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WheelRail Interface Working Group

Rail Vehicle Wheelset Back-to-Back Distance Measurement and Monitoring Practices

Abstract: This rail white paper aims to assemble the best practices for measurement and monitoring of rail vehicle wheelset back-to-back distance.

Keywords: back-to-back distance, derailment safety, vehicle/track interaction

Summary: Rail vehicles operate on a fixed guideway with the basic assumption that the wheelset assembly should not allow any movement between the wheels and the axle. This is usually ensured by using an interference fit during the mechanical assembly of the axle and wheels along with other components to form a wheelset. Any relative movement between the wheels and the axles results in changing the back-to-back distance measurement and could result in derailment of the rail vehicle. This white paper will include best practices for measurement and monitoring of the rail vehicle wheelset back-to-back distance.

Scope and purpose: This document will help agencies understand the best practices of wheelset back-to-back distance measurement and monitoring including the method of measurement and frequency of measurement. This document will cover only the back-to-back distance measurement and monitoring practices. This document will not cover wheelset assembly and press fit requirements. For commuter and intercity rail vehicles, wheelset assembly requirements are addressed in APTA PR-M-S-019-17, "Passenger Wheel Set Assembly." For rail transit vehicles, given the variability between the designs, it is best to follow manufacturer guidelines.

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Introduction

This introduction is not part of APTA RT-WRI-WP-001-23, "Rail Vehicle Wheelset Back-to-Back Distance Measurement and Monitoring Practices."

On November 1, 2021, the FTA issued Safety Advisory 21-1 to require State Safety Oversight Agencies (SSOAs) to report information to FTA regarding out-of-tolerance wheel gauges, and to advise SSOAs to require fleet-wide inspections of wheel gauges on all rail transit rolling stock in revenue service.

The safety advisory stems from the FTA and NTSB investigation of a WMATA 7000 series rail car derailment. The NTSB is still investigating this safety event, focusing on the pressed wheel–axle interface and widening wheel gauge on wheels and axles.

The practices outlined within this document are an attempt to incorporate safety management system (SMS) principles by using information from track engineering, vehicle engineering, passenger and employee incident reporting, and rail operations experts on a continuous and predictable basis. Rail agencies need to be clear in the roles, responsibilities and authorities of these teams, and also provide the time and opportunities for these teams to collaborate in order to produce the results needed.

APTA, on behalf of its rail operators, initiated the development of this white paper to collect information on rail vehicle wheelset back-to-back distance measurement and monitoring practices used by the rail industry. This white paper is intended to collect information from all rail modes including rail transit, commuter and intercity rail.

APTA recommends the use of this document by:

- individuals or organizations that operate rail transit systems;
- individuals or organizations that contract with others for the operation of rail transit systems; and
- individuals or organizations that influence how rail transit systems are operated (including but not limited to consultants, designers and contractors).

Rail Vehicle Wheelset Back-to-Back Distance Measurement and Monitoring Practices

1. Overview

Rail vehicle wheelset back-to-back dimension is an important parameter during design and operations of rail vehicles over a chosen nominal gauge track. It is the measurement between the back (inside) faces of the running wheels of a rail vehicle. This parameter must be designed and controlled to prevent rail vehicle derailments.

Currently, the rail industry has two types of wheels that are used on locomotives and cars. Wheels are either solid or resilient (multiple components) designs. Three different examples of rail vehicle wheelset designs are shown in **Figure 1**, **Figure 2**, and **Figure 3** to illustrate the back-to-back measurement (labeled "A").

