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Development of Proposals for Increasing the Efficiency of Using Domestic High-Capacity Rolling Stock in the South of Russia

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ABSTRACT

The main trend in development of high-capacity rolling stock used in the South of Russia is specialisation of coaches. The article considers the advantages of double-decker trains compared to traditional single-decker trains. Double-decker trains make it possible to carry out multimodal transportation of passengers in conditions of increased demand and a decrease in alternative offers from other modes of transport, increase the capacity of passenger rolling stock, the transit capacity of the railway infrastructure, and ensure the most rational use of the dimensions of the rolling stock. As a result, the carrying capacity of railway lines increases with minimal costs since energy costs for traction and traction-related costs are reduced.

The authors analysed and constructed a model for replacing traditional single-decker rolling stock with more spacious double-decker rolling stock. The dependence of the volume of traffic on passenger flow and a potential area of replacing single-decker trains with double-decker trains are shown. A nomogram is presented for the dependence of the volume of transport services for the population on the regularity of train schedule. A general algorithm for assessing and selecting potential opportunities for assigning double-decker trains in the South of Russia is considered.

Scenarios have been proposed for changing the category of transport services under the conditions of increased demand while replacing single-decker cars with double-decker ones. The annual effect from replacing single-decker cars with double-decker ones was calculated together with the total investment effect.

Keywords: *railway transport, rolling stock, route, transportation, passenger flow, transport accessibility, algorithm, model, increased demand.*

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INTRODUCTION

In modern conditions of increased demand for passenger travel, the use of passenger coaches with increased capacity is an effective tool for improving the implementation of the passenger transport capacity, along with organisational measures to optimise the route network and increase the ratio of operation of time and technical resources of rolling stock [1]. An increase in the number of seats in a coach without worsening travel conditions for passengers is achieved through creation and operation of double-decker passenger rolling stock [2].

Currently, foreign and domestic manufacturers have a wide product line of double-decker rolling stock, for use with both locomotive and multiple unit traction:

1) Bombardier Double-deck Coach – a model of a German-made double-deck passenger train[1];

2) TGV Duplex – a model of a French-made double-decker passenger train[2];

3) Stadler KISS RUS – a model of double-decker Swiss-made passenger train operated by LLC Aeroexpress[3];

4) Double-decker passenger coaches manufactured in Russia by Tver Carriage Works, operated by Russian Railways[4].

Advantages of double-decker trains compared to traditional (single-decker) comprise:

1. The ability to assign double-decker trains at a convenient time to transport a large number of passengers in conditions of limited transit capacity without occupying a scarce additional line of the schedule.

2. Reduced ticket prices for 2-class sleeping compartment and 1-class sleeping compartment due to the larger number of seats provided and lower unit costs (cost) of transportation.

3. Modern, technologically advanced and environmentally friendly trains that meet high performance standards.

The capacity of double-decker coaches is significantly higher than that of single-decker coaches, as shown in Table 1.

As an example, the 2022/2023 schedule of double-decker trains on the routes shown in Table 2 is considered.

In addition, double-decker electric trains produced by the Swiss company Stadler Rail are used by LLC Aeroexpress to organise multimodal transportation of passengers from/to airports of Moscow aviation hub [3; 4].

The *objective* of the study was to analyse and construct a model of replacement of conventional single-decker rolling stock with double-decker coaches of enlarged capacity using the example of routes towards the South of Russia.

RESULTS

For the analysis and further construction of a model for replacing traditional single-decker rolling stock with more spacious double-decker rolling stock, the following train operating directions were selected (Table 3).

The analysis of existing routes of double-decker trains indicates the identified patterns:

1. The routes of double-decker trains connect transport areas with high-intensity passenger traffic. Such transport connections are typical for correspondence with (from) the capital of the Russian Federation – Moscow and cities with a population of over a million, resorts of federal significance and centres of federal districts.

2. St. Petersburg is a point of attraction as well with similar types of transport connections and the status of transport centre.

3. On the routes of double-decker trains, there are also significant traffic volumes operated by traditional single-decker trains, which provide a high level of transport accessibility to the destinations.

4. The appointment of a double-decker train to replace several single-decker trains on a route may already be advisable with an annual passenger flow of more than 500–600 thousand people in one direction and the presence of 5–6 daily trains.

Pic. 1 shows the relationship between the size (volume) of traffic and passenger flow and the potential area for replacing single-decker trains with double-decker trains.

