version of financial plan	Type of packing	Locomotive series	Type of wagons	Number of wagons in the composition	Autotransport	Type of terminals and warehouses	Storage time
FP1	Packages	2ES4K	Covered	22	Own	Retrofit	Interim storage (1.5 days)
FP12	Packages	2ES4K	Covered	35	Own	Retrofit	Interim storage (1.5 days)
FP13	Packages	2ES4K	Covered	47	Own	Retrofit	Interim storage (1.5 days)

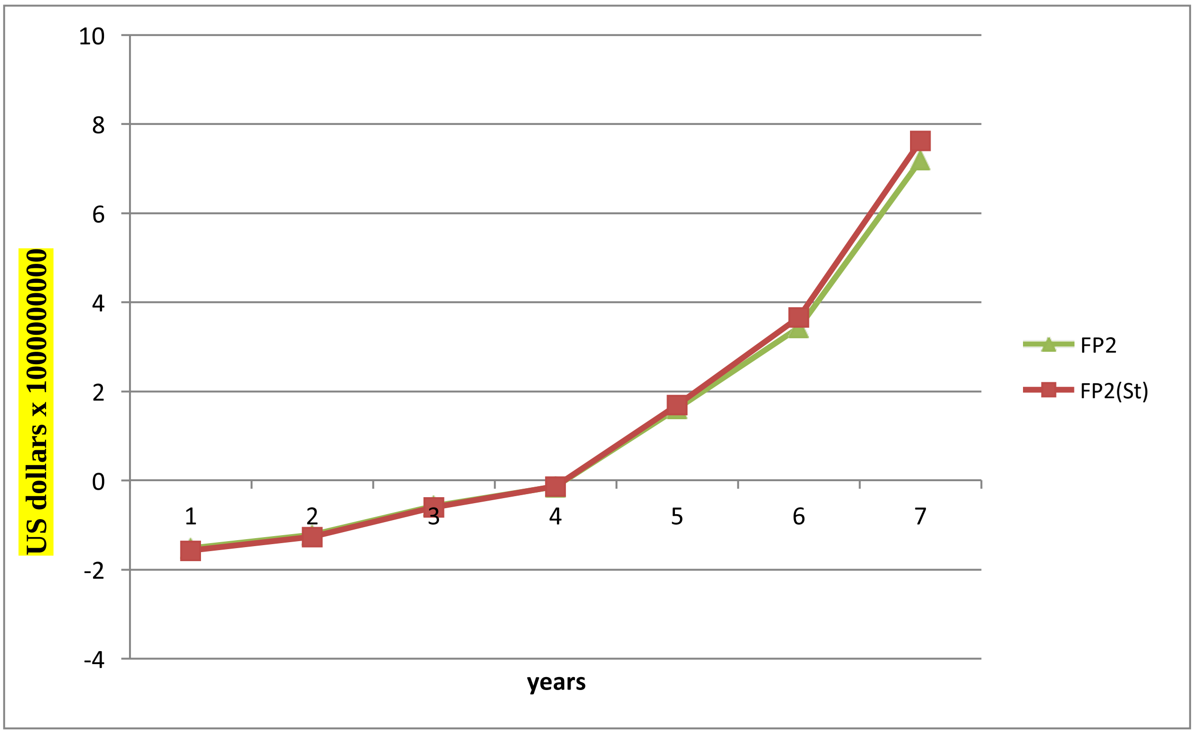

Figure 6. NPV for financial plan options depending on the period of storage of goods (Table 12)

Table 12. Variants of the financial plan depending on the period of storage of goods

Version of financial plan	Type of packing	Locomotive series	Type of wagons	Number of wagons in the composition	Autotransport	Type of terminals and warehouses	Storage time
FP2	Packages	2ES4K	Covered	22	Own	Retrofit	Interim storage (1.5 days)
FP2(St)	Packages	2ES4K	Covered	22	Own	Retrofit (costs increased)	Long-term storage (8 days)

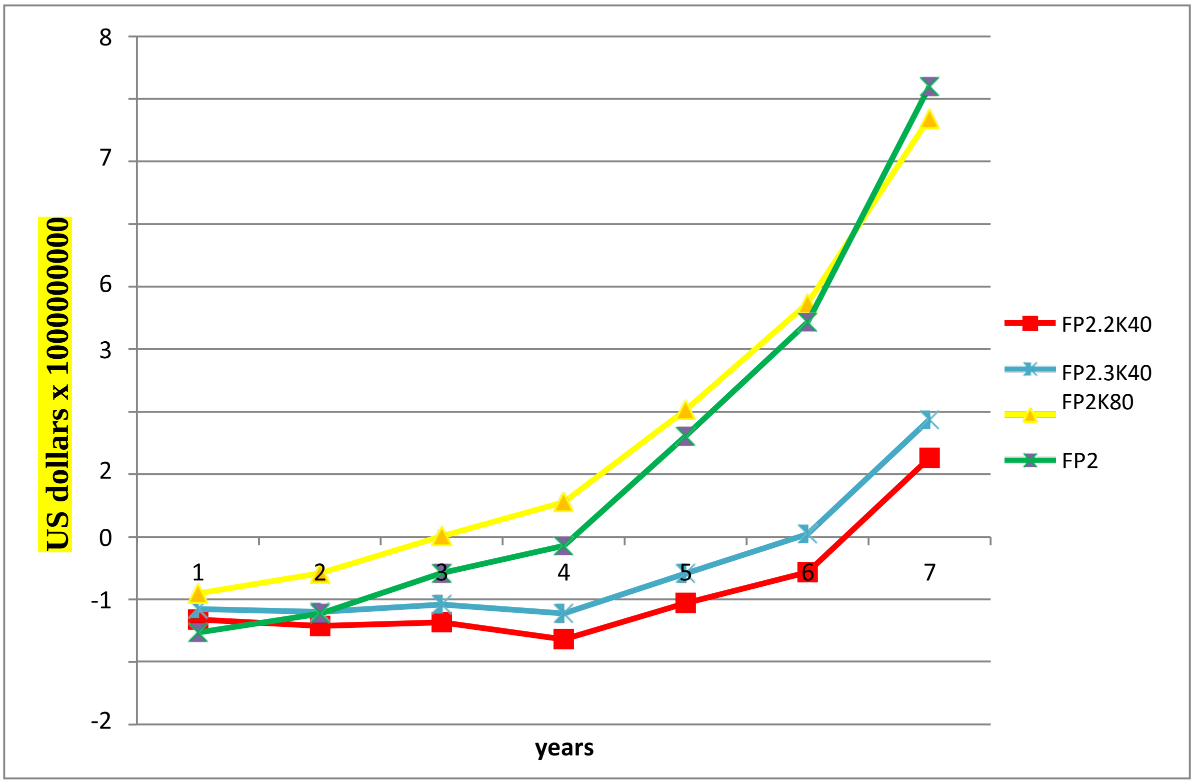

Figure 7. NPV for financial plan options comparing transport of containers with shipping in rack wagons (Table 13)

Table 13. Variants of the financial plan when comparing transport of containers with shipping in rack wagons

Version of financial plan	Type of packing	Locomotive series	Type of wagons	Number of wagons in the composition	Autotransport	Type of terminals and warehouses	Storage time
FP2.2K40	Container 40 ft	EP20	Platform 40 ft 120 km/h	27	Own	Retrofit	Interim storage (1.5 days)
FP.3K40	Container 40 ft	2ES4K	Platform 40 ft 90 km/h	27	Own	Retrofit	Interim storage (1.5 days)
FP2K80	Container 40 ft	EP2K	Platform 80 ft 90 km/h	15	Own	Retrofit	Interim storage (1.5 days)
FP2	Packages	2ES4K	St1	22	Own	Retrofit	Interim storage (1.5 days)

Calculations for financial options FP1, FP12 and FP13 with a different number of wagons in the composition show that larger number of wagons in the composition reduce the incidence of the investment in traction rolling stock.

Graphs of changes in NPV (Figure 5) show that, with a larger number of wagons in the composition, investments implementation pay off more quickly, despite an increase in rolling stock idle time in nodes related to the need for marshalling in the terminals.