FIGURE 1
Typical Example of a Resilient Wheelset Assembly

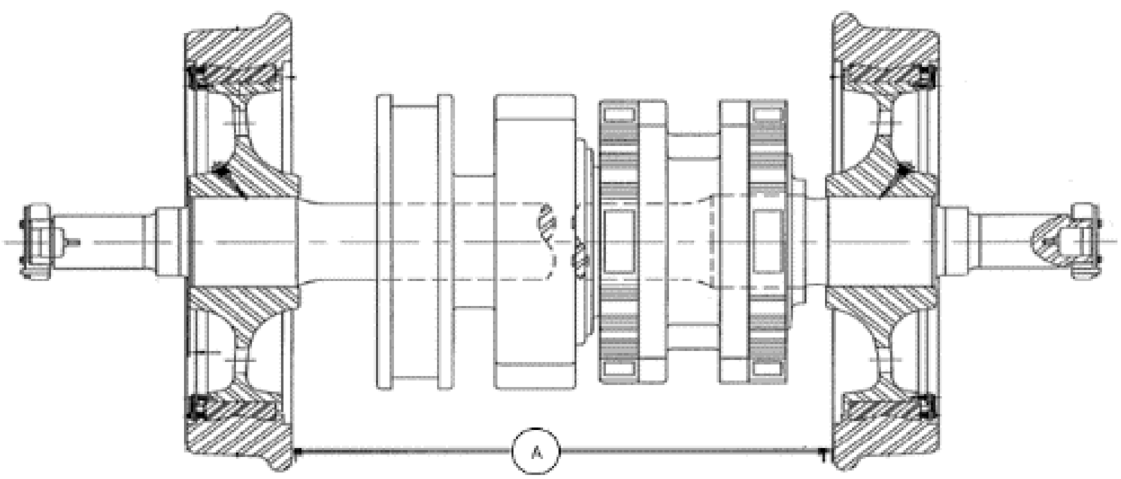


FIGURE 2
Typical Passenger Coach Wheelset Assembly with Back-to-Back Measurement Definition

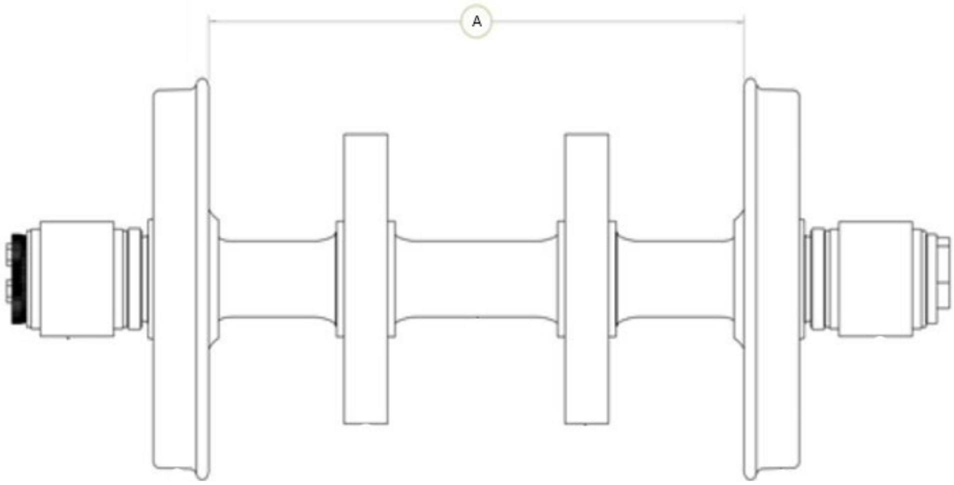
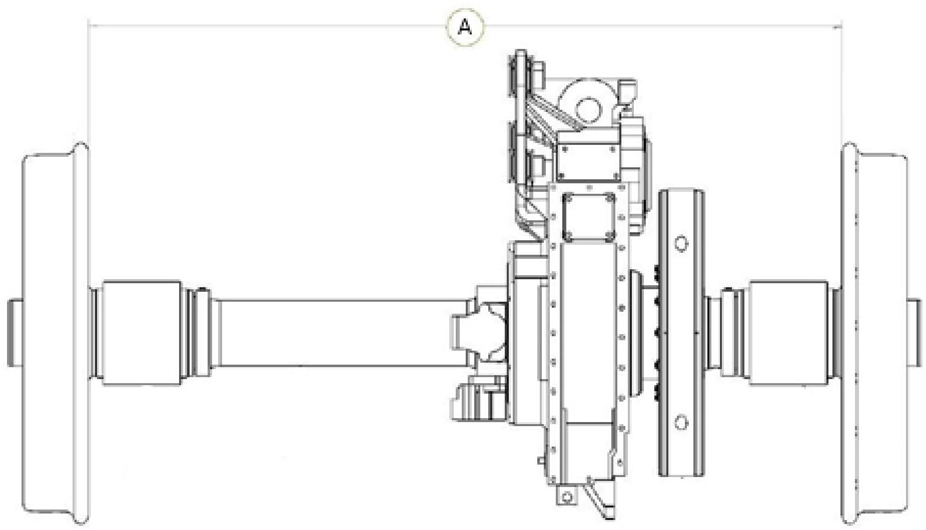


FIGURE 3
Typical Powered Multiple Unit Wheelset Assembly with Traction Motor and Back-to-Back Measurement Definition

