Wheel/rail-force–based maintenance interval extension of the C80 series wagon

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Received 11 October 2023
Revised 13 October 2023
Accepted 13 October 2023

Abstract

Purpose – This study aims to introduce the achievements and benefits of applying wheel/rail-force–based maintenance interval extension of the C80 series wagon in China.

Design/methodology/approach – Chinese wagons' existing maintenance strategy had left a certain safety margin for the characteristics of widely running range, unstable service environment and submission to transportation organization requirements. To reduce maintenance costs, China railway (CR) has attempted to extend the maintenance interval since 2020. The maintenance cycle of C80 series heavy haul wagons is extended by three months (no stable routing) or 50,000 km (regular routing). However, in the meantime, the alarming rate of the running state, a key index to reflect the severe degree of hunting stability, by the train performance detection system (TPDS) for the C80 series heavy haul wagons has increased significantly.

Findings – The present paper addresses a big data statistical way to evaluate the risk of allowing the C80 series heavy haul wagons to remain in operation longer than stipulated by the maintenance interval initial set. Through the maintenance and wayside-detector data, which is divided into three stages, the extension period (three months), the current maintenance period and the previous maintenance period, this method reveals the alarming rate of hunting was correlated with maintenance interval. The maintainability of wagons will be achieved by utilizing wagon performance degradation modeling with the state of the wheelset and the often-contact side bearing. This paper also proposes a statistical model to return to the average safety level of the previous maintenance period's baseline through correct alarming thresholds for unplanned corrective maintenance.

Originality/value – The paper proposes an approach to reduce safety risk due to maintenance interval extension by effective maintenance program. The results are expected to help the railway company make the optimal solution to balance safety and the economy.

Keywords Full-continuous wheel–rail force measurement, TPDS, Shattered rim, Hunting, C80 series heavy haul wagons, Maintainability

Paper type Research paper

1. Introduction

So far, there are 900,000 vehicles on China's railways, which is astonishing. And these vehicles operate throughout China, so the operating environment is diverse and complex. So the maintenance system of China's railway freight cars mainly adhered to the principle of "safety first, prevention first" and followed the planned preventive maintenance mode to ensure transportation safety. Reduction of maintenance costs has a high focus in the railway industry (Huang, 2016). For this reason, requests to increase maintenance intervals of wheelsets and wheelset bearings in operation are standard. Since 2020, China Railway Group Corporation has carried out the repair system reform of railway freight wagons. The maintenance cycle of C80 series heavy haul wagons was extended by three months (no stable

Railway Sciences
Vol. 2 No. 4, 2023
pp. 514-524
Emerald Publishing Limited
e-ISSN: 2755-0915
p-ISSN: 2755-0907
DOI 10.1108/RS-10-2023-0032

routing) or 50,000 km (regular routing). There are two major persisting issues in freight train, hunting and wheel tread damages. Extended maintenance cycle leaded these issues more prominent. This research introduced the achievements and benefits of applying wheel/rail-force–based detection technology in extending the maintenance cycle of vehicles in China.

Due to structural parameters and wear and tear of railway freight cars, the dynamic performance of railway freight cars presents great discreteness in a service cycle. To the statistical results, the number of train performance detection system (TPDS) hunting alarms for C80 series heavy haul wagons in 2020 increased significantly compared to in 2019, reflecting the reduced dynamic performance of freight wagons via the active online detection of hunting, the system guarantees the running safety of the freight railway system. Based on the extensive data analysis between the matching of wagon wheel repair data (51C) and TPDS monitoring data, this paper studies the influence and main reasons of the extended maintenance period on the lateral dynamic performance of the wagon from the two dimensions of time and maintenance. It brings a statistical model of extending maintenance intervals and ensuring safe operation, which may see a balance between safety and economy.

