 https://doi.org/10.1051/e3sconf/202340212011

Evaluating the efficiency of rail gauge maintenance in Siberia

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Abstract. The state of gauge geometry is the basis for safe and uninterrupted train operations under the mixed traffic conditions, as well as in the sections where trains with increased weight and length, including wagons with an increased axle load, are handled. When passing such trains, the state of gauge geometry deteriorates. This leads to increased labour costs for track maintenance, which is also caused by climatic features. Under such conditions, it is important to carry out effective gauge maintenance works. To analyse an impact of maintenance on gauge geometry, it is offered to determine the effect of uneven settlement of the under sleeper base in spring on the dynamics of each type of deviation. To evaluate the efficiency of preventive track alignment in the plan and profile, an analysis of graphical charts for the state of gauge geometry depending on track maintenance by gangs of track fitters and preventive track alignment by machine systems was carried out. It is also revealed that the efficiency of preventive alignment is significantly reduced under harsh climatic conditions, especially for the tonnage handled exceeding 600 million tonnes gross, and should therefore be carried out more frequently.

1 Introduction

The state of gauge geometry has a major impact on safety and uninterrupted running of trains at prescribed speeds. Providing the stability of gauge geometry is especially important for sections with handling of both passenger and freight trains. The vertical and horizontal forces from freight trains significantly increase the intensity of track geometry deterioration, which has an impact on both traffic safety and economic losses due to train delays with the speed limit.

Providing high density of freight traffic flow and handling trains of increased weight and length, including wagons with increased axle loads, requires a high quality of maintenance. In its turn, the quality of maintenance largely depends on conditions under which it is carried out. With increasing axle loads, there is an increase in the intensity of track deterioration. [1-3] Investigations reveal that there is firstly a degradation of the under sleeper base and an increased wear of rail fastening elements [4; 5], which is primarily reflected in the state of gauge geometry.

Heavier freight and higher traffic density to increase the volume of coal traffic in the especially heavy-duty sections of Siberia leads to a reduction in empty track time for

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maintenance works. At the same time, the transportation of characteristic freight significantly contributes to the overall ballast section state, and later to the degradation of drainage and strength properties.

Additionally, harsh climatic conditions result in increased labour costs for track maintenance. The existence of mud splashes in spring and autumn, the need to organise works for clearing track and turnouts from snow, as well as sections with heaving soils, complicate the organisation of track maintenance in the line sections. As a result, with a high volume of works and a limited number of full-time employees from structural subdivisions, the already identified gauge deviations are not fully eliminated to have an impact on both traffic safety and overall track degradation. The staffing issue is particularly urgent in the sparsely inhabited areas of Eastern Siberia and the Far East, where the number of inhabitants is not enough to provide structural subdivisions with a sufficient number of employees. At present, JSC Russian Railways organises maintenance of these sections on a rotational basis, which does not always provide high quality maintenance due to the lack of motivation among employees. The experience of foreign researchers indicates that a possible solution to the problem of limited human resources for the gauge geometry maintenance is an increased level of mechanisation, in particular, an increased frequency of track alignment by a machine system. [6]

It is worth bearing in mind that when organising machine alignment, changes in the train timetable within a track possession must be taken into account. Researches in the field of determining effective time intervals between trains under conditions of heavier train traffic for execution of gauge maintenance works revealed that it is necessary to obtain comprehensive data on the actual state of gauge geometry and its further change. [7; 8] Papers [9; 10] consider the process of gauge geometry degradation based on a simulation model using multivariate statistical analysis. There is also ongoing research in the field of predicting the state of gauge geometry with the help of a neural network. [11-13] The issue of gauge geometry degradation due to uneven settlement of ballast and subgrade is considered in [14-16] over the long term taking into account the accumulation of residual deformations.

At present, there is no possibility of a complete transition to gauge maintenance with the use of machine systems in Russian rail transport, both due to the need for substantial capital investment and harsh climatic conditions requiring occasional local interventions. The railway track maintenance in terms of track geometry is divided into two sets of works. The first one involves the gauge width adjustment, which is carried out by gangs of track fitters in the line sections, and the second one implies the track alignment in the plan and profile. Moreover, the use of specific track alignment technological operations depends on the state of under sleeper base. When the ballast is frozen, the track alignment is carried out using adjustment pads. At other times, tools of small-scaled mechanisation are used for ballast tamping. The use of alignment systems is only possible during this period, which in Siberia is accepted from late April to early October. This paper considers the issue of rational use of the alignment system to reduce labour costs for gauge maintenance.