An analysis of the warehouse services market led to the conclusion that Class A warehouses (high quality services and availability of additional services) are the most suitable for accelerated freight trains of established composition.

The changes in the NPV on the financial plan options depending on the storage period of the goods in the warehouse (Figure 6) show that investments in the variant with the long-term storage of cargo pay off a little faster, with large investments in terminal and warehouse.

Diagrams of changes in the NPV on the financial plan options when comparing the transport of containers with shipping in rack cars (Figure 7) show that the return period on the FP2 investment is lower than the FP2.2K40 and FP2.3K40 plans, because the C_{wag} tariff in the first case is much higher. This is due to the difference in mass-dimensional characteristics provided by the cargo room of the racking wagon and the internal volume of the container for the goods transported in them. At the same time, the payback period of investments according to the plans of FP2 and FP2K80 is comparable.

The results of calculations on the options of financial plans explains that with different versions of the implementation of accelerated freight traffic, the payback period for investments in most cases is variable from 3 to 5 years and 6 years for the FP2.2K40 variant only. For financial plans using covered wagons and terminal warehouses, the amount of investment in the first 5 years is from 5÷8 billion US dollars, for container transport options 3.4÷4.7 billion US dollars.

CHAPTER III: PLAN FOR FORMING ACCELERATED FREIGHT TRAINS

3.1. Methods for planning the composition of freight, passenger and postal baggage trains

Various aspects of planning a network of accelerated freight traffic and the principles for the composition of related trains, basing on data on the directions and volumes of road transport flows were in[23]. A simplified approach was adopted thanks to the limited amount of cargo traffic streams, though it is not universal, ensuring the optimal development of non-bulk cargo traffic. Therefore, a more general and scientifically based approach is necessary.

The purpose of planning routes and composition for conventional freight trains is the most appropriate basis for the distribution of work across loading, unloading and sorting stations.

All classical methods of analytical calculations are normally applicable only to limited polygons of stations, taking into consideration mono-directional wagons flows and no restrictions in stations.

The method for planning the composition of single-unit freight trains made possible to solve the problem for the entire railway network, by taking into account restrictions on the allowable number of single-group train appointments per station as well as user-defined, banned and mandatory assignments.

The planning of multi-group freight trains to accelerate the delivery of goods, with the related financial and economic advantages, showed a decrease in total costs of 10% due to a 33% reduction of wagons operational time, thanks to the concentration of traffic.

Under market conditions, the methodology for organizing freight traffic and planning the composition of trains should take into account the results of a survey on the transport market, the demand for transport services and the associated operational costs.[24]

The currently used methodology for the organization of traffic flows in the freight traffic is poorly adapted to market conditions, basing on competitive struggle among shippers. In this regard, the allocation of accelerated freight traffic in a separate category can play an important role to attract customers and their goods to the railway transport.

The new accelerated freight by rail is fundamentally different from the transport of bulk cargo and from the existing of accelerated freight traffic. Therefore, the planning methodology used for them is not applicable for the composition of accelerated freight trains.

The features of accelerated freight trains handling are conceptually and technologically closer to the principles of organizing passenger transport.

Therefore, the thesis work analyzed the methods for planning passenger trains, the main

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[23] Prokofiev, M.N. Route network of expedited shipments. The world of transport. 2010. No. 5. P. 78-83.

[24] Shefer, Jon. Rail Freight Transport: How To Save Thousands Of Dollars & The Environment. Wayback Machine. 2015. P. 4

drawback of which is normally the lack of accounting for the demand for categories of seats in various typology of coaches and the resulting profits from the inclusion of more comfortable coaches. Thus, the best option is often the cheapest, which does not take into account the interests of passengers in terms of ride comfort.

Therefore, in the planning method for passenger trains, proposed in[25], the task is taking into account the demand for places of different categories for each destination separately and the composition plan is under evaluation, in terms of both costs and incomes.

The planning of accelerated freight traffic and the principles of its calculation should take into account:

- Dedicated standard cargo areas in stations;
- Operation of trains on schedule;
- Operation of trains without re-composition and with loading and unloading without uncoupling;
- Minimization of downtime thanks to the intensification of loading and unloading operations;
- Corresponding reduction in the number of technical inspections along the route and extension of turnarounds times of wagons;

3.2. Planning method for the composition of accelerated freight trains

An important condition for solving the problem of planning accelerated freight trains is to ensure the carriage of goods without modifying composition and cargo handling. Re-shaping and reloading reduce the competitiveness and can be justifiable only for a small share of the total volume of transported goods. In many cases, it will be more efficient to increase the concentration of such goods transport, which will eliminate or reduce the need of reshaping or reloading and set a condition for ensuring uninterrupted cargo transport by accelerated freight trains, which will simplify the modal integration.

The planning of accelerated freight trains was using the traditional methodology based on the density of freight traffic, which does not take into account the capacity limitations of railway lines, so the calculation is basing on the corresponding forecast of freight traffic.[26] Therefore, the condition for ensuring the development of cargo flows without reforming the composition and cargo handling will be as follows:

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[25] Lewandowski, Krzysztof. "New coefficients of rail transport usage". International Journal of Engineering and Innovative Technology (IJEIT*)*. 2015. P. 89–91

[26] Arcot, V. C. Modeling Uncertainty in Rail Freight Operations: Implications for Service Reliability. Master’s thesis, Academy of Maryland. 2007

$$O_{iq} = \sum_{j=1}^{J} \sum_{v=1}^{n} \delta_{ijvq} \gamma_{ijvq} \qquad \forall i; \forall q$$

Where:

- O_{iq} is the weight (in tons) of the q-th kind of cargo of the i-th correspondence of the cargo flow;

- γ_{ijvq} is the mass of the cargo of the i-th correspondence of the freight traffic transported in the trains of the j-th destination, with the v-th composition in wagons of the q-th kind;

- δ_{ijvq}= 1 if the departure and destination stations of the i-th correspondence of the freight traffic are included in the train route of the j-th destination and there are q-th wagons in its v-th composition; otherwise δ_{ijvq}= 0;

- j is the number of train appointments;

- n is the number of train compositions.

The implementation of the proposed accelerated freight by rail provides for various options for the organization of terminal warehouse service, which reflects on the principles for formation and operation of accelerated freight trains.

The structure of transport of non-bulk cargoes includes various typologies of cargo, therefore various compositions of accelerated freight trains is to consider. At the same time, the linear programming apparatus makes it possible to solve the problem of calculating the plan for the formation of accelerated freight trains with the schemes of their compositions.

To build a methodology for planning accelerated freight trains, three approaches are possible:

1) Specialized terminal and warehouse including those corresponding to the schemes of terminals TSK-S1.1, TSK-S1.2, TSK-S2 and TSK-S3 (Appendix 1) and specialized schemes of accelerated freight trains consisting of one type of wagon. This option is preferable for large cargo traffic and maximum use of the existing infrastructure; if the minimum competitive train frequency (1 per weekday) is maintained;

2) Two ways terminal and warehouse including those corresponding to the schemes of terminals TSK-D1 and TSK-D2 (Appendix 2) and combined schemes of accelerated freight trains consisting of two or more types of wagons. This option can be claimed when homogeneous cargo flows do not provide the minimum frequency of accelerated freight trains, then the calculation is made for combined train compositions including in the financial plan additional costs (relative to

the first option) for the development of terminal and warehouse;

3) Specialized terminal and warehouse equipped with cargo fronts for processing wagons of various types and using combined schemes of accelerated freight trains consisting of two or more types of wagons with composition uncoupled into parts consisting and rearranged to the corresponding cargo fronts. The application of this scheme requires careful justification because it excludes the most important principle of the new accelerated freight trains without shunting operations. This option can reduce the cost of developing terminal and warehouse infrastructures respect to the second option. The calculation is for combined train compositions, while taking into account additional costs for the development of terminal and warehouse infrastructures and costs associated with shunting operations.

Thus, the formation plan (FP) of an accelerated freight train may include three variants of calculation algorithm (Figure 8).

