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

SAFETY ISSUES INVESTIGATION REPORT
SII R05-01

ANALYSIS OF SECONDARY MAIN-LINE DERAILMENTS AND THE RELATIONSHIP TO BULK TONNAGE TRAFFIC

Canada

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Executive Summary

Introduction

In the winter of 2003–2004, a series of train derailments on secondary main lines in western Canada involving broken rails prompted the Transportation Safety Board of Canada (TSB) to initiate this safety issues investigation. To develop an understanding of the factors underlying these occurrences, the investigation examined the commonalities among these occurrences, reviewed relevant TSB data, and used data provided by the railways to test a specific hypothesis.

Scope

Subdivisions included in this investigation consisted of those involved with the initial derailments, plus other subdivisions that were selected on the basis of

- track characteristics (that is, secondary main line),
- traffic characteristics,
- geographic location (that is, western Canada), and
- recent derailment history.

Information on rail infrastructure components, renewal programs, testing, maintenance and inspection practices, workforce levels, traffic density, and axle loading was reviewed to establish qualitative relationships among track condition, traffic, defect levels, and derailment frequency. The five-year track geometry and rail defect histories, traffic type and density, derailment history, causes and contributing factors were analyzed to identify potential safety deficiencies. This qualitative analysis of derailment occurrences included both Canadian National (CN) and Canadian Pacific Railway (CPR) data.

Statistical analyses were conducted to test the hypothesis that bulk tonnage traffic, independent of cumulative tonnage, is associated with increased derailment risk due to rail defects. The quantitative analysis was conducted only on CPR subdivision data because an insufficient number of CN subdivisions met the selection criteria either to furnish a sample of sufficient size to analyze or to determine if CN data and CPR data were sufficiently similar to allow them to be aggregated into a single sample.

Results

A statistically significant relationship was established between the incidence of rail defects and the level of bulk traffic. Where rail weight is less than 130 pounds, increased bulk unit train tonnage significantly increases rail defects, resulting in a higher risk of broken rail derailments. This safety issues investigation report identifies risks related to the problems in balancing track maintenance and degradation to the comprehensiveness of the *Railway Track Safety Rules* and to deficiencies in rail inspection capabilities and maintenance practices.

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1.0 Introduction

1.1 Background

Between October 2003 and March 2004, a number of main-track derailments in western Canada on secondary, non-signalled main lines[1] resulted from infrastructure failures. An initial review of eight of these occurrences (see Table 1 and Figure 1) suggested commonalities in geography, track type, and causal factors (see Appendix A for summaries of Table 1 occurrences). It was noted that these occurrences were similar in nature to the 04 December 2002 derailment of 42 tank cars loaded with molten sulphur at Mile 11.8 of the Canadian Pacific Railway (CPR)[2] Taber Subdivision in Alberta (TSB report R02E0114).

The following are relevant findings from that investigation:

- The condition of the track, the level of defects, and the component failures on the Taber Subdivision indicate an accelerated rate of track deterioration due in part to the high volume of heavy axle traffic and the increased tonnage being handled over the subdivision.

- Although railways are able to meet the minimum safety standards of the TSR [*Railway Track Safety Rules*] by reducing speed, current TSR may be insufficient to ensure the long-term safety of increased train traffic and heavy axle loads over secondary or feeder track systems.

- While regulatory activities on the Taber Subdivision indicated growing concern with the deteriorating track condition, the absence of prompt action by the railway to address these concerns allowed the associated risk of derailment to remain unmitigated.

- Increasing the maximum gross weight on rails without corresponding infrastructure improvements increases the risk of track-related derailments, especially when heavier traffic is carried over the long term.

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1 For the purpose of this investigation, secondary main lines are non-signalled.

2 See Glossary at Appendix E for all abbreviations and acronyms.

Table 1. Derailment Occurrences

Occurrence No.	Class	Date	Derailed	Location	Track/Train Speed	Type of Rail	Cause	Testing
R03E0091	4	12 October 2003	19 cars on CPR train 269-11	Mile 46.9, Aldersyde Subdivision	Track speed – 45 mph	1974 Algoma 115-pound continuous welded rail (CWR) with 3/8-inch head wear and 5/16-inch flange wear	Sections of rail broke out, creating a 38-foot gap in the high rail of a four-degree left-hand curve	The last rail flaw detection test was done July 30. No internal defects were recorded within 10 miles of the point of derailment (POD). The next test was scheduled for the week of October 13.
R03E0092	4	15 October 2003	14 cars on CPR train 863-017	Mile 40.4, Taber Subdivision	Track speed – 40 mph with a 25 mph temporary slow order in place due to poor ballast conditions	1953 Dominion 100-pound, 66-foot jointed head free rail on tangent track, relaid in the 1980s	Broken rail due to a 15-inch vertical split head (VSH) and head and web separation	Rail was ultrasonically tested one week prior on October 8, but defect was missed due to operator misinterpretation (false negative)
R03C0101	3	24 October 2003	16 cars on CPR train 269-21	Mile 10.75, Moyie Subdivision	Track speed – 25 mph; train speed – 27 mph	136-pound RE CWR manufactured by Algoma between 1980 and 1985 with 5/8-inch head wear and 7/16-inch flange wear	Rail break in the high rail within the body of a six-degree left-hand curve due to a transverse detail fracture extending from the gauge corner of the high rail to a depth of 1¾ inches. Two rail sections were joined together with fully bolted joint bars, as a temporary repair of a previous broken rail on October 7.	The last ultrasonic test before the derailment was done on September 19 with no defects noted in the area. In the area of the POD, the rail flaw detector car showed an intermittent response typical of poor rail head surface condition and no further action was required or taken by the rail test operator.
R04E0001	4	01 January 2004	28 loaded grain cars on CN train A44351-01	Mile 58.90, Camrose Subdivision	Proceeding at 40 mph, slowing for a 25 mph permanent slow order between Mile 49.2 and Mile 58.4	1949 Algoma 100-pound, 39-foot jointed rail (four bolt joints) with 7 mm head loss	Broken rail in a joint on tangent track likely due to a bolt hole crack	
R04C0002	4	05 January 2004	15 cars on CPR train 266-02	Mile 76.4, Crowsnest Subdivision	Track speed – 35 mph; train speed – 30 mph	1982 Algoma 115-pound partly worn CWR cascaded from the CPR main line in northern Ontario with 1/4-inch head wear and 1/8-inch flange wear (within allowable limits)	Broken high rail in transition between five- and six-degree curves – transverse defects in 12 of the 14 fractures	The last ultrasonic test done 03 October 2003 indicated a possible transverse defect near the POD, but the rail ultrasonic operator decided that the defect was less than 10 per cent and took no action because the rail surface was poor (significant checking and shelling)
R04C0014	4	26 January 2004	11 intermodal service cars on southward CPR train 104-26	Mile 46.1, Red Deer Subdivision near Didsbury, Alberta	Normal track speed – 55 mph; train speed – 21.7 mph; 35 mph cold weather slow order in effect	1983 Algoma 115-pound CWR on tangent track with six-hole joint bars	Broken rail/joint bars in west rail. Fatigue cracks had developed from bolt holes; well-developed fatigue defects on fracture surfaces of both joint bars. Poor joint inspection and maintenance were contributing factors in this derailment.	The last ultrasonic test done 10 November 2003 identified a defective plant weld immediately north of the POD (not considered causal)
R04C0031	4	22 February 2004	22 intermodal platforms on westbound CN train Q11531-19	Mile 37.21, Oyen Subdivision	Track speed – 40 mph; train speed – 34 mph	1956 RA Dominion 100-pound, 78-foot jointed rail (four bolt joints) on tangent track	Broken rail due to a VSH in a joint near a crossing	No rail defects recorded in the area during prior ultrasonic rail test conducted 17 June 2003
R04E0027	3	04 March 2004	20 cars on westbound CPR train 575-03	Mile 86.03, Red Deer Subdivision near Penhold, Alberta	40 mph slow order in effect in the area due to excess cross-level variation (not considered causal); train speed – 39.2 mph	1984 Algoma 115-pound CWR	Train derailed as it passed over a rail joint in tangent track that had broken and separated. Broken rail punctured one residue car of anhydrous ammonia.	The last rail flaw detector test was conducted between Mile 67.3 and Mile 95.6 on 13 February 2004 with no defects found