To display the dependence of the level of transport accessibility on the regularity of transport services, a nomogram was developed that is presented in Pic. 2. The x-axis indicates

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[1] Bombardier to Deliver TWINDEXX Double-deck Coaches and TRAXX Locomotives for Long-distance Routes to Deutsche Bahn AG. [Electronic resource]: https://bombardier.com/en/media/news/bombardier-deliver-twindexx-double-deck-coaches-and-traxx-locomotives-long-distance. Last accessed 27.09.2023.

[2] Perren B. Modern Railways, 2009, № 725, p. 63–69 [materials of the company Alstom (www.transport.alstom.com/home)].

[3] Two-level high-speed electric train ESh2 KISS RUS (AERO). Innovation digest. JSC Russian Railways. Last accessed 24.09.2023.

[4] The bilevel passenger car with sleeping compartments. Tver Carriage Works. [Electronic resource]: http://www.tvz.ru/catalog/passenger/item_detail.php? ELEMENT_ID=1949. Last accessed 17.09.2023.

Table 1

Comparison of a single-decker coach with a double-decker one*

Type of a car	Single-decker car of a train	Double-decker car of a train	Increase percentage (%)
2-class sleeping compartment	36	64	77,8
SV (sleeping car of increased comfort)	18	30	66,7
Staff compartment car	18–24	50	108,3–177,8

*Tables 1–3, charts and graphs in Pics. 1–3 are compiled by the authors based on the data published by JSC FPC.

Table 2

Double-decker train routes

Train number	Name and train route	Frequency
№ 3/4	Branded train «Caucasus» Kislovodsk – Moscow	daily
№ 5/6	Branded train Moscow – St. Petersburg	daily
№ 17/18	Branded train «Karelia» Petrozavodsk – Moscow	daily
№ 21/22	Branded train «Ulyanovsk» Ulyanovsk – Moscow	daily
№ 22/21	Train St. Petersburg – Murmansk	daily
№ 24/23	Branded train «Premium» Moscow – Kazan	daily
№ 25/26	Branded train «Italmas» Moscow – Izhevsk	daily
№ 25/26	Branded train «Smena A. Betancourt» Moscow – St. Petersburg	five times a week, in summer – daily
№ 29/30	Train St. Petersburg – Belgorod	daily
№ 35/36	Branded train «Northern Palmyra» St. Petersburg – Adler	daily
№ 43/44	Train St. Petersburg – Kostroma	twice a week, in summer – daily
№ 49/50	Branded train Samara – Moscow	daily
№ 51/52	Branded train «Sura» Penza – Moscow	daily
№ 53/54	Branded train «Chuvashia» Cheboksary – Moscow	daily
№ 57/58	Branded train «Mari El» Yoshkar-Ola – Moscow	daily
№ 65/66	Train Tolyatti – Moscow	daily
№ 104/104	Branded train Moscow – Adler	daily
№ 107/108	Train Moscow – Bryansk	on certain dates, from 15.05.22 – once a week
№ 137/138	Train Moscow – Orenburg	daily, the route was extended to Orsk and the train was rebranded as «Orenburg» Moscow – Samara – Orsk train under number 31/32.
№ 159/160	Train Petrozavodsk – Moscow	daily
№ 175/176	Train St.Petersburg – Moscow	in summer twice a week
№ 542/541	Train Adler – Moscow	in September-October 2022 on certain dates
№ 569/570	Train Samara – Imeretinskiy kurort	from June to September 2022 on certain dates
№ 737/738	Rapid train «Ivan Paristiy» Moscow-Bryansk	daily
№ 739/740	Rapid train «Ivan Paristiy» Moscow-Bryansk	daily
№ 741/742	Rapid train «Ivan Paristiy» Moscow-Bryansk	daily
№ 737/738	Rapid branded train Moscow – Voronezh	daily
№ 739/740	Rapid branded train Moscow – Voronezh	daily

Table 3

Double-decker train routes (for analysis and calculations)

Train number	Name and train route	Frequency
№ 3/4	Branded train «Caucasus» Kislovodsk – Moscow	daily
№ 5/6	Branded train Moscow – St.Petersburg	daily
№ 22/21	Train St.Petersburg – Murmansk	daily
№ 24/23	Branded train Moscow – Kazan	daily
№ 49/50	Branded train Samara – Moscowa	daily
№ 104/104	Branded train Moscow – Adler	daily
№ 741/742	Rapid train «Ivan Paristiy» Moscow – Bryansk	daily

the regularity of the train: from once a week to the shuttle-like (equal interval) mode. Categories of transport services offered to passengers are indicated on the ordinate axis.