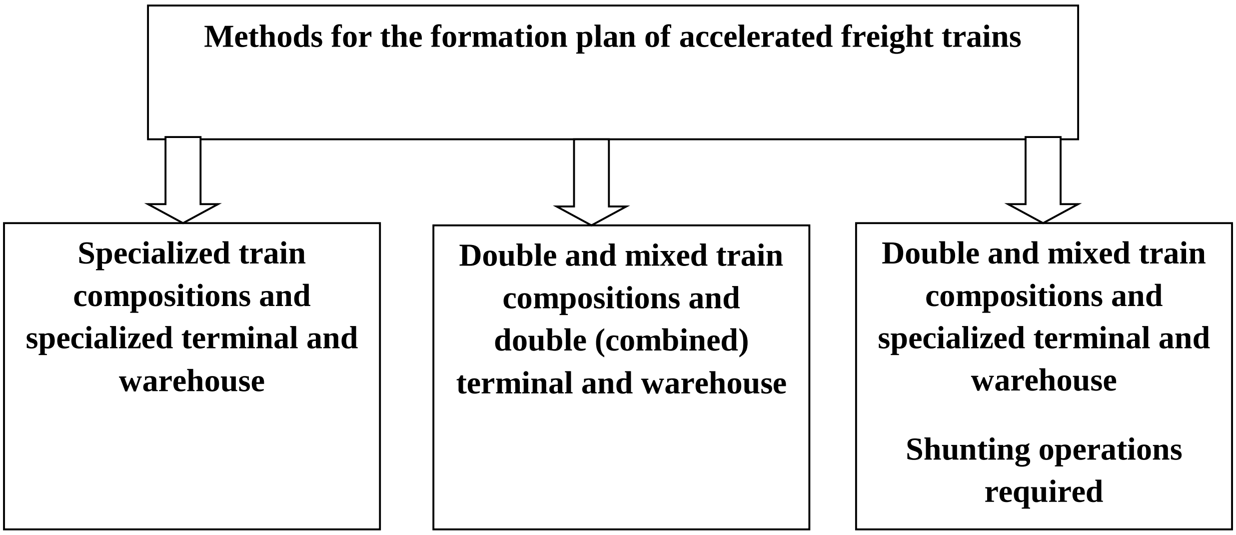

Figure 8. Variants of the algorithm for planning the formation of accelerated freight trains

The choice of the calculation algorithm is depending on technical and economic conditions and marketing strategies of the carrier company.

To solve the task, it is necessary to enter the condition for the development of cargo traffic correspondence, where the number of cargo places in accelerated freight trains of a specific destination will be greater or equal to the total weight of the cargo transportable without recomposing the train and reloading the cargo at the destination. This condition is separately valid for each section included in the route of the train destination. Then, the condition for the development of correspondence of freight traffic will be[27]:

$$\sum_{i=1}^{I} \delta_{ijvkq}\gamma_{ijvq} \leq \delta_{jvkq}\, a_q V_{jvq}; \quad \forall_j, \forall_q, \forall_k, \forall_v$$

Where:

- γ_{ijvq} is the mass of the cargo, the i-th correspondence of the cargo traffic transported in trains of the j-th destination, the v-th composition in wagons of the q-th type;

- a_q is the static load of q-type wagons;

- V_{jvq} – the number of wagons of the q-th type of j-th train destination in the v-th composition of trains;

- k is the number of the section of the traffic flow;

- I is the number of correspondence assignments of freight traffic;

- $\delta_{ijvkq} = 1$, if the k-th section is between the stations of origin and redemption of the i-th correspondence of the freight traffic, and these stations are included in the train route of the j-th destination, v-th track and in its composition there are q-th carriages; otherwise $\delta_{ijvkq} = 0$;

- $\delta_{jvq} = 1$, if the trains of the j-th destination, the v-th composition follow the k-th section; otherwise $\delta_{jvq} = 0$.

The problem of the composition of accelerated freight trains is undefined; therefore, we introduce a condition consisting in establishing the correspondence between the maximum number of wagons for a specific destination and the total number of wagons of various types for this purpose:

$$(m_j^{max} - Q)x_{jv} \geq \sum_{q=1}^{Q} V_{vjq}; \qquad \forall j, \forall v$$

Where:

- m_j^{max} is the maximum number of wagons in the train of the j-th destination;

- Q is the number of wagon types;

- $m_j^{max} - Q$ is the maximum number of wagons in the train, rounded to an integer value.

[27] Bonsra, K. and Harbolovic, J. Estimation of run times in a freight rail transport network. Thesis (M. Eng. in Logistics), Massachusetts Institute of Technology. 2012

The dependence of operating costs on the number of wagons in the composition is relatively small; therefore, for a rational solution of the problem, it is necessary to impose a limit to the minimum number of wagons in a train:

$$m_j^{min} x_{jv} \leq \sum_{q=1}^{Q} V_{vjq} \qquad \forall j, \forall v$$

Where:

- m_j^{min} is the specified minimum number of cars in the train of the *j*-th destination;

- $\boldsymbol{x_{jv}}$ is the number of trains of the *j*-th destination of the *v*-th composition.

The composition of the freight train is determined after the calculation of the formation plan by the formula:

$$\boldsymbol{m_{jvq}} = \sum_{q=1}^{Q} \left\{ \left[\frac{\boldsymbol{V_{jvq}}}{\boldsymbol{x_{jv}}} \right] + \boldsymbol{1} \right\}; \ \forall \boldsymbol{j}, \forall \boldsymbol{v}$$

Where $\left[\frac{V_{jvq}}{x_{jv}}\right]$ is the whole part of $\frac{V_{jvq}}{x_{jv}}$.

Should the criterion of optimality for this task be the minimum operating costs, which are divided into two components: train ($C_j x_j$) and wagon ($c_{jl} V_{jl}$), then the objective function will be:

$$\boldsymbol{F} = \sum_{j=1}^{J} \sum_{v=1}^{n} \boldsymbol{C_j x_{jv}} + \sum_{j=1}^{J} \sum_{v=1}^{n} \sum_{q=1}^{Q} \boldsymbol{c_{jq} V_{jvq}} \rightarrow \boldsymbol{min}$$

Where:

- C_j is the operating cost for the train components (infrastructure fee, locomotive, work of locomotive personnel, formation and turnover of trains, etc.) attributable to the commissioning of the first train of the *j*-th destination;

- c_{jq} is the operating cost of the carriage components (infrastructure fees, wagons repairs, etc.) per carriage of *q*-type and *j*-th destination.

The estimation of costs for the train components *Cj* for the *j*-th destination is in accordance with Table 7 (calculation for the postal-baggage train). The cost of the carriage component taken by the tariff scheme I_2 for postal-baggage trains. Due to the differences in the cost of operating the wagons adopted for the formation of accelerated freight trains (fitting platforms and covered wagons) and the cost of operating the baggage wagons, component I_2 was accordingly downwards.

The cost of the luggage component I_3 is absent.

Accounting for capacity limitations is introducing restrictions on the daily number of freight trains in sections and assigning them to appointments along the routes.

The task is a typical transport problem solvable by integer linear programming. To solve the problem on an Electronic Calculating Machine (ECM), the used software was LPsolve IDE (version 5.5.2.0) with a free license. The solution was by the simplex method.

3.3. Example of planning the formation of accelerated freight trains

As an example of calculating the plan for the formation of accelerated freight trains, we consider its calculation when developing cargo traffic of non-mass cargoes that follow two motor transport corridors: M10 (Milan – Naples) and M7 (Naples – Turin).

The results of the study of the volume and structure of road haulage along the M10 and M7 routes made it possible to establish the correspondence of non-bulk cargo traffic. In the example of calculating the formation plan, six traffic correspondences are mastering six assignments of accelerated freight trains (Figure 9).