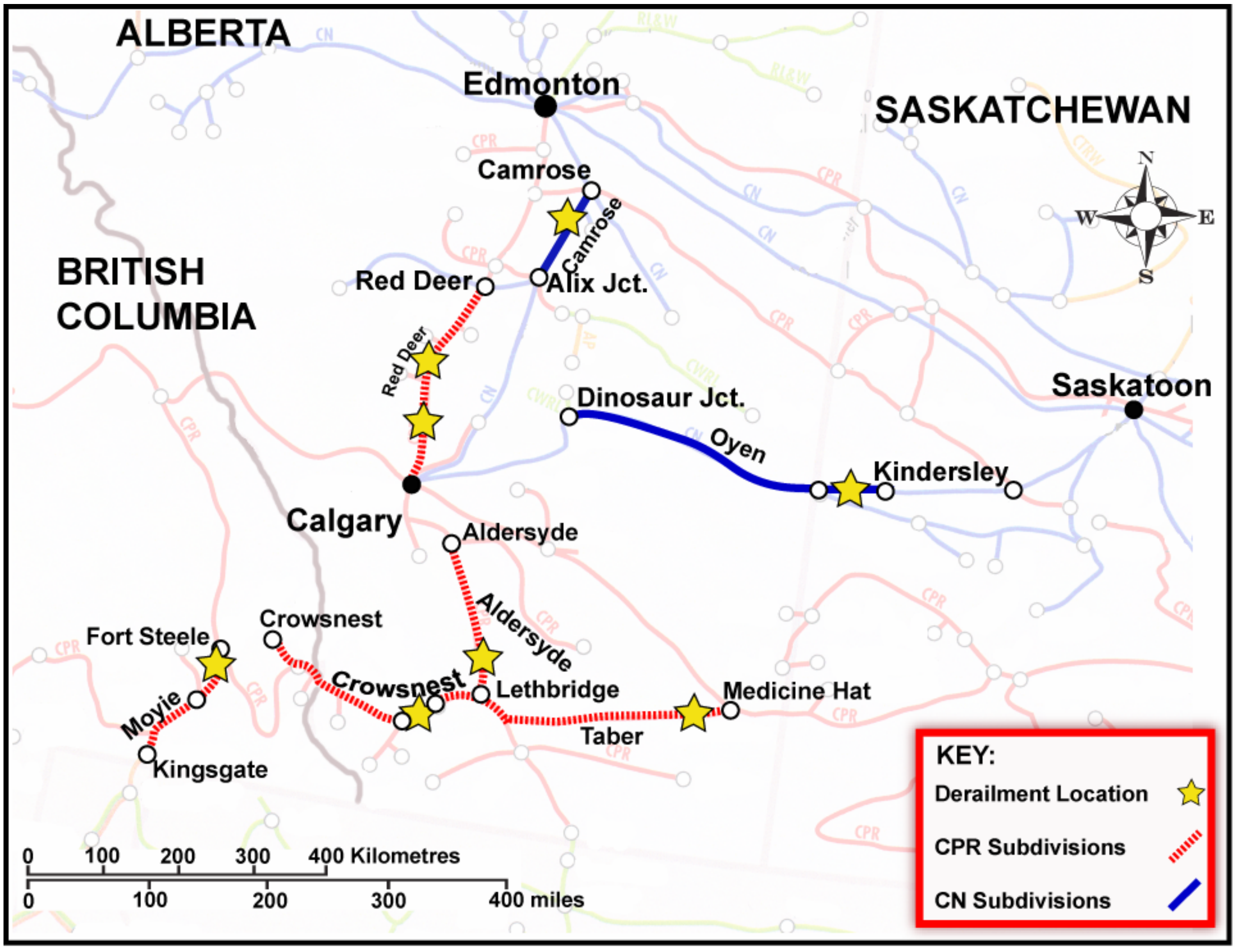

Figure 1. Location and subdivision of the eight occurrences

These similar occurrences prompted a search for underlying systemic factors. This search took the form of a safety issues investigation (SII) into derailments on Canadian National (CN) and CPR secondary main lines in western Canada. It was recognized that the factors involved would likely be at play on subdivisions in addition to those involved in the Table 1 occurrences. Therefore, the scope of the SII was expanded to include similar subdivisions. Subdivisions were selected on the basis of track characteristics (secondary main track), traffic characteristics, geographic location (western Canada), and recent derailment history. The 13 selected subdivisions consisted of 5 subdivisions[3] along the CPR secondary main-line route (527 miles) between North Portal, Saskatchewan, and Kingsgate, British Columbia, 2 subdivisions (116 miles) between Calgary and Lethbridge, Alberta,[4] and 6 CN subdivisions (837 miles) in Alberta and Saskatchewan.[5] The railways provided information on infrastructure components, renewal programs, testing, maintenance and inspection practices, workforce levels, traffic density, and loading.

