Retrospective assessment and forecast of the level of development of intelligent transport infrastructure (using the example of JSC Russian Railways)

Y. Egorov[1*] and *M.* Fedorova[1]

[1]Emperor Alexander I St. Petersburg State Transport University, 190031, 9 Moskovsky pr., Saint Petersburg, Russia

Abstract. Objective: conduct a retrospective assessment and obtain a forecast of the level of development of the intellectual transport infrastructure of JSC Russian Railways in 2004-2027. Methods: econometric modeling, analysis, comparative approach, statistical method, generalization. Results: the system of indicators for assessing the level of development of an organization's intelligent transport infrastructure has been developed; using the developed system of indicators, the level of development of the intellectual transport infrastructure of JSC Russian Railways was assessed retrospectively and dynamically during 2004-23; forecasts of these indicators for 2024-27 has been built on the basis of models of autoregression with their accuracy assessment; also the comparison has been made of the level of development of JSC Russian Railways intellectual transport infrastructure with the similar levels for BNSF railway company (USA) and CN railway company (Canada). Main conclusions: the results obtained can be used in further research of the development of the organization's intelligent transport infrastructure.

1 Introduction

The development of digital (and, more broadly, intelligent) systems is considered among the most important trends of the last decade in all areas of national economies, including transport. The most important tasks of such systems in transport include protecting critical elements of transport infrastructure, increasing its reliability, efficiency and operational safety. With a high level of integration of intelligent transport systems into the transport infrastructure, we can talk about intelligent transport infrastructure (including railway transport). For strengthening the technological sovereignty of national economy the level of development of such transport infrastructure is being viewed increasingly important.

Recently various aspects of intelligent transport infrastructure development (including railway transport) are dealt with in the works of Degrande T. et al [1], Francis F. et al [2], Adrian E. Coronado Mondragon et al [3], Jie L. et al [4], Ján P. et al [5], Corentin S. et al

* Corresponding author: orion56@mail.ru

[6], Moussa I. et al [7]. The works of Tretyak V. et al [8], Zhuravleva N. et al [9], Bubnova G. et al [10] are devoted to the development of digitalization (intelligent systems) in railway transport. This issue is indirectly addressed in the papers by Gulyi I. [11], Chechenova L. [12], Egorov Y. et al [13], Volkova E. [14].

We admit the contribution of these authors to the issue research, but researchers rarely try assessing the level of intelligent transport infrastructure development, especially in railway transport. This allows us to recognize the relevance of this research and helps to determine its objective: to conduct a retrospective assessment and obtain a forecast of the level of development of the intelligent transport infrastructure of JSC Russian Railways in 2004-2027.

2 Materials and methods

In this research, we developed and applied the following indicators, which can be used to assess the level of development of intelligent transport infrastructure (formulas (1)-(4)) (To calculate these indicators using formulas (1)-(4) for the period 2004-23, as well as to forecast these indicators for the period 2024-27 the following source used: 1) Financial statements of JSC Russian Railways in accordance with Russian accounting standards for 2004-23. [Electronic resource]. URL: https://company.rzd.ru/ru/9471?ysclid=luq20oa274145608814 [accessed 03/30/24]):

$$K\_IOS_t = PO\_BD_t * 10000 / OS_t, \tag{1}$$

where K_IOS_t – coefficient of fixed assets intellectualization at time t, units;

PO_BD_t – item of intangible assets «Computer programs, databases» on the balance sheet at time t, thousand rubles;

OS_t – item «Fixed assets» on the balance sheet at time t, thousand rubles;

$$K\_ITIN_t = PO\_BD_t * 10000 / SOOR\_PS_t, \tag{2}$$

where K_ITIN_t – coefficient of transport infrastructure intellectualization at time t, units;

PO_BD_t – item of intangible assets «Computer programs, databases» on the balance sheet at time t, thousand rubles;

$SOOR\_PS_t$ – item of fixed assets «Structures and transmission devices» on the balance sheet at time t, thousand rubles;

$$K\_intNIOKR_t = RIS\_R_t * 10000 / OS_t, \tag{3}$$

where $K\_intNIOKR_t$ – R&D intensity coefficient at time t, units;

RIS_R_t – item «Results of research and development» on the balance sheet at time t, thousand rubles;

OS_t – item «Fixed assets» on the balance sheet at time t, thousand rubles;

$$K\_sNAOS_t = NA_t * 10000 / OS_t, \tag{4}$$

where K_sNAOS_t – coefficient of intangible and fixed assets ratio at time t, units;

NA_t – item «Intangible assets» on the balance sheet at time t, thousand rubles;

OS_t – item «Fixed assets» on the balance sheet at time t, thousand rubles.