In order to calculate the plan for the formation of accelerated freight trains according to the developed methodology, the following initial data are necessary:

- The landfill of the railway network, including the hubs of Milan, Naples and Turin;
- The type of packing: 40 ft containers (index 1) and packages (index 2).
- Freight traffic correspondence: monthly volumes of each type of non-mass cargo (containerized and packaged), which can be mastered by accelerated freight train; the correspondence between cargo flows and their daily volumes in tons are presented in Figure 9.
- Types of wagons: fitting platforms for containerized cargoes with static load t = 21 tons (10.5 tons per 1 TFE (twenty-foot equivalent) with a 40% empty container run) and covered wagons for packaged cargoes with static load a = 35 tons.
- Number of wagons in the composition on the site: the number of wagons in all sections is variable between 18 and 24 pcs;
- Number of train compositions: up to three tracks per train destination (n = 3);
- Calculation of expenses: costs of organizing the movement of accelerated freight trains shown in Table 14.

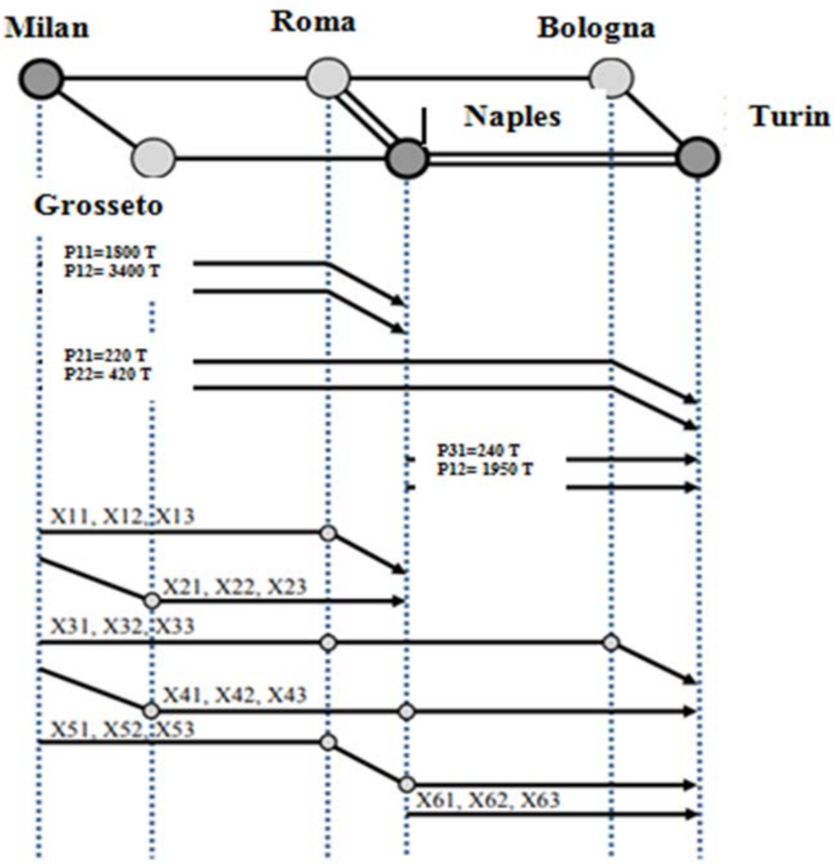

Figure 9. Correspondence of freight traffic and possible destinations of accelerated freight trains for their development on a given landfill of the railway network

Table 14. Transport costs for train C_j and wagonload c_{jq} components

Destination number (*j*)	Train component C_j [US dollars]	Carriage component c_{jq} [US dollars]	
		Fitting platforms	Covered wagons
1	374000	1300	1500
2	382000	1300	1500
3	444000	1600	1700
4	523000	1800	2000
5	481000	1700	1900
6	184000	700	700

Limit bandwidth: prohibited the admission of freight trains along the route Milan – Naples and restriction of capacity on the route Milan – Grosseto-Roma (6 pairs per day).

We will calculate the formation plan by combining two types of wagons. The results: calculation of the size of the movement and the compositions of accelerated freight trains by destination are in Table 15.

To optimize the result, we translate one covered wagon from destination X41 to destination X31, which will improve the conditions for processing trains of these appointments at terminals and simplify the maintenance of rolling stock (Table 15).

Table 15. Frequency and composition of accelerated freight trains in accordance with the calculated formation plan for option No. 2

Destination	Accelerated Freight Train Routes	Traffic [trains/day]	Composition number	Composition [number and type of wagons]
X11	Milan – Naples (via Roma)	5	1	15 fitting. platforms 5 covered wagons
X21	Milan – Naples (via Grosseto)	4	1	18 covered wagons
X31	Milan – Turin (via Roma and Bologna)	1	1	6 fitting platforms 12 covered wagons
X41	Milan – Turin (via Grosseto and Naples)	1	1	18 fitting platforms 1 covered wagon
X63	Naples – Turin	3	3	4 fitting platforms 19 covered wagons
After adjustment				
X31	Milan – Turin (via Roma and Bologna)	1	1	6 fitting platforms 13 covered wagons
X41	Milan – Turin (via Grosseto and Naples)	1	1	18 fitting platforms

The resulting designation for number and composition of accelerated freight trains are in Figure 10.

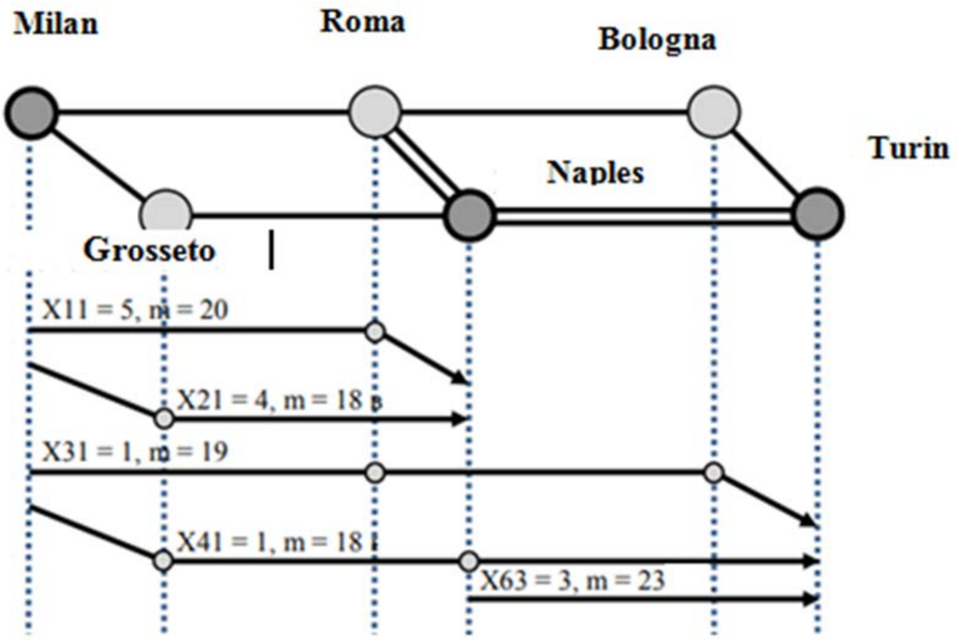

Figure 10. Appointment of accelerated freight trains, obtained as a result of calculation for

option No. 2 of the methodology

The disadvantage of the proposed method for the planning of accelerated freight trains is the inability to specify the calculation of trains with a selected typology of wagons as a priority. Accounting for this factor requires introducing into the task the *if-then* condition, only implementable within the framework of the linear programming apparatus. It requires the use of another tool or the creation of a special program to calculate more rational train compositions. We will carry out the calculation according to option No. 1 of the methodology for the composition of accelerated freight trains of the same kind of wagons. Baseline data remain unchanged. The calculation is for each type of cargo separately, in two stages, to take into account the limitations of throughput it at the second stage on the results of the first stage.

The results of the first stage of calculation are in table 16.

Table 16. Frequency and composition of accelerated freight trains after the first stage of calculation for option No. 1 of the methodology

Destination	**Accelerated Freight Train Routes**	**Traffic [trains/day]**	**Composition number**	**Composition [number and type of wagons]**
X11	Milan – Naples (via Roma)	4	1	22 fitting platforms
X51	Milan – Turin (via Roma and Naples)	1	1	22 fitting platforms

The appointments and the sizes of trains occupy 5 available slots for the accelerated freight trains on Milan – Roma section; for the second stage of the calculation, 1 slot remains free.