[3] Moyie, Cranbrook, Crowsnest, Taber, and Weyburn subdivisions

[4] Macleod and Aldersyde subdivisions

[5] Blackfoot, Vegreville, Brazeau, Camrose, Sangudo, and Three Hills subdivisions

1.2 TSB Occurrence Record for Selected Subdivisions

A total of 51 main-track derailments were reported on the selected subdivisions between 01 January 1998 and 12 February 2004. Derailments on CPR subdivisions (33) have varied between 3 and 9 annually since 1998. Total derailments on CN subdivisions (18) were 5 or fewer annually. In all, 27 of these 51 derailments were track-related, with 16 due to broken rails/joints (3 on CN track and 13 on CPR track). A total of 11 of CPR's 13 broken rail/joint derailments occurred on the North Portal–to–Kingsgate route.

Although the CN and CPR lines have similar infrastructure, the CN subdivisions are primarily lighter-traffic feeder lines, while the CPR subdivisions between North Portal and Kingsgate are part of a secondary main line between central North America and the west coast. For the purposes of this safety issues investigation, the TSB defines "feeder lines" and "secondary main lines" as lines that are not part of a transcontinental main-line system. For the statistical analysis, the safety issues investigation subdivisions were chosen because they had an annual tonnage greater than 10 million gross tons (MGT) and a majority of rail weight under 130 pounds. Traffic on all five subdivisions on the North Portal–to–Kingsgate route has increased in the past five years with the Weyburn and Cranbrook subdivisions carrying the highest tonnage. Five of the derailments occurred on the Weyburn Subdivision in 2001 and early 2002, before the completion of major infrastructure renewal programs, including rail and turnout relays and tie programs. Rail defects per 100 miles tested have decreased on the Weyburn Subdivision, remained steady at less than 10 defects per 100 miles tested on the Cranbrook Subdivision, but have increased on the Taber, Moyie, and Crowsnest subdivisions.

1.3 Transport Canada Inspections

Transport Canada (TC) is responsible for the safety overview of federally regulated railways through promotion, monitoring, and enforcement. TC administers and enforces provisions of the *Railway Safety Act* (RSA) and related regulations, rules, standards, and orders, based on the underlying philosophy that the primary responsibility for safety lies with the railways.

TC monitors the railway infrastructure by auditing data records, processes, and procedures and by ensuring that the railways comply with the RSA and its related regulations. It also conducts inspections of selected railway trackage, focusing on the railway's safety systems and patterns of compliance to identify systemic safety problems. This approach is a departure from the track monitoring programs in effect before the coming into force of the *Railway Safety Management System Regulations*, which were almost all inspection-based.

A review of TC records indicates that TC has inspected most of the selected subdivisions in recent years, some of them completely and others partially. While the inspections recorded various TSR violations, no systemic safety problems were noted on most of the subdivisions. However, these records indicated that three subdivisions—Moyie, Cranbrook, and Taber—drew increased attention as TC uncovered persistent and systemic deteriorating track conditions on these subdivisions due to increased traffic and increased bulk unit train traffic.

1.4 Focus of Safety Issues Investigation

Given the foregoing, this investigation focused on the effects of bulk unit train traffic on secondary main lines. The following areas were examined:

- railway processes to handle increased loading on secondary main lines;
- maintenance, inspection, and testing;
- rail grinding;
- rail joints; and
- Transport Canada–approved *Railway Track Safety Rules* (TSR).

1.5 The Effects of Bulk Unit Train Traffic on Secondary Main Lines

In recent years, railways in North America have increased axle loading on their networks from 33 tons (263 000 pounds) to 36 tons (286 000 pounds). Heavier loading results in increased plant capacity and asset utilization, and lower train operating costs because fewer locomotives, cars, and trains can handle a greater volume of commodities. Railway customers benefit through more attractive rates. Although unit train car weights of 263 000 pounds are very common in the industry with few movement restrictions, the occurrence record suggests that an increased volume of unit train traffic may be an issue on secondary main lines.

The intent of this investigation is to analyze the adverse effects of bulk unit train traffic on secondary main lines. Strong bridges and superior track infrastructure made loading up to 263 000 pounds feasible on most main lines. To enable the rolling stock to handle increased axle loading, the design of components such as trucks, springs, and axle bearings was improved. However, when volumes of bulk unit train traffic on secondary main lines increased, track infrastructure quickly emerged as a potential limiting factor.

Railways have some flexibility to choose their traffic, operating and maintenance practices, and routes over which the traffic is moved. By using its southern route for certain west coast unit train traffic, CPR increases utilization of its secondary network, gaining an operational advantage by relieving main-line congestion, clearing slots for priority trains. Consideration of the type of traffic to be handled is an important preparatory aspect to managing infrastructure. It is possible to occasionally operate unit trains on secondary main-line track without inflicting significant damage. Increased volume of this type of traffic over the long term will result in a rapid increase in track deterioration unless mitigated.

Loaded high-capacity rail cars in unit trains pose special problems to secondary main lines where weak track conditions (ties, ballast, and subgrade) may be common. A unit train consist is usually uniform; that is, all cars of the same design and loading with the car trucks and car bodies responding more or less as one unit. Therefore, each rail car on the train responds to track irregularities in the same manner as the previous car, thereby concentrating cumulative impacts at whatever irregularities are encountered in the track structure. Trains with numerous rail cars of the same design and with high load capacity provide the track little or no opportunity for elastic recovery[6] during their passage. As a result, permanent and usually non-uniform track deformation is hastened.

Track degradation and the resultant maintenance requirements increase with heavy axle loading (HAL). While the effects of HAL (axle loading ≥ 286 000 pounds) on principal main lines have been well studied over the years, the effects of HAL on secondary main lines have not been as well addressed. The Association of American Railroads (AAR), through its research arm, the Transportation Technology Center Inc. (TTCI), has been involved in the development and extensive testing of new track and mechanical components under HAL conditions at its facility in Pueblo, Colorado, over the past two decades. The United States Federal Railroad Administration (FRA) Office of Railroad Development has done work specific to bridge capacity on short lines under HAL, but no research into HAL effects on secondary main line infrastructure has been, or is currently being, done by either the AAR or FRA. The American Short Line and Regional Railroad Association has been actively involved in studying the HAL issue[7] in response to demand for increased axle loading across its networks. The Railway Association of Canada (RAC) commissioned a study[8] on upgrading short-line railroad track to 286 000-pound standards. These studies all reach a similar conclusion: HAL traffic on secondary main lines increases track component and surface degradation at a higher rate than on principal main lines, and measures must be taken to operate HAL equipment safely on an ongoing, long-term basis.

