RETROSPECTIVE ANALYSIS OF EFFICIENCY OF RAILWAY FREIGHT OPERATIONS

Macheret, Dmitry A., *Russian University of Transport, Joint Scientific Council of JSC Russian Railways, Moscow, Russia.*
Kudryavtseva, Anastasia V., *Joint Scientific Council of JSC Russian Railways, Moscow, Russia.*

ABSTRACT

A detailed analysis of efficiency of operational work in conditions of reforming of the national economy and railways (1992–2017) is carried out. The need for a significant increase in efficiency based on implementation of technologically and economically sound innovative solutions in the long term to 2030 is emphasized. It is noted that freight transportation is the main income-generating business of the industry and, at the same time, a large part of the operating costs of railway transport is also falling on them, that is why the level of organization of work in cargo traffic is of crucial importance for economically efficient and sustainable operation of railways. It is concluded that in order to further enhance the efficiency of their operational activities, new dynamics of innovations in the framework of the general innovation-oriented development of the industry is required.

Keywords: railway transport, innovation-focused development, efficiency of operational work, train weight, section speed, technical speed, train performance, coefficient of usefulness of train operation.

Background. *The main activity of the Russian railways is freight transportation. Freight turnover accounts for over 90 % of the total volume of work, and its share is characterized by a long-term trend towards growth [1]. Accordingly, freight transportation is the main income-generating business of the industry, and the greater part of the operating costs of railway transport is used for their implementation.*

Objective. *The objective of the authors is to provide a retrospective analysis of efficiency of operational work of domestic railways regarding particularly freight traffic.*

Methods. *The authors use general scientific methods, comparative analysis, economic evaluation, statistical method, logics, analytical tools.*

Results.

Indicators of operational work

The basis of organization of operational work is the technology of train traffic. At the same time, the economy of a train as an integrated resource unit, in which all the main resources of the industry are united into one system, is, in fact, the focus of the entire economy of railway transport [2].

The efficiency of train work is determined by the values of weights and speeds of train traffic and their ratios: speed coefficient and weight coefficient[1] [3]. Weights and speeds have a multiplier effect on work and performance of a train.

The average hourly operation of a freight train performed per hour of traffic on a section can be defined as the product of gross weight of a train at technical speed. This indicator has a significant impact on the level of operating costs [4].

The average hourly capacity of a freight train, defined as a product of net weight of a train at a section speed, can be considered as a general indicator of quality of organization of operational work of railway transport in freight traffic. This figure has a significant impact on the industry's revenues. And the ratio of average hourly capacity of a train to average hourly work, which is called coefficient of usefulness of train operation, characterizes the integrated efficiency of operational work, affecting the ratio of income and expenses from freight traffic [5]. It is this ratio that characterizes the economic efficiency of operational activities of railways [3, 6]. Consequently, an increase in coefficient of usefulness of train operation is the basis for increasing economic efficiency of the railway transport.

At the same time, the ratio of operating costs to transportation revenues is affected by price factors that can substantially distort the real efficiency of railway transport [7]. It should be noted that during existence of centrally planned economy in our country, prior to the beginning of the 1990s, system accounting and analysis of price factors were not implemented, which makes it practically impossible to eliminate their influence in a long-term retrospective. Therefore, to analyze efficiency of railway transport, it is preferable to use natural indicators: average hourly capacity of a train and coefficient of usefulness of train operation.

Retrospective efficiency analysis

In general, for a period of more than a century, average hourly operation of a train increased by more than 15 times, with an average annual growth rate of over 2,6 % (Table 1). This is due to the simultaneous increase in gross weight of a train and technical speed of trains.

Increasing weights and speeds of trains is often considered as an alternative [8, 9]. However, retrospective analysis shows the reality of their simultaneous growth based on implementation of innovative technological and managerial decisions and, accordingly, possibility of setting targets for ensuring such growth in the framework of innovation-focused development of railway transport [10, 11].