The results of the second stage of the calculation are in Table 17. Appointments, number and composition of accelerated freight trains, calculated in two stages for option No. 1 of the methodology, are in Figure 11.

Table 18 compares the planning for the formation of accelerated freight trains according to both methods: option number 1 has a markedly greater profitability of transport due to the development of a given size of cargo traffic by a smaller number of trains.

The calculation for option No. 3 of the methodology, which involves shunting operations for combined trains, requires the introduction of the *if-then* condition for the related costs into the task, not implemented within the framework of the linear programming apparatus; therefore, the calculation for option 3 is not fully in the program mode.

Table 17. Frequency and composition of accelerated freight trains after the second stage of calculation for option No. 1 of the methodology

Destination	Accelerated Freight Train Routes	Traffic [trains/day]	Composition number	Composition [number and type of wagons]
X12	Milan – Naples (via Roma)	1	2	22 covered wagons
X22	Milan – Naples (via Grosseto)	3	2	22 covered wagons
X42	Milan – Turin (via Grosseto)	1	2	22 covered wagons
X62	Naples– Turin	3	2	19 covered wagons

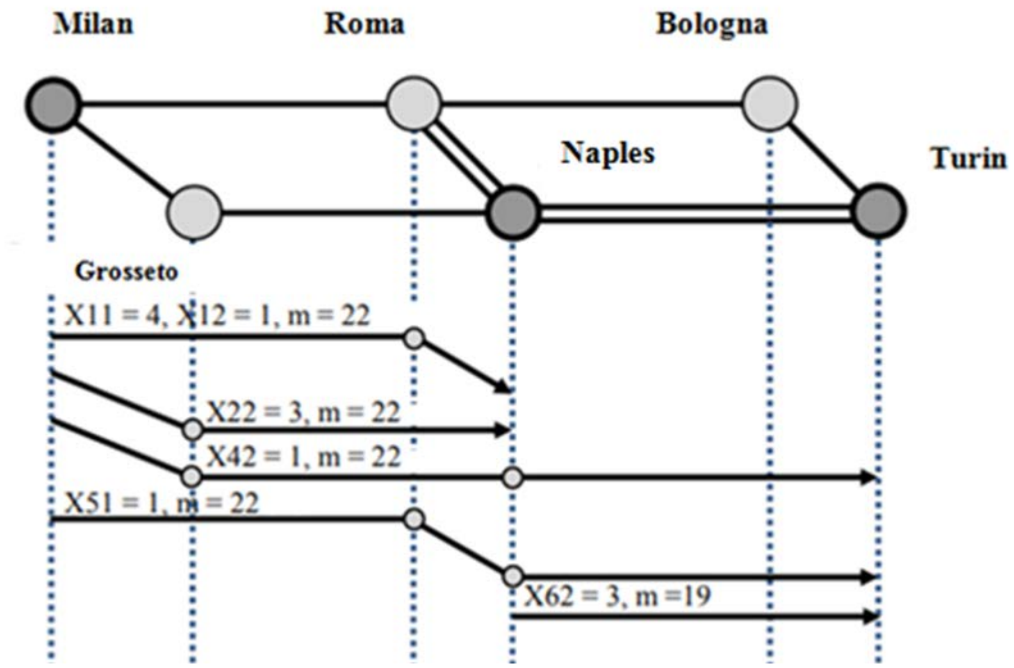

Figure 11. Appointment of accelerated freight trains, calculated in two stages for option No. 1 of the methodology

However, such a calculation takes place in two stages:

1) Plan for the formation of accelerated freight trains calculated for option No. 2 of the methodology;

2) Consideration of expenses for shunting operations of trains with combined formations schemes.

Comparison of the results of calculations of the plan for the formation of accelerated freight trains according to options n°1 and n°2

Indicators	The results of the calculation of the formation plan according to the methods	
	option No. 1	option No. 2
Total number of wagons in trains (without rounding) [wagon/day]	273	273
Total number of wagons in trains (including rounding) [wagon/day]	277	278
Total number of trains per day	13	14
Operational costs for the accelerated freight trains [US dollars x 1000 / day]	5134.5	5466.5
Tariffs for cargo transport in *terminal-to-door* services [US dollars x 1000 / wagon]	34.1 for a covered wagon 24.8 for a fitting platform	
Revenues from transport of goods [US dollars x 1000 / day]	6041	6041
Profitability of the railway freight carriage [%]	30.0	24.4

The proposed method allows solving the planning problem for the accelerated freight trains and determine the schemes of their compositions without re-formation and cargo handling, with segmentation of cargo traffic by types of packages.

The objective function is to minimize the cost of organizing transport, while fulfilling the constraints: mastering of cargo traffic, continuity of the transport process, carrying capacity of lines.

The technique is universal because it is basing on the method for planning the formation of long-distance passenger trains.

CONCLUSIONS

The main results obtained by the thesis work are the following:

1) Studies concluding that there is a market sector for the implementation of the proposed accelerated freight traffic in the Italian railways.

2) Proposals for the implementation on the railway transport of:

- New concept of accelerated freight by rail, in comparison with existing domestic and foreign technologies, introducing the implementation of a number of new organizational principles in the transport process, the transition to the free sale of cargo packages in accelerated freight trains (fixed composition and schedule), complexity and versatility,
- Classification of accelerated freight trains into accelerated (up to 1300 km/day), high-speed (from 1300 to 2500 km/day) and high-speed (over 2500 km/day),
- Organizing work with clients (shippers) of accelerated freight traffic, with higher level of service even compared to road haulage;

3) Technique for determining the compositions of accelerated freight trains basing on the analysis of the structure of non-bulk cargo transport and organization of loading and unloading operations at cargo terminals, the number of trains of different compositions was determined depending on the group of factors determining them: unified length of 425 m with a composition from 15 to 27 wagons and three weight categories of train sets depending on their schemes: 1350, 1600, 2100;

4) Technical support of accelerated freight traffic in terms of rolling stock necessary for the organization of the new concept, mainly produced by domestic undertakings;

5) Principles for a rack-type wagon providing the technical support to the transition to the operation of cargo from one package on a pallet. Rack wagons will be used both in the framework of the new transport concept and for the existing rail freight services;

6) Preliminary calculation of the cost of transport of non-bulk cargo by the proposed innovative concept: the profitability of rail transport of packaged cargo at a rate of 570 US dollars/cargo space (excluding VAT) is:

- -47% when handling a 22-wagons accelerated train composed by covered wagons with a body volume of 140 m^3 under the *terminal-to-door* scheme;
- -23% when transporting containers of 15 fitting platforms with a length of 80 ft according to the *door-to-door* scheme;

7) Recommendations for formation and successful operation of terminal and warehouse infrastructures designed for accelerated freight traffic:

- Two typologies of terminals: *transshipment* and *long-term storage*,

- Possibility of end-to-end train traffic through the terminal,
- Train received at the terminal without re-composition, with a minimum total length corresponding to the unified length of the accelerated freight train (425 m);

8) Variants of modular terminal and warehouse schemes for general schemes, including two-sided terminals allowing the combination of processing for packaged and containerized cargoes on one front of the terminal-warehouse system;

9) Comprehensive economic model of business processes for the new concept, which allows to determine:

- Effectiveness of investment in various technical solutions,
- Most rational variants of implementation for a specific transport corridor or network;

10) Methodology solving the problem of planning the formation of accelerated freight trains with the definition of the schemes for their compositions, to ensure the development of cargo traffic on a specific corridor or network, while minimizing the costs for organization: model calculations were built for services linking Milan, Naples and Turin;

11) Recommendation to construct new lines, including high-speed, as the most important factor in the development of accelerated rail transport of cargos;

12) Effectiveness of the implementation of the proposed accelerated freight by rail, suitable to be organized into regular and high-speed services;

13) Prospects for further engineering and scientific research in the field of improving the accelerated freight traffic by rail, starting from the refining of the proposed concept for specific implementation conditions and their efficiency.