There was little actual 286 000-pound loading on the subdivisions examined during this investigation. However, the conclusions of the above-mentioned studies are considered relevant to secondary main lines as increased track degradation and maintenance costs also result from higher volumes of 263 000-pound bulk unit train traffic.

1.6 Statistical Analysis

A statistical analysis was performed to quantitatively assess the effect of bulk unit train loading. The experimental hypothesis was that this type of traffic would be significantly correlated with the rail defect rate (per track mile). Annual averages, computed from a two-year period, were analyzed. Correlations were determined for the variables (overall tonnage, bulk unit train tonnage, rail defects per track mile, and surface roughness index[9] [SRI]).

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6 Elastic recovery refers to the track's ability to return to its original shape after being loaded and unloaded.

7 Heavy Axle Loads Needs Assessment for the American Short Line and Regional Railroad Association, Zeta-Tech Associates, May 2000.

8 Upgrading Short Line and Regional Railways Infrastructure to Accommodate Heavier Axle Loads, IBI Group, 2002.

9 Surface roughness index (SRI) is an average of the number of occurrences of surface defects; that is, track geometry–related defects. Comparison of SRI values between runs gives an indication of track condition over time, with a lower number indicating better track.

1.6.1 *Sample Selection*

Subdivisions were selected using two criteria: a subdivision had to carry more than 10 MGT annually and the majority of its rail had to be under 130 pounds. The TSB initially requested data for 13 western subdivisions (7 from CPR and 6 from CN) that might meet the selection criteria. Examination of provided data revealed that only 4 CPR subdivisions and 3 CN subdivisions met the selection criteria. Consequently, data were requested for 7 additional CPR subdivisions, 2 of which met the selection criteria. Additional data were not requested of CN because it was believed that no additional CN subdivisions would meet the selection criteria. Table 2 lists the subdivisions for which data were initially requested from CPR and CN, as well as the subdivisions included in the follow-up request to CPR. Subdivisions that are struck out did not meet the selection criteria. Figure 2 shows the locations of the selected CPR subdivisions.

Table 2. Subdivision Sample Selection

Canadian National
Initial request
Camrose
Vegreville
Blackfoot
~~Three Hills~~
~~Brazeau~~
~~Sangudo~~

Canadian Pacific Railway	
Initial request	**Follow-up request**
Taber	Red Deer
Weyburn	Leduc
Macleod	~~Hardisty~~
Aldersyde	~~Wilkie (section of 10 MGT+)~~
~~Moyie~~	~~Nelson~~
~~Cranbrook~~	~~Estevan (section of 10 MGT+)~~
~~Crowsnest~~	~~Sutherland (Lanigan to Saskatoon)~~

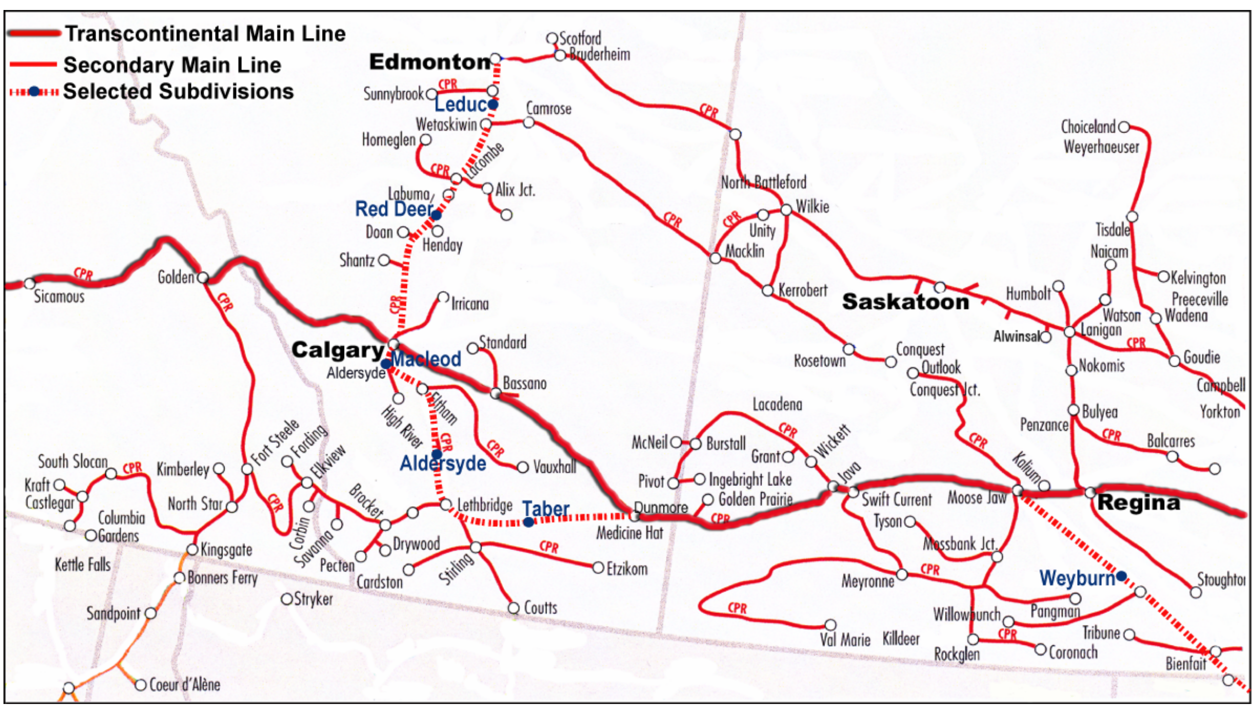

Figure 2. CPR main line map with selected subdivisions

The 9 remaining CN and CPR subdivisions could only be collapsed into a single data set for subsequent analysis if the independent variable (that is, railway) had no significant effect on the dependent variable (that is, rail defect rate). A standard technique to determine if the difference between the two data sets is statistically significant is to apply a *t*-test.[10] If no statistically significant difference is found, the data are collapsed across all levels of the variable and are disregarded in all subsequent analyses. However, the *t*-test (or any relevant statistical technique) requires a sample of at least five for each level of the variable.[11] With a sample of only three CN subdivisions, a statistically rigorous test for differences across railways could not be carried out, nor could an independent analysis of the CN sample be conducted. Therefore, a statistical test of the hypothesis was applied to the CPR data only.