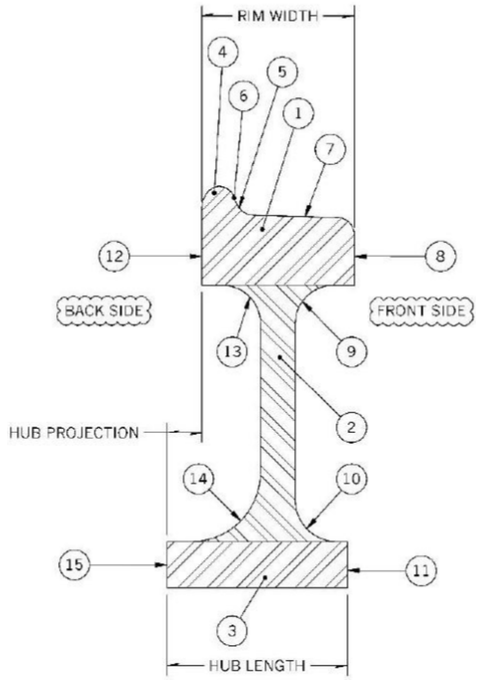


2. Requirements

2.1 Measurement terminology

The wheelset back-to-back distance is specifically the lateral (transverse) measurement between the back rim faces of the wheels on the same axle. The measurement should be made at the same relative position on both wheels perpendicular to the flat sections of the back rim faces excluding grooves, undercuts, etc. A typical wheel nomenclature is provided in **Figure 4**.

FIGURE 4
Wheel Nomenclature



Key
1: Rim
2: Plate
3: Hub
4: Flange
5: Flange throat
6: Gage point
7: Tread
8: Front rim face
9: Front rim fillet
10: Front hub fillet
11: Front hub face
12: Back rim face
13: Back rim fillet
14: Back hub fillet
15: Back hub face

2.2 Measurement approaches

2.2.1 Classification of measurement approaches

Back-to-back measurement devices can be divided into two basic classes: manual and automatic. Manual approaches are those that require human interaction to make measurements. Automated systems make measurements without human intervention.

Measurement approach for manual devices may be go/no-go, analog or digital. Automated devices typically generate digital data using noncontact approaches.

Device readings may be recorded either manually (with human intervention) or automatically by direct transfer of readings to a storage device. Manual devices may use either a manual or an automated recording system. Automatic devices typically use automatic record keeping.

In summary, back-to-back devices fall into the categories shown in **Table 1**.

TABLE 1
Classification of Back-to-Back Measurement Devices

Ref.	Device class	Data	Recording type
1	Manual	Go/no-go	Manual
2	Manual	Analog measurement	Manual
3	Manual	Digital measurement	Manual
4	Manual	Digital measurement	Automatic
5	Automatic	Digital measurement	Automatic

Various systems in existence at the time of publication of this white paper are mentioned in the following sections.

