Transportation Safety Board of Canada
Bureau de la sécurité des transports du Canada

RAIL TRANSPORTATION SAFETY INVESTIGATION REPORT R18W0007

MAIN-TRACK TRAIN DERAILMENT

Canadian National Railway Company
Freight train M31731-04
Mile 166.33, Redditt Subdivision
Rennie, Manitoba
06 January 2018

Canada

ABOUT THIS INVESTIGATION REPORT

This report is the result of an investigation into a class 3 occurrence. For more information, see the Policy on Occurrence Classification at www.tsb.gc.ca

The Transportation Safety Board of Canada (TSB) investigated this occurrence for the purpose of advancing transportation safety. It is not the function of the Board to assign fault or determine civil or criminal liability.

Citation

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Summary

On 06 January 2018, at about 0125 Central Standard Time, Canadian National Railway Company freight train M31731-04 was proceeding westward at about 50 mph on the Redditt Subdivision when it experienced a train-initiated emergency brake application. A subsequent inspection revealed that 23 cars (the 38th to the 60th car from the head-end) had derailed at Mile 166.33. Eight of the derailed cars, which included 1 residue car, were transporting dangerous goods. There were no injuries, and no product was released.

1.0 FACTUAL INFORMATION

1.1 The accident

On 04 January 2018, Canadian National Railway Company (CN) freight train M31731-04 was assembled at CN's MacMillan Yard in Vaughan, Ontario. In accordance with regulatory requirements, a mechanical certified car inspection (CCI) was performed on the train's freight cars, during which no defects were noted. The train then departed westward, destined for Winnipeg, Manitoba. While en route, in accordance with regulatory requirements, the train received a total of 5 pull-by inspections at various terminals. In addition, the train traversed a number of CN automated wayside inspection systems (WISs), which noted no defects.

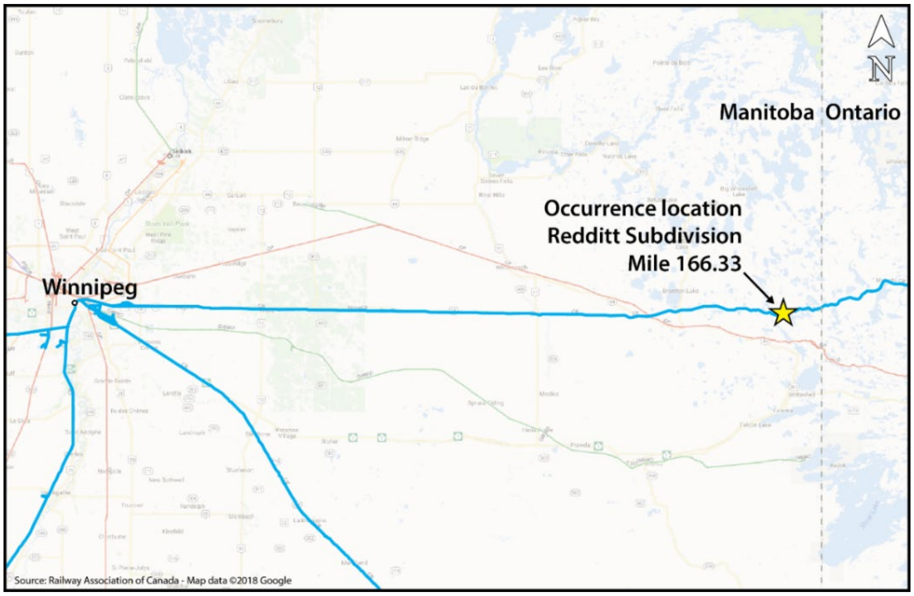
On 05 January 2018, at about 1925 Eastern Standard Time,[1] the train departed Sioux Lookout, Ontario, on CN's Redditt Subdivision. The train was composed of 2 head-end locomotives, 21 loaded cars, 32 empty cars, and 11 residue tank cars. The train weighed about 4343 tons and was approximately 4334 feet long. The crew consisted of a locomotive

1 All times are Central Standard Time unless otherwise indicated.

engineer and a conductor. Both crew members were qualified for their respective positions, were familiar with the territory, and met established fitness and rest standards.

On 06 January 2018, at about 0125, the train was proceeding westward at 50 mph near Mile 166.7 of the Redditt Subdivision with the throttle in position 3, when an undesired train-initiated emergency brake application occurred (Figure 1).

Figure 1. Map showing the occurrence location (Source: Railway Association of Canada, Canadian Railway Atlas, with TSB annotations)



A subsequent inspection determined that 23 cars, the 38th to the 60th from the head-end, had derailed at Mile 166.33.

Eight of the derailed cars were carrying dangerous goods: 3 tank cars were loaded with liquid hydrocarbons (UN 3295), 1 tank car was loaded with petroleum distillates (UN 1268), 1 tank car was loaded with a corrosive liquid (UN 3264), 1 tank car was carrying a residue amount of liquefied petroleum gas (UN 1075), and 2 gondola cars were loaded with 54 bags of nickel sulphides (UN 3077).

There were no injuries, and no product was released.

At the time of the occurrence, the temperature was −29 °C, with the wind at 11 km/h from the northeast.

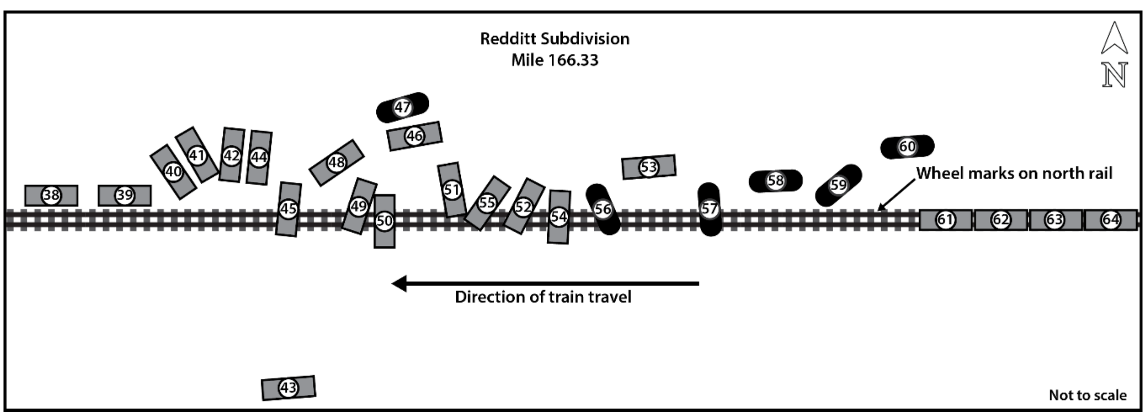
1.2 Site examination

The first 2 derailed cars were the 38th and 39th cars from the head-end, which had overturned to the north side of the track. Both were open-top gondola cars, loaded with bags of nickel sulphides that spilled onto the railway right-of-way (Figure 2). However, no product was released from the bags.

Figure 2. Nickel sulphide bags spilled from first derailed car (Source: TSB)

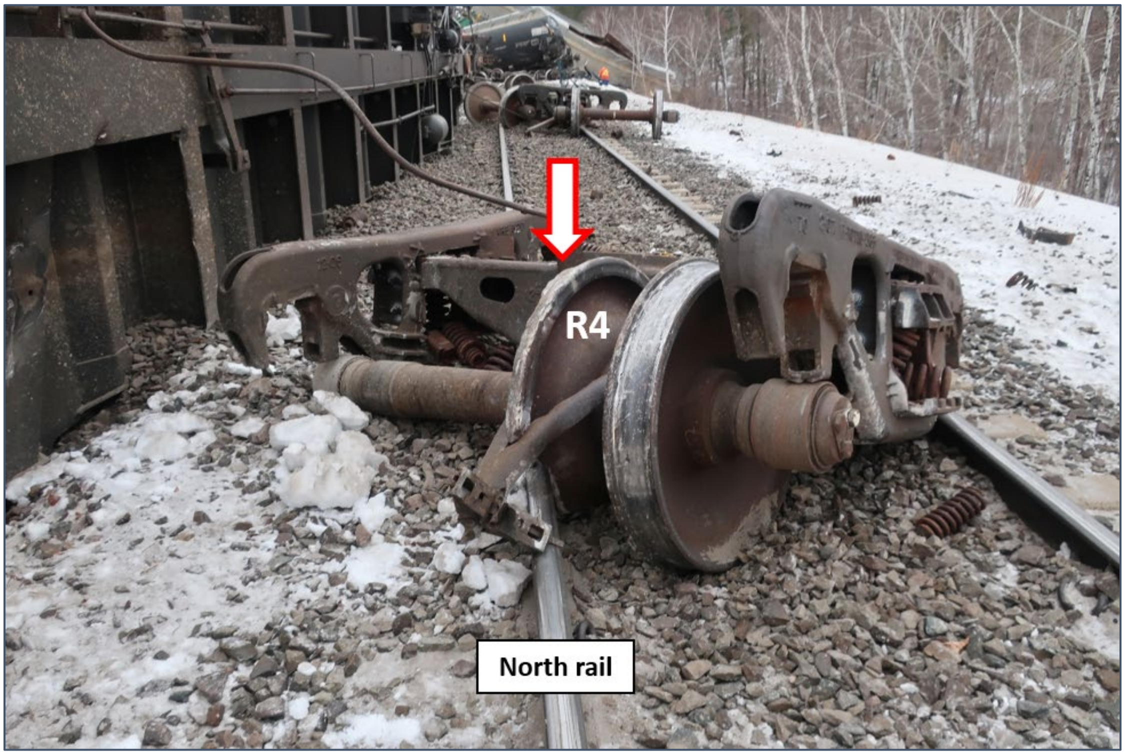
The following 21 cars had derailed and come to rest either to the north of, or along, the track in various positions over the following 650 feet (Figure 3).