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APPENDIX 1

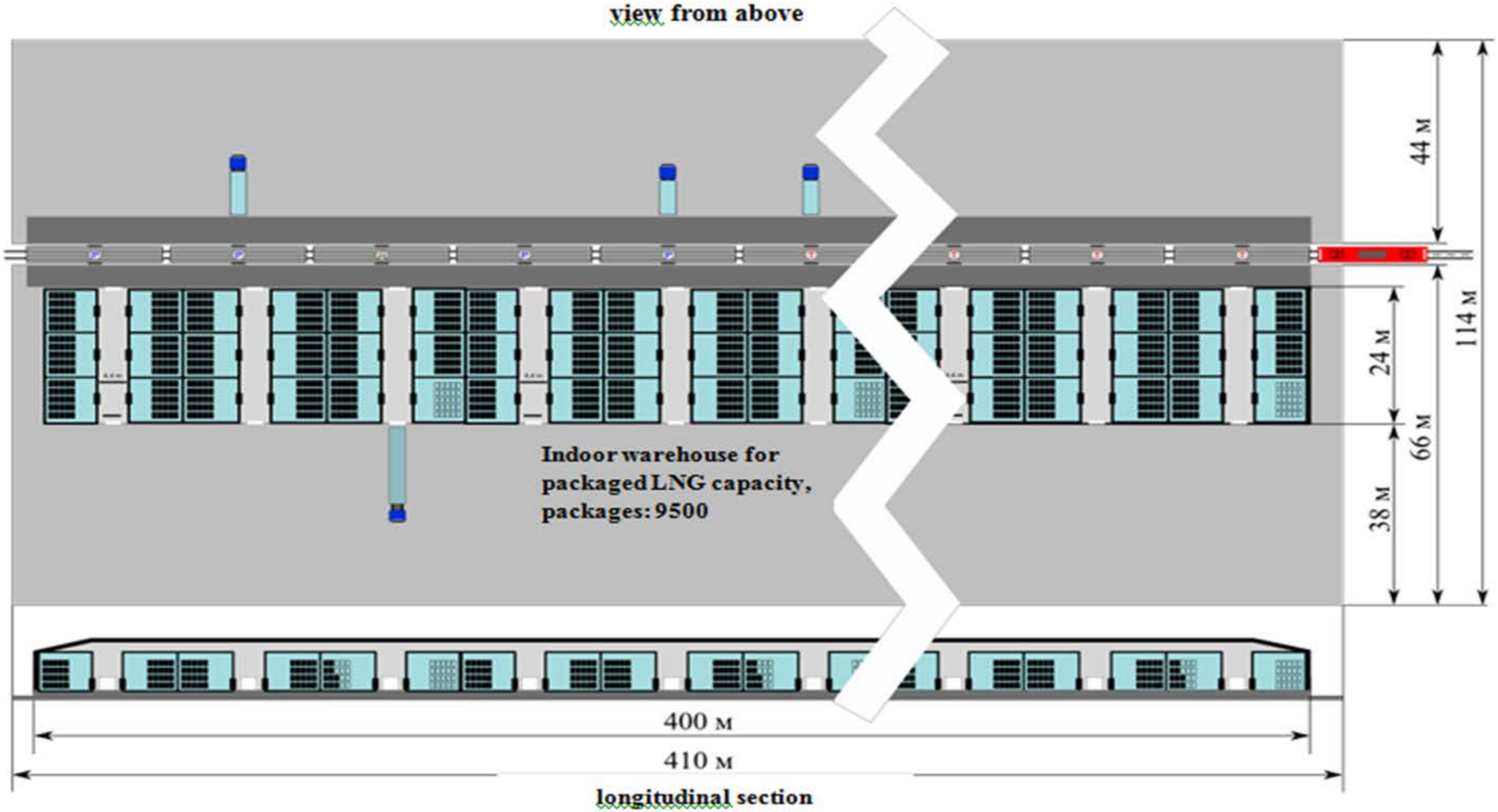

Figure A1.1. Sketch scheme of a terminal-warehouse complex type TSK-S1.1 designed to work with perishable goods

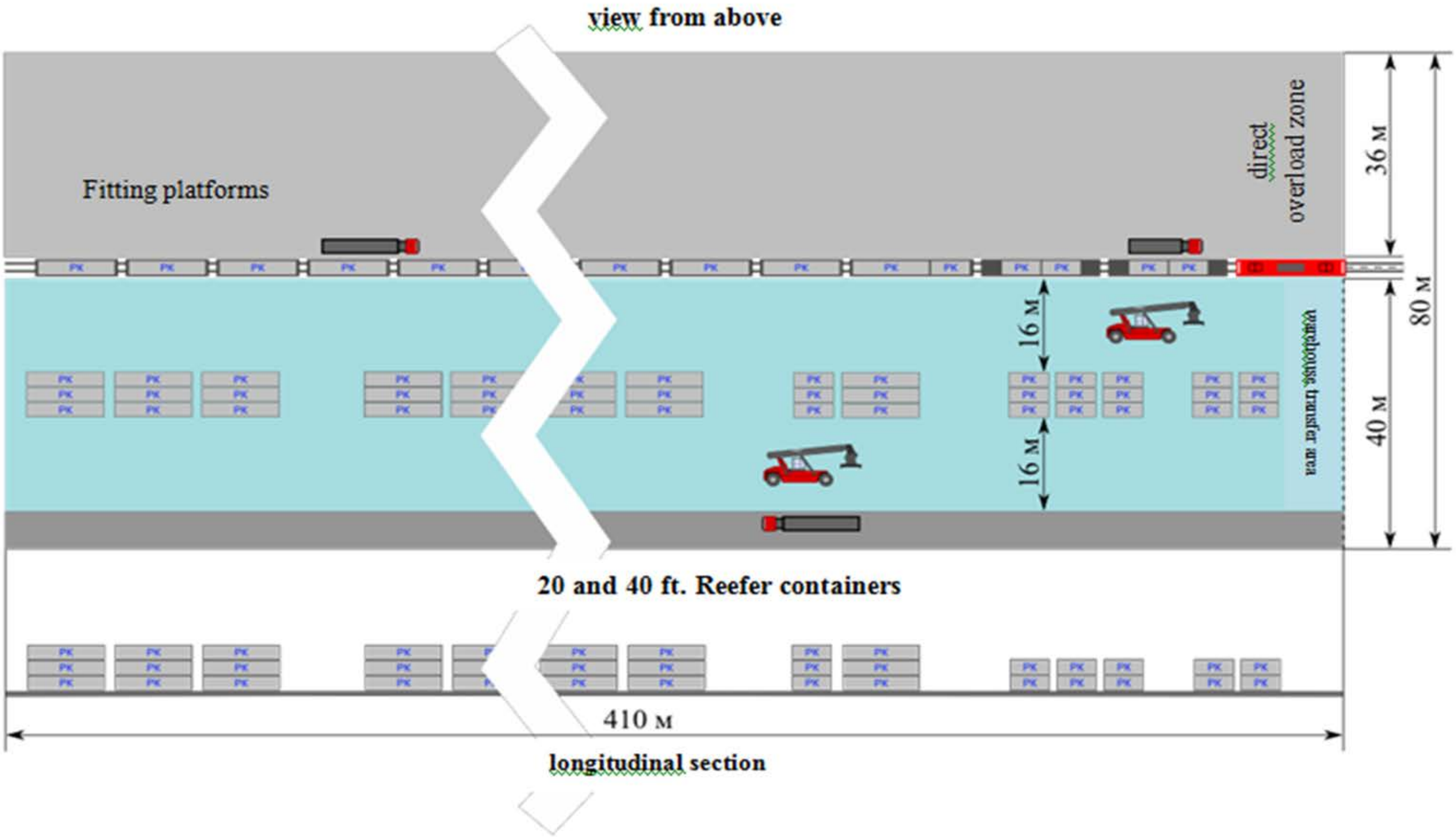

Figure A1.2. Sketch scheme of a terminal-warehouse complex of type TSK-S1.2 designed to work with goods in refrigerated containers