Based on the data in Table 3, nomograms of selected routes for double-decker and single-decker trains were constructed as presented in Pic. 3.

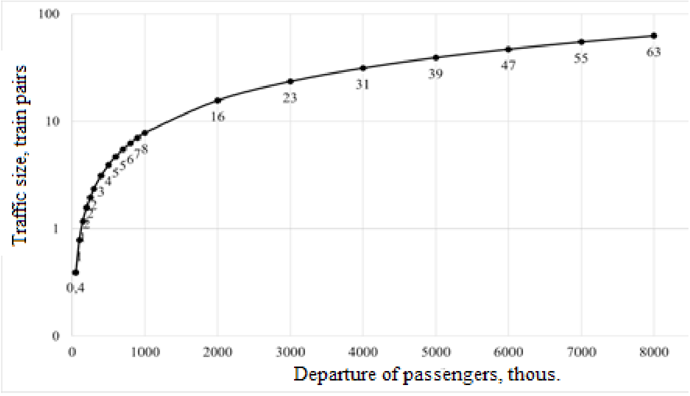
Analysis of the nomogram allows us to conclude that three routes provide a high level of transport service according to quality criteria:

– Moscow – Bryansk;
– St. Petersburg – Murmansk;
– Moscow – Kislovodsk.

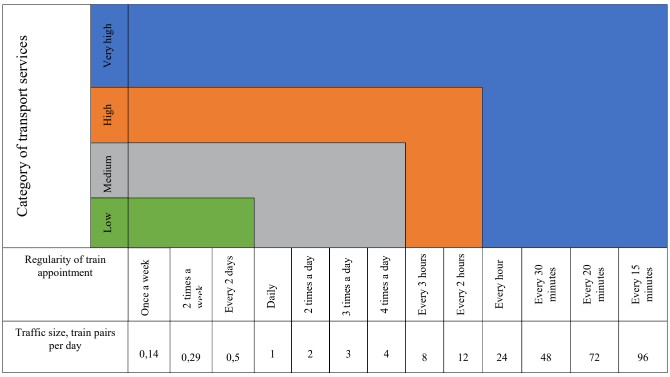
Four routes provide a very high level of transport service:

– Moscow – St. Petersburg;
– Moscow – Kazan;
– Moscow – Samara;
– Moscow – Adler.

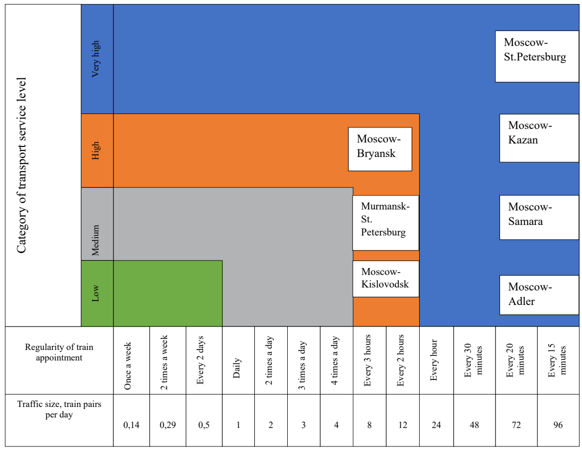
Based on the analysis and nomograms developed the dependence of the level of transport accessibility on the regularity of communication between transport centres, the



Pic. 1. Graph of dependence of traffic size per day on the number of passengers departed.



Pic. 2. Nomogram of dependence of category of transport service for passengers on regularity of train appointment.



Pic. 3. Nomogram of the category of transport service for passengers for the selected double-decker trains.

conditions can be formulated for replacing traditional single-decker rolling stock with more spacious double-decker cars [5].

To select potential destinations for double-decker trains, an algorithm and a two-step model have been developed, presented in Pic 4.

At the first step, the compliance of the selected route for organisation of traffic of double-decker trains with the set of the following conditions is sequentially checked:

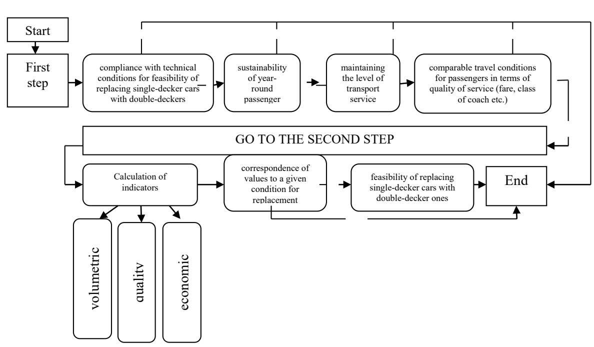
1. Availability of the technical ability to organise traffic of double-decker trains in terms of dimensional limitations of railway transport infrastructure facilities (tracks and artificial structures, contact network, dimensions of approaching buildings), traction rolling stock, as well as double-decker passenger coaches themselves, including their dimensions, equipment, maintenance and planned types of maintenance and repair, the ability of stations and stopping points to carry out operations for boarding and disembarking passengers.