Figure 3. Site diagram showing location of derailed cars after the accident (Source: TSB)



The 38th car (car ATW 400515), the first derailed car, had come to rest at Mile 166.48. The car's trucks were on the track next to the ends of the car. The R4 wheel from the leading A-end truck of the car had broken, come off its axle wheel seat, and moved inboard along the axle body before coming to rest against the L4 (mate) wheel (Figure 4).

Figure 4. The R4 wheel of car ATW 400515 (indicated by the arrow) had been displaced from the axle wheel seat and had moved inboard adjacent to the L4 wheel, coming to rest on the north rail. (Source: TSB)



The R4 wheel rim had fractured circumferentially. The outer portion of the rim was not recovered. The tread and flange were damaged, and a section of the wheel tread and plate had broken away. Two additional pieces of the wheel were found between the rails about 100 feet and 190 feet east of the truck, respectively. A 6-inch portion of the wheel rim/tread was never located. The wheel and recovered wheel pieces were forwarded to the Transportation Safety Board of Canada (TSB) for detailed examination.

At the east end of the derailment site, a wheel mark was observed on the running surface of the north rail at Mile 166.33, starting in the middle of the running surface and extending westward for about 9 inches toward the gauge side of the rail. A small piece of wheel tread was observed between the rails adjacent to the wheel mark. Immediately west of the wheel mark, there was damage to the track fastener (gauge side) and to the concrete tie (Figure 5).

Figure 5. Wheel marks on the top of the north rail and the damaged gauge-side track fastener and tie (shown in the box) at Mile 166.33 (Source: TSB)

Three feet further west, the tie was damaged on the field side of the south rail, and, about 15 feet beyond the wheel mark, the north rail was broken (Figure 6).

Figure 6. Broken north rail 15 feet beyond the wheel mark on top of the rail (Source: TSB)

1.3 Subdivision information

The CN Redditt Subdivision extends westward from Sioux Lookout (Mile 0.0) to Winnipeg (Mile 252.1). Train movements on the subdivision are governed by the centralized traffic control system, as authorized by the *Canadian Rail Operating Rules,* and supervised by a rail traffic controller (RTC) located in Toronto. The authorized track speed for westbound freight trains through the area of the derailment was 50 mph. At the time of the occurrence, there were no slow orders in effect.

The track was classified as Class 4 according to the Transport Canada (TC)–approved *Rules Respecting Track Safety*, also referred to as the Track Safety Rules. In 2017, an average of 16 freight trains per day traversed the Redditt Subdivision, and the annual rail traffic was 50.2 million gross ton-miles per mile.

1.4 Track information

The track at Mile 166.33 was tangent with a slight ascending grade in the direction of travel (westward). The track consisted of 136-pound continuous welded rail, manufactured in 1976 by Sydney Steel Corporation, mounted on concrete ties. The rail was secured to the concrete ties with 4 spring clips and insulators per tie. The ties, tie pads, and insulators were generally in good condition. The ties were supported by ballast as per CN standard.

During the most recent track geometry test, conducted in the vicinity of Mile 166.33 on 13 November 2017, no urgent or near-urgent track defects were identified. The most recent ultrasonic inspection of the rail had been conducted on 15 December 2017, and no defects had been noted near the east end of the occurrence site. On 04 January 2018, the track supervisor had conducted a visual inspection of the track and noted no exceptions.

1.5 Failure modes of broken wheels

Although wheel sets can be removed for a number of wheel tread, rim, and flange defects, broken wheels predominantly result from either a shattered rim (SR) failure or a vertical split rim (VSR) failure.

1.5.1 Shattered rim wheel failure

SR wheel failures are typically related to manufacturing defects that progress horizontally in a plane parallel to the wheel tread surface. These defects become exposed to the wheel tread running surface, resulting in the surface breaking away owing to wheel tread shelling[2] or spalling.[3] Since in-service wheel failures often result in derailment, sometimes with significant adverse consequences, the industry has introduced several initiatives to reduce such failures:

- Since the early 1990s, when the most common wheel failures were those due to an SR defect, railway wheel manufacturers have improved the quality of wheel steel through enhanced casting/forging, heat treating, and quality control processes.
- In the early 1990s, the railway industry introduced wheel impact load detectors (WILDs) as part of the expanding WIS network. This technology was primarily designed to protect track from wheel impacts; however, wheels with emerging SR defects exhibit wheel tread surface anomalies or defects that would generate a higher-than-usual wheel tread impact. Once the wheels were identified by a WILD, they could be removed from service before they caused further damage to track infrastructure and to rolling stock components, or before they failed.
- In the early 2000s, the Association of American Railroads (AAR) required railway wheel shops to implement ultrasonic testing (UT) for the wheel tread surface of reprofiled (previously used) wheels to detect sub-surface defects during wheel set reconditioning. Wheels with such defects could then be removed from the supply chain, eliminating the risk of an SR wheel failure. However, there was no requirement for UT of the rim face of reprofiled wheels.

These initiatives began to reduce the number of in-service SR wheel failures.

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2 Shelling is when contact rolling fatigue leads to checking or cracking on a wheel tread surface, eventually causing small pieces to chip out.

3 Spalling is a wheel tread defect resulting from a thermal event, such as wheel slide, in which high temperatures are followed by the rapid cooling of the surrounding metal, resulting in a patch of hard, brittle martensite.

1.5.2 Vertical split rim wheel failure

In contrast to SR failures, VSR wheel failures tend to originate from wheel tread surface conditions such as checking, spalling, or shelling, and usually occur at 90° (perpendicular) to the tread surface (i.e., parallel with the wheel rim face). Because of their orientation, VSR defects are unlikely to be detected using the current wheel shop UT method. VSR wheel failure continues to be studied by the rail industry and is not yet fully understood.

Research into wheel residual stress patterns and VSR failures has determined that service-worn Class C wheels exhibit compressive residual stress at the wheel tread, which is balanced by tensile axial stresses deeper in the rim.[4] When cracks from the tread surface propagate into this sub-surface axial tensile zone, VSR failure can occur under additional service loads. Wheels that may have emerging VSR defects and that record impacts do not always exhibit significant wheel tread damage. In these situations, the wheel tread surface can sometimes deteriorate rapidly, and this may not always be detected by a WILD.

The AAR Transportation Technology Center, Inc. (TTCI) conducted a study[5] that examined 24 broken wheels. VSR was the failure mode for 17 (71%) of these wheels, and WILD data were available for 12 of them, of which 6 had a recorded impact load that exceeded 90 kips[6] before failure.

1.6 Wheel impact load detectors

In the early 1990s, WILD technology was developed and implemented as an industry initiative to enhance safety by proactively identifying and removing wheels with tread defects that could generate high impact loads on rail.

WILD systems are WISs that are usually installed on tangent track with an authorized track speed of 50 mph. They are intended to record the measured impact at track speed. The measured wheel impact force is directly related to speed: the faster a train travels, the greater the measured wheel impact force will be if a wheel tread defect is present. Similarly, the slower a train travels, the lower the measured wheel impact force will be.

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4 C. Lonsdale and J. Oliver, "Further research into wheel rim axial residual stress and vertical split rim failures," Proceedings of the ASME/ASCE/IEEE 2012 Joint Rail Conference, Philadelphia, Pennsylvania (17–19 April 2012).

5 Transportation Technology Center, Inc., Technology Digest TD-09-008, *Broken Wheel Inspections* (March 2009).

6 1 kip = 1000 pounds of force.

1.7 Regulatory requirements for wayside inspection systems

The TC-approved *Rules Respecting Key Trains and Key Routes* require a company to perform an inspection of any bearing of a key train[7] that is reported to be defective by a wayside defective-bearing detector.

The TC-approved *Railway Freight Car Inspection and Safety Rules* do not have any provisions for condemning in-service wheels due to high wheel impact loads. There are currently no regulatory requirements or guidance for WILD thresholds used in Canada or the United States.

Following several incidents and accidents involving broken wheels (Appendix A), in December 2011, the TSB issued Rail Safety Advisory Letter 11/11, "Broken Wheels with Previous AAR Condemnable WILD Readings." In response to this letter, TC indicated that

- it would create a joint TC–industry forum to undertake a comprehensive review of WIS and WILD criteria; and
- it might, based on this review, create guidelines, standards, or rules governing the use of WIS, including WILD.

To date, there has not been any significant progress by TC in establishing guidelines, standards, or rules for the use of WILD technology.