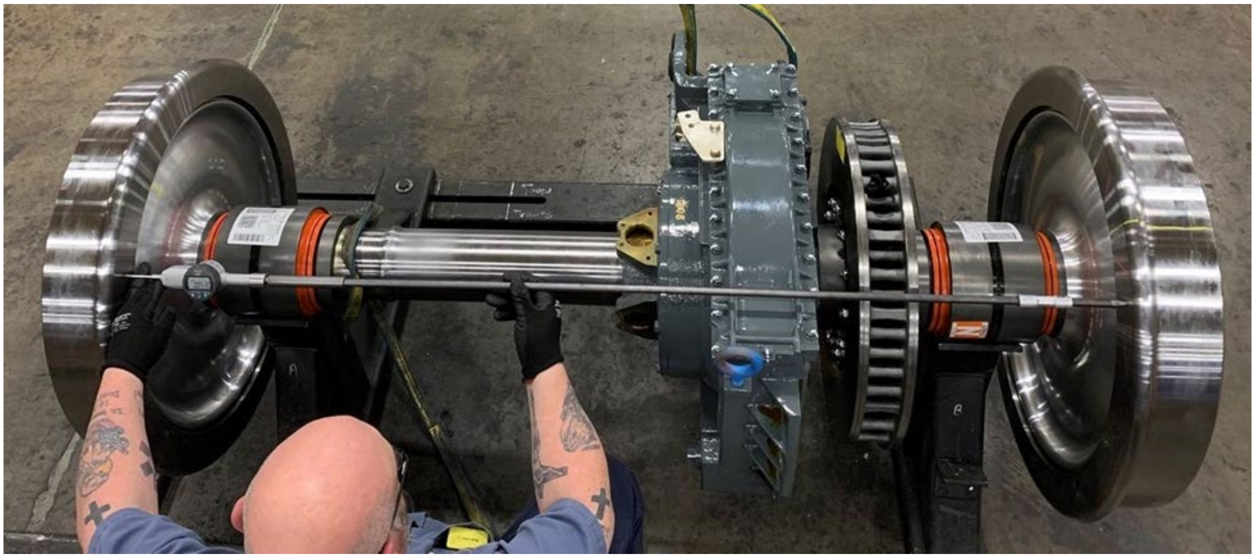
2.2.2 Analog AAR type systems

These types of devices are basic hand gauges that require the user to perform the measurement and record that measurement. These Association of American Railroads (AAR) type hand gauges are simple to attach and have a relatively low purchase cost. Typically, the graduation on these devices is $\frac{1}{16}$ in.

2.2.3 Go/no-go gauge

Some railroads use go/no-go gauges to verify that the back-to-back parameter falls within an acceptable range. This approach typically uses two gauges of calibrated lengths on the same device. The shorter of the two gauges is the go gauge and has a length set to the lowest acceptable back-to-back distance. The go gauge must fit between the back faces of the wheelset. The no-go gauge has a length set at the largest acceptable distance between the back rim faces of the wheelset and must not pass through the two wheels. This method verifies that the wheelset falls within an acceptable range but has the disadvantage of producing a “pass” or “fail” result rather than a numerical value that could be tracked.

2.2.4 Back-to-back hand gauge with digital measurement readout



This type of measurement device includes a digital readout. Typically, the accuracy of such devices is in the range of ±0.04 µm (±0.0015 in.).

2.2.5 Handheld digital systems with data storage

These devices typically are handheld systems that capture and store measurements electronically. These devices attach to the wheelset with a positive reference and utilize direct contact or laser-based approaches.

2.2.6 Direct contact units

One direct contact measurement process involves attaching a bar with two calibrated profilometers to the wheelset. This direct contact system measures each of the wheels with a profilometer, as well as the back-to-back distance capturing each measurement at the same specific measurement point on both wheels. Measurements and the wheel profiles are transmitted to a digital notebook or tablet PC.

2.2.7 Handheld laser-based units

There are handheld laser-based systems available as well. The one shown above, with the optional clamping mechanism, attaches to the wheel in a similar fashion to the direct contact back-to-back system. Once attached, this laser unit is used to scan two rings located on the bar to capture back-to-back distance. Measurements are electronically captured and stored in the unit and/or on a computer.

2.2.8 Automated measurement

Back-to-back measurements may also be performed by automated wheel profile measurement systems. Measurements, including profile wear and back-to-back, are collected as the rail vehicle passes over the measurement system. The measurement system also typically collects vehicle number, axle, wheelset and wheel identification using the vehicle's RFID tag and uses this to collate data in a database. The data that is collected can be used to flag exceptions, perform fleet analyses, and implement proactive back-to-back maintenance activities as supplemental data to periodic inspections. The most common methods for automated wheel profile measurement are laser-based technologies, but other methods are also available.

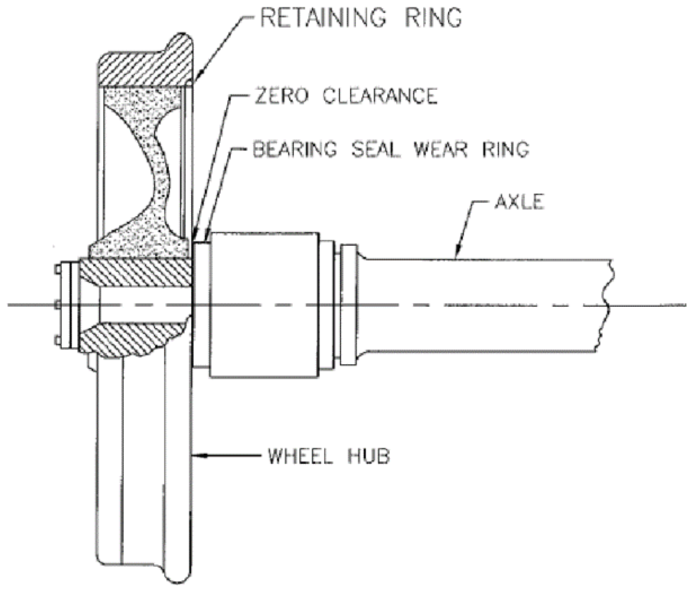
2.2.9 Alternative strategy

An alternative method to repeatedly measuring back-to-back distance from the back rim faces is to instead monitor for deviation from an initially measured back-to-back distance from the back rim faces as described in the sections above. In this scenario, the back rim face back-to-back dimension is measured with great accuracy at axle build or overhaul. Then once in service, if there is another dimension that can be verified to maintain this relationship, that is the dimension that is checked.