This does not mean that CN is immune from the effect of unit train tonnage on the defect rate of rail under 130 pounds. Simply stated, CPR had enough subdivisions that met the selection criteria to allow a statistical test of the hypothesis, while CN did not. Appendix B gives a more detailed description of the data used in the following statistical analysis.

1.6.2 Results

Table 3. Correlations Among Variables

	Overall Tonnage	Bulk Unit Train Tonnage	Rail Defects per Track Mile	Surface Roughness Index
Overall Tonnage	1.00	0.44	0.29	-0.34
Bulk Unit Train Tonnage		1.00	0.92*	0.57
Rail Defects per Track Mile			1.00	0.71
Surface Roughness Index				1.00
* indicates a level of statistical significance at < 0.05				

10 A *t*-test is a statistical technique for determining if two samples are significantly different.

11 T.C. Krehbiel (2003), "Correlation coefficient rule of thumb," submitted to *The Decision Science Journal of Innovative Education* (Dr. Krehbiel is Professor of Decision Sciences and Management Information Systems, Richard T. Farmer School of Business, Miami University). The article is a rigorous proof that the critical correlation (that is, the lowest statistically significant correlation) is given by $2 / \sqrt{n}$, which is only possible if $n \geq 5$.

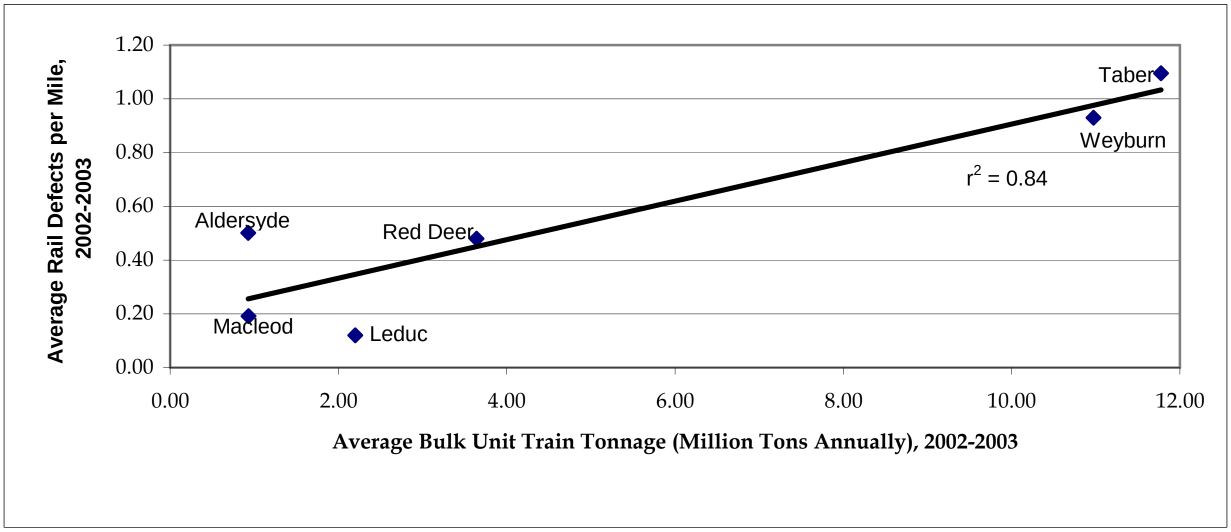

Figure 3. Relation of rail defect rate to bulk unit train tonnage on six CPR western subdivisions

The correlation of bulk unit train tonnage to rail defects per track mile was significant ($r = 0.92$, $p < 0.05$), indicating that 84 per cent of the variance in the number of rail defects is accounted for by bulk unit train tonnage, as shown in Table 3 and Figure 3. This means that there is a strong direct relationship between overall rail defect rates and annual bulk unit train tonnage for the six subdivisions that met the selection criteria.

The correlation coefficient, r, represents the linear relationship between two variables. Where $r = 1.00$, this represents a perfect positive correlation. The coefficient of determination, r^2, represents the strength or magnitude of the relationship between two variables. The statistical significance value, p, indicates the probability that the relationship is due to chance. Convention dictates that results that yield $p < 0.05$ are statistically significant. Results that lie between 0.01 and 0.001 are highly significant. The actual calculated value of p in this analysis was 0.0102.

The correlation of overall tonnage to rail defects per track mile was not statistically significant. Additionally, the correlation of rail defects per track mile to SRI was not statistically significant.

Neither overall tonnage nor bulk unit train tonnage was significantly correlated with SRI.

2.0 Discussion

2.1 Causal Link Between Bulk Tonnage Traffic and Rail Defect Rate

According to the statistical analysis, annual bulk tonnage traffic is strongly correlated with rail defect rate at a statistically significant level, while overall tonnage is not.

Although correlation alone does not prove causality, logic and expert knowledge can be used in conjunction with a significant correlation to construct a valid causal argument. Regarding the statement that an increase in bulk unit train traffic causes an increase in rail defects, one of three causal hypotheses must be true: 1) bulk unit train traffic causes rail defects; 2) rail defects cause bulk unit train traffic; or 3) both are caused by an unmentioned factor or linked set of factors. The second causal hypothesis is false. The third hypothesis requires a causal factor or factors that are linked to both bulk unit train traffic and rail defect rate, but not linked to overall tonnage, because defect rate is not significantly associated with overall tonnage (ruling out an increase in inspections, for example). No such plausible alternative factor can be posited, so by elimination, bulk unit train traffic causes rail defects.

Maintenance was not included as a variable in the analysis, so the mitigating effects of track maintenance on the sample subdivisions remain in the data. It therefore follows that the track maintenance that was carried out on those subdivisions did not fully address the relationship between bulk tonnage traffic and the occurrence of rail defects.

Track speed was also not included as a variable in the analysis, so the same logic applies. That is, the track speed limits and slow orders that have been imposed have not fully addressed the relationship between bulk tonnage traffic and the likelihood of rail defects.