1.8 Association of American Railroads wheel impact load detector wheel-removal thresholds

Rule 41 of the *2018 Field Manual of the AAR Interchange Rules* states, in part

> Rule 41
>
> STEEL WHEEL DEFECTS—OWNER'S RESPONSIBILITY
>
> A.1. Condemnable at Any Time
>
> [...]
>
> r. Wheel Out-of-Round or 90,000 Pounds (90 kips) or Greater Maximum Peak Impact.
>
> (1) Detected by a wheel impact load detector reading 90,000 pounds (90 kips) or greater for a single wheel. The detector used must meet the calibration and validation requirements of *MSRP* [*Manual of Standards and Recommended Practices*] Section F, Standard S-1601. The detector must reliably measure peak impacts and must provide a printable record of such measurements. Device calibration records

7 The term "key train" is defined as "an engine with cars

a) that includes 1 or more loaded tank cars of dangerous goods that are included in Class 2.3, Toxic Gases, and of dangerous goods that are toxic by inhalation subject to Special Provision 23 of the *Transportation of Dangerous Goods Regulations*; or

b) that includes 20 or more loaded tank cars or loaded intermodal portable tanks containing dangerous goods, as defined in the *Transportation of Dangerous Goods Act, 1992* or any combination thereof that includes 20 or more loaded tank cars and loaded intermodal portable tanks." (Source: Transport Canada, *Rules Respecting Key Trains and Key Routes*, Section 3.4)

> must be maintained. Wheels with condemnable slid flat spot(s) are handling line responsibility and must not be billed otherwise.
>
> […]
>
> A.2. Condemnable When Car Is on Shop or Repair Track for Any Reason
>
> […]
>
> e. Detected by a Wheel Impact Load Detector reading a Maximum Peak from 80 kips to less than 90 kips for a single wheel. The detector used must have been calibrated per *MSRP* Section F, Standard S-1601. The detector must reliably measure peak impact and must provide a printable record of such measurements. Device calibration records must be maintained. Wheels with condemnable slid flat spots are handling line responsibility and must not be billed otherwise. This will be considered an Opportunistic Repair for the repairing party. Wheels removed for this condition are not to be stenciled SCRAP as referenced in Rule 41.E.8.c.

While Rule 41 section A.1.r identifies WILD criteria for which wheels can be condemned at any time, it does not require immediate removal of wheels that meet the AAR-condemnable criteria.

Similarly, section A.2.e of Rule 41 identifies WILD criteria for which wheels can be condemned when a car is on a shop or repair track for any reason, but, similarly, it does not require the removal of the wheels that meet the AAR condemnable criteria.

The AAR Wheels, Axles, Bearings and Lubrication Committee was responsible for developing and implementing Rule 41. It decided to use 90 kips as the condemning limit based on a number of technical studies conducted in the early 1990s.[8] Engineering analysis from these studies supports 90 kips as a wheel-removal threshold that would help limit the damage to both equipment and track infrastructure.

1.9 Wheel impact load detector thresholds established by Canadian railways

In addition to the AAR condemning limits for wheel impacts, Canadian railways have developed their own wheel-removal thresholds. Typically, these thresholds are based not on engineering analysis but on each railway's operating practices and conditions as well as its capacity to manage the volume of wheels removed following WILD-recorded impacts. The WILD wheel-removal thresholds for each railway vary throughout the industry and have evolved over time.

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[8] S. Kalay and A. Tajaddini, Transportation Technology Center, Inc., Research R–754, *Condemning Wheels Due to Impact Loads: Preliminary Survey – Six Railroads' Experience* (February 1990).
A. Tajaddini and S. Kalay, Transportation Technology Center, Inc., Research R–810, *Vehicle/Track System Response Due to Condemnable Wheel Tread Defects* (April 1992).
S. Kalay, Transportation Technology Center, Inc., Research R–829, *Wheel Impact Load Detector Tests and Development of Wheel-Flat Specification* (May 1993).
D.R. Ahlbeck, Transportation Technology Center, Inc., Research R–851, *Evaluation of Railroad Wheel Impact Load Damage Factors* (October 1993).
D.R. Acharya, T.S. Guins, S. Kalay and A. Tajaddini, Transportation Technology Center, Inc., Research R–855, *Economic Analysis of High Impact Load Wheels* (December 1993).

Although the typical train speed through a WILD site is 50 mph, this can vary due to track slow orders or train speed restrictions. Railway WILD thresholds are used to evaluate the actual (measured) peak impact for a given wheel (recorded at the speed that a train traverses a WILD site) and the calculated peak impact, corrected for a nominal speed of 50 mph. The use of the calculated impact allows the railway to evaluate all wheel impacts at a normalized speed of 50 mph.

However, each railway's algorithm may vary and is sensitive to wheel defect type, low-speed conversion, and assumed linearity. For these reasons, the calculated impact value is not as accurate as the measured impact value, and there is no common Canadian or AAR condemning limit established for calculated values.

1.9.1 Canadian National Railway Company guidelines for alerts and alarms for freight car wheel impact load detectors

CN has the following WILD alarm thresholds for measured (peak) impacts of 140 kips or greater:

- For cars with a single measured impact over 160 kips or a calculated impact over 200 kips, the RTC must immediately restrict the speed of the train to 25 mph. If the impact is on an inbound train, the car must be set out at the terminal. If the impact is on an outbound train, the car must be set out at the first designated siding. The car will be bad-ordered[9] with Code WI by the RTC mechanical service representative (RTC Mech), who will advise the responsible repair personnel.
- For cars with a single measured impact from 150 to 159 kips, the RTC must immediately restrict the speed of the train to 10 mph less than the speed recorded at the WILD site. The RTC will then decide whether the car should be set out at the inbound terminal (if inbound) or at the first designated set-out location (if outbound). If neither set-out location is practical, the car can be moved to another convenient location for set-out but should never move beyond the next location, where it will receive a certified car inspection (CCI). The car will be bad-ordered with Code WI by the RTC Mech, who will advise the responsible repair personnel.
- For cars with a single measured impact from 140 to 149 kips, the RTC must immediately restrict the speed of the train to 5 mph less than the speed recorded at the WILD site. If the temperature at the WILD is −25 °C (−13 °F) or colder, the speed reduction must be 10 mph less than the speed recorded at the WILD site. The RTC will then decide whether the car should be set out at the inbound terminal (if inbound) or at the first designated set-out location (if outbound). If neither set-out location is practical, the car can be moved to another convenient location for set-out but should never move beyond the next location, where it will receive a CCI. The car will be bad-ordered with Code WI by the RTC Mech, who will advise the responsible repair personnel.

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9 To "bad-order" a car is to flag it in an electronic system and send it for repair.

In each of these situations, the subject wheel must be replaced before the car is released back into service.

In addition to the WILD thresholds for measured (peak) impacts greater than 140 kips, CN has maintenance guidelines for measured impacts from 80 to 139 kips. The guidelines specify the following:

- Cars arriving on CN lines from interchange with wheel impacts previously recorded on another railway are automatically identified.
- For impacts from 80 to 89 kips, wheel sets must be removed when a car is on a shop or repair track, as per AAR Rule 41, and these are considered opportunistic repairs.
- For cars with single wheel impacts 80 kips or higher and measured wheel rim thickness 16/16-inch or less, an automated alert is generated. The CN RTC Mech will arrange for en route inspections and hammer tests,[10] as well as change-out at the next CCI, in accordance with AAR Rule 41.
- Although wheel sets with recorded impacts from 90 to 139 kips are condemnable at any time under AAR Rule 41, CN treats these as opportunistic repairs, and the wheel sets are removed when the car is empty or loaded at the next CCI location.

1.9.2 Canadian Pacific Railway guidelines for wheel impact load detector thresholds

By comparison, Canadian Pacific Railway (CP) WILD guidelines require

- a car to be bad-ordered when empty (BOE) for measured wheel impacts of 90 kips or greater. Once a car is identified as BOE, the car can proceed to its destination with no restrictions and can be repaired once it is empty;
- a car to be bad-ordered immediately (BOI) for measured wheel impact of 140 kips or greater or a calculated wheel impact of 170 kips or greater.[11] Once a car is identified as BOI, the train speed is reduced, and the car is set out at the next designated location for repair;
- a car to be bad-ordered terminal (BOT) when a CP predictive model determines that a BOE will become a BOI en route. The predictive model allows CP to identify a WILD impact that is trending toward a measured impact of 140 kips or a calculated impact of 170 kips. Once a car is identified as BOT, the train speed is reduced and the car is set out at the next designated location for repair;
- for calculated impacts of from 90 to 110 kips, CP has a number of opportunistic threshold limits (OP1 to OP4). In these situations, CP flags the car in its car information management system but does not bad-order the car. The car can proceed to its destination without restrictions and may be repaired when

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10 The hammer test involves tapping the rim of a wheel with a hammer. A good wheel will ring like a bell while a cracked wheel will have a distorted sound.

11 All thresholds based on calculated impact values also imply that the measured impact values are greater than or equal to 90 kips, as per the *2018 Field Manual of the AAR Interchange Rules*, Rule 41.A.1.r.

operationally convenient. However, the car may also return to service without the subject wheel set being removed.

1.10 Canadian National Railway Company wheel impact load detector wheel removals, 2013–2018

Table 1 presents the number of wheel sets that CN removed before failure in Canada from 2013 to 2018, in accordance with its WILD policy.

Table 1. Canadian National Railway Company wheel set change-outs in Canada as per its wheel impact load detector policy threshold

	Measured (peak) impact						
Year	80 to < 90 kips	80 to < 90 kips and rim thickness 16/16-inch or less	90 to < 140 kips	140 to < 150 kips	150 to < 160 kips	160+ kips (peak) or 200 kips (speed-corrected)	Total wheel sets removed
2013	2303	0	46 857	1089	560	442	51 251
2014	7626	0	54 833	1339	694	639	65 131
2015	7990	96	47 538	621	250	305	56 800
2016	11 132	76	41 005	311	138	122	52 784
2017	13 309	211	47 444	419	168	215	61 766
2018	12 102	294	57 522	427	219	189	70 753
Total	**54 462**	**677**	**295 199**	**4206**	**2029**	**1912**	**358 485**

1.11 Canadian National Railway Company broken wheels, 2013–2018

1.11.1 Broken wheels in Canada by failure mode

Table 2 presents the number of broken wheels that CN removed in Canada from 2013 to 2018, categorized by the primary mode of failure.