2 Methods

To analyse the effect of maintenance on the gauge geometry state, a statistical analysis of especially heavy-duty railway sections within the Trans-Siberian and Central Siberian Railways was carried out. Firstly, an impact of uneven settlement of the under sleeper base in spring on the dynamics of developing each type of deviation, except gauge deviation, was sized up. For this purpose, the results of gauge geometry state evaluations by track measuring tools for the period from May 2010 to December 2019 were used.

To evaluate the efficiency of preventive alignment in the plan and profile, an analysis of graphical charts on the gauge geometry (GG) state depending on track maintenance by gangs of track fitters and preventive alignment (PA) machine systems was carried out.

The efficiency of works carried out was determined by evaluating the reduction of comparison parameters, in particular, the average number of deviations in the section under study, the labour costs for gauge maintenance in the plan and profile. The labour costs were estimated on the basis of deviation lengths and time standards for their elimination, taking into account the type of fastening and season of operation.

3 Results

To analyse the impact of under sleeper base heterogeneous thawing on the deviations in the plan and profile, charts illustrating the dependence of these deviations on the month of operation were plotted (Fig. 1).

An analysis of the gauge geometry condition in the sections revealed a number of regularities.

With an increased share of curves and a decreased radius, the average number of deviations increases. The average number of deviations in the sections with the reinforced concrete rail 65 (RCR-65) fastening (an average radius is 830 m; a share of curves is 69 %) amounts to 14.9 pcs/km, while in the section with the RCR-65 fastening (an average radius is 450 m; a share of curves is 92 %) the average number of deviations for the whole period under study is 1.5 times higher (21.7 pcs/km).

It should be noted that the largest increase in the number of deviations accounts precisely for the gauge width (an increase in narrowing is 7.7 times, in widening is 1.9 times), and also for deviations in the plan (an increase in straightening is 1.7 times), while the number of deviations in the profile has increased slightly (an increase in track twists is 1.25, in track depressions is 1.2, in track level is 1.003).

The dynamics of gauge deviations in all sections has considerably increased in 8-9 years of operation, with tonnage handled of 650 - 750 million tonnes gross, which is caused by an increase in the lateral wear of rails, as well as by wear and tear of fastening elements. That, at late replacement of fastening elements, leads to local deviations of high length (at a number of kilometres the number of deviations by widening exceeded 30 pieces, with a length of 3 to 12 metres). These works on curved track sections should be carried out in one piece along the entire curve to avoid the occurrence of deviations at adjacent areas. A significant influence of the operation season (climatic conditions) expressed in uneven thawing of the under sleeper base on the general state of gauge geometry was revealed, with high amplitude jumps in the average number of deviations taking place in the late April - early May.

It is worth noting that with the increased tonnage handled (a general track degradation), an impact of uneven thawing of the under sleeper base increases to a large extent. Thus, in the case of handling 300 million tonnes gross through one of the sections, the average number of deviations excluding the gauge width increased by 1.5 times from April to June compared to the beginning of the year (8.7 pcs/km vs. 5.6 pcs/km). With 500 million tonnes gross, there was an increase in 3.14 times (18.37 pcs/km vs. 5.6 pcs/km) over the same period. When handling 800 million tonnes gross, there was a decrease in dynamics. There was an increase in 2.26 times (27.85/km vs. 12.3/km), which was due to an increase in the average number of deviations for the entire period and for the beginning of the year in particular.