2. Methodology: the principle of TPDS alarms

The TPDS is based on full-continuous wheel–rail force measurement. Compared with discontinuous technology, the benefits of full-continuous measurement are apparent. The equipment with full-continuous technology can easily cover kinds of wheels 100%, enhancing wheel/vehicle monitoring effectiveness. More importantly, such equipment will provide reliable and consistent data for further network assessment and simplify related implementation. The figure illustrates how the wayside equipment covers the wheel surface, from which we can get the wheel coverage of any wayside W/R force equipment from the point of view of capturing impact load. Obviously, the performance of a complete continuous device is much better than that of a discontinuous device.

TPDS achieved full-continuous wheel–rail force by 2D force plate and shear force sensor. The basic principle is to set several vertical pressure sensors under the rail track between two shear force sensors to form a wide detection area (Figures 1 and 2). The data collected from the two types of sensors can be calculated by modeling to obtain the wheel force of the wheel and rail at any position in the survey area. The “moving vertical force detection method” can substantially increase the length of the effective detection area without increasing the distance between sleepers and without deteriorating the smoothness of the track. Thanks to the extended continuous detection area, the average value and change trend of the wheel–rail force change process data can be measured for an extended period rather than an instantaneous value of the fluctuation process, which not only improves the detection accuracy but also dramatically increases the speed range applicable to the device.

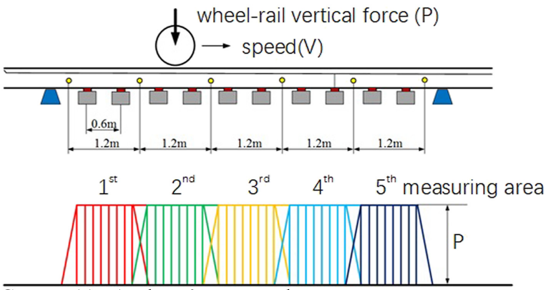

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Figure 1. Schematic diagram of wheel–rail vertical force

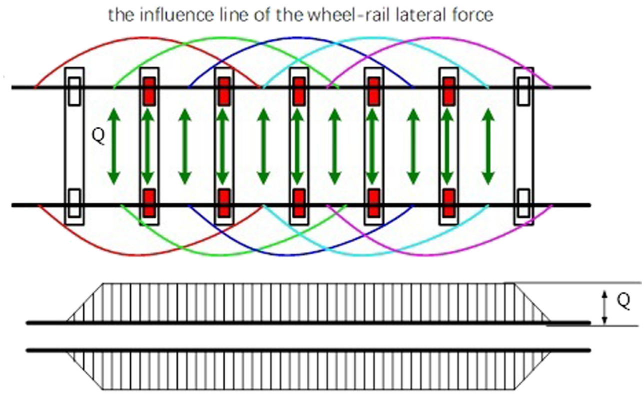

Figure 2.
Schematic diagram of wheel–rail lateral force

Source(s): Authors' own work

So based on wheel–rail force measurement, TPDS has two functions. The first one is tread damage detection. A feature factor was created: Equivalent Impact Value(EIV), comprehensively considering wheel–rail impact force, running speed and wheel load to evaluate the degree of wheel tread damage. The second one is hunting detection. Single TPDS set calculated individual scoring by wheel load reduction rate, derailment coefficient and axle lateral force and use multiple scoring from different TPDS sets to achieve network evaluation. The advantages of TPDS are low monitoring cost, many objects and high frequency. However, the results of a single evaluation will be affected by random factors, including the angle of attack, marshalling and longitudinal force of the train. Therefore, the general principle of TPDS hunting alarms is "decentralized detection and centralized alarm". The specific process includes: (1) data collection of detection stations; (2) calculation of basic parameters; (3) scoring of detection stations; (4) network evaluation. Each TPDS station will score the running status of empty wagons with a passing speed of more than 50 km/h. The TPDS data center collects every single score of TPDS stations and conducts an online assessment of the running status of each wagon according to the above model. The TPDS network evaluation adopts the method of "sliding and accumulating". And the window length of "sliding and accumulating" is seven valid passes. The network score of each wagon's hunting equals the sum of the hunting scores of its last seven valid passes (empty wagons above 50 km/h). The network score of hunting characterizes the wagon's recent dynamic performance. In 2015, according to the actual application of TPDS in the early stage, the China Railway Company established the alarm threshold of 60 points for the network of TPDS hunting alarms and the alarm threshold of the Da-qin line was 110 points (Yu, Hu, & Zeng, 2013).