It is important to note the stable long-term trend of accelerated growth of average hourly capacity of a train in comparison with average hourly work. This means that the train's productivity grew not only due to the increase in the amount of work performed by a train on average per hour, but also due to the increase in its efficiency, which is characterized by an increase in the coefficient of useful train work. This became possible due to a significant increase in both weight coefficient and, in particular, speed coefficient (coefficient of usefulness of train operation is equal to the product of these coefficients). In other words, in the long run it is not easy to simultaneously increase weights and speeds of trains, but also its intensive nature: net weight of a train grew faster than gross weight of a train, and section speed is compared to the technical one. This became the basis for the overall increase in efficiency of operation of domestic railways.

[1] Weight coefficient – ratio of net weight of a train to gross weight of a train. Speed coefficient is a ratio of a mean speed of passing of a railway section by a train to the technical speed (which is calculated without taking into account time spent for stops).

Table 1

Long-term changes in quality and efficiency of operational work in freight traffic

Indicator	1913	2017	Growth rate in whole for the period, times	Growth rate on average for a year, %
Gross weight of a train, t	573	4041	7,05	1,90
Net weight of a train, t	302	2402	7,95	2,01
Ratio of train net weight to gross train weight («weight coefficient»)	0,527	0,594	1,13	0,12
Technical speed, km/h	22,0	47	2,14	0,73
Section speed, km/h	13,6	40,7	2,99	1,06
Ratio of section speed to technical speed («speed coefficient»)	0,618	0,866	1,40	0,32
Average hourly operation of a train, thousand tons • km gross	12,6	189,9	15,07	2,64
Average hourly capacity of a train, thousand tons • km net	4,1	97,8	23,85	3,10
Coefficient of usefulness of train operation	0,326	0,515	1,58	0,44

Table 2

Average annual growth rates of quality and efficiency indicators of operational work in freight traffic, %

Time interval (years)	Gross weight of a train, t	Net weight of a train, t	Ratio of net weight of a train to gross weight of a train («weight coefficient»)	Technical speed, km/h	Section speed, km/h	Ratio of section speed to technical speed («speed coefficient»)	Average hourly work of a train, thous. t • km gross	Average hourly capacity of a train, thous. t • km net	Coefficient of usefulness of train operation
1913–1928	2,42	2,20	-0,17	-0,30	0,20	0,52	2,11	2,46	0,36
1928–1940	3,95	4,68	0,70	3,82	3,08	-0,71	7,93	7,91	-0,02
1940–1950	0,95	1,15	0,20	0,21	-0,10	-0,30	1,16	1,05	-0,12
1950–1965	3,42	3,33	-0,09	1,97	3,48	1,48	5,46	7,61	1,39
1965–1980	1,17	1,36	0,20	-0,25	-0,62	-0,37	0,91	0,72	-0,18
1980–1991	0,85	0,68	-0,17	0,10	1,04	0,93	0,95	1,73	0,77
1991–2003	1,29	1,46	0,17	0,50	1,00	0,58	1,79	2,54	0,74
2003–2017	0,81	1,00	0,17	0,03	0,31	0,28	0,84	1,31	0,46

At the same time, in some segments of the long-term period, the trends of all these indicators varied significantly (Table 2).

The highest rates of growth in train productivity were achieved during the «first five-year plans» (1928–1940), but efficiency of train work did not grow, but even decreased somewhat. This again confirms the conclusion about the cost of the «mobilization» variant of economic development realized in that period [7].

Almost the same high growth rates of train performance were in the 1950s and the first half of the 1960s, during implementation of a number of significant innovations on railway transport and some liberation of people's creative forces. During this period, the highest dynamics of operational efficiency was ensured. In the second half of the 1960s and 1970s, when the general slowdown in development of domestic railways began [16], while cargo and passenger loads increased markedly [14], the rate of growth in train performance dropped dramatically, and efficiency of train operations decreased. However, in the next decade, due to systemic measures to intensify the use of rolling stock, it was possible to significantly improve the dynamics of quality indicators and the efficiency of train work.

At the stage of reforming

It is necessary to dwell in more detail on the dynamics of indicators of efficiency of operational work in freight traffic during formation and development of railway transportation market (1992–2017). These indicators changed under the influence of macroeconomic factors, specific processes occurring in the transportation market and changes in the technology of the transportation process (Table 3). And all three of these groups of factors are interrelated.