 https://doi.org/10.1051/e3sconf/202340212011

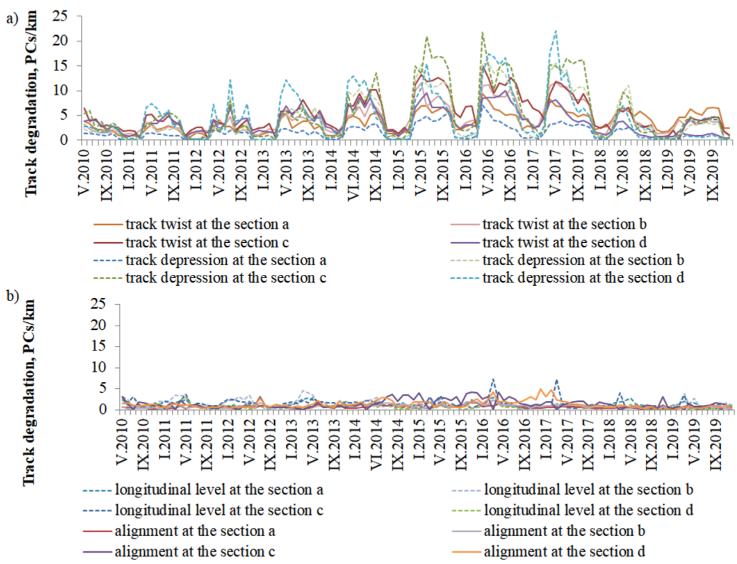

Fig. 1. Dependence of average number of deviations in the plan and profile on the operation season: a) for track twists and track depressions; b) for levelling and realigning

A significant impact of uneven thawing of the under sleeper base on deviations in the profile, particularly twists and depressions, has been found in all sections. In the case of level deviations as well as deviations in the plan (realigning), the average number of these deviations does not change significantly over the year for all sections under study (Fig. 1, b). The average number of level and realigning deviations (depending on the average radius of sections and intermediate rail fastening (IRF) type) ranges from 0.7 to 1.3 pcs/km and 0.7 to 1.4 pcs/km respectively. Whereas twists and depressions are characterised by a sharp surge in deviations during springtime, which is clearly visible in Fig. 1, a.

The largest increase in the number of these deviations during springtime compared to the beginning of the year happened with tonnage over 710 million tonnes gross. In the case of depressions, the number of deviations increased by 6.2 to 16.9 times, depending on the IRF type and average curve radius. In the case of twists, the number of deviations increased by 2.3 to 2.9 times.

In the case of maintenance, the distribution of labour costs is based on planning depending on the total amount of works for track maintenance. It is not always possible to organise the full-scale gauge geometry maintenance as a part of track maintenance, which leads to a 'queue' of deviations requiring elimination, but not eliminated in a given time. These deviations may remain unchanged until the next inspection by a geometry wagon, or may increase both in length, resulting in more work in the following period, and in magnitude impacting on the degree of deviation (up to degree IV - faults requiring prohibited measures).

In turn, one should bear in mind that maintenance works are carried out at localised sections and are most often expressed in point detection of major peak deviations with their further elimination (Figure 2). The performance of these works largely depends on a foreman's experience and the quality of work executed by contractors. In addition, during springtime, the intensity of deviation development increases considerably, making it necessary to re-conduct the works at each kilometre several times a month, as can be clearly illustrated by Figure 2.

To analyse the impact of preventive maintenance, the sections of track I (an especially heavy-duty section) of the Central Siberian Railway were chosen; the value of tonnage handled was 283 million tonnes gross as of 01.01.2018.

A working assessment of gauge geometry on 05.05.2018 (Fig. 2) identified 10 deviations of degree II and 2 deviations of degree III. All deviations were eliminated after the ongoing maintenance works, however, 2 deviations were detected within the inspection assessment two weeks later (Fig. 2). The first one was the deviation of degree II caused by an incomplete elimination of the deviation identified during the previous inspection (number 5 in Figure 2). The second one was the deviation of degree III (number 6 in Figure 2) caused by poor elimination of the deviation of degree II identified during the previous inspection.