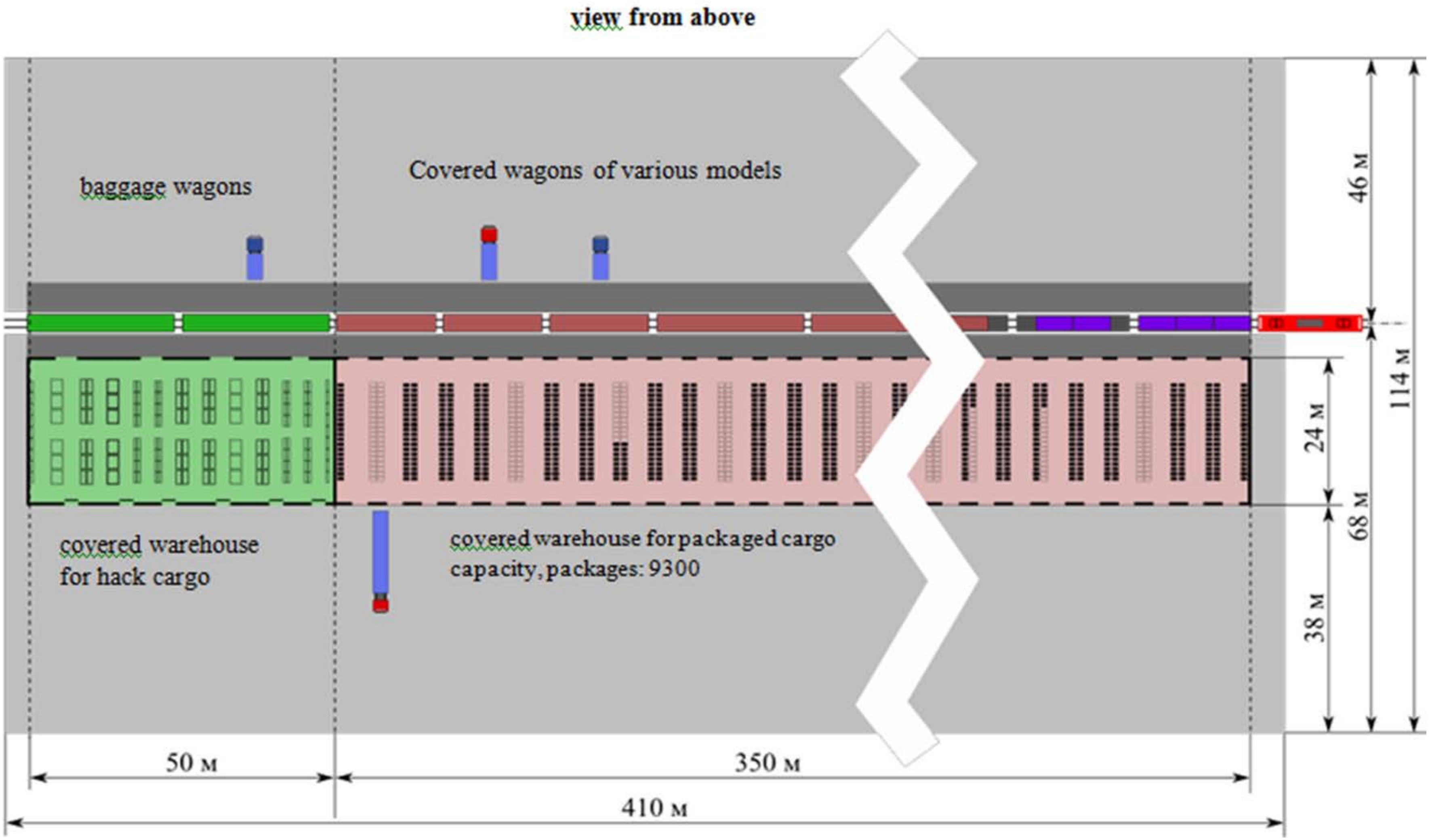

Figure A1.3. Sketch scheme of a terminal-warehouse complex such as TSK-S2 designed to work with packaged cargo and cargo luggage

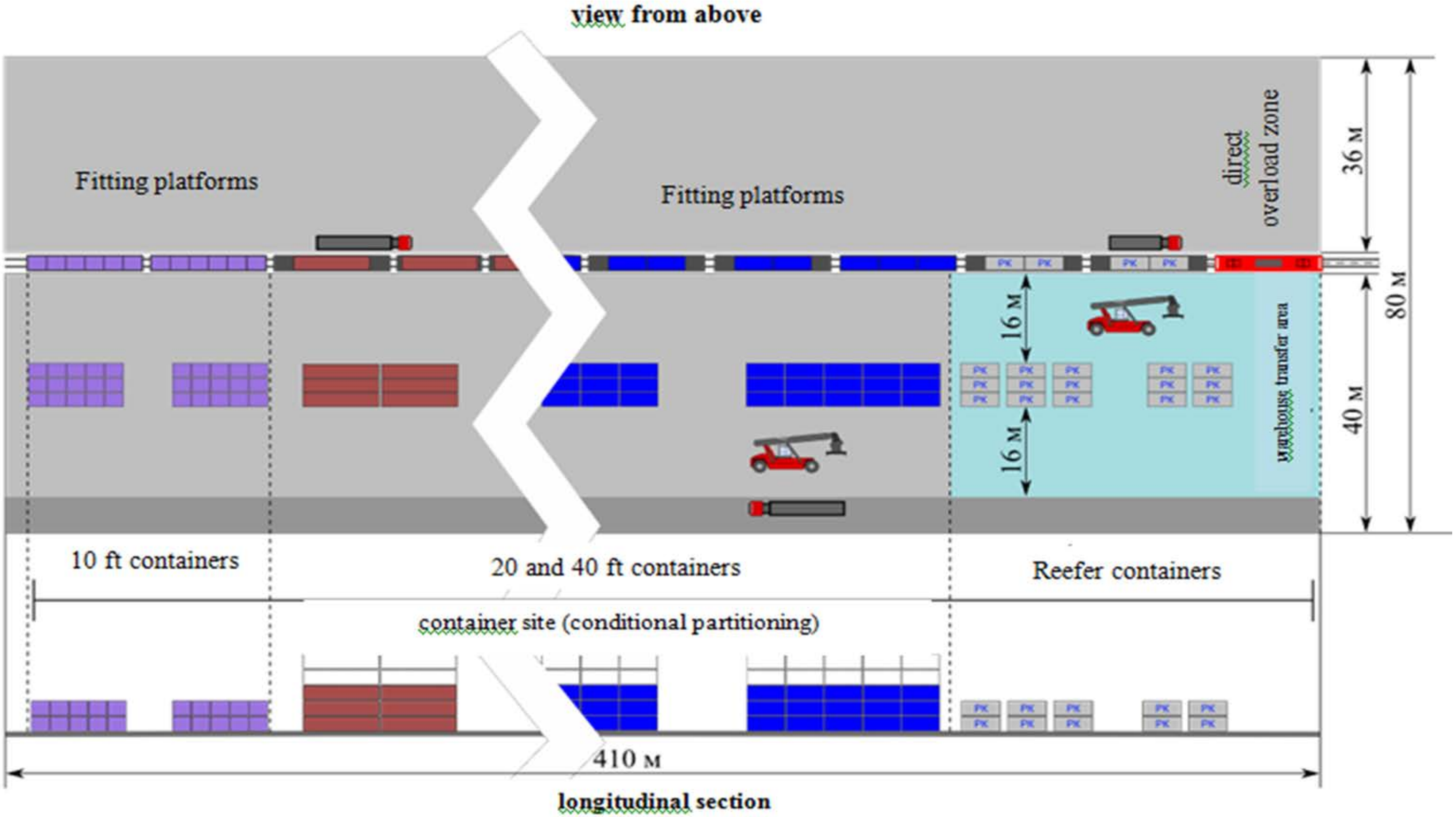

Figure A1.4. Sketch scheme of the terminal-warehouse complex type TSK-S3 designed to work with cargo in containers