This approach is useful in vehicles with inboard mounted bearings, where the axle bearings are pressed against a bearing shoulder on the axle and the wheel centers are pressed against the bearing. If a sufficient tonnage spike is achieved, it can be assured that the wheel center and bearing are fully seated against the rolled axle lip.

While these vehicles are in service, a technician can easily inspect this interface between a wheel center and bearing seal wear ring for zero clearance with a feeler gauge during regularly scheduled maintenance intervals. If there is no gap between the two, it can be assured that no relative movement has occurred between the wheel bore and axle seat, and the initially measured back-to-back distance between back rim faces has not changed. See **Figure 5**.

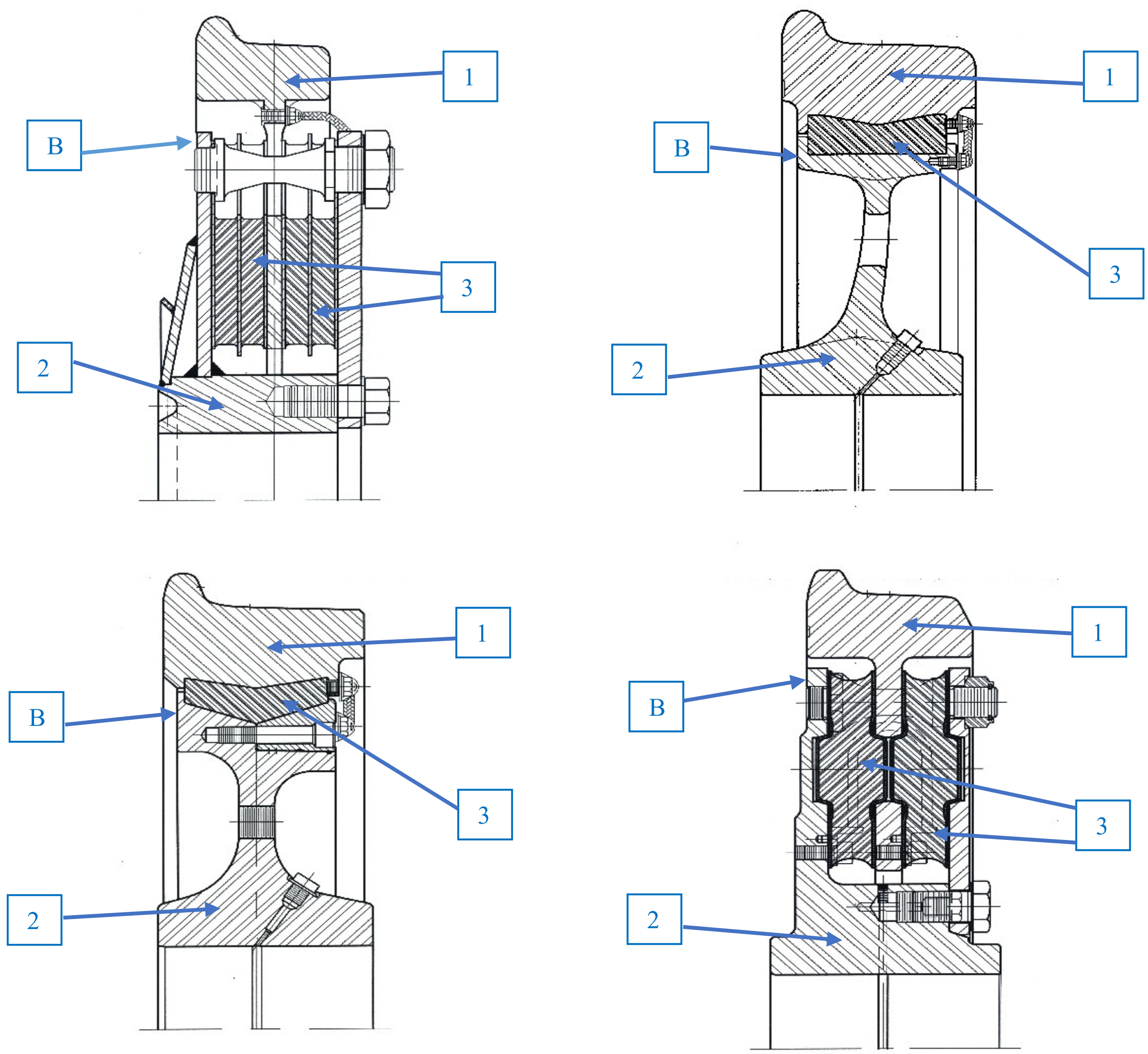
FIGURE 5
Inboard Bearing Wheelset



2.2.10 Resilient wheelsets

Check with the wheelset designer for the applicability of this whitepaper to trucks that do not contain traditional axle designs.

FIGURE 6
Resilient Wheel Nomenclature



Key: 1: Tire, 2: Wheel hub, 3: Resilient elements

Resilient wheels, which are generally made up of a wheel hub or hub assembly, a wheel tire or rim, and a resilient (elastomeric) element between the two, require a different approach from monobloc wheelsets when measuring back-to-back distances. Actual back-to-back distances measured at the back rim face of the tires may vary considerably in service due to the resilient elements. The proper approach is to measure the distance between the outermost area of the hub (noted as point "B" in **Figure 6**) on the axle and then to check the condition of the elastomers. As there are many types of resilient wheels, check with the OEM for "in service" elastomer inspection criteria. Use the distance measurement between wheel centers along with the elastomer inspection results to evaluate a wheelset's acceptability for service.

If there is a mechanical interference preventing a direct measurement between wheel hubs at point B shown above, then measure the back-to-back between tires and also measure the distance between the tire and hub at point B on both wheels. The measurements between the tire and hub need to be taken in the same area the back-to-back measurement was taken on the tires. Add or subtract (as appropriate) the distance measured between the tire and hub on each wheel to the back-to-back measurement between tires to determine the back-to-back distance between wheel hubs.

2.3 Tolerances

Wheelset back-to-back tolerances are largely specific to the wheelset design. The tolerance is influenced by a number of factors and is generally chosen during the system design phase.

The typical back-to-back tolerance in the freight industry is 0.125 in. For transit systems, back-to-back tolerances range from 0.040 to 0.286 in. This considers transit systems ranging from streetcars traveling short distances at low speeds to commuter rail and Amtrak trains traveling long distances at higher speeds.