Table 2. Canadian National Railway Company broken wheels in Canada by failure mode, 2013 to 2018

Year	Failure mode				Total
	Cracked plate	Broken/chipped flange	Shattered rim	Vertical split rim	
2013	2	15	2	51	70
2014	4	22	11	37	74
2015	6	7	1	25	39
2016	0	6	0	20	26
2017	0	9	2	18	29
2018	4	12	3	32	51
Total	**16**	**71**	**19**	**183**	**289**

Of the 289 broken wheels removed by CN in Canada from 2013 to 2018,

- 183 (63%) broke as a result of a vertical split rim;
- 71 (24%) broke as a result of a broken or chipped flange, most of which were relatively minor;
- 19 (7%) broke as a result of a shattered rim; and
- 16 (6%) broke as a result of a cracked wheel plate.

1.11.2 Detection of broken wheels

Since 2014, CN has been documenting how each broken wheel was detected. Before 2014, the method of detection was either not consistently recorded or unknown.

CN uses various methods to identify broken wheels, including

- detection by an RTC when a train "drops a block;"[12]
- derailment;
- detection by mechanical staff on repair track;
- visual inspections, which include train crew inspection, train pull-by inspection, and mechanical inspection; and
- WISs, which include wheel profile detectors (WPD), WILDs, and dragging equipment detectors (DED).

To supplement various visual wheel inspections, CN has installed an extensive WIS network that includes over 25 WILD sites as well as WPD and DED sites.

Table 3 presents the number of broken wheels that CN removed in Canada from 2013 to 2018, categorized by the method of detection.

Table 3. CN broken wheels in Canada by method of detection, 2013–2018

Year	Unknown	RTC	Derailment	Repair track*	WIS			Visual inspection			Total
					WPD	DED	WILD	Crew	Pull-by	Mechanical	
2013	55	0	2	0	0	0	13	0	0	0	**70**
2014	0	2	4	1	1	0	10	1	3	52	**74**
2015	0	0	2	1	0	2	6	3	0	25	**39**
2016	0	0	2	1	0	0	7	1	0	15	**26**
2017	4	1	1	1	0	0	3	1	2	16	**29**
2018	8	0	3	4	0	1	6	2	4	23	**51**
Total	**67**	**3**	**14**	**8**	**1**	**3**	**45**	**8**	**9**	**131**	**289**

* Repair track: a broken wheel found by mechanical staff on repair track.

Of the 289 broken wheels removed by CN in Canada from 2013 to 2018,

- 148 (51%) were detected by various methods of visual inspection, of which

[12] "Dropping a block" describes a situation in which an RTC notices that a centralized traffic control block is still being displayed as occupied, even after the train has exited the block. This could indicate that the rail has broken, possibly as a result of wheel impacts from the train as it travelled through the block.

  - 131 (45%) were detected by mechanical visual inspection, and
  - 17 (6%) were detected by either operating crew or pull-by visual inspection;
- 49 (17%) were initially detected by CN WIS, of which
  - 45 (16%) were initially detected by a WILD impact in excess of CN WILD guidelines, of which 43 (96%) were VSR failures, and
  - 4 (1%) were detected by other automated WIS;
- 11 (4%) were detected by the RTC or on the repair track;
- 67 (23%) were detected, but there was no record of the detection method; and
- 14 (5%) resulted in a derailment before the broken wheel was detected.

1.11.3 Canadian National Railway Company broken wheels that resulted in a derailment

Table 4 presents a summary of the 15 CN broken wheels, including this occurrence, that resulted in a derailment in Canada from 2013 to 2018.

Table 4. Canadian National Railway Company broken wheels that resulted in a derailment in Canada, 2013–2018

Car identification and wheel position	Failure date	Mile and subdivision	Wheel design	Year manu-factured	Defect	Last WILD date	Broken wheel impact (kips)		Number of cars derailed
							Peak	Speed-corrected	
CN 109650 – L3	2013-11-19	0.0 Edson	H36	2004	VSR	2013-11-17	43.71	44.16	1
AEQX 90036 – R3	2013-12-30	2.5 Albreda	CH36	2000	Broken flange	2013-12-29	68.97	69.63	1
CRDX 15109 – L3	2014-01-08	149.3 Napadogan	CH36	1991	SR	2014-01-06	41.75	43.75	16
GATX 200505 – R3	2014-03-22	203.3 Kingston	H36	1993	VSR	2014-03-22	35.02	36.57	1
DLPX 17020 – L1	2014-04-06	143.6 Ft Frances	CH36	1998	VSR	2014-04-06	86.24	86.24	2
PTEX 21558 – R2	2014-09-15	121.6 Ashcroft	J36	1999	SR	2014-09-14	58.1	61.23	1
BCOL 91092 – L3	2015-01-09	0.0 Matane	CJ33	2000	Cracked plate				1
IC 295879 – R3	2015-01-31	22.0 Bala	CH36	1994	VSR	2015-01-31	71.45	75.16	2
DTTX 469967 – L1	2016-01-09	21.8 Redditt	CJ33	2012	VSR	2016-01-09	99.32	102.72	31*
TAEX 2511 – L1	2016-02-07	125.2 Caramat	H36	2005	VSR	2016-02-07	51.75	54.91	1
FURX 850981 – L2	2017-12-31	79.0 Kashabowie	CH36	1995	SR	2017-12-31	68.92	71.66	20

Car identification and wheel position	Failure date	Mile and subdivision	Wheel design	Year manu-factured	Defect	Last WILD date	Broken wheel impact (kips)		Number of cars derailed
							Peak	Speed-corrected	
CN 598285 – L1	2018-01-02	216.0 Edson	CJ36	2015	Cracked plate	2018-01-02	65.35	66.34	1
ATW 400515 – R4	2018-01-06	166.0 Redditt	H36	2008	VSR	2018-01-05	109.45	115.52	23
CNA 385872 – R2	2018-06-01	107.0 Wainwright	H36	1998	Cracked plate	2018-05-22	52.18	62.50	13
TBOX 666650 – R4	2018-12-23	147.0 South Bend	H36	2011	Cracked plate	2018-12-23	38.33	40.34	1

* TSB Railway Investigation Report R16W0004.

Of the 15 CN broken wheels that resulted in a derailment in Canada from 2013 to 2018,

- 7 (47%) were caused by a VSR defect,
- 4 (27%) were caused by a cracked wheel plate,
- 3 (20 %) were caused by an SR defect, and
- 1 (6%) was caused by a broken flange.

Only 2 (13%) of the 15 broken wheels had recorded WILD impacts in excess of 90 kips (the AAR Rule 41 condemning criterion) before the derailment. None of the broken wheels had recorded WILD impacts in excess of the CN guidelines for freight car WILD alerts and alarms that required CN to take immediate action.

1.12 Car ATW 400515

Car ATW 400515 was a gondola car built in 2007. It was 70 feet 10 inches long and had a maximum gross rail load of 286 000 pounds. The car had a tare weight (empty) of 73 600 pounds and a load limit of 212 400 pounds. On the occurrence trip, the loaded car weighed 270 000 pounds.

On 12 October 2017, car ATW 400515 traversed a CN WPD located near Toronto. Table 5 presents the WPD results for the #4 wheel set of car ATW 400515.

Table 5. Car ATW 400515 #4 wheel set wheel profile detector readings

Measurements	L4 wheel	R4 wheel
Flange height (inches)	1.131	1.164
Flange thickness (inches)	1.235	1.225
Rim thickness (inches)	1.273	1.231
Tread hollow (mm)	0.000	0.000
Back-to-back gauge (inches)	53.076	53.076

All measurements met the required standards.

Table 6 presents a summary of WILD data recorded for the R4 wheel on car ATW 400515 from 06 December 2017 to 06 January 2018. During that time, car ATW 400515 was evaluated by a WILD 18 times. The car was empty until 02 January 2018, during which time no readings greater than 80 kips were recorded for the R4 wheel. Once the car was loaded, from 02 January 2018 to 06 January 2018 it traversed CN WILD sites 10 times and recorded peak WILD values in excess of 90 kips 5 times. In accordance with its WILD guidelines, CN flagged the wheel set in its system, so it would have been replaced at the next CCI location, whether the car was loaded or empty.

Table 6. Wheel impact load detector data for R4 wheel on car ATW 400515

WILD site	Mile and subdivision	Date	Speed (mph)	Loaded (LD) Empty (MT)	WILD peak (kips)	WILD speed-corrected (kips)
Watson IL U.S.	206.1 Champaign	2017-12-06	45.2	MT	27.4	28.8
Torrence IL U.S.	29.1 Matteson	2017-12-07	30.3	MT	25.1	28.8
Wakelee MI U.S.	133.3 South Bend	2017-12-07	46.4	MT	28.6	29.8
Aldershot ON	33.0 Oakville	2017-12-08	32.2	MT	29.3	33.5
Clarke ON	290.5 Kingston	2017-12-10	36.3	MT	25.2	27.9
Cedars QC	29.2 Kingston	2017-12-10	36.8	MT	33.6	37.5
Bagot QC	117.2 Drummondville	2017-12-10	43.1	MT	33.6	36
Alward NB	26.8 Napadogan	2017-12-11	52.3	MT	36.2	36.2
Alward NB	26.8 Napadogan	2018-01-02	50.1	LD	82.1	82.1
Bagot QC	117.2 Drummondville	2018-01-03	45.1	LD	73.3	76.2
Cedars QC	29.2 Kingston	2018-01-03	34.4	LD	73.6	80.8
Clarke ON	290.5 Kingston	2018-01-03	33.6	LD	86.3	96.2
Vandorf ON	48.5 Bala	2018-01-04	56.3	LD	99.5	99.5
Suez ON	270.6 Bala	2018-01-04	36.7	LD	92.5	101.7
Elsas ON	183.4 Ruel	2018-01-05	39.3	LD	93.3	101.3
Hornepayne ON	6.8 Caramat	2018-01-05	34.8	LD	76.7	84.3
Auden ON	186.9 Caramat	2018-01-05	44.9	LD	90.7	95.1
Hudson ON	10.8 Redditt	2018-01-05 Time: 2040	44.5	LD	109	115.5

The CN WILD site located at Mile 10.8 of the Redditt Subdivision (Hudson) recorded a peak WILD value of 109 kips for the R4 wheel on car ATW 400515 about 4½ hours before the accident.