2.2 Railway Processes to Handle Increased Loading on Secondary Main Lines

Railways have increased traffic on secondary main lines to increase network capacity and the use of expensive, underutilized infrastructure, and to relieve congestion on their main lines. Canada's two main railways, CN and CPR, have similar approaches for handling of HAL traffic on secondary main lines. Before accepting this type of traffic over secondary main lines, a business model is developed that balances customer service commitments, accelerated and increased infrastructure degradation, and revenue. The adverse effect of this type of traffic on infrastructure is well recognized, and engineering considerations do dictate how this traffic will be handled.

Railway Safety Management System Regulations, which became effective 31 March 2001, require all federally regulated railway companies to implement safety management systems (SMS). Part 2e of these regulations requires that the SMS include a process for

i. identifying safety issues and concerns, including those associated with human factors, third-parties, and significant changes to railway operations, and
ii. evaluating and classifying risks by means of a risk assessment.

Part 2f of these regulations requires that the SMS include risk control strategies.

According to CN's basic criterion, HAL traffic will be accepted if the line has at least 100-pound jointed rail. Appropriate speeds are set based on bridge capacity, tie condition, anchoring, spiking, and overall track condition. For rail weight less than 100 pounds, a lower track speed is used to reduce the degradation of the infrastructure, the impact on bridges, and the risk of derailment.

In CPR's case, a wholesale review of its secondary main lines to determine 286 000-pound loading suitability was conducted in 1995. Timetable, bridge, track, motive power, and clearance restrictions were all reviewed, and trackage was classified red (no HAL), yellow (HAL with restrictions) or green (no restrictions). All CPR secondary main lines are now considered green, unless the infrastructure degrades.

Some minor track upgrade programs have been undertaken by both CN and CPR in the short term, such as installation of additional rail anchors, spot tie replacement, and selected rail relays. Occasionally, railways will reduce the operating speed and class of track to ensure compliance with the TSR. Reducing speed reduces the impact loading and the rate of track degradation, allowing infrastructure upgrade programs and/or increased maintenance to be deferred in the short to medium term. Axle loadings up to 286 000 pounds are permitted on most of the subdivisions examined during this investigation; however, the overall percentage is low.[12] Where the heavier loading is permitted, speed reductions are usually in place on bridges and sub-standard track sections to mitigate the effects of increased loading.

As most of the unit train traffic on CPR secondary main lines consists of bulk commodities that are not time sensitive, reducing speed in these circumstances is acceptable to the customer and to railway operations, at least in the short term. Slow-speed railway operations are costly because more crews, locomotives, and cars are required. There is an operational incentive to remove speed restrictions when traffic continues in the long term.

In addition to speed reductions, railways increase inspection and testing, closely monitoring the track degradation against their standard practice circulars (SPCs) and the TSR. Both railways currently use their SPCs as their maintenance standard. The TSR prescribe the minimum safety requirements and are generally less stringent than railway SPCs.

Industry testing and experience has shown that heavier axle loads can be operated safely over conventional track systems with 100-pound rail on well-supported track. In fact, both CN and CPR accept limited volumes of 286 000-pound loads over 100-pound rail. However, if the volume of heavier axle traffic continues or increases over the long term, improved or upgraded rail, ties, track fastenings, ballast, and subgrade conditions are required. Major infrastructure renewal programs are rarely done before accepting HAL traffic. These programs are usually implemented when operational restrictions such as reduced speed and/or axle load become unacceptable. The cost of these measures is significant and must be weighed against the rate of track degradation, operational considerations, expected duration of the traffic, and revenue stream. Railways are careful where they allocate resources and a strong business case is

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[12] CN's 286 000-pound loading ranged from 5.2 per cent on the Blackfoot Subdivision to 15.7 per cent on the Three Hills Subdivision. CPR's 286 000-pound loading ranged from less than one per cent on the Crowsnest, Aldersyde, and Macleod subdivisions to 4.19 per cent on the Taber Subdivision. However, the total 286 000-pound tonnage was lower on CN.

required to upgrade secondary main lines, especially if such resources are to be diverted from the principal main lines. Because engineering activities cost, rather than generate, revenue, it is more difficult to develop an economic justification for increased expenditures on secondary main lines.

In the absence of major infrastructure component upgrade programs, increased maintenance, inspection, and rail and track strengthening are necessary to ensure that increased axle loading does not reduce the level of safety.

Railways recognize the accelerated rate of track degradation associated with bulk unit train traffic on secondary main lines. All railways use temporary speed reductions to address sub-standard track conditions that are minor and can be quickly repaired. These speed reductions are removed as soon as track conditions are restored to standard. Both CN and CPR have rigorous assessment processes for more extensive, scheduled track work, but resources are limited and must be prioritized. If programs are deferred, railways may lower the class of track to ensure compliance with the TSR until resources are available. This is a normal process for all railways, and is not limited to CPR. CPR spends more than double the track maintenance cost per gross ton-mile on secondary main lines than on principal main lines. Despite this, the occurrence record indicates that an appropriate balance between increased track degradation and timely infrastructure maintenance and/or renewal has not been achieved.

2.3 Maintenance, Inspection, and Testing

Railways have several options to address the issues associated with accelerated track degradation. Not all efforts to maintain heavy axle traffic on secondary main lines require costly infrastructure renewal programs. For example, increased maintenance, inspection, and testing can help defer major expenditures in the short term and ensure regulatory compliance.

Infrastructure renewal programs (such as installing partly worn continuous welded rail [CWR] with bigger double-shouldered tie plates on sharper curves; increased anchoring, spiking, and spot tie renewal programs; installation of high-strength joint bars; and, in some cases, increased ballast and surfacing programs) have been implemented to strengthen the track structure in selected locations. However, the high number of recent occurrences and geometry defects on the CN and CPR subdivisions suggest that tie renewal, ballast, and surfacing renewal programs may not be keeping pace with the rate of track deterioration.

From 1995 to 2000, the United States FRA safety data showed an upward trend in the number of derailments on main-line track caused by broken rails. Under FRA sponsorship, the Rail Integrity Task Force was convened in April 2002 to identify the "best practices" in the railroad industry for the inspection, maintenance, and replacement of rail. The task force is comprised of subject-matter experts from the major heavy haul railroads, the AAR, FRA's Office of Safety Assurance and Compliance, FRA's Office of Railroad Development, as well as technical support from the Volpe National Transportation Systems Center in Cambridge, Massachusetts. The task force has also received input from all the service providers in the field of non-destructive testing (NDT) of rail. The task force goal is to reduce rail-related accidents and casualties resulting from derailments caused by broken rail. Both CN and CPR are participating railroads.