Due to the wide range of trains that encompass "rail transit," a single tolerance for back-to-back cannot be set. The original design tolerance for each wheelset should be followed in lieu of an industry standard applicable across all modes of rail transit. Consult OEM drawings to find the tolerance for individual wheelset designs.

Temperature and weight variance may also be considered when measuring back-to-back distance during maintenance.

2.4 Measurement frequency

In general, it is recommended that rail agencies obtain and follow locomotive/car manufacturer(s) indicated procedures and time intervals for wheelset back-to-back measurements. If the agency wants to conduct less frequent measurements than the manufacturer's recommendation, an approval process for the change must go through a hazard analysis and safety risk evaluation. Once fully approved, the frequency of measurements should be adopted into the written procedures and/or SOPs.

The initial wheelset back-to-back measurement is conducted whenever new wheels or wheel centers are pressed onto an axle by qualified individuals following documented procedures. If no such time interval for wheel back-to-back measurement is indicated by locomotive/car manufacturer(s), then at a minimum, the following time interval of wheelset back-to-back measurements should be conducted:

- at initial wheel/wheel center installation
- at resilient wheel servicing
- when abnormal wheel wear, such as excessive flange wear, is indicated
- in the event of a derailment

Locomotives require that the back-to-back distance be checked as part of 49 CFR 229.23. This also applies to cab cars and MUs but is not required for coaches.

Some operational datapoints are as follows:

- A current Tier II (up to 150 mph) operation measures the whole trainset every 14 days.
- Existing intercity Tier I trains get measured every 92 days.

- An upcoming Tier III (up to 160 mph) operation intends to measure back-to-back on a daily basis.
- A rail transit agency that operates up to 80 mph includes back-to-back measurement as a part of its normal scheduled maintenance when a car comes into a shop for a 60-day or 90-day inspection, depending on the fleet design. Additionally, wheel to journal bearing gap checks are conducted at the same time.
- Another rail transit agency that operates a heavy and light rail system (maximum operating speed of 60 mph) conducts these measurements every 30 days.
- Another rail transit agency has conducted this measurement annually but is moving to a 60-day interval. This same agency also operates commuter rail where the measurement is conducted every 92 days or 184 days depending on fleet design.
- Another rail transit agency conducts this measurement every 120,000 miles.