Note that the $K\_intNIOKR_t$ indicator is not, as such, an indicator of the level of development of intelligent transport infrastructure, but this indicator can affect the speed of development of the company's intelligent transport infrastructure. The K_sNAOS_t indicator is correct for measuring the level of development of intelligent transport infrastructure with a large share of the item «Computer programs, databases» in intangible assets.

To predict the performance indicators of formulas (1)-(4), standard dynamic econometric models are used, shown in Table 1.

Table 1. Models used to predict the performance indicators of formulas (1)-(4).

Model number	Performance variable	Model equation	Model evaluation method
I	K_IOS_t	Autoregression AR (1)	OLS (least squares method)
II	K_ITIN_t	Autoregression AR (1)	OLS
III	$K\_intNIOKR_t$	Autoregression AR (3)	GLM (generalized least squares method) (method for adjusting the heteroskedasticity of the random component)
IV	K_sNAOS_t	Autoregression AR (1)	OLS (Cochrane-Orcutt procedure with lags 1, 6)

Source: built by the author.

To carry out a forward-looking forecast ex ante for 2024-27 of endogenous variables of forecast models I-IV with the calculation of relative forecast errors, the method of Kufel, T. [15] was used.

The basis for the review of existing scientific research on the issues under development was scientific papers and monographs.

General scientific methods are also used in the work: analysis, comparative approach, statistical method, generalization.

3 Results

The results of testing forecast models I-IV are shown in Table 2. The quality of all models is high (R^2>0.7 for all models, for the models I, II, IV R^2 is close to 1.0), the models successfully passed all the tests we used for verification.

Table 2. Test results for models I-IV.

Names of tests used	Model I	Model II	Model III	Model IV
R^2 (adjusted)	0.96	0.97	0.77	0.95
Testing results to identify («+» - the result of testing is positive, «-» - the result of testing is negative.):				
statistical significance of model parameters	+	+	+	+
statistical significance of model	+	+	+	+
heteroskedasticity	-	-	-	-
normality of distribution of residuals	+	+	+	+
autoregressive variability of conditional variance	-	-	-	-
autocorrelation of residuals	-	-	-	-

Source: based on the author's assessment of models I-IV.

A retrospective assessment and forecast of the level of development of the intellectual transport infrastructure of JSC Russian Railways was made by calculating the indicators K_IOS_t, K_ITIN_t, $K\_intNIOKR_t$, K_sNAOS_t in 2004-2023 along with their ex ante forecast using models I-IV for 2024-27 (graphically the values of these indicators are shown in Fig. 1-4, respectively) (In Figures 1-4, the red line is the endogenous (predicted) variable, the blue line is the forecast of the endogenous variable, the green lines are the boundaries of the 95% confidence interval of the forecast).