The American Railway Engineering and Maintenance of Way Association (AREMA) Committee 18 is responsible for developing and publishing information and recommended practices regarding the special engineering, economic, and maintenance needs of light-density and short-line freight railways. The Committee is currently in the process of compiling recommended standards for upgrading light-density lines to HAL capability.

Both railways have increased the frequency of ultrasonic testing of their networks, particularly in the colder winter months when the number of rail defects increases. CN has initiated a joint bolt maintenance/replacement program that permits a close joint bar inspection at the same time and replacement with high-strength bars if required. Gauge restraint measuring is done by both railways to identify weak tie areas, and annual rail defect testing programs have increased to three or more times per year. CN has contracted hi-rail test cars to monitor gauge, cross-level, and alignment more frequently than regularly scheduled TEST car runs. In addition to these measures, both railways have annual rail grinding programs on secondary main lines to ensure more reliable rail defect testing. All these measures serve to closely monitor track degradation and to provide objective support for infrastructure renewal programs. Both railways have installed hot box and dragging equipment detectors on the selected subdivisions to monitor the condition of rolling stock. CPR has installed a wheel impact load detector (WILD) on the Red Deer Subdivision. In addition, a WILD site on the Swift Current Subdivision was strategically placed to protect traffic entering the Weyburn and Taber subdivisions and all westward traffic out of Moose Jaw.

The CPR track evaluation car measures track geometry at frequencies defined in CPR's SPC 34. Urgent and priority surface, elevation, alignment, cross-level, and gauge defects are identified and action is taken as defined in the SPCs. The track evaluation car calculates a SRI, which is an average of the number of surface-related defects per mile. Comparison of SRI values between runs gives an indication of track condition over time. The lower the SRI number, the better the track. The CN TEST car performs the same function and calculates a Track Quality Index (TQI), which represents the average quality of each quarter-mile of track for surface, cross-level, gauge, and alignment. The values range from 0 to 1000 with 1000 representing perfect track.

2.3.1 Rail Testing

With increased traffic at higher speeds and heavier axle loads, rail inspection is more important than ever. Until the early years of the last century, rail inspections for defects were performed solely visually, and were limited to finding external defects only and sometimes the subtle signs of large internal problems. Sperry Rail Service, which performs all rail testing on CN and CPR trackage under contract, started to develop an induction method of testing rail for internal defects in the 1920s. The system involves creating a strong magnetic field in the rail by passing a large amount of low-voltage current through it. The presence of an internal defect changes the magnetic field and the defect indication is recorded on a strip chart. The induction method inspects mainly the rail head, and although transverse fissures can be found, many other manufacturing and service-related defects and fatigue cracks below the rail head are not detectable.

To complement induction testing, ultrasonic NDT and inspection was developed from early medical applications. Ultrasonic testing uses transducer-generated high-frequency sound energy propagated through material in the form of waves. When there is a discontinuity such as a crack in the wave path, part of the energy is reflected back from the flaw surface. The reflected wave signal is transformed into an electrical signal by the transducer and is displayed on a screen. The reflected signal strength is displayed versus the time from signal generation to when an echo was received. Signal travel time can be directly related to the distance the signal travelled and accurate information about the reflector location, size, and orientation can immediately be gained. North American railways have been inspecting rails using the ultrasonic method since the first all-ultrasonic inspection car was introduced in 1959, and this is the most common method in use today.

Ultrasonics provide a fast, cost-effective, efficient, and productive way to test the thousands of miles of rail in the North American rail network. Technological advances have made the process more accurate and information processing faster, and have enhanced the visual presentation of the test results, reducing the amount of human interpretation/intervention required. The rail testing contract establishes performance specifications that specify minimum-sized defects to be detected and reliability ratios. Railways measure performance by monitoring in-service failures within 30 days of a rail test.

As with all NDT methods, ultrasonic inspection has its limitations. Transverse-oriented flaws are detected in the head and upper web area. While the rail head receives a good test, the current technology does not allow thorough inspection of the web and base. Mid-web and lower transverse flaws are almost impossible to detect due to their orientation or location. Longitudinal flaws can be detected in the head and web sections as well as in the base area below the web if they are large enough. Defects located in the outer area of the web (away from the web towards the outer base area) cannot be detected because there is no ultrasonic signal transmitted into this area of the rail.

Rail testing is not an exact science—skill, training, and experience are required to properly interpret test data and identify rail defects. The cars usually operate with a driver, operator, and an assistant who is usually a trainee. The driver is responsible for the safe operation of the car and the operator is responsible for the rail testing. Ultrasonic operators are required to perform a number of tasks simultaneously while testing including monitoring the six channels of test data as the car scrolls by, and the rail conditions and track features as the car moves. All this is carried out while endeavouring to maximize daily test miles in an environment of reduced work windows. Defects must be large enough, and oriented to present a reflective surface big enough to be detected. Deficiencies in any of these areas can and have resulted in operator misinterpretation with defects not being properly identified or smaller defects being missed.

A TSB human performance assessment was conducted on a Sperry Rail Service test vehicle on 30 July 2004 to determine whether the conduct of rail testing was a reasonable task given human performance limitations. Although there is a significant level of judgment required by the operator, it was concluded that the task is manageable for an experienced operator.

Rail surfaces must be smooth and clean to accept and properly reflect the ultrasonic signal. Any condition that results in the ultrasonic signal being reflected before reaching the expected location at the base or side of the rail will result in a defect being suspected at that location. Such spurious reflections are most frequently caused by poor surface condition or contamination of the rail surface and the operator must exercise good judgment to determine the validity of the indication. The operator may erroneously conclude that a rail defect is present when in fact it is not (false positive) or that an indication is spurious when in fact it is real (false negative).

Following a broken rail derailment, one of the first pieces of information obtained during the investigation is the most recent rail test results. The test tape is reviewed to see if a defect was missed. In most cases, the defect, if it existed, was too small to be detected or the defect was masked by poor rail surface condition or contamination. Defects are rarely missed due to a false negative; however, one recent CPR derailment was the result of such an error.[13] Although equipment sensitivity can be increased, this provides little value since it results in increased false positives, which slows the testing operation.

The FRA and the AAR are sponsoring research into improved rail flaw detection under AAR Strategic Research Initiative 7A. The objective is to improve the reliability and safety of railway operations by developing improved flaw detection methods and fostering development of improved flaw detection systems. Phased-array ultrasonics target higher reliability to detect defects 20 per cent in size or smaller. Laser-based ultrasonics provide the capability to inspect the entire rail section and to inspect rail with poor surface conditions because the sound is not restricted to entering the rail from the top.