TABLE 2
Preventive Maintenance Procedures (example)

1 Month		
4016(A) 4041(B) 4051(C)	Axles, Wheels & Tires	1. Check condition and security of wheel shunts. 2. Inspect each wheel for cracks, shelling (pieces of metal breaking off), flat spots, and grooving, etc. of the tread. Look for misshapen rims, metal buildup and any other defects. 3. Check for indication of loose wheel/tire or wheel/tire movement. Check the tire resilient rubber blocks for evidence of movement, through cracks and dislodged rubber blocks. 4. Inspect axles for fatigue cracks or other defects. 5. Inspect axle coupling elements (spiders and bushings) for damage or any abnormal condition. 6. Check rail guard to rail head clearance to be 3½ to 4½ in. 7. Visually inspect rail guard hardware to ensure that torque seal is not broken. If torque seal is broken, replace hardware, torque to 150 ft lbs. and apply new torque seal. (Confirm that ATS coil height is correct after adjusting rail guards.)
6 Months		
4402	LRV Tire Measurement Test	1. Use the OptiWheeler or another approved tire measurement system in place to measure all tire sizes. a. Condemning limit for wheel is 26.0 in. b. Any trucks that show 0.050 in. wear between profile template and wheel tread at the tapeline require reprofiling. Hollow tread limit for revenue service is 0.100 in. 2. If any tires are found to be out of spec, generate a service request from the PM checklist. 3. Enter test results into Maximus test page.
4424	Back to Back Wheel Measurement	1. Check back-to-back wheel measurement using back-to-back go/no-go gauge. Measure the tire at two points along the inside of the flange, taking the measurements approximately 120 deg. apart from each other. Condemning limit is less than 53 in. and greater than 53½ in. 2. If any wheelsets are found to be out of spec, generate a service request from the PM checklist. 3. Enter test results into Maximus test page.

2.5 Infrastructure considerations

Known infrastructure indicators primarily involve the gauge of restrained/guarded track. Influences on wheel gauge migration come from configurations of track in which the wheels are straddled by rail located within the wheel gauge. These track configurations include where double guarding exists and frog locations adjacent to the guard/check rail on turnouts. Double guarding and frog locations must not have guard face gauge that meets or exceeds the wheel back-to-back gauge, as the back of wheel flanges will be squeezed across these rails. During such conditions, the back of wheels will receive an outward pushing force that would directly influence wheel gauge migration.

Frequent inspection measurements of guard face gauge and proper installation of the restraining rail and frogs at the appropriate gauge standard, being smaller than the wheel back-to-back gauge, are the best approaches to avoid and limit wheel migration influences. Rapidly progressing rail wear along the gauge face of restraining rails indicates that the guard face gauge may be improper and too wide for double-guarded track. This may be seen at frog locations where a guard face gauge is too large; the wing rails of the frog and the adjacent guard rail would crowd the wheels. Evidence of this would be wear on the gauge side of the frog's wing rail, as wear in this location typically does not occur. The positioning of the frog and the flangeway or the adjacent guardrail must be checked with conformance with standards. Additional guidance for FRA-regulated properties can be found in 49 CFR 213, Track Safety Standards.

Maintenance-of-way departments should incorporate into track inspection sheets standardized conditions that track inspectors are required to be looking for and recording during each track inspection. This would need to be supported with training of these track inspectors to ensure consistent and reliable observations. The focus should be on infrastructure damage, such as horizontal/vertical guardrail damage, and excessive or unusual wear at interlocking, switches, crossovers and frogs.

Ensure that track inspections personnel note unusual wear near interlocking and curves, and instruct these personnel on how to record those observations in a consistent manner, using standardized language and labels, in inspection records.

Track inspection observations need to be standardized using standard language to describe observed track conditions, which will enable useful data mining. Frontline maintenance supervisors of track inspectors, supervisors of rail operators and compliance managers for track inspections/maintenance departments should also be trained on the expectations of how to scour these inspection records to gain useful information that might indicate wheel migration of rail cars. The departments that these individuals work in should have a mechanism for this information to be shared with track engineering and vehicle engineering departments, at predictable intervals.

2.6 Recordkeeping

It is important to measure and capture wheelset back-to-back distance in a consistent manner so data can be compared over time. With properly aligned data, railways can do more than identify back-to-back distance exceptions; they can trend data to see if there have been any significant changes over time.