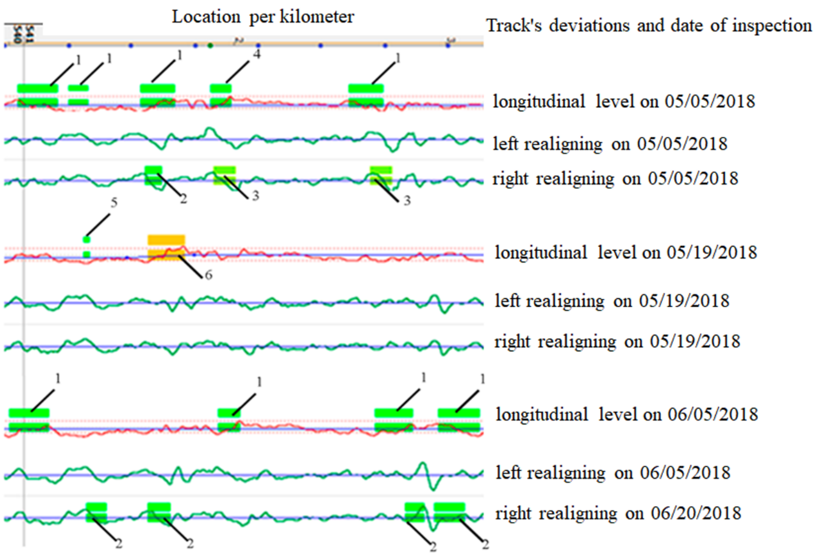

Fig. 2. Results of track assessment by a geometry wagon in the Central Siberian Railway section . 1 – twist of degree II; 2 – realigning of degree II; 3 – realigning of degree III; 4 – level of degree II; 5 – level of degree II; 6 – twist of degree III

In the case of level deviation, the presence of this deviation is due to the fact that no additional 4 metres of level deviation were identified by the foreman during the site survey and they were not eliminated. A twist of degree III is caused by poor elimination of the II degree twist identified in the previous inspection. In particular, it was decided to eliminate only one peak twist value. An uneven settlement of the under sleeper base caused an increase in the second peak value in the following 2 weeks, which was not eliminated resulting in a twist of degree III.

A working assessment on 05.06.2018 identified 8 II degree deviations (Fig. 2). 2 twists and 1 realigning of these deviations occurred in the same locations as a month ago.

Thus, even if the deviations are completely eliminated, there is a risk of their reoccurrence during the under sleeper base thawing. Additionally, with limited labour resources, to reduce the number of deviations (reducing or eliminating the "queue" of deviations), the maintenance works in terms of eliminating deviations are limited to the local elimination of single deviations in an effort to reduce labour costs, which has an impact on the work quality. In a machine preventive alignment, the work is carried out in one piece at a time, thus eliminating the elasticity transfer points of the under sleeper base, as occurs with local alignments within maintenance operations. In addition, this type of alignment can provide a minimum number of deviations over the medium term, if supported by timely maintenance works.

In particular, Figure 3 illustrates the results of track assessment by a geometry wagon before and after preventive alignment.

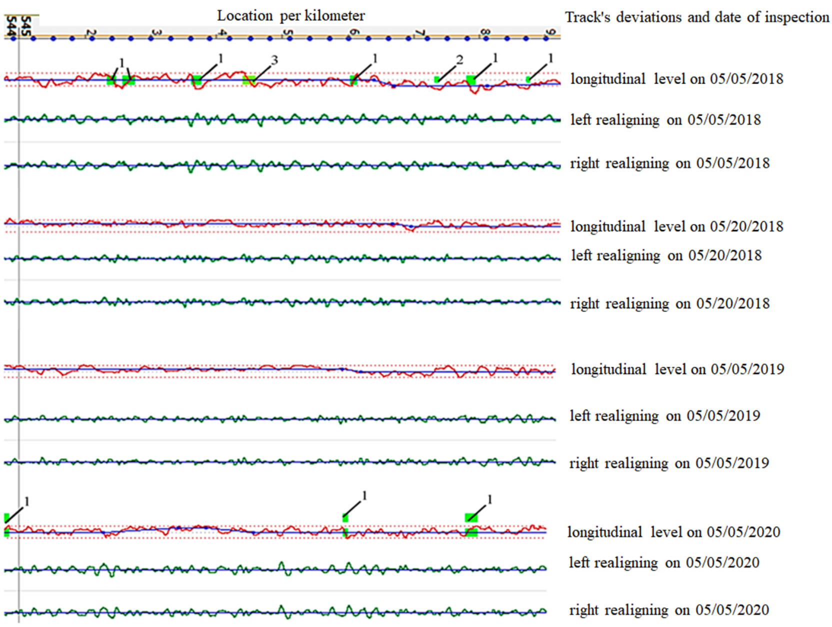

Fig. 3. Results of track assessment before preventive alignment: 1 – twist of degree II; 2 – level of degree II; 3 – twist of degree III

Prior to the regular track alignment, the average number of deviations from January 5 to May 5, 2018 was 2.8 pieces (according to the results of working and control inspections). The largest number of deviations of 9 pieces was identified during the working inspection in May 2020 (Fig. 3).