3. Application: extended maintenance cycle

By the end of 2022, China had built 169 sets of TPDS equipment. The coverage rate of freight trains reached more than 80%. The annual data on TPDS (Figure 3) shows that the number of freight cars monitored increased yearly, reaching 135 m in 2022. The alarming rate of tread damage for freight cars decreased from 15.49% in 2007 to 0.08% in 2022, a decrease of 99.5%. During the same period, significant component breakages have decreased by more than 97%, including pillow cracks, side frame cracks, brake beam failures, etc. Compare with Figures 4 and 5, the alarming rate of tread damage and failure number of critical components shows the same trend. This means "Remove high impact wheel" decreases the defect rate of components significantly.

New features of continuous technology such as "full coverage," "wheel diameter" and "impact frequency" make condition repair based on vehicle damage, performance and risk assessment more reasonable. To ensure safety while reducing cost, CR establishes maintenance cycles based on components defect rates, safety, and economy considerations. Thanks to the effective monitoring of wheel tread defects by the TPDS system, the failure rate and service life of wheels and critical components of freight cars have been significantly improved and the maintenance cycle of freight cars has been extended. Since 2022, the segment repair cycle for 60-ton freight cars was extended by two months; for 70-ton freight cars by three months; for C80 series heavy-duty freight cars belonging to Da-qin Railway by 50,000 km from 400,000 km. But the extension of the maintenance cycle also brought safety risks to freight car operations.

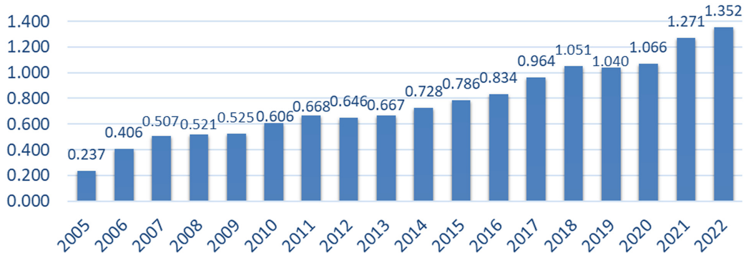

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Figure 3. The annual date on TPDS

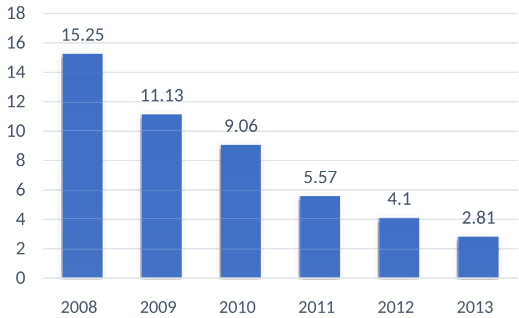

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Figure 4. The alarming rate of tread damage (%)

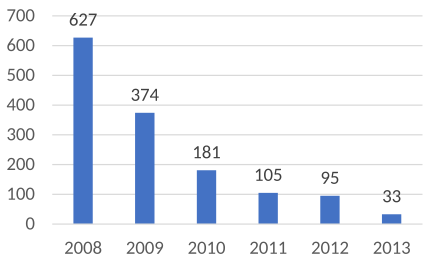

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Figure 5. Failure number of critical components

3.1 Risk 1: shattered rim

The first safety risk is rim crack failure. As we know, for the cases with similar impact force, the thinner the rim thickness, the higher the risk. Inevitably having internal defects in the manufacturing process of wheels will initiate cracks. The crack initiation and propagation process will intensify as the rim becomes thinner and thinner, and heavier axle load brings more significant internal pressure on the rim. Rim crack has a certain concealment and is very difficult to detect at an early stage. The inspection frequency cannot be guaranteed. Once it occurs, it will seriously endanger driving safety. Based on full-continuous technology, we can quickly get the wheel's circumference, assess rim thickness and draw a more reasonable operation based on risk assessment.