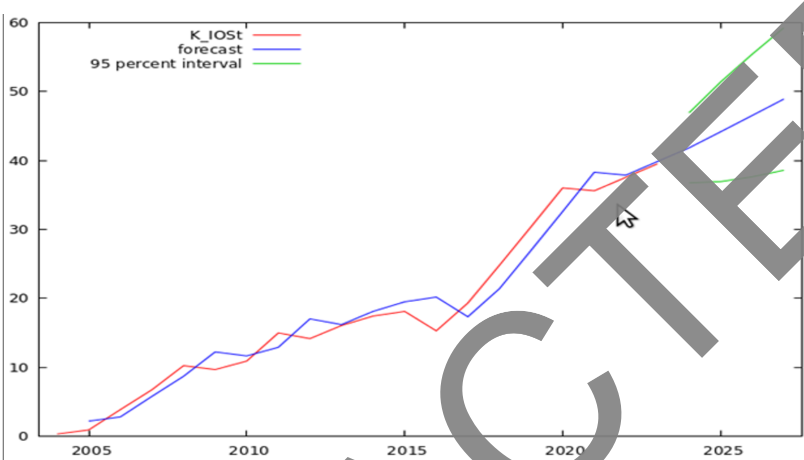

Fig. 1. Retrospective assessment in 2004-2023 and forecast for 2024-27 of the indicator K_IOS_t
Source: estimated by author using Model I.

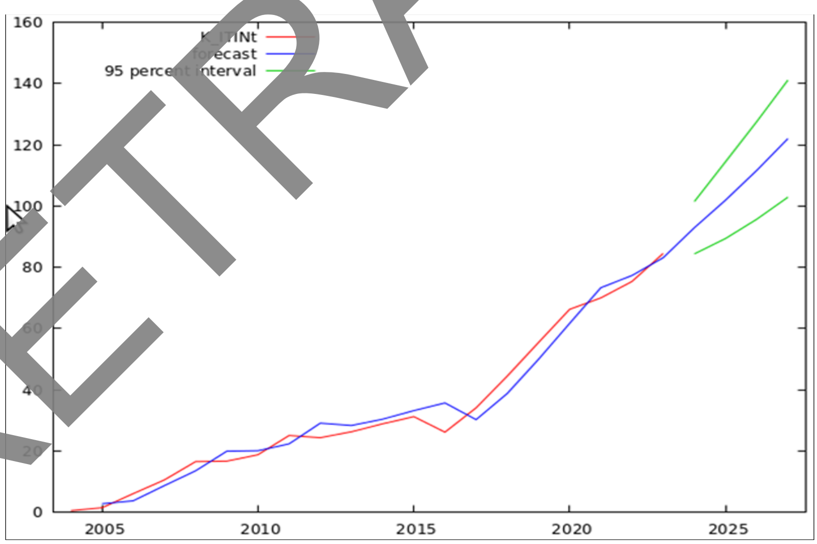

Fig. 2. Retrospective assessment in 2004-2023 and forecast for 2024-27 of the indicator K_ITIN_t
Source: estimated by author using Model II.

 https://doi.org/10.1051/e3sconf/202454908027

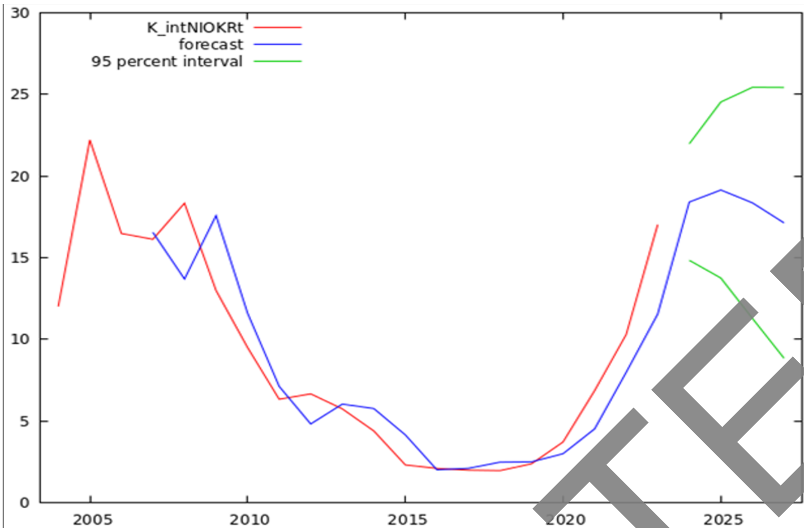

Fig. 3. Retrospective assessment in 2004-2023 and forecast for 2024-27 of the indicator $K\_intNIOKR_t$ Source: estimated by author using Model III.