APPENDIX 2

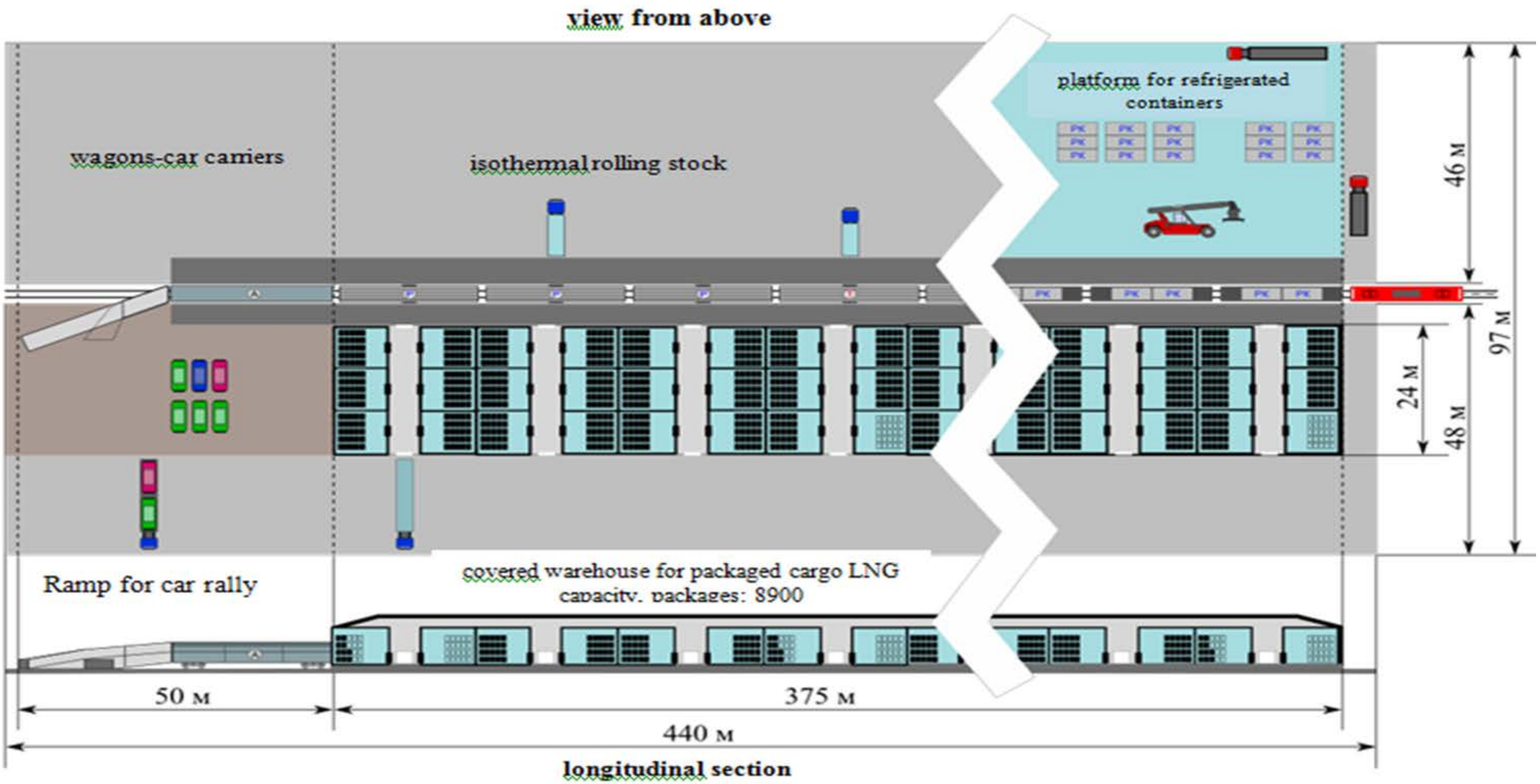

Figure A.2.1. Scheme of a terminal-warehouse complex of two-sided layout of type TSK-D1 designed to work with packaged perishable goods and refrigerated containers

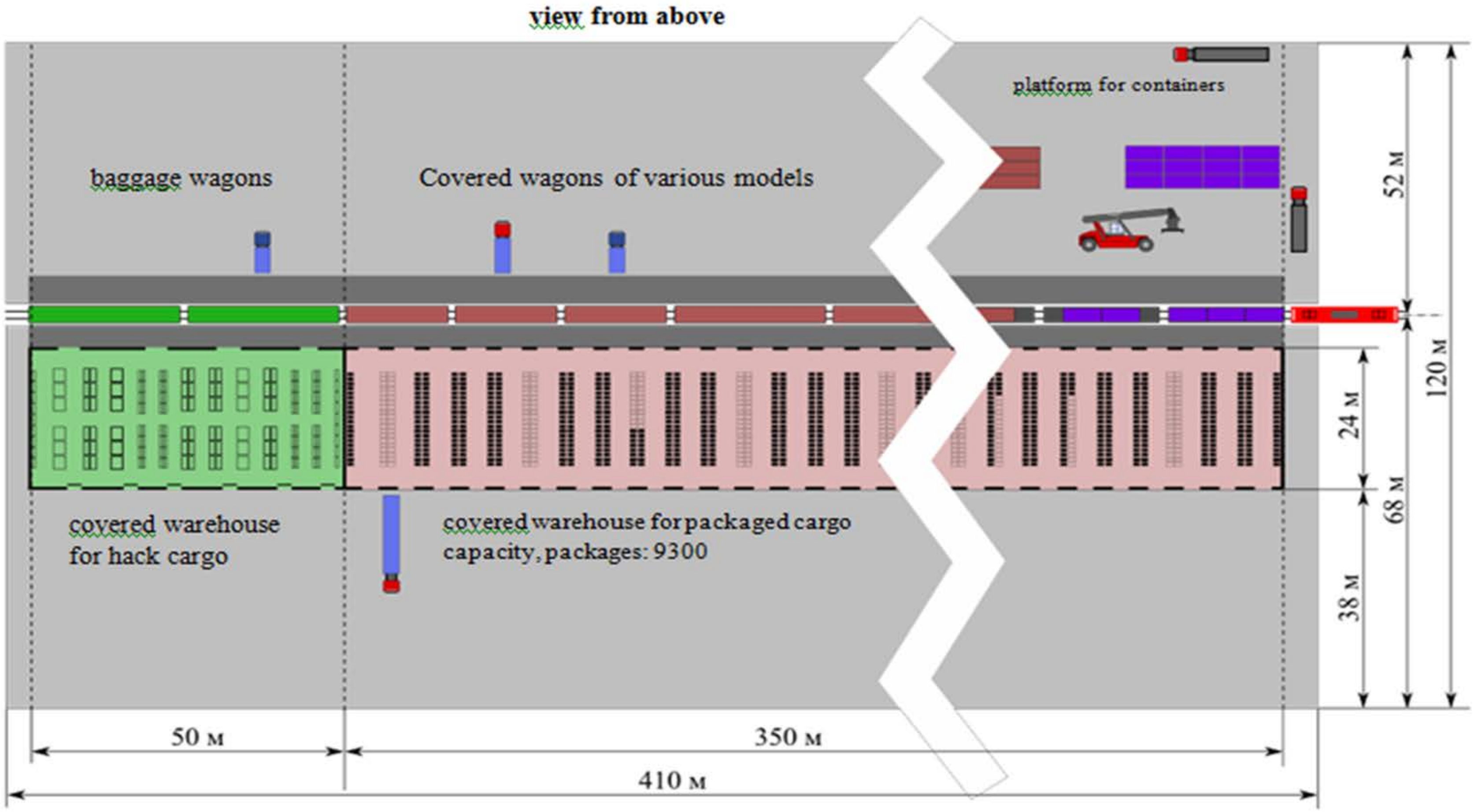

Figure A.2.2. Sketch scheme of a terminal-warehouse complex of two-sided layout such as TSK-D2 designed to work with packaged cargo and large-capacity containers