2. The presence of a stable year-round passenger flow between transport centres on the route, the status of transport centres identified in this section, as well as sufficient intensity of transport connections between transport centres on the potential route of a double-decker train, providing for the need for daily assignment of trains with great regularity throughout the day [6].

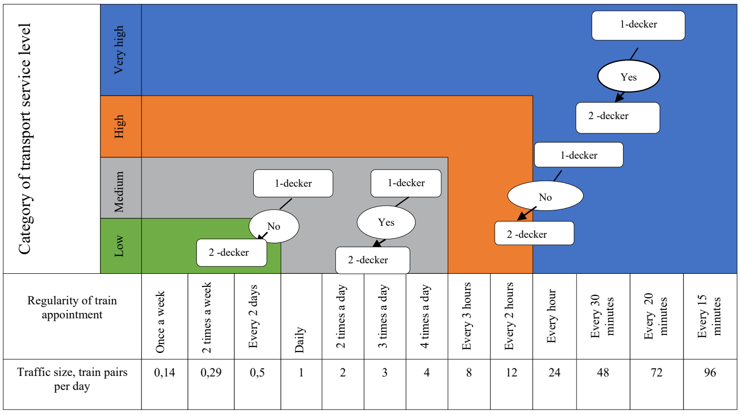
3. Maintaining (not deteriorating) the level of transport services for the passengers when replacing two single-decker trains with one double-decker. The reduction in traffic volume caused by replacement should not be accompanied by a decrease in the category (quality) of transport services indicated on the nomogram (Pic. 4).

4. The coaches within a double-decker train must provide travel conditions for passengers comparable with those in the single-decker trains it replaces in terms of the number of seats, class of coaches, fare, and range of services.

Thus, all four conditions are evaluated sequentially. At the same time, a critical condition for the potential start of operation of a double-decker train is maintaining the quality of the transport services offered to passengers [7]. Pic. 5 shows possible scenarios in which replacing trains with single-decker coaches with double-decker trains is possible or impossible.



Pic. 4. General algorithm for assessing and selecting potential destinations for double-decker trains [developed by the authors].



Pic. 5. Scenarios for changing the category of transport service and the possibility of replacing single-decker trains with double-decker trains [developed by the authors].

The second step of the proposed model for selecting potential destinations for double-decker trains involves performing calculations to assess the volumetric, quality, and economic indicators of train operation for various alternatives for the use of passenger rolling stock, as well as assessing the effect of making these decisions [8].

At the same time, to consider the operating features of double-decker coaches replacing single-decker coaches, the methodology should be completed with several features:

1) It is necessary to take into account that one double-decker train on the same route replaces 2 single-decker trains, providing a comparable volume of passenger transportation.

2) This circumstance will entail for a double-decker train a twofold reduction in the size of traffic, of the need for infrastructure services, locomotive traction and passenger cars.

3) To organise traffic for a double-decker train, the use of series of traction rolling stock of similar power will be required, which will not affect the cost of paying for locomotive traction services. This is due to differences in the weight of single-decker and double-decker coaches within 10–20 % and an equal number of coaches in the train.

4) The cost of double-decker passenger coaches is almost 2 times higher compared to single-decker coaches. Also, the costs for planned types of technical maintenance and repair are higher (according to expert evaluation by 1,7 times). At the same time, the cost of servicing one double-decker coach in terms of wages of car attendants is lower than for two single-decker coaches.

5) When determining the feasibility of replacing double-decker trains with single-decker ones, the condition of invariability of indicators associated with the use of the car's time budget and its technical resource is accepted (the same schedule and turnover of the passenger train is maintained, the use of the coach's technical resource is assumed to be the same) [9].