In January 2020, the wheels of a C70E wagon triggered two consecutive damage alarms when passing through the TPDS detection station (Table 1). After inspection by the operation workshop, it was found that the wheel had a circumferential crack of 468 mm, a radial crack of 310 mm and a rim crack of 28 mm (Figure 6). The car was immediately detained to prevent a possible wheel failure. Therefore, using TPDS, we can timely detect rim crack failures and prevent wheel collapse from causing train derailment.

3.2 Risk 2: hunting

Another safety risk is hunting. Since 2020, the number of hunting detection alarms for freight cars has increased rapidly yearly (Figure 7). Significantly since 2020, this number has surged. Since May 2020, with the extension of the maintenance cycle and the increase in freight volume, more than 500 wagons are reported to be TPDS hunting alarms every month, including more than 39 C80 series wagons every month. In 2020, TPDS detected 468 vehicles/times of C80 series heavy haul wagons, reducing dynamic performance. The number of alerts has more than doubled compared to 2019.

To objectively reflect the actual service interval of the C80 series wagon wheelset in the extension of the repair process, this paper uses big data to make macro statistics of the wheel change interval and the accumulated wheelset mileage during the maintenance cycle of the C80 series wagons.

3.2.1 Statistics at the same time interval. The number of days between repair sections is calculated as the difference between the date of passing the TPDS detection station and the record time of the previous cycle. According to statistics (Figure 8), from January to July 2019, the detected C80 series wagons took 337–436 days of the prior process. This number goes to 390–509 days during the same time interval in 2020. The number of days reflects that the maintenance cycle of C80 series wagons had been extended in 2020. From the monthly statistical changes, the average rotation interval from January to May in 2020 increased month by month, while it fell slightly from June to July. The reason is that some of the vehicles whose service performance has deteriorated have entered the temporary repair and wheel change ahead of schedule because of the sharp increase in the number of TPDS hunting alarms.

Table 1. Detection results of TPDS for C70E 1685778

No.	Station	Line	Passing time	Speed (km/h)	Wheel no.	EIV
1	GUI XI	HUKUN	2020-01-26 12:57	59	A8	19
2	GUI XI	HUKUN	2020-01-16 10:43	73	A8	17
3	YINGTAN	HUKUN	2020-01-12 10:59	27		0
4	XIANGTANG	JINGJIU	2020-01-12 08:37	42		0
5	3 JIANGZHE	JINGJIU	2020-01-09 06:21	54		0

Source(s): Authors' own work

wagon number
(a)

a circumferential crack of 468 mm
(b)

a rim crack of 28 mm
(c)

Source(s): Authors' own work

Figure 6.
Shattered rim of C70E 1685778

The accumulated mileage is calculated based on the accumulated mileage of the wheelset from loading to the day when it passes the TPDS detection station (Table 2). As of August 2020, a sample of 28,545 vehicles passed through the TPDS detection station this year, with an average accumulated mileage of 228,900 km, located at half the mileage of 450,000 km between sections and repairs, with a normal distribution. In addition, 265 vehicles' network points of TPDS hunting alarms reach 90, whose average accumulated mileage is 277,000 km;

in comparison, 34 vehicles' network points of TPDS hunting alarms earn 110, whose average accumulated mileage is 282,900 km.

In 2019, the average number of days since the previous repair of C80 series wagons was 360 days, and 185 wagons were alerted by TPDS. In 2020, the average number of days was 480 days, and 467 wagons were alerted. The statistics of the average travel mileage reveal that the average accumulated travel mileage of wagons with network points above 90 is significantly higher than the average of all samples. The greater the network points, the longer the average accumulated travel mileage. Therefore, with the extension of the segment repair period, the extension of the service period of the freight wheelset leads to a significant increase in the number of alarms of poor operation status compared with the previous year.