1.13 Detailed examination of broken R4 wheel on car ATW 400515

The broken R4 wheel on car ATW 400515 was a one-wear wrought Class C low-stress curved plate wheel manufactured by Standard Steel in February 2008. The wheel was mounted onto the axle during the same month by American Allied at its wheel shop facility in Washington, Illinois. Table 7 presents the pertinent wheel set information.

Table 7. Wheel set information

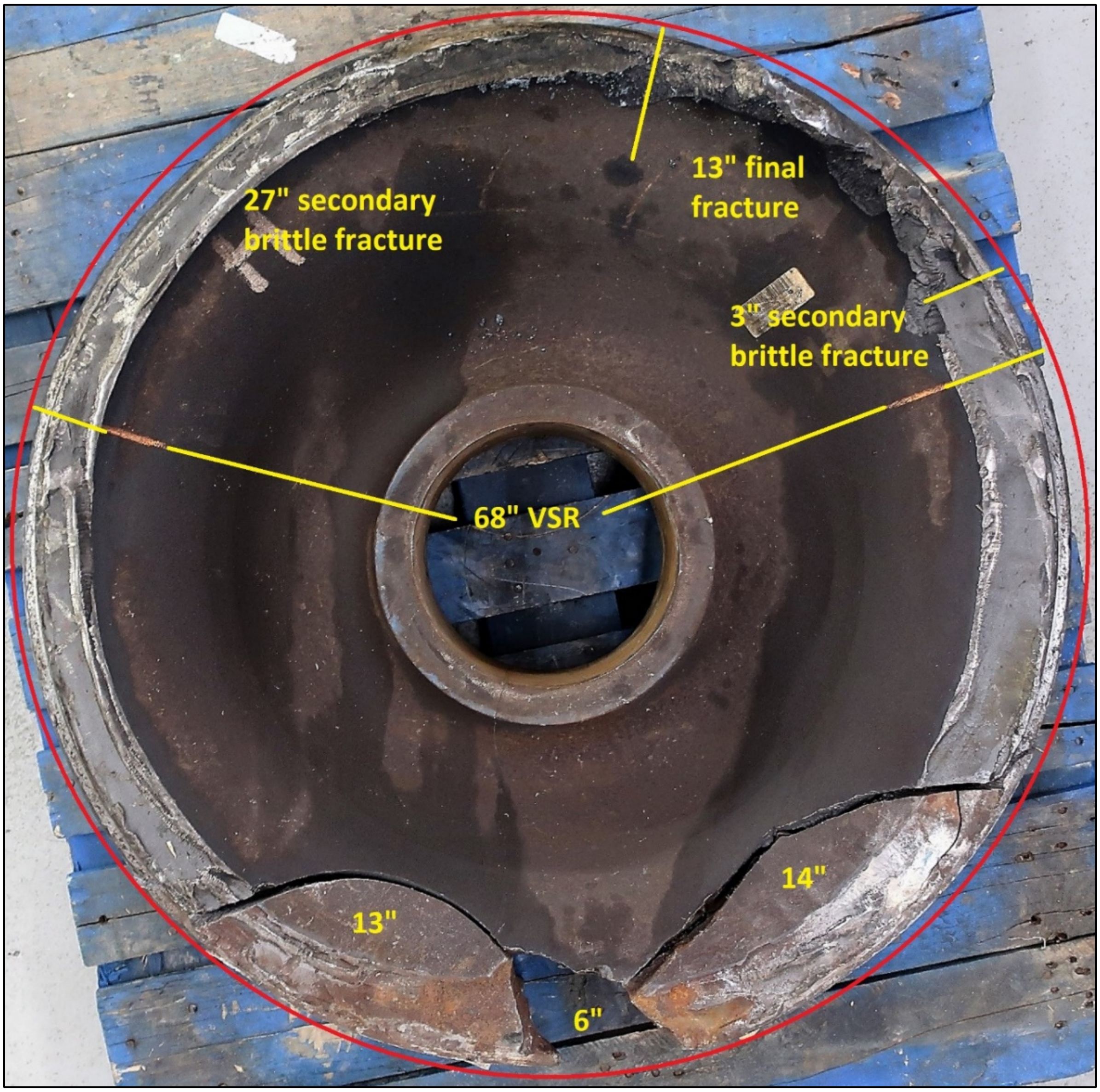
Item	R4 (failed)	L4 (mate)
Manufacturer	Standard Steel	Standard Steel
Date made	February 2008	February 2008
Serial number	10910	10694
Design	H36	H36
Class	C	C
Wheel mount date	02 ARX 08 W	02 ARX 08 W
Tread thickness	16/16 inch	17/16 inches
Flange wear	WF 7	WF 0
Flange height	1 31/64 inches	1 7/16 inches
Locking plate info	PRXJ PRS – L R 04/13	PRXJ PRS – L R 04/13
Roller bearing type	Both Timken 6½ × 9	Both Timken 6½ × 9

Reconditioned roller bearings were applied to the wheel set in April 2013. To meet reconditioning profile requirements, the wheels would have been turned and subjected to UT of the wheel treads before the reconditioned roller bearings were applied.

Visual examination of the R4 wheel revealed the following:

- The primary wheel failure was caused by a VSR.
- The unsupported wheel rim/tread overhang had failed in brittle and catastrophic modes around the wheel's entire circumference (111 inches). The severed rim measured 2 inches at its widest point. None of the wheel rim's separated, unsupported overhang was recovered.
- The VSR displayed vertically oriented, progressive, brittle growth rings on the rim face fracture surface, which propagated circumferentially in opposite directions from an initial fracture origin, reaching an overall length of 68 inches (Figure 7).

Figure 7. Fracture surfaces and failure zones of the R4 wheel on car ATW 400515 (Source: TSB)



The R4 wheel rim fracture surfaces exhibited mechanical damage, due to contact with the north rail, and several zones of progressive failure throughout its circumference.

- The primary failures involved 3 adjoining pieces of the wheel rim's unsupported overhang and tread, measuring 14 inches, 6 inches, and 13 inches. Oxidation was present on the 13-inch and 14-inch sections, indicating that some portion of the fractures had existed for some time before the final failure.
- Fractures extended into the wheel plate and resulted in the separation of the 3 pieces. The 6-inch wheel rim/tread piece was not recovered. Retracing the patterns observed on the fracture surface indicated that the VSR likely originated in the missing 6-inch tread piece.
- Brittle fractures, characterized by the presence of v-shaped chevron patterns, continued from the extremities of the VSR; these measured 3 inches and 27 inches, circumferentially.

- There was a zone of final failure measuring 13 inches circumferentially.

1.14 Ultrasonic testing of railway wheel treads

The AAR requires both new and reprofiled wheels to be subjected to UT before being released into service.

For new wheels manufactured for North American service, AAR specification M-107/208 (Wheels, Carbon Steel)[13] outlines the UT process that wheel manufacturers must adhere to. It requires that the wheel treads and rim faces be scanned axially and radially for cracks before being released into service. An axial scan covers the front and back rim face of the wheel, while a radial scan covers the wheel tread. Wheels that do not meet the UT requirements must be scrapped.

For reprofiled wheels, AAR Recommended Practice 631 (RP-631)[14] states that AAR-approved wheel shops in North America must perform UT on all reprofiled railway wheels before they are released back into service. However, RP-631 only requires the wheel treads to be scanned radially for cracks; there is no AAR requirement for a UT axial scan of the front and back rim face of a reprofiled wheel.

1.15 Emerging technologies to detect cracked wheels

Current AAR research indicates that about 74% of broken wheels fail in service without reaching WILD limits.[15] Since 2013, CN WILDs and visual inspections (crew, pull-by, and mechanical) have detected 193 broken wheels before they failed. However, wheels with defects that may not be detectable by a WIS or visual inspection continue to progress to failure and cause derailments before they are identified and removed from service. Consequently, the industry is researching additional technologies that may be able to detect emerging sub-surface cracks in wheels.

Such emerging technologies include the following:

- Automated cracked-wheel detection system
- WILDCaRD system
- Wheel impact trending

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13 Association of American Railroads (AAR), *Manual of Standards and Recommended Practices*, Manual G, Wheels Carbon Steel, Specification M-107/M-208 Section 18, Inspection, Adopted 1962, Revised 2017, pp. 12–18 and 31–36.

14 Ibid., Manual G-II, Recommended Wheel Shop Practices, Section 2.9, Ultrasonic Inspection of Reprofiled Wheels, 20 March 2012, pp. 51–56.

15 A. Poudel and M. Witte, "Effectiveness of cracked rim detectors to identify broken wheels," 23rd Annual TTCI Research Review, Colorado Springs, CO (March 2018).