No deviations were identified after the regular track alignment inspection in May (Fig. 3). In addition, it is clearly visible that there has been a smoothing of all parameters (level, realignment, depression). Over the next 6 months, the average number of deviations at this kilometre was 0.15 deviations per assessment, a year later the average number of deviations was 0.63 pieces, and only 2 years later by May 2020 it had increased to 1.14 pieces, indicating the quality and efficiency of this work.

Therefore, it is obvious that a timely preventive track alignment together with high-quality maintenance makes it possible to provide a minimum number of track deviations within an almost two-year period. This raises the question concerning the efficiency limits of preventive track alignment proceeding from a number of conditions. The following can be taken as efficiency parameters: the average number of deviations and estimated labour costs for their elimination. Estimated labour costs are determined based on the type of deviation, its length, as well as the method of elimination (an adopted technological operation).

To reduce the effect of different operating conditions (line layout, tonnage, existence of separation layer), sections of track I in the Central Siberian Railway were chosen to be maintained under similar climatic and operating conditions.

The average number of deviations and estimated labour costs for their elimination before and after the preventive alignment were determined and compared for the analysis. Particular attention was paid not only to the average value of efficiency parameters before and after the preventive alignment, but also to their value during the period of uneven thawing of the under sleeper base.

To thoroughly analyse the impact of preventive alignment by machine systems on gauge geometry, a scheme of preventive alignment for all the sections under study was drawn from the analysis of actual implementation of the targeted plans (Fig. 4)

	2012	2013	2014	2015	2016	2017	2018	2019	2020
Section 1	OR	PM			PM			PM	
Section 2	OR	PM			PM		PM	PM	PM
Section 3				OR	PM				PM
Section 4				OR	PM		PM		PM
Section 5				OR	PM		PM		
Section 6	OR	PM		PM				PM	
Section 7	OR	PM	PM					PM	PM

OR - overall repair
PM - preventive maintenance by track renewal train

Fig. 4. A scheme of preventive maintenance in the sections under study

The sections under study can be divided into two groups, depending on the year of laying. In the case of sections 1, 2, 6 and 7, a significant difference is clearly visible in the number of deviations compared to sections 3, 4 and 5 (Fig. 5). In addition, Figure 3 shows the dynamics of reducing the effect of uneven settlement period (USP) while thawing the under sleeper base on the average number of deviations.