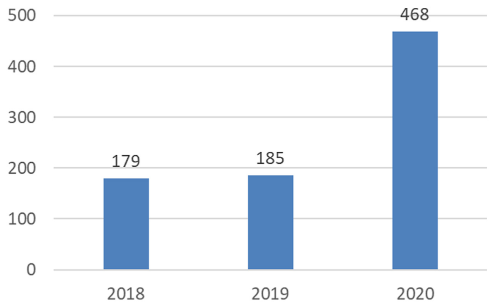

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Figure 7.
C80 series wagon's number of TPDS hunting alarms

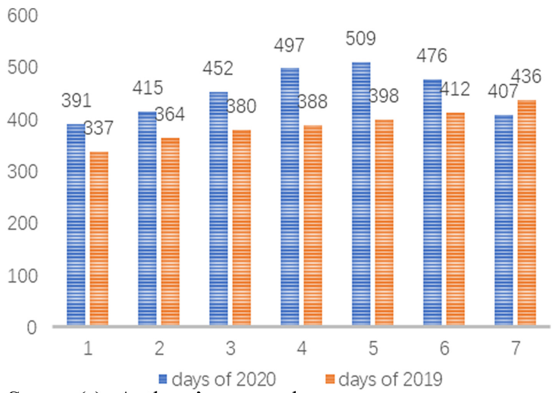

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Figure 8.
The average days between repair sections of C80 series wagons (Jan–Jul)

Table 2.
The average mileage of C80 series wagons as of Aug 2020

Condition	Samples	Average mileage (km)
All	28,545	228,989
Reach 90	265	276,958
Reach 110	34	282,912

Source(s): Authors' own work

3.2.2 Statistics in the same repair section. Take the C80 series wagons entering section-level repair in 2020 as an example. Take the measurement data from the 51C card data of the entire C80 wagon in 2020, and require data items such as income time, model, vehicle number, 1–4 axles left and right wheel diameters of income size, etc. Click on the complete data to get a total of 11,858 wagon data. Among them (Table 3), there were 341 wagons with TPDS hunting alarms and 491 alert times, and more than half of the alerts occurred in the extended period of the maintenance cycle. There were only 74 wagons with TPDS hunting alarms and 87 alert times in the same sample during the previous maintenance period.

Figure 9 counts the monthly alarms of these wagons in the last operating cycle. In the standard maintenance cycle of the latest maintenance period (24 months), the number of TPDS hunting alarms of the C80 series wagons also increased month by month. However, after entering the extension period, the number of monthly alarms nearly doubled and the highest in the 27th month, reaching 46 vehicles per month. Obviously, the extension of the repair system is the main reason for the increase in the number of TPDS hunting alarms in 2020.

4. Discussion on key factors for maintainability

Because of the increasing number of TPDS hunting alarms of C80 series wagons, the decomposition detection and statistical analysis of the C80 series wagons with TPDS hunting alarms are carried out. The decomposition test results point to the state of the wheelset and the often-contact side bearing are the key factors of TPDS hunting alarms and maintainability of wagons.

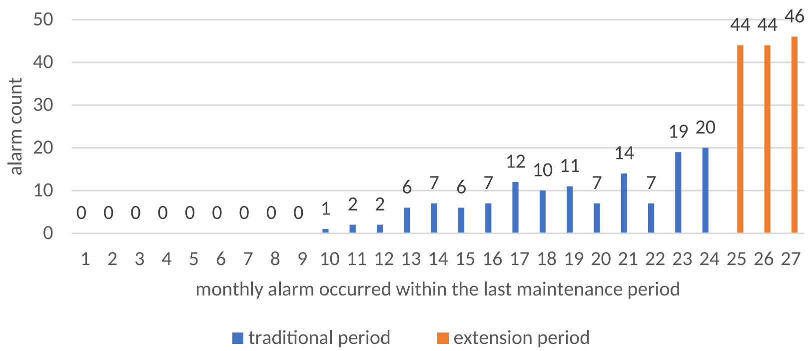
4.1 Analysis of wheelset test results

Take the measurement results of wheelsets from $C80_{BH}$4390230 with TPDS hunting alarms as an example. The wheelset has the phenomenon that the left and right wheels wear