In the period of 1992–1998 there was a «transformation crisis of the economy, during which market relations were formed in the country» [12, p. 138]. As a result of the crisis, the volume of freight transportation and freight turnover on railway transport decreased more than twice [13].

In the period leading up to the recession, in the late 1980s, domestic railways operated with an ultra-high level of capacity filling [14], which led to a reduction in traffic speeds. So, in 1988, with the maximum traffic volumes

Table 3

Dynamics of indicators of quality and efficiency of operational work in freight traffic, 1992–2017

Indicator	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Gross weight of a train, t	3090	3080	3085	3119	3170	3210	3295	3345	3380	3536	3554	3608	3670	3716	3747	3778	3815	3855	3867	3868	3891	3911	3929	3966	4006	4041
Net weight of a train, t	1744	1714	1724	1761	1787	1817	1890	1954	1975	2065	2068	2091	2127	2159	2177	2209	2227	2231	2249	2262	2280	2288	2301	2334	2366	2402
Ratio of net weight of a train to gross weight of a train («weight coefficient»)	0,564	0,556	0,559	0,565	0,554	0,566	0,574	0,584	0,584	0,584	0,582	0,580	0,580	0,581	0,581	0,585	0,584	0,579	0,582	0,585	0,586	0,585	0,586	0,589	0,591	0,594
Technical speed, km/h	44,3	43,6	43,7	43,8	44,4	45,0	45,5	45,2	45,7	45,9	45,8	46,8	47,5	48,4	48,7	48,9	49,1	49,3	49,3	46,5	45,2	45,6	45,6	46,4	46,7	47,0
Section speed, km/h	35,7	35,7	36,7	36,9	37,9	38,6	39,3	38,5	38,6	38,7	38,2	39,0	39,6	40,2	40,3	40,3	40,6	41,6	41,2	37,1	36,0	36,8	37,7	39,1	39,7	40,7
Ratio of section speed to technical speed («speed coefficient»)	0,806	0,819	0,840	0,842	0,854	0,858	0,864	0,852	0,845	0,843	0,834	0,833	0,834	0,831	0,828	0,824	0,827	0,844	0,836	0,798	0,796	0,807	0,827	0,843	0,850	0,866
Average hourly performance of a train, thous. t • km net	62,3	61,2	63,3	65,0	67,7	70,1	74,3	75,2	76,2	79,9	79,0	81,5	84,2	86,8	87,7	89,0	90,4	92,8	92,7	83,9	82,1	84,2	86,7	91,3	93,9	97,8
Average hourly train operation, thous. t • km gross	136,9	134,3	134,8	136,6	140,7	144,5	149,9	151,2	154,5	162,3	162,8	168,9	174,3	179,9	182,5	184,7	187,3	190,1	190,6	179,9	175,9	178,3	179,2	184,0	187,1	189,9
Coefficient of usefulness of train operation	0,455	0,456	0,469	0,476	0,481	0,486	0,495	0,498	0,494	0,492	0,485	0,483	0,483	0,483	0,481	0,482	0,483	0,488	0,486	0,467	0,467	0,472	0,484	0,496	0,502	0,515

on the network, section and technical speeds of freight trains were approximately 4% lower than in 1965.

Reducing the load on the network in the 1990s objectively contributed to higher speeds. From 1992 to 1998, technical speed increased by 2,7%, and section speed – by 10,1%. The speed coefficient reached its maximum historical level, which was surpassed only in 2017.

At the same time, a significant decrease in intensity of freight transportation makes it difficult to increase train weight (and even maintain it at the achieved level). And in the first years of decrease in transportation volumes, indeed, there was a slight decrease in train weights. But then the railways adapted to the requirements of the market, they overcame these difficulties: from 1992 to 1998, gross weight of a train was increased by 6,6%, and net weight – by 8,4%.

Increase in train weights was also intensive, the weight coefficient increased noticeably.