1.15.1 Automated cracked-wheel detection system

The AAR TTCI has been working with Nanjing Tycho Information Technology Company Ltd. (Tycho) to monitor and evaluate the performance of an automated cracked-wheel detection system).[16,17] This involves a wayside UT system that inspects wheel treads for internal cracks. The Tycho system is installed in track at a fixed location where trains are limited to a maximum speed of 15 mph.

The system consists of a foundation, trackwork, ultrasonic probes, a water couplant delivery and recirculation system, wayside components, cameras, and a central processor housed in a nearby control building. The system incorporates UT, using a couplant that is sprayed onto the wheel tread and outboard rim face as probes scan the surfaces. Spring-loaded UT probes are arranged in lines between the rails and guardrails. The trackwork contains a wide-gauge segment to allow the wheel tread to contact the probes. Guardrails butt up to the backs of the wheels and keep the axles centred on the track while the wheels ride on the outer edge of the tread.

There are a total of 720 ultrasonic probes at a frequency of 2.5 MHz: 480 probes at angles of 0°, and 240 probes angled at 70°. The ultrasonic probes that face straight up into the tread (0°) detect circumferential cracks oriented parallel to the tread surface, whereas the probes angled at 70° detect cracks perpendicular to the tread surface oriented in a radial direction. The probes are connected to a central computer that analyzes the ultrasonic signals. The system has demonstrated a capability to detect emerging VSRs and SRs on wheels with shallow sub-surface cracks. However, some challenges still remain with the couplant maintenance and servicing system at the installation site. In particular, after the couplant is applied, small amounts are carried off by each wheel. Debris and blowing snow can also cause problems by plugging the system drains. While the system reliability is improving, it has not been widely implemented by North American railways.

1.15.2 WILDCaRD system

Another enhancement to a WILD system currently being tested is known as the WILDCaRD system. Many wheels with VSR exhibit damage near the edge of the tread on the field side of the wheel. This area is not fully scanned by WILDs, which are traditionally installed on tangent track and record wheel impacts toward the middle of the wheel tread (tapeline).[18]

For these tests, a second WILD is installed on a curve following a traditional WILD installation on tangent track. The WILD gauges are secured to the low rail of the curve,

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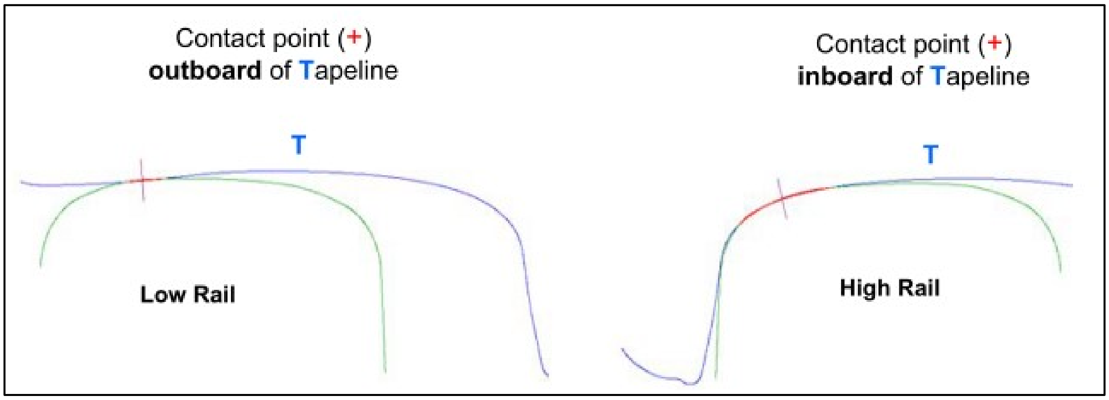
16 A. Poudel and M. Witte, Transportation Technology Center, Inc., Technology Digest TD-17-002, *Automated Cracked Wheel Detection with Tycho ACWDS* (January 2017).

17 A. Poudel and M. Witte, Transportation Technology Center, Inc., AAR Technology Digest TD-18-033, *Monitoring of Sub-Surface Fatigue Cracks in Railway Wheels Using ACWDS*, Anish Poudel Ph.D. and Matthew Witte Ph.D., (November 2018).

18 A. Poudel and M. Witte, "Effectiveness of cracked rim detectors to identify broken wheels," 23rd Annual TTCI Research Review, Colorado Springs, CO (March 2018).

which permits the field side of the wheel tread to be scanned as it traverses the low rail of the curve (Figure 8).

Figure 8. Contact points for wheel impact load detector installation in curves (Source: A. Poudel and M. Witte, "Effectiveness of cracked rim detectors to identify broken wheels," 23rd Annual TTCI Research Review, Colorado Springs, CO [March 2018].)



The recorded impact loads from the tangent WILD and the WILD installed on the curve are compared. Significant differences between the recorded impact loads typically identify wheels with damage on or near the edge of the tread on the field side of the wheel. One challenge for installing this system is to find curves that have relatively high train speeds and curvatures greater than 7°.

The BNSF Railway Company has been experimenting with a similar concept. However, instead of installing WILDs on curves, BNSF installs additional WILDs on tangent track that is purposely gauge-widened. This set-up allows the edge of the tread on the field side of the wheel to be evaluated more effectively for high impact loads.[19]

1.15.3 Wheel impact trending

Another method to identify cracked wheels comes under an AAR Strategic Research Initiative being conducted by TTCI. The study evaluates trending models of multiple WILD passes for the same wheels based on data provided by the BNSF Railway Company and Union Pacific Railroad. The trending is based on monitoring wheels that had previously registered an impact exceeding 90 kips. Once such a "suspect" wheel set is identified, trending analyses are performed.

One analysis identifies whether there is a prompt and significant jump in WILD dynamic vertical load on the same wheel. Such a wheel load increase is compared with readings from the 3 previous WILD sites traversed by the wheel. Alerts are issued based on the magnitude of the sudden increase of the dynamic impact load as well as the time duration. Rules can then be implemented for the removal of such wheels from service.

Another trending analysis evaluates the "dynamic difference" between wheels. The dynamic difference method looks at the differences in impact loads between 2 wheels on the same

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19 Ibid.

axle over the last 6 consecutive WILDs. A typical trend line for a good wheel set is determined, and subsequent trend lines for each wheel set are calculated, showing variances in dynamic loads between the 2 wheels. If a trend line exceeds a given threshold, an alarm is generated to remove the wheel set from service.[20]

These approaches use information already recorded by a railway and may provide an additional layer of safety by identifying suspect wheels based on multiple WILD passes in addition to the existing criterion of a single, maximum, peak-impact value.

1.16 Previous derailments related to wheel impacts

Rail steel is known to have reduced fracture toughness and ductility at low temperatures, particularly if there is a rail defect, which can act as a stress raiser. The industry also recognizes that wheels producing high-impact loads can cause damage to equipment (such as wheels, axles, bearings, and journals) and to track infrastructure, primarily in the form of broken rails.

Since 1999, the TSB has conducted detailed follow-up on 8 occurrences (including this derailment) that involved either broken wheels or rails and in which wheel impact was a factor that contributed to the occurrence (Appendix A). In each of these occurrences, railway WILD records had identified cars with recorded impacts that exceeded the AAR WILD removal threshold (90 kips) but that were below the railway's WILD thresholds or wheel set removal thresholds. Six of the 8 occurrences involved VSR wheel failures.

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20 T. Sultana, I. Aragona and M. Witte, Transportation Technology Center, Inc., Technology Digest TD-18-006, *WILD Trending for Broken Wheel Detection* (March 2018).

2.0 ANALYSIS

The train was handled in accordance with regulations and company instructions. No track defects in the vicinity of the occurrence were considered causal or contributory. Hence, the analysis will focus on the broken R4 wheel from gondola car ATW 400515, wheel impact load detector (WILD) thresholds, the ability of WILDs to detect emerging vertical split rim (VSR) defects, research into detection of cracked wheels, and wheel shop ultrasonic testing (UT) of reprofiled wheels.

2.1 The accident

The derailment occurred when the R4 wheel on car ATW 400515 failed progressively as a result of a VSR fracture that had been developing for some time. The VSR fracture propagated circumferentially in opposite directions from the point of origin, reaching a length of 68 inches. The unsupported overhang of the wheel rim separated from the wheel, and the wheel dropped inside the gauge of the north rail at Mile 166.33.

The wheel travelled on the ground for about 800 feet until additional pieces of the wheel rim/tread separated from the wheel; as a result, car ATW 400515 came to a stop at Mile 166.48 and the trailing 22 cars derailed. The source of the VSR defect could not be determined owing to the mechanical damage to the wheel during the derailment. The fracture likely originated in a 6-inch section of wheel rim/tread, which was never found.

2.2 Broken R4 wheel on car ATW 400515

The dimensional attributes of the R4 wheel on car ATW 400515 were within the Association of American Railroads (AAR) limits for wear, and there were no defects noted for the car during mechanical or crew visual inspections while the train was being assembled or while it was en route.

Rule 41 section A.1 of the *2018 Field Manual of the AAR Interchange Rules* (Rule 41) states that a wheel that records a peak WILD impact of 90 kips or greater is condemnable at any time. However, the rule does not require immediate removal of the wheel set. In contrast, Canadian National Railway Company (CN) WILD guidelines require freight cars that record peak WILD readings from 90 to 140 kips to be set out at the next certified car inspection (CCI) location. CN requires a car to be immediately set out only when a wheel records a peak WILD impact of 160 kips or more.