Maintenance period	Alarm wagons	Alarm times	Alarm times within extended period
Last	341	491	210
Previous	74	87	–

Source(s): Authors' own work

Table 3. Comparison of TPDS lateral stability alarms of C80 series wagons in different repair cycles



Source(s): Authors' own work

Figure 9. The monthly data of alarms wagons in the last maintenance period

asymmetrical, and the tread wear exceeds the operating limit. The specific manifestations are the difference between the left and right wheels, including circumferential wear of tread, rim thickness and wheel diameter, which are very large. See Table 4 for details.

Figure 10 shows the measured comparison results of the tread profiles of the left and right wheels of the first axle of the $C80_{BH}$4390230. It can be seen that the tread wear of the left and right wheels of the car is very different.

Take the measurement data from the 51C card data of the entire C80 wagon in 2019, and require data items such as income time, model, vehicle number, 1–4 axles left and right wheel diameters of income size, etc. Click on the complete data to get a total of 30,380 wagon data. Query the single and network score of TPDS hunting alarms of the above wagons passing through the TPDS detection station within 60 days before the income date. Considering the influence of the wheel diameter difference on the vehicle dynamics, the maximum wheel diameter difference of the four wheelsets in the same wagon can reflect the most unfavorable wheel diameter difference, representing the wheel diameter difference for statistical analysis.

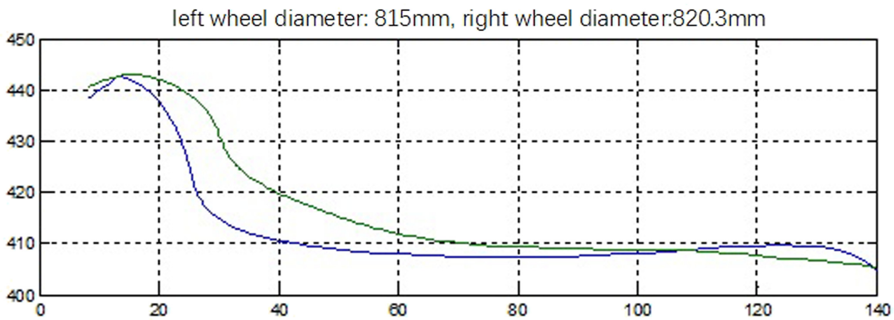
According to statistics (Table 5), the average wheelset wheel diameter difference of C80 series wagons in 2019 for section-level repair on the whole road is 2.69 mm. The middle wheel diameter difference of wagons with TPDS hunting alarms at the time of income is 3.66 mm; the average wheel diameter difference of wagons with a network score of 50 points is 5.2 mm.

Therefore, the treadwear exceeds the limit and the asymmetric wears are the fundamental reasons for network TPDS hunting alarms from the specific decomposition cases and big data statistical results.

Table 4.
$C80_{BH}$4390230 First axle wheelset test result

Wheel no.	Tread circumference wear (mm)	Rim thickness (mm)	Wheel diameter (mm)	Wheel diameter difference (mm)
1	5.6	31	820.3	5.3
2	8.1	25	815	

Source(s): Authors' own work



Source(s): Authors' own work

Figure 10.
The tread profiles of C_{80}BH 4390230 first axle

Table 5.
The average wheel diameter difference of C80 series wagons in 2019

Condition	All	TPDS alarm	Network score reach 50
Average wheel diameter difference	2.69	3.66	5.2

Source(s): Authors' own work

4.2 Analysis of side bearing test results

The side bearing is an essential part of the vehicle structure. The constant contact side bearing provides a considerable proportion of the slewing resistance torque to control the bogie shaking. So heavy haul wagons are all equipped with constant contact side bearings. Under the condition that the side bearing clearance is too large or the preload is insufficient, it is difficult for the side bearing to provide sufficient turning resistance torque for the vehicle, which will lead to a decrease in the lateral dynamic performance of the wagon in the empty state.