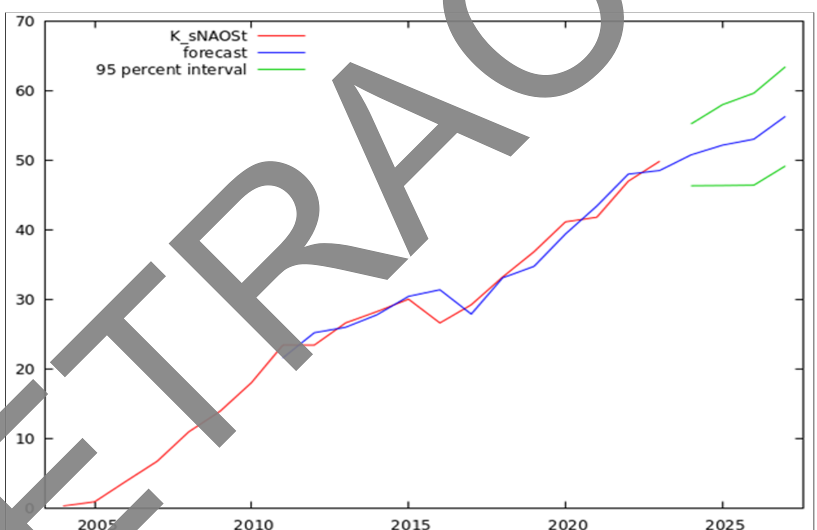

Fig. 4. Retrospective assessment in 2004-2023 and forecast for 2024-27 of the indicator K_sNAOS_t Source: estimated by author using Model IV.

Table 3 shows the relative ex ante forecast errors for models I-IV. For all models, these errors do not exceed 10%, which indicates the suitability of the forecasts for practical use (the only exception is forecasts for model III (i.e. for the $K\_intNIOKR_t$ indicator) for 2025-27).

Table 3. Relative errors of ex ante forecast for models I-IV, %.

Period	Relative error of ex ante forecast from the model, %:			
	I	II	III	IV
	Model I	Model II	Model III	Model IV
2024	5.76	4.36	9.04	3.97
2025	7.75	5.83	13.13	5.06
2026	9.06	6.77	17.95	5.66
2027	10.00	7.43	22.55	5.75

Source: based on the author's assessment of models I-IV.

4 Discussion

The results obtained indicate that the level of development of the intelligent transport infrastructure of JSC Russian Railways grew almost continuously during 2004-23: the K_IOS_t indicator increased from 0.33 to 39.52 (Fig. 1), the K_ITIN_t indicator increased from 0.52 to 84.49 (Fig. 2), the K_sNAOS_t indicator increased from 0.34 to 49.88 (Fig. 4). Forecasting these indicators using models I, II, IV indicates with a high degree of probability in favor of further continuation of such growth throughout 2024-27 (Fig. 1, 2, 4 and table 3).

As for the R&D intensity of Russian Railways, measured by the $K\_intNIOKR_t$ indicator and capable of influencing the speed of development of the company's intelligent transport infrastructure, not everything is so simple here. In 2004-2009 this indicator exceeded 10.0 (the maximum was reached in 2005 – 22.2), but by 2016-17 it decreased to 2.0; in subsequent years growth resumed and by 2023 the value of $K\_intNIOKR_t$ reached 17.0 (Fig. 3). Model III predicts that in 2024 $K\_intNIOKR_t$ will increase to 18.41, but forecasts for this indicator for the subsequent period 2025-27 do not have sufficient accuracy for practical use (Table 3).

To make international comparisons we calculated indicators of the level of development of intelligent transport infrastructure for the BNSF railway company (USA) (Table 4) and the CN railway company (Canada) (Table 5).

Table 4. Indicators of the level of development of intelligent transport infrastructure of the BNSF railway company (USA) (For the calculation sample data for 2010-17 were used according to source: 1) BNSF Annual report, form 10-K 2010-17. [Electronic resource]. URL: https://www.sec.gov/edgar/browse/?CIK=15511 [accessed 03/30/24]).