All this led to an accelerated growth of average hourly capacity in comparison with train work and a very significant, by 1,09 times, increase in the coefficient of useful work of train operation. The increase in efficiency of operational work during the complicated period for Russian railways, following establishing of market economy in Russia, has undoubtedly played a role in ensuring the financial and economic sustainability of the industry, including period of reduction of rail freight tariffs in 1997–1998 [15, p. 183], which had an important macroeconomic significance. «As a result, the transport component in the final cost of industrial products decreased significantly, which, along with other factors, helped to overcome the economic crisis» [16, p. 171].

After transition of the economy to the phase of market growth (1999–2007) [17] rail freight transport began to grow dynamically. The load on the network has increased again. This created objective opportunities for dynamic growth of train weights, and they were realized. Gross weight of a train increased by 14,7% (to the level of 1998), net weight – even more – by 16,9%, which significantly increased the weight coefficient. At the same time, the increase in traffic intensity was complicated by the increase in section speed, which grew significantly slower than the technical speed (2,5% vs. 7,5%). Accordingly, the coefficient of speed has decreased quite drastically, resulting in a decrease in the coefficient of useful work of train operation.

The period of market recession associated with the global economic crisis (2008–2009) was used by Russian railways to improve operational efficiency. Despite a significant decrease in the volume of freight transportation and freight turnover [18, 19], the further growth of train weights was ensured. True, the increase in net weight of a train lagged behind the increase in gross weight of a train. But the section speed increased significantly while there was only a slight increase in technical speed. As a result, both speed coefficient and the coefficient of usefulness of train operation have increased.

In the period of turbulent post-crisis development of the economy [20], starting from 2010, the operational parameters were influenced primarily by the combination of changes in the railway transportation market and the transportation process technology.

In the conditions of structural reform of railway transport and creation of conditions for development of other rolling stock's operators' business, since 2003, there has been an increase in the fleet of freight cars. In 2011–2013, it accelerated, and in early 2015 the car fleet reached its maximum value – over 1 million 230 thousand cars, which is by 1,5 times more than the fleet that existed at the beginning of the reform [21, p. 93].

At the same time, the structure of the car fleet changed: if before 2009 about 60% of the car fleet belonged to JSC Russian Railways and its subsidiaries, then in 2011 the cars of private companies became dominant in the fleet, and the fleet belonging directly to JSC Russian Railways became close to zero [22, p. 96]. (It should be recalled that in accordance with the program of structural reform in the railway transport, at its final stage, JSC Russian Railways should have had 40% of the car fleet [23]).

Thus, in 2011–2013 the car fleet has increased dramatically, and its structure has radically changed. It became completely private, that complicated the management of car flows and required reorganization of the technology of operational work. At the same time, inadequate development of the railway infrastructure, many facilities of which were reduced at the end of 20th – beginning of 21st century, became obvious [22, 24] (it should be recalled that in the mid-1990s, researchers of Russian University of Transport (then MIIT) warned against hastily liquidating infrastructural facilities, on the possible negative economic consequences of such decisions [25]). In these conditions, a fundamental economic law manifested in railway transport – the law of diminishing returns [26]. One of its manifestations was a reduction in train productivity in 2011–2012, primarily due to a decrease in train traffic speed. In 2011–2012, the coefficient of usefulness of train operation decreased. Since 2013, traffic speed and train performance have started to increase, the performance level of 2009–2010 was exceeded in 2016. At the same time, the coefficient of useful use of train work for the first time exceeded the level of 0,5. In 2017, it, like the average daily performance of a train, updated historical highs. Train weights also reached the maximum values. The speeds are still below the 2009–2010 level, but the speed coefficient has reached its maximum. These results were achieved due to the consistent development of heavy traffic [27, 28], systemic improvement of the technology of the transportation process, including introduction of polygon technologies [29, 30].

Thus, during formation and development of the railway freight transportation market and implementation of the structural reform of the industry, the efficiency indicators of the operational performance of Russian railways in freight traffic have substantially improved. This improvement was not linear, but in recent years, positive trends have strengthened, and key indicators have reached historic highs. To further improve the efficiency of operational activities, new radical changes and new dynamics of innovations in the framework of innovation-focused development of rail transport are required [31, 32].