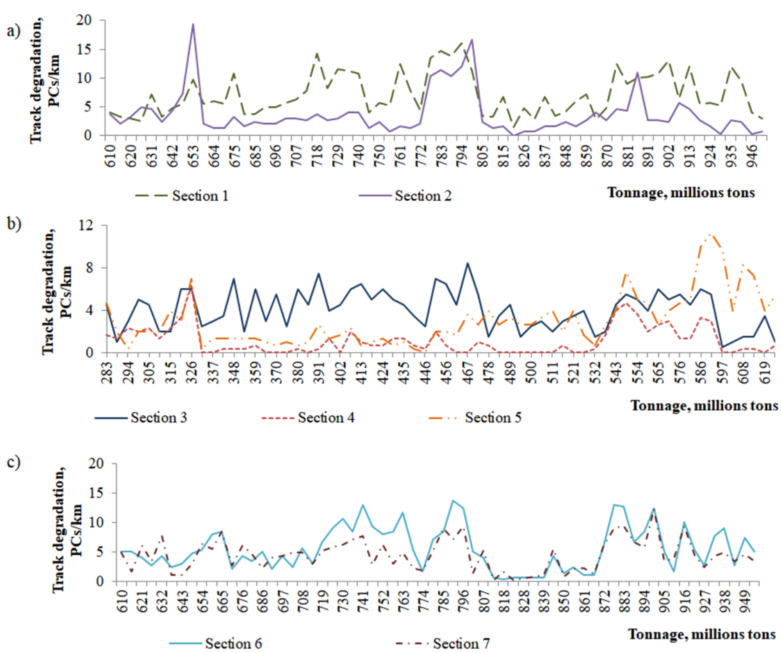

Fig. 5. Charts explaining the effect of preventive alignment on the rail gauge geometry: a) for sections 1 and 2; b) for sections 3, 4 and 5; c) for sections 6 and 7

Consider the sections where, at the time of preventive alignment in 2018, the tonnage handled ranged from 300 to 350 million tonnes gross. Sections 4 and 5, following the preventive alignment in May 2018, managed to reduce the average number of track deviations from 6.3 and 7 pcs /km to 0 and 0.3 pcs /km, respectively.

During further operation of the sections, due to current maintenance the average number of deviations was 0.6 and 1.2 pcs/km until the next period of uneven settlements. Whereas in section 3, where machine alignment was carried out only in May 2020, the average number of deviations was 4.9 pcs/km over the same period. Table 1 presents the overall analysis of sections in terms of the preventive alignment effect on the gauge geometry stage.

Table 1. The results of an analysis of preventive alignment effect on gauge geometry

Comparison parameter	Period of comparison	Average value of a comparison parameter						
		Section number						
		1	2	3	4	5	6	7
Average number of deviations, pcs./km	before PA	3.9	3.5	3.3	1.8	2.2	4.0	3.6
	USP (2018)	6.7	10.3	4.7	4	4.7	6.6	5.8
	after PA	-	2.3	-	0.5	1.2	-	-
	USP (2019)	13.9	12.1	6.4	0.7	2.4	10.3	7.6
	after PA	5.6	2.7	-	-	-	4.2	3.8
	USP (2020)	10.5	3.6	5.4	2.3	7.8	6.9	6.6
	after PA	-	1.5	1.5	0.2	-	-	3.8
Average value of estimated labour costs for eliminating deviations, man-hours/km	before PA	5.1	5.9	8.3	2.7	3.6	8.8	5.1
	USP (2018)	12.7	21.1	11.0	10.4	9.5	13.8	11.4
	after PA	-	3.9	-	0.8	2.2	-	-
	USP (2019)	25.5	20.6	13.5	0.85	3.9	20.1	15.6
	after PA	9.3	3.7	-	-	-	8.1	6.9
	USP (2020)	18.5	5.9	9.0	5.6	13.1	15.3	12.1
	after PA	-	3.4	2.7	0.2	-	-	7.2

Note: PM - Preventive Alignment;
USP - uneven settlement period, from mid-April to early June.

Based on the results of this analysis, it can be concluded that to evaluate the efficiency of preventive machine alignment, in addition to the average number of deviations, the estimated labour costs for eliminating deviations can also be used, as the dynamics of labour cost changes adequately respond to machine alignment and also provide a transparent indicator of the labour costs level required for gauge maintenance.

At sections where the tonnage handled ranges from 300 to 600 million tonnes gross, the most significant effect is revealed when the preventive alignment is carried out every two years (240-280 million tonnes gross). The average number of deviations after machine alignment in 2018 reduced by almost 3 times and accounted for 0.9 pcs/km over two years (taking into account the USP) and reduced to 0.2 pcs/km after the maintenance alignment in 2020 (section 4).

When only one preventive maintenance alignment is carried out over the period analysed (from 280 million tonnes to 630 million tonnes), the efficiency is significantly reduced. However, the period of machine alignment relative to the tonnage handled also has an impact. Thus, the average number of deviations in section 3 before the preventive alignment in 2020 (from 01.012018 to 20.05.2020) was 4.3 pcs/km, when in section 5 the machine alignment was carried out in 2018 and the average number of deviations was 2.5 pcs/km for the same period.

In the sections where the tonnage handled ranges from 600 to 900, the best effect of preventive alignment has been achieved with annual machine alignment (section 2).