Indicator	2010 year	2011 year	2012 year	2013 year	2014 year	2015 year	2016 year	2017 year
K_sNAOS_t	380.9	295.6	222.6	154.9	90.7	76.2	69.1	62.9
Share of computer equipment and software in fixed assets, %	0.5	0.5	0.5	0.5	0.9	1.4	1.5	1.7

Source: calculated by the author using formula (4).

Table 5. Indicators of the level of development of intelligent transport infrastructure of the CN railway company (Canada) (For the calculation sample data for 2010-11, 2016-19, 2021-23 were used according to source: 1) CN Annual report, form 40-F 2010-23. [Electronic resource]. URL: https://www.sec.gov/edgar/browse/?CIK=16868&owner=exclude [accessed 03/30/24]).

Indicator	2010 year	2011 year	2016 year	2017 year	2018 year	2019 year	2021 year	2022 year	2023 year
K_sNAOS_t	23.6	22.6	19.8	18.1	19.3	38.3	33.8	31.5	29.4
Share of computer equipment and software in fixed assets, %	2.3	2.3	1.7	2.2	2.9	3.2	3.5	3.5	3.5

Source: calculated by the author using formula (4).

Comparison of JSC Russian Railways (Fig. 4) with BNSF (Table 4) with the help of K_sNAOS_t indicator may indicate a higher level of development of the intelligent transport infrastructure of BNSF in 2010-17: this indicator of the American railway company significantly exceeded the similar indicator of JSC Russian Railways. As for the second indicator (the share of computer equipment and software in fixed assets) calculated for BNSF, it increased more than 3 times during 2010-17.

Comparison of JSC Russian Railways (Fig. 4) with CN (Table 5) according to the K_sNAOS_t indicator may indicate a higher level of development of the intelligent transport infrastructure of JSC Russian Railways in 2011, 2016-18 and 2021-23: this indicator for Russian Railways exceeded that of the Canadian company. As for the second indicator (the share of computer equipment and software in fixed assets) calculated for CN, it decreased from 2.3% in 2010-11 to 1.7% in 2016, but then increased to 3.5% in 2021-23.

We note, however, that a comparison of Russian Railways JSC with BNSF and CN in terms of the K_sNAOS_t indicator can give only partially correct conclusions due to the application of different accounting and reporting standards (Russian Railways JSC - RAS (Russian Accounting Standards), BNSF and CN - US GAAP (United States Generally Accepted Accounting Principles)), as well as due to different structures of intangible assets and accounting policies of companies. Thus, in JSC Russian Railways, the item «Computer programs, databases» occupies about 80% or more of the total value of intangible assets throughout the entire period 2004-23. At BNSF in 2015-17 only franchises and customer contracts are included in intangible assets (unlike 2010-14, when intangible assets also included the cost of internally developed software), and in CN in 2016 and 2023 intangible assets consist primarily of customer contracts and relationships acquired through past acquisitions (whereas the capitalization of internally developed software in CN is included into the «Properties» section of the balance sheet, distinct from the «Intangible assets» section of the balance sheet).

Improving the results obtained in this research is possible by increasing the accuracy of the forecast model III (for example, one can present additional exogenous variables in the model III), by developing additional indicators on the basis of international financial reporting standards to improve the system of worked out indicators of the level of intelligent transport infrastructure development.

5 Conclusion

This research deals with a retrospective assessment and forecast of the level of development of intelligent transport infrastructure (using the example of JSC Russian Railways). The research developed a system of indicators for assessing the level of development of an organization's intelligent transport infrastructure, which includes the coefficient of transport infrastructure intellectualization, the R&D intensity coefficient, the coefficient of fixed assets intellectualization, the coefficient of intangible and fixed assets ratio. Using the developed system of indicators, the level of development of the intellectual transport infrastructure of JSC Russian Railways was assessed retrospectively and dynamically during 2004-23; forecasts of these indicators for 2024-27 were also made using autoregressive models with an assessment of their accuracy (suitability for practical use). A comparison was made of the level of development of the intelligent transport infrastructure of JSC Russian Railways with similar levels of the railway companies BNSF (USA) and CN (Canada).

The results obtained can be used in further research of development of the organization's intelligent transport infrastructure.

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