Measure the clearance between the lower plane of the upper and the side bearing wear plate and the upper plane of the roller in the state of the whole wagons and the distance between the plane of the side bearing wear plate and the roller in the free state and the preload of each side bearing can be obtained (Table 6).

It can be seen from Table 6 that the wagons with TPDS hunting alarms have insufficient side bearing preload. For example, the preload of the 1-position side bearing of C804373501 is only 1 mm, which is much lower than the standard value of 9 mm of side bearing preload, so the side bearing cannot provide sufficient rotational damping torque, resulting in the deterioration of lateral dynamic performance.

5. Discussion on macro-characteristic indicators

According to the analysis of the above reasons, the wheel diameter difference is a crucial factor affecting the running stability of the wagons. Therefore, the average value of the wheel diameter difference measured during the section-level repair income can be used as a macro-characteristic index to reflect the overall level of the wagon's dynamic performance. Under the premise of the original maintenance cycle, the average wheel diameter difference of the income wheelset in 2019 is 2.69 mm. This indicator has increased slightly after implementing the new maintenance cycle standard in 2020. Still, through the TPDS hunting alarms, the wagons with problems will be detained in time for temporary maintenance, which ensures the overall operational safety. Therefore, to keep the average wheel diameter difference of section-level repairs income is still con-trolled at the level of 2.69 mm to ensure that the overall safety level under the new maintenance cycle is not reduced. Lowering the current TPDS hunting network alarms from 60 points and 110 points (Da-qin line) to 50 points and 90 points (Da-qin line), respectively, to deduct and repair problems wagons timelier and more effective might be good.

6. Discussion on economic estimates

The total number of C80 series wagons in China is 79,909. According to the three-month extension, compared with 2019, there will be about 370 fewer maintenance wagons per month

Wagon	Project	Design	Position 1	2	3	4
C804373501	Completed clearance(mm)	6 ± 1	10	6.5	6.8	9.2
	Free high(mm)	15	11	11.7	13.1	12.5
	Preload(mm)	9	1	5.2	6.3	3.3
C804373749	Completed clearance(mm)	6 ± 1	8.5	10	6.5	7
	Free high(mm)	15	14	14.5	11	13
	Preload(mm)	9	5.5	4.5	4.5	6

Source(s): Authors' own work

Table 6. The often-contact side bearing test result of C80 series wagons with TPDS lateral stability alarms

in 2020, and the average monthly maintenance for TPDS hunting alarms is 39 wagons. Therefore, after implementing the new maintenance cycle, 3,972 C80 series wagons were exempted from maintenance throughout the year. Nearly 80 million yuan could be saved based on the repair cost of 20,000 yuan per wagon (Xie, Cui, Zhang, & Li, 2021). The C80 series wagon has a design life of 25 years. If calculated according to the whole life, the wagon needs about nine section-level repairs and two to three factory-level repairs. The new maintenance strategy can reduce at least one section-level or factory-level repair, saving an average cost of 100,000 yuan per wagon. According to the current calculation of 79,909 wagons in China, the accumulated saving is 7.9 bn yuan.

7. Conclusions and recommendations

Through the above analysis, it can be concluded that the extension of the repair system can significantly reduce the maintenance and operation cost of wagons. At the same time, using the TPDS hunting network alarms can accurately identify the problem vehicles, timely and effectively eliminate the hidden safety hazards in the extension of the repair process and achieve a win-win situation in railway freight safety and economy. Full-continuous wheel–rail force measurement is the key for CR to ensure safety while reducing cost.

It is recommended to take the average wheel diameter difference of section-level repairs income as the macro-control index and dynamically adjust the threshold criteria of TPDS hunting network alarms. Lowering the current TPDS hunting network alarms from 60 points and 110 points (Da-qin line) to 50 points and 90 points (Da-qin line), respectively, to deduct and repair problems wagons more timely and effective might be good.

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