From 06 December 2017 to 06 January 2018, car ATW 400515 was evaluated by a CN WILD 18 times. No readings greater than 80 kips were recorded for the R4 wheel while the car was empty, before 02 January 2018. The car was loaded on 02 January 2018, 4 days before the occurrence. In the 2 days preceding the derailment, the R4 wheel on car ATW 400515 recorded 5 wheel impacts that exceeded the AAR Rule 41 condemning criterion of 90 kips; however, CN's guidelines for WILDs permitted the car to continue to the next CCI location.

Consequently, the wheel remained in service and failed about 4½ hours after recording a peak impact of 109 kips at the CN WILD site located at Mile 10.9 of the Redditt Subdivision.

As demonstrated in this and other Transportation Safety Board of Canada (TSB) investigations (Appendix A), some wheels with recorded impacts in excess of the AAR's Rule 41 condemning criterion have rapidly progressed to failure owing to an undetected defect.

2.3 WILD limits

Causal links have long been established between high wheel-impact loads and wheel failures, and much of the discussion around WILD technology has focused on what the wheel-removal threshold should be. According to AAR Rule 41, a wheel that records a measured (actual) WILD impact of 90 kips or greater is condemnable at any time, and a wheel with a measured WILD impact from 80 kips to less than 90 kips is condemnable when the car is on a shop or repair track for any reason. These AAR thresholds are supported by engineering analysis that shows they are reasonable thresholds to help limit the damage to equipment and track infrastructure.

In comparison, Canadian industry WILD thresholds and wheel-removal protocols vary between companies. Railway peak WILD thresholds that require the immediate set-out of a car and the removal of a wheel set can be up to 60% higher than the AAR Rule 41 condemning limit of 90 kips. The railway WILD thresholds were established primarily by industry best practice based on operational needs rather than on engineering analysis, at a level that makes it easier to manage the volume of wheels removed because of recorded WILD impacts.

While the Transport Canada (TC)–approved *Rules Respecting Key Trains and Key Routes* require a company to perform an inspection of any bearing of a key train reported defective by a wayside defective bearing detector, the TC-approved *Railway Freight Car Inspection and Safety Rules* have no provisions for condemning wheels due to recorded high impacts. There are no other regulatory requirements or guidelines in Canada or the United States on the use of wayside inspection systems (WISs), including WILDs. Consequently, the location of WILD sites, the distance between them, and the intervention thresholds differ for each railway.

Although TC had indicated that it would create a joint forum to conduct a comprehensive review of WIS and WILD criteria, to date, there has not been any significant progress by TC regarding guidelines, standards, or rules for the use of WILD technology.

2.4 Ability of wheel impact load detectors to identify emerging vertical split rim defects

Effective safety systems usually include defences in depth, with multiple barriers. Developing and installing WILD systems was primarily an industry initiative. These systems provide an additional level of safety, complementing visual train inspections performed by railway personnel. As a preventive tool, WILD systems identify high-impact wheels so that they can be removed before causing damage to the track infrastructure or the rolling stock.

CN has one of North America's most comprehensive networks of WILDs. From 2013 to 2018, in Canada, CN removed 358 485 wheel sets (an average of about 60 000 per year) under its own condemnable WILD criteria as well as those of AAR Rule 41. The sheer volume of wheel sets removed leaves little doubt that many at-risk wheels were removed before failure. Despite significant improvements in detection and inspection, wheels continue to break in service, sometimes resulting in derailments.

The most common type of wheel failure is due to a VSR. From 2013 to 2018, CN recorded 289 broken wheels in Canada. Of these broken wheels

- 183 (63%) resulted from a VSR;
- 45 (16%) were detected by a WILD before failure, of which
    - 43 (96%) were VSR failures; and
- 14 (5%) resulted in a derailment before the wheel failure was detected, of which
    - 7 (50%) were caused by a VSR defect,
    - only 2 recorded WILD impacts in excess of the AAR Rule 41 condemning criterion of 90 kips before failure, and
    - none recorded WILD impacts in excess of the CN guidelines for freight car WILD alerts and alarms that required CN to take immediate action.

AAR research indicates that up to 74% of broken wheels fail in service without reaching WILD limits. While 43 of the 183 CN broken wheels caused by VSR were initially detected by a WILD impact in excess of 90 kips, 140 wheels with VSR defects progressed to failure and were identified by other means or caused derailments before being detected by a WILD. In some cases, wheels with emerging VSR defects do not exhibit significant wheel tread damage, and wheel failure can occur rapidly between WILD sites.

This suggests that, despite significant industry investments in WILD technology, there are still gaps in the industry's ability to detect emerging VSR defects in wheels. This has led to additional AAR and industry research initiatives to detect cracked wheels.

2.4.1 Automated cracked-wheel detection system

Wheel failures result primarily from sub-surface cracks that cause the 2 major types of failures, due to VSRs and to shattered rims (SRs).

The AAR Transportation Technology Center, Inc. (TTCI) has been developing an automated cracked-wheel detection system (ACWDS). An ACWDS is a wayside UT system that inspects wheel treads for internal cracks. It is installed in track at a fixed location where trains are limited to a maximum speed of 15 mph. ACWDS testing has demonstrated success in detecting emerging SR and VSR wheel defects, and the system reliability is improving. However, it has not been widely implemented in North America and may need to be protected from the elements by an enclosure that could be located outside of a major rail yard where track speed is limited to 15 mph.

2.4.2 WILDCaRD system

Many cracked wheels due to VSR exhibit damage near the edge of the tread on the field side of the wheel. This area is not fully scanned by conventional WILDs, which tend to record wheel impacts toward the middle of the wheel tread (tapeline). Additional WILDs positioned in curves or in purposely gauge-widened track may be able to scan the edge of the tread on the field side of the wheel more effectively.

2.4.3 Wheel impact trend analysis

In this occurrence, over a 3-day period, the R4 wheel on car ATW 400515 recorded 5 impacts that exceeded the AAR Rule 41 condemning criterion of 90 kips but were below CN WILD guidelines that required immediate removal of the wheel set. When multiple high WILD impacts are recorded for a given wheel, enhanced trend analysis of WILD data may provide an additional layer of safety by identifying suspect wheels based on multiple WILD passes in addition to identifying a single, maximum, peak-impact value.

Thus, despite the railway industry's extensive implementation of WIS over the years, the industry continues to research the detection of emerging VSR defects before wheel failure. Without the implementation of additional enhancements for cracked-wheel detection to augment WILD technology, there is a continued risk that a wheel with an emerging VSR defect will not be identified and removed before it fails.

2.5 Wheel shop ultrasonic testing of reprofiled wheels

The AAR requires that both new and reprofiled wheels must be ultrasonically tested before being released into service.

For new wheels, the wheel treads and rim faces of all wheels must undergo UT for cracks, involving an axial scan, which includes the front and back rim face of the wheel, and a radial scan, which covers the wheel tread. Any wheels that do not meet the UT requirements must be scrapped.

The AAR also requires that wheel shops in North America perform UT on all reprofiled wheels before they are released back into service. However, only the wheel treads are subjected to UT by being scanned radially for cracks. There is no AAR requirement for a wheel shop to perform UT on the rim faces of a reprofiled wheel.

SR failures are typically related to manufacturing defects that progress horizontally in a plane parallel to the wheel tread, become exposed to the wheel tread running surface, and break away owing to wheel tread shelling or spalling. To prevent emerging SR defects in reprofiled wheels, the AAR requires that railway wheel shops implement UT for the wheel tread surface of reprofiled wheels.

Since this implementation, VSR defects have emerged as the primary cause of broken wheels in the industry. VSRs tend to originate from the roots of wheel tread surface conditions, such as checking, spalling, or shelling, and usually occur at 90° (perpendicular) to the tread surface, parallel with the wheel rim face. However, there is no AAR requirement for wheel shops to perform UT on the rim face of reprofiled wheels, as there is for new wheels.

Thus, to prevent wheels with internal defects from being placed in service, the AAR requires that both new and reprofiled wheels be subjected to UT. Although new wheels must be scanned both axially (rims) and radially (treads), there is no requirement for the rim faces of reprofiled wheels to be scanned axially. If axial UT is not performed following wheel reprofiling at railway wheel shops, wheels with VSR defects may be released back into service, increasing the risk of a derailment due to a broken wheel.

3.0 FINDINGS

3.1 Findings as to causes and contributing factors

1. The derailment occurred when the R4 wheel on car ATW 400515 failed progressively as a result of a vertical split rim fracture that had been developing for some time.

2. The vertical split rim fracture propagated circumferentially in opposite directions from the point of origin, reaching a length of 68 inches.

3. The unsupported overhang of the wheel rim separated from the wheel, and the wheel dropped inside the gauge of the north rail at Mile 166.33 of the Redditt Subdivision.

4. The wheel travelled on the ground for about 800 feet until additional pieces of the wheel rim/tread separated from the wheel; as a result, car ATW 400515 came to a stop at Mile 166.48 and the trailing 22 cars derailed.

5. In the 2 days preceding the derailment, the R4 wheel on car ATW 400515 recorded 5 wheel impacts that exceeded the Association of American Railroads Rule 41 condemning criterion of 90 kips; however, Canadian National Railway Company's guidelines for wheel impact load detectors permitted the car to continue to the next certified car inspection location.

6. The wheel remained in service and failed about 4½ hours after recording a peak impact of 109 kips at the Canadian National Railway Company wheel impact load detector site located at Mile 10.9 of the Redditt Subdivision.

3.2 Findings as to risk

1. Without the implementation of additional enhancements for cracked-wheel detection to augment wheel impact load detector technology, there is a continued risk that a wheel with an emerging vertical split rim defect will not be identified and removed before it fails.

2. If axial ultrasonic testing is not performed following wheel reprofiling at railway wheel shops, wheels with vertical split rim defects may be released back into service, increasing the risk of a derailment due to a broken wheel.