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The average number of deviations after preventive regular alignments in 2018 reduced by 2.5 times and amounted to 2.3 pcs./km until the next period of uneven settlement, where it increased to 12.3 pcs/km. After machine alignment in 2019, this value reduced to 2.7 pcs/km. In spring of 2020, the average number of deviations was 6.7 pcs/km and, after the next preventive alignment, decreased to 2.6 pcs/km, with a tonnage of over 900 million tonnes gross.

When only one preventive alignment is carried out over the period analysed (sections 1 and 6), there is only a short-term effect (average of 6 months). On average, the average number of deviations decreased by 1.3 times in these sections as a result of one machine alignment.

If, however, the efficiency of maintenance alignment is considered in terms of the estimated labour costs for the maintenance of key gauge geometry parameters, the most informative figure is Figure 4, where the dynamics of the estimated labour costs from the maintenance alignment by the machine system in different periods can be clearly seen.

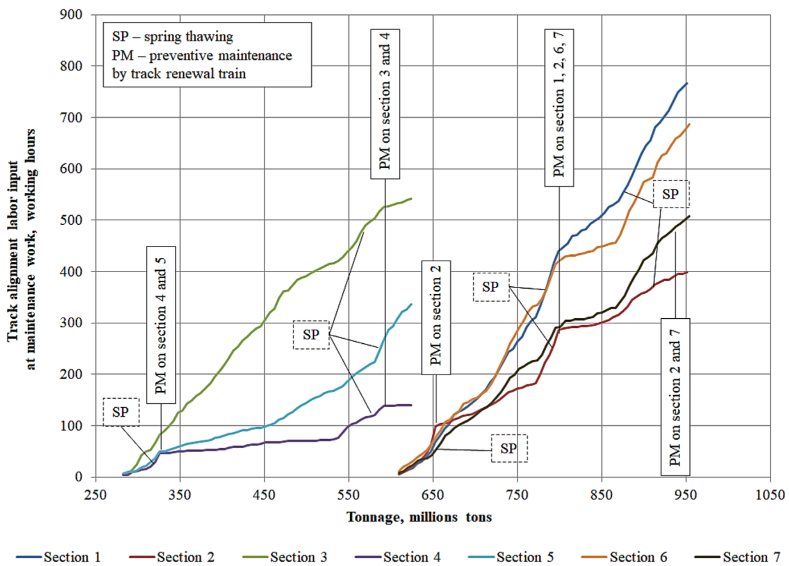

Fig. 6. Estimated labour costs, cumulative for the period from 01.01.2018 to 01.09.2020

It is clearly visible that machine alignment reduces the labour costs for maintenance of the key gauge geometry parameters. In addition, it is worth considering the total number of maintenance alignments since track laying (Figure 4). In sections laid in 2015, the largest number of PA during the operational period (3 pcs.) was in section 4, which has the lowest labour costs over the period analysed, while section 3 revealed the highest labour costs, with 2 machine alignments, yet with an interval of 4 years (2016 and 2020).

In the case of sections laid in 2012, the most efficient frequency of preventive alignment in terms of estimated labour costs is section 2 (Figure 4). After the post-settlement alignment in 2013, the first preventive alignment was carried out three years later (after 310 to 330 million tonnes gross), the next one was carried out two years later (220 million gross tonnes), and once a tonnage of 700 million tonnes had passed, a machine alignment was carried out annually (every 110-140 million gross tonnes).

The lowest efficiency was revealed in section 1, where preventive alignment was carried out every three years regardless of the handled tonnage volume.

4 Discussion

The research reveals that to increase the efficiency of railway track maintenance under the climatic conditions of Siberia, the efficiency of production processes for rail gauge maintenance should be increased.

The best solution is to increase the frequency of track alignment due to a machine system. Existing schemes for frequency of overhauls and intermediate repairs have no specific recommendations for adjustments under harsh operating conditions for especially heavy-duty railway sections (with the overhaul period of 1400 million tons), therefore, it is necessary to elaborate the recommendations for frequency of preventive track alignment under the harsh conditions of Siberia.