Whether measurements are collected manually or automatically, data should be organized with stock number (owner), vehicle number, bogie/truck number, axle number and wheel ID. The latter is also important should other inspection and measurement activities be conducted at the same time, such as wheel profiles measurement, wheel damage assessment, etc.

Once wheelset locations are identified, measurements may be consistently added and correlated for longer-term analyses. Collection should also be based on a consistent scheme where inspection begins at either the A-end or B-end of the vehicle. For example, when starting at the A-end of a vehicle with three bogie/truck design, measurements and recordkeeping would be captured as axles 1, 2, 3, 4, 5 and 6. If inspection were to begin at the B-end of the same vehicle, measurement and record keeping would be captured as axles 6, 5, 4, 3, 2 and 1. In this manner, regardless of which end of the vehicle is selected, the collected data can be aligned.

2.7 Data analysis

If resources allow, rail agencies may benefit from analyses that extend beyond the immediate measurement of a single wheelset. Considering the measurements across an entire fleet, or the measurements from a single wheelset over its lifespan, can enable maintenance practices that shift from a reactive approach to a proactive one. This enables the identification of problematic wheelsets before they exceed limits for back-to-back spacing and allows them to be replaced as part of the normal maintenance cycle of the vehicle. This can reduce unplanned vehicle maintenance activities and therefore contribute to improved vehicle availability and service reliability.

The type of measurement approach employed by the agency may preclude the application of some types of analyses. Binary go/no-go data is not suitable for these proactive maintenance strategies, as it offers no advance warning that a wheelset will exceed the prescribed limits. Further, the influence of differing measurement procedures between maintenance personnel should also be considered, as it could increase the variability of measurements and obscure emerging trends.

The effective sample size provided by the data should also be considered. A higher inspection frequency increases the number of measurements per wheelset, which benefits trending analyses utilizing historical data. Similarly, a larger fleet enables the use of a wider variety of statistical analyses but may preclude the ability of one individual or group of individuals from effectively monitoring the entire fleet, necessitating the use of more automated approaches.

The analysis approaches considered in this section can broadly be grouped into three categories: manual, semi-automated and fully automated.

2.7.1 Manual analysis

This approach is characterized by a manual review of measurements by maintenance personnel to identify outliers. Readily available tools as spreadsheet and database applications may be utilized to both store and visualize the data. Analyses may be scheduled or initiated on an ad hoc basis and allow the individual performing the analysis to take immediate action to report or correct the identified problem.

While this approach can provide sufficient predictive capabilities on its own, it might also be employed as an ad hoc supplement to the other approaches discussed below for deep dives or specific investigations.

2.7.2 Semi-automated analysis

This approach is characterized by a manual application of established rules, involving statistical analyses focused on wheelsets exceeding defined limits, standard deviations, percentiles of measurements, or trending rates of change of a running average for measurements from a specific wheelset. Handheld digital instruments that electronically capture and store measurements also come with software application to batch process and automate vehicle and fleet analyses. Data is typically stored in a digital, tabular format such as spreadsheets and databases. It may be employed to filter, analyze, and visualize the data. Analyses can be manually scheduled or initiated on an ad hoc basis. Reporting or correction of identified problems is manually initiated by the individual performing the analysis.

2.7.3 Fully automated analysis

This approach is characterized by the application of big data principles for data management and analysis, where exceptions can be flagged and trending of multiple measurements can be performed to identify and predict problematic wheelsets. Data is typically stored in a centralized database that can be locally or cloudbased, with the ability to incorporate data from multiple measurement systems. Retention of data is desirable for long term trend analysis. Exceptions may be reported via automated email alerts or to the enterprise asset management (EAM) system to generate work orders, if the system is connected to the agency's asset management system. A dedicated team is typically employed or retained to develop and maintain the infrastructure and processes required to support this approach.

Related APTA standards

APTA PR-M-S-019-17, "Passenger Wheel Set Assembly"

Abbreviations and acronyms

AAR	Association of American Railroads
ATS	Automatic Train Stop/Automatic Train Supervision
FTA	Federal Transit Administration
MU	multiple unit
NTSB	National Transportation Safety Board
OEM	original equipment manufacturer
RFID	radio frequency identification
SMS	safety management system
SOP	standard operating procedure
SSOA	State Safety Oversight Agency
WMATA	Washington Metropolitan Area Transit Authority

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