Table 4

Regularity of train traffic in the southern direction (number of pairs of trains per day)

Route	Number of pairs of trains per day	Regularity of appointment (average) (interval in hours)
Moscow – Adler	7	Every 3 hours 40 minutes
Moscow – Simferopol	6	Every 4 hours
Moscow – Novorossiysk	6	Every 4 hours
Moscow – Anapa	8	Every 3 hours

Table 5

Regularity of train traffic, adjusted when double-decker trains are introduced in the southern direction (number of pairs of trains per day)

Route	Number of pairs of trains per day	Regularity of appointment (average) (interval in hours)
Moscow – Adler	6	Every 4 hours
Moscow – Simferopol	5	Every 4 hours 55 minutes
Moscow – Novorossiysk	5	Every 4 hours 55 minutes
Moscow – Anapa	7	Every 3 hours 24 minutes

Table 6

Calculation of financial results from replacing single-decker coaches with double-decker coaches

Indicator	Indicator's value		Effect from indicator's change
	Single-decker cars	Double-decker cars	«-» – saving, «+» – increase
Passengers transported, thous. persons	416,0	416,0	0,0
Passenger-km, mln	742,3	742,3	0,0
Number of trains, units	8	4	-4,0
Number of coaches, units	64	32	-32,0
Operating expenses, million rubles	1768,9	1021,4	-747,5
Revenues, million rubles	1725,1	1725,1	0,0
Financial result (EBIT) per year, million rubles	-43,7	703,8	747,5
Financial result (EBITDA) per year, million rubles	110,9	852,8	741,9

Table 6

Calculation of financial results from replacing single-decker coaches with double-decker coaches

Indicator	Indicator's value		Effect from indicator's change
	Single-decker cars	Double-decker cars	«-» – saving, «+» – increase
Passengers transported, thous. persons	416,0	416,0	0,0
Passenger-km, mln	742,3	742,3	0,0
Number of trains, units	8	4	-4,0
Number of coaches, units	64	32	-32,0
Operating expenses, million rubles	1768,9	1021,4	-747,5
Revenues, million rubles	1725,1	1725,1	0,0
Financial result (EBIT) per year, million rubles	-43,7	703,8	747,5
Financial result (EBITDA) per year, million rubles	110,9	852,8	741,9

Table 7

Total investment effect from replacing single-decker coaches with double-decker coaches

Indicator	Indicator's value		Effect from indicator's change
	Single-decker cars	Double-decker cars	«-» – saving, «+» – increase
Required number of coaches, units	64	32	-32
Average cost of coaches' purchase, million rubles	55,4	106	50,6
Expenses for coaches' purchase, million rubles	3545,6	3392	-153,6
Required number of train locomotives, units	8	4	-4
Average cost of purchasing a train locomotive, million rubles	172,3	172,3	0,00
Expenses for purchase of train locomotives, million rubles	1378,7	689,3	-689,3
Savings in investment costs for rolling stock, million rubles	-842,9		

To test the model of replacing single-decker coaches with double-decker ones, the authors selected a set of southward routes that demonstrate an urgent need to assign double-decker trains in a larger volume:

– Moscow – Adler;
– Moscow – Simferopol;
– Moscow – Novorossiysk;
– Moscow – Anapa.

The routes fully comply with the conditions of three stages of checking the first step of the algorithm, except for one, that of compliance (non-deterioration) with the initial category of the transport services offered.

To determine the category of the transport services offered, Table 4 presents a possible regularity of traffic (number of pairs of trains per day).

According to the nomogram shown in Pic. 3, all routes fall into the «high level» category of quality of services offered. If two single-decker trains are replaced with one double-decker train on the given routes, the number of pairs of trains per day, as well as the regularity of destinations, will decrease (Table 5).

The results obtained allow us to conclude that Moscow – Simferopol and Moscow – Anapa routes, in case of replacing two single-decker trains with one double-decker, would be subject to reduction of quality of transport service by one category: going from high to medium one. This condition is critical in the model, so these directions are excluded from the algorithm [10; 11].

Two routes Moscow – Adler and Moscow – Novorossiysk are allowed to be considered at the second step of the algorithm for calculations.

To carry out the calculations, the route Moscow – Adler was chosen.

The results of calculations comparing options for organising transportation on the route Moscow – Adler in single-decker and double-decker trains are shown in Tables 6 and 7.

CONCLUSIONS

Thus, the study made it possible to develop an algorithm and model for assessing feasibility of replacing traditional single-decker rolling stock with a double-decker one for routes with a stable high passenger flow while maintaining the quality of transport services offered to passengers. This study was conducted to substantiate the need to replace single-decker coaches with double-decker ones under the conditions of increased demand.

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