3.3 Other findings

1. The source of the vertical split rim defect could not be determined owing to the mechanical damage to the wheel during the derailment. The fracture likely originated in a 6-inch section of wheel rim/tread, which was never found.

2. Some wheels with recorded impacts in excess of the AAR's Rule 41 condemning criterion have rapidly progressed to failure owing to an undetected defect.

4.0 SAFETY ACTION

4.1 Safety action taken

The Board is not aware of any specific safety action that has been taken as a result of this occurrence.

This report concludes the Transportation Safety Board of Canada's investigation into this occurrence. The Board authorized the release of this report on 18 September 2019. It was officially released on 13 November 2019.

Visit the Transportation Safety Board of Canada's website (www.tsb.gc.ca) for information about the TSB and its products and services. You will also find the Watchlist, which identifies the key safety issues that need to be addressed to make Canada's transportation system even safer. In each case, the TSB has found that actions taken to date are inadequate, and that industry and regulators need to take additional concrete measures to eliminate the risks.

APPENDICES

Appendix A – Previous TSB investigations involving wheel impacts

TSB Railway Investigation Report R99H0010: On 30 December 1999, Canadian National Railway Company (CN) freight train U-783-21-30 was travelling westward on the north track of the Saint-Hyacinthe Subdivision. At Mile 50.84, near Mont-Saint-Hilaire, Quebec, the train derailed, and cars fouled the adjacent south main track. At about the same time, CN freight train M-306-31-30 was travelling eastward on the south track and collided with the cars of train U-783-21-30, which had just derailed. The temperature at the time of the occurrence was −11 °C. Two crew members on train M-306-31-30 were fatally injured in the accident.

The investigation determined that an existing pre-crack in the south rail of the north track was sufficient to initiate rail failure, given the effect of stresses induced on the rail by the combination of low ambient temperatures and wheel impact loads of 103 to 112 kips, which were above Association of American Railroads (AAR) condemning criteria, but below CN's wheel impact load detector (WILD) thresholds.

TSB railway occurrence R03T0030:[21] On 23 January 2003, while travelling at 34 mph, Canadian Pacific Railway (CP) freight train 213-22 (23 loaded cars, 69 empty cars) derailed 29 cars at Mile 78.2 of the White River Subdivision, in Ontario. The temperature at the time of the occurrence was −20 °C.

The derailment occurred when the R2 wheel on the 10th car from the head end sustained a vertical split rim (VSR) failure. Impacts from the broken wheel caused the south rail to fail, resulting in the derailment. Two days previously, the same wheel had recorded a measured impact of 99 kips while travelling at a speed of 30 mph, which equates to a calculated impact of 136.5 kips. Although the measured impact force was above the AAR's Rule 41 condemning limit of 90 kips, both the measured and calculated impacts were below CP's WILD wheel-removal thresholds. Consequently, no maintenance action was initiated for the wheel set after the impact measurement.

TSB Railway Investigation Report R03T0064: On 02 February 2003, while travelling at about 37 mph, CP freight train 938-12 was inspected at a WILD site near Raith, Ontario, about 59 miles (95 km) west of Thunder Bay, Ontario. Although there were no wheel impacts greater than 140 kips, 4 of the recorded impacts were from 90 kips to 116 kips, equating to calculated impacts of from 109 kips to 144 kips. Although the measured impacts were above the AAR's Rule 41 condemning limit of 90 kips, both the measured and calculated impacts were below CP's WILD wheel-removal thresholds. No maintenance action was taken or required.

On 13 February 2003, the train was proceeding southward at about 42 mph when 21 of its cars derailed at Mile 39.5 of the Parry Sound Subdivision near Nobel, Ontario. The

21 A detailed follow-up review was conducted with the railway.

temperature at the time of the occurrence was −27 °C. The investigation determined that wheel impacts had likely initiated a brittle fracture from the root of a pre-crack through the base of the rail, facilitating the final catastrophic rail failure.

TSB Railway Investigation Report R11V0039: On 12 February 2011, CN coal train C-751-51-11 was travelling westward on the Nechako Subdivision at about 45 mph when a train-initiated emergency brake application occurred at Mile 93.45, near Fort Fraser, British Columbia. A total of 36 cars derailed.

The derailment occurred when the L2 wheel on car BCNE 900534 failed catastrophically after sustaining a VSR failure.[22] The fracture originated at the base of a shell that had developed as a result of rolling contact fatigue and extended through the unsupported portion of the wheel tread throughout one fourth of the wheel circumference.

Less than 3 hours before the derailment, the wheel recorded a WILD reading of 94.4 kips at a WILD site located about 78 miles ahead of the derailment site. On 3 other occasions in the previous 1½ months, the same wheel had recorded impacts of over 80 kips. The investigation determined that company WILD policies may not provide adequate guidance to identify emerging wheel defects when wheel impacts are above the AAR Rule 41 condemning limits but below company thresholds.[23]

TSB railway occurrence R11T0072: On 27 March 2011, CN freight train M30511-26, transporting 97 loaded and 19 empty cars, was proceeding westward at about 50 mph on the Kingston Subdivision when a train-initiated emergency brake application occurred, and 25 cars derailed near Port Hope, Ontario (Mile 268.50). The derailment occurred when the R4 wheel on tank car PROX 43452 failed catastrophically after sustaining a VSR failure. The fracture originated at the base of a shell, about ¼ inch below the tread surface. The fracture origin developed as a result of rolling contact fatigue and extended through the unsupported portion of the wheel tread throughout one fourth of the wheel circumference.[24]

From 29 December 2010 to 27 March 2011, the R4 wheel on car PROX 43452 had recorded 5 WILD impacts that exceeded the AAR Rule 41 condemnable limit of 90 kips. These impacts included a reading of 94.2 kips on the day of the derailment. Despite multiple WILD readings that exceeded AAR WILD thresholds and a number of opportunities for a targeted inspection and/or removal of the wheel in the 3 months preceding the accident, the wheel remained in service until it failed.[25]

TSB Railway Investigation Report R13T0060: On 03 April 2013, CP freight train 420-02 was proceeding eastward at about 35 mph on the Heron Bay Subdivision when an undesired emergency brake application occurred at Mile 9.16, near White River, Ontario.

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22 TSB Engineering Laboratory Report LP 022/2011 – Wheel Examination.

23 TSB Rail Safety Advisory Letter 11/11, "Broken Wheels with Previous AAR Condemnable WILD Readings."

24 TSB Engineering Laboratory Report LP 037/2011 – Wheel Examination.

25 TSB Rail Safety Advisory Letter 11/11, "Broken Wheels with Previous AAR Condemnable WILD Readings."

The temperature at the time of the occurrence was −11 °C. Subsequent inspection determined that 22 cars (19 loads and 3 empties) had derailed, 7 of which were dangerous goods tank cars loaded with petroleum crude oil (UN 1267). During the derailment, a number of cars rolled down an embankment. Two of the dangerous goods tank cars released approximately 101 700 litres of product, and another non–dangerous goods tank car released approximately 18 000 litres of product. There were no injuries.

The derailment occurred when an impact from the broken R1 wheel of the 34th car (DBUX 302383) fractured the south rail (low rail) in the curve at Mile 9.41 of the Heron Bay Subdivision. The R1 wheel fractured due to a VSR, which had originated about ½ inch below the surface of the wheel tread at the root of a shell and resulted in the separation of about 80 inches of the outboard wheel rim. The R1 wheel had previously recorded 6 WILD impacts that met or exceeded the AAR Rule 41 removal criteria. However, the WILD impacts did not meet CP removal criteria, so the wheel remained in service and subsequently failed.

TSB Railway Investigation Report R16W0004: On 09 January 2016, CN freight train M31331-07 was proceeding westward on the Redditt Subdivision at about 46 mph when a train-initiated emergency brake application occurred at Mile 21.74, near Webster, Ontario. The temperature at the time of the occurrence was −18 °C. Subsequent inspection determined that a total of 26 cars (29 platforms) had derailed. The derailed cars included 6 Class 111 dangerous goods residue tank cars that had last contained diesel fuel (UN 1202). There were no injuries and no product was released.

The accident occurred when the L1 wheel on the 2nd car from the head end (DTTX 469967) failed progressively from a VSR that had been present for some time. The VSR crack propagated circumferentially for 43¾ inches from the initial fracture and resulted in 3 pieces of rim separating from the wheel at Mile 13.35.

The resulting gap in the tread surface of the wheel led to high cyclical impacts, promoting the propagation of an overstress brittle fracture and the separation of a larger wheel tread/plate section. The overstress fracture then propagated to the wheel bore, which resulted in the L1 wheel losing its interference fit with the axle wheel seat and allowed the wheel to move inboard on the axle, drop between the rails, and derail at Mile 13.45 (the initial point of derailment).

The remaining portion of the L1 wheel was dragged over the ties and ballast until the derailed No. 1 wheel set contacted the track work associated with the Webster siding east switch at Mile 20.40. After 2 larger pieces of the wheel tread/plate separated at Mile 20.55 and Mile 21.00, a train-initiated emergency brake application occurred at Mile 21.74, and the head end of the train came to rest at Mile 21.86 with the trailing 26 cars (29 platforms) derailed.

Despite the LI wheel recording an impact at the CN WILD site at Hudson (Mile 10.80) that was condemnable under AAR Rule 41, CN WILD guidelines permitted the L1 wheel on car DTTX 469967 to remain in service. The wheel failed shortly thereafter, about 2½ miles west of the CN Hudson WILD site.