The results of the study revealed that the efficiency of preventive alignment significantly reduces with an increase in tonnage handled. If tonnage in the range of 300 to 600 million tonnes gross is handled through especially heavy-duty sections of Siberia, preventive alignment should be carried out every 2 years. For tonnage between 600 and 900 million tonnes gross, an annual maintenance alignment is required.

Also, during the preventive alignment, the thickness of frost penetration of the under sleeper base should be taken into account, since when the preventive alignment is carried out at the time of incomplete thawing of the under sleeper base, the efficiency of machine alignment significantly reduces (the process of uneven thawing of the under sleeper base leads to formation of new deviations after alignment). It is therefore necessary to rank the Siberian regions by sections depending on the thickness of frost penetration of the under sleeper base for the most effective distribution of machine systems at the initial stage of alignment (from April 15 to June 1 for the West Siberian Railway).

References

1. Kosenko, S., Akimov, S.: Design of track structure for corridors of heavy-train traffic. MATEC Web Conf. 239, 1–12 (2018). Article No. 05005.
2. Kosenko, S., Akimov S., Surovin P. Technology of rail replacement at end stresses. MATEC: Web of Conferences. Volume 216, pp 1–8 (2018).
3. Kosenko, S. A., Akimov S.S. Performance characteristics of differentially quenched. Magazine of Civil Engineering. Volume 7, pp 94-105 (2017).
4. Victor Kochergin, Igor Maksimov, Victor Pevzner and Evgeniya Polunina. Track loading on Russian Railways under modern maintenance conditions. E3S Web Conf. Volume 135, Article 02002
5. Victor Pevzner, Valerii Kaplin. Improving the Railway Stability in the Joint Zone for Modern Operating Conditions. Transportation Research Procedia. Volume 54, pp 328-333 (2021).
6. Weston P., Roberts C., Yeo G, Stewart E. Perspectives on railway track geometry condition monitoring from in-service railway vehicles. Vehicle System Dynamics. Volume 53, pp 1063-1091 (2015).
7. Kasraei, Ahmad , Zakeri, Jabbar Ali. Effective time interval for railway track geometry inspection. Archives of Transport. 2020. Volume 53, issue 1, pp 53—65 (2020).
8. Khajehei H, Ahmadi A., Soleimanmeigouni I., Nissen A. Allocation of effective maintenance limit fir railway track geometry. Structure and Infrastructure Engineering. 2019. Volume 15, pp 1597-1612 (2019).

9. Guler H., Jovfnovic S., Evren G. Modelling railway track geometry deterioration. Proceedings of the Institution of Civil Engineers. Volume 164. Issue 2, pp 65-75 (2011).
10. Sadeghi J. Development of Railway Track Geometry Indexes Based on Statistical Distribution of Geometry Data. Journal of Transportation Engineering. Volume 136. p. 693-700 (2010).
11. Guler H. Prediction of railway track geometry deteriorationusing artificial neural networks: A case study for Turkish state. Structure and Infrastructure Engineering. Volume 10, Issue 5, pp 614-626 (2014).
12. Sadeghi J., Askarinejad H. Application of neural networks in evaluation of railway track quality condition. Journal of mechanical science and technology. Volume 26, Issue 1, pp 113-122 (2012).
13. Kasraei A., Zakeri J., Bakhtiary A. Optimal track geometry maintenance limits using machine learning: A case study. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit. Volume 235, Issue 7, pp 876-886 (2020).
14. A. Ivanova, A. Butsanets, V. Breskich, T. Zhilkina, Autonomous Shipping Means: the Main Areas of Patenting Research and Development Results, Transportation Research Procedia, Volume 54, 2021, Pages 793-801, https://doi.org/10.1016/j.trpro.2021.02.132
15. Jens C., Nielsen O., Li X. Railway track geometry degradation due to differential settlement of ballast/subgrade – Numerical prediction by an iterative procedure. Jornak of Sound and Vibration. Volume 412, pp 441-456 (2018).
16. Pevzner V.O., Nadezhin S.S., Anisin A.V., Tretyakov I.V. Assessment of railway track deformability at the sites of its deterioration and of possible changes in track alignment time specifications due to increase in freight car axle-loads. JSC Railway Research Institute (JSC VNIIZhT). Volume 4, pp 44-48 (2013).