Prospects for increasing efficiency

In studies [10, 11], the possibility of increasing train productivity in the future period up to 2030 by an average annual rate of 3% was substantiated. Practices show the realism of these estimates. In the period 2015–2017, the average annual growth rate of train performance was 4,1%, which is significantly higher than in previous years. Thus, a good reserve for the future is created, but at the same time ensuring an average annual rate of about 3% until 2030 is a difficult task that can be solved only on an innovative basis.

In the study [3] proceeding from long-term trends of innovation-focused development of domestic railways, the parameters of weights and train speeds,

Table 4

Forecast values of quality indicators and efficiency of operational work in freight traffic for the perspective up to 2030

Indicators	Calculated variant	Optimized variant
Gross weight of a train, t	5211	4815
Net weight of a train, t	3130	3130
Ratio of net weight of a train to gross weight of a train («weight coefficient»)	0,601	0,650
Technical speed, km/h	51,5	51,5
Section speed, km/h	45,6	45,6
Ratio of section speed to technical speed («speed coefficient»)	0,885	0,885
Average hourly train work, thous. t • km gross	268,4	248,0
Average hourly capacity of a train, thous. t • km net	142,7	142,7
Coefficient of usefulness of train work	0,532	0,575

weight and speed coefficients for the perspective up to 2030 were calculated. These figures, as well as the corresponding values of hourly average work and train performance and the coefficient of usefulness of train operation are shown in Table 4, in the column «calculated variant». Nevertheless, although achievement of such parameters seems to be possible in principle, increasing the average gross weight of a train by 29 % to the existing level (while significant exceeding 5000 tons) is still an extremely difficult task, even taking into account the prospects for development of heavy traffic.

In addition, it is necessary to pay attention to essentially different trajectories of measuring the speed coefficient and the weight coefficient. The speed coefficient as a whole grew much more dynamically, and its advance over the weight coefficient, which was 1,17 times in 1913, increased to 1,46 times by 2017. At the same time, its absolute value is close to 0,9, and it is obvious that the possibilities of its further increase, even on purely theoretical, mathematical grounds, are very limited. The weight coefficient for more than a century has not undergone cardinal changes, having increased from 0,527 to 0,594. And its value in the mid-1990s was approximately at the level of the 1930s.

The value of the weight coefficient for the perspective up to 2030 (0,601), calculated taking into account such trends, is not an ambitious parameter. Using the logical-analytical method [33, 34], it can be concluded that breakthrough changes are possible precisely in increasing the weight coefficient.

A significant increase in weight coefficient can be achieved on the basis of a combination of a reduction in the share of empty run and a reduction in the tare ratio of cars. The first of these tasks can be solved on the basis of economic incentives for the operator companies to reduce the empty run and improve the commercial dispatching of the car fleet. The solution of the second task requires modification of the design of cars and materials for their manufacture. It seems that implementation of a set of these measures can increase weight coefficient in the long run to 0,650. Then the achievement of the calculated net weight of a train will be provided with a gross weight of a train of 4,815 tons, which is a much more realistic task in terms of traction and transportation technology.

Accordingly, the estimated average hourly performance of a train, taking into account this optimization, will be achieved with a significant, by 7,6 %, less, average hourly operation of a train. Given that ton-kilometers gross are the key flow meter of operational work [35], savings in operating costs will also be very significant. The optimized version will dramatically improve the efficiency of operational activities – the coefficient of usefulness of train operation will increase to 0,575.

Conclusion. *Thus, in the long term, a significant increase in the efficiency of the operational activity of the railway transport is necessary and possible on the basis of implementation of technologically and economically sound innovative solutions.*

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Information about the authors:
Macheret, Dmitry A. – D.Sc. (Economics), professor of Russian University of Transport, First Deputy Chairman of Joint Scientific Council of JSC Russian Railways, Moscow, Russia, macheretda@rambler.ru.
Kudryavtseva, Anastasia V. – Ph.D. (Economics), research fellow of Joint Scientific Council of JSC Russian Railways, Moscow, Russia, anastasiya.izmaykova@mail.ru.

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