Small test units that can be lifted and operated by one person have been developed for single- or two-rail testing of crossings, switches, and frogs. These portable units can be used in yards without tying up a larger test vehicle, and they reduce disruption to railway operations. Work continues to be directed at increased test speeds, increased detection reliability through pattern recognition software, automation of operator decision-making tasks, and enhanced sensor performance.

While rail defect testing reduces the risk of broken rail derailments, the detection of all internal rail defects is not within the capacity of the systems currently in use.

2.3.2 Rail Grinding

A number of broken rail derailments on CN and CPR subdivisions in recent years have been attributed to the failure of ultrasonic testing to detect internal rail defects due to poor rail surface.[14] Adequate grinding increases the effectiveness of ultrasonic testing by providing a clear and smooth rail surface.[15] The primary purpose of rail grinding is to control rail surface fatigue defects by removing a thin surface layer of metal, thus preventing the growth of micro-cracks. Grinding also improves wheel–to–rail contact geometry and reduces contact stresses.[16]

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13 R03E0092 (15 October 2003, Mile 40.4, Taber Subdivision) Some of the occurrences referenced in this report have been the subject of a preliminary TSB investigation only. However, summary reports are available upon request.

14 R04C0002, R03C0101, R03E0091

15 AREMA Committee 4, Sub Committee 9 presentation to the AREMA annual convention in September 2003 in Chicago, Illinois.

16 As the rail wears with tonnage over the surface, non-conformal wheel–to–rail contact geometry creates excessive stresses that cause rail surface plastic flow and surface fatigue (spalling, shelling, and head checks) and that mask other internal defects. As rail wears, stresses in the rail come into contact with internal inclusions and act as a nucleus for various types of defect growth.

Recent studies conducted by the AREMA on four Class 1 railways show that longer grinding intervals, increased grinding speed, and reduced grinding of the gauge corner lead to increased fatigue damage on curves and a major increase in detail fracture rates. The AREMA recommends frequent, single-pass grinding on principal main lines.

Preventive grinding cycles are tonnage- or time-based grinding intervals that remove and control the small initiating surface fatigue cracks caused by millions of wheel cycles over the rail. The grinding interval also depends on rail hardness and curvature. The AREMA recommends that curves of three degrees or more with standard rail be ground after bearing 8 to 12 MGT, that curves of less than three degrees be ground after bearing 16 to 24 MGT, and that tangent rail be ground after bearing 40 to 60 MGT. In other words, the AREMA recommends that the interval of grinding should be determined by the curvature of the track in combination with traffic levels. These intervals are based on one pass at a grinding speed of 6 to 14 mph. Because rail grinding is a costly maintenance-of-way activity, both CPR and CN concentrate their grinding programs on heavier tonnage subdivisions.

All subdivisions that are part of this investigation received some grinding in recent years (see Figure 4). Being secondary main lines, the grinding was corrective and was performed in multiple passes less frequently. The time between corrective grinding programs may allow surface defects to develop and propagate, resulting in an increased incidence of undetected rail defects.

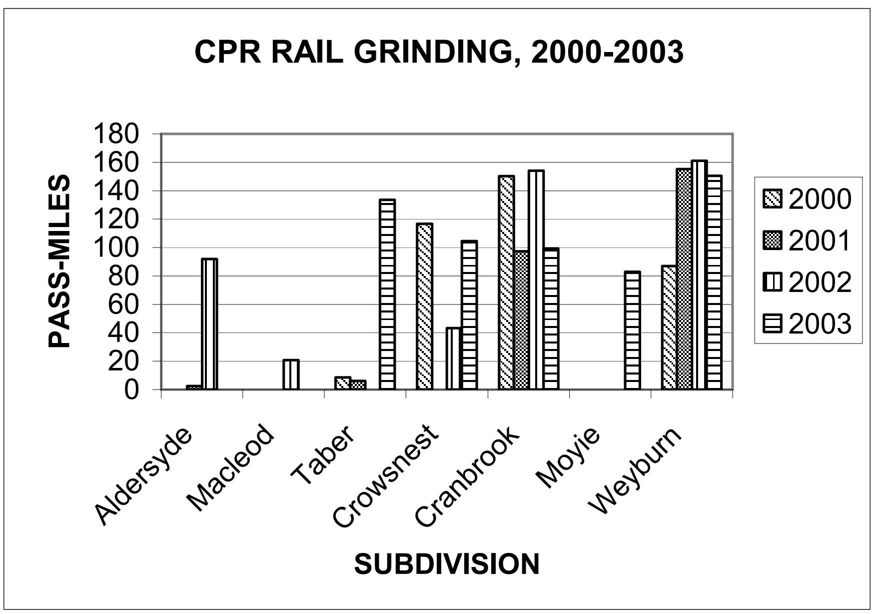

Figure 4. Rail grinding activity on selected CPR subdivisions, 2000–2003

2.3.3 *Rail Joints*

Rail joints are a common track feature even in CWR and are a necessary track discontinuity that occur at switches, at track circuit limits, and where defective sections of rail have been cut out and replaced with rail plugs. Joint bars/angle bars are designed to keep both rail ends in line vertically and horizontally and, ideally, should have the same strength and stiffness as the rails they are joining. The flexural rigidity of a joint is three-quarters of the beam strength of the adjacent rail in the track system. Therefore, even when the joint bars are attached tightly to the rails, the resulting joint is still a weak spot in the track structure that is known to cause derailments due to breaking. As a result, joints and their supporting structure require high track maintenance. Consequently, railways have put great effort into eliminating joints by installing CWR and thermite welding.

Joints must be firmly supported on sound ties on well-tamped, free-draining, clean ballast. Joints must be fully bolted (if timely thermite welding is not planned) and tightened with the recommended torque. Otherwise, wheel impact forces will quickly lead to increased vertical rail deflections, causing loosening and deterioration of the joint assembly, rail head batter, and degradation of the ties, ballast, and subgrade under the joint. If these conditions are not addressed, both the joint bars and bolt hole edges are prone to the development of fatigue cracks and eventually lead to either joint bar(s) and/or rail failure. Testing has shown that even a small crack in the centre of a joint bar significantly reduces the bar's strength. The TSB has investigated four rail/joint bar failure derailments on the selected subdivisions in recent years.[17] An additional nine occurrences[18] have been investigated since 1998 on other subdivisions.

The United States National Transportation Safety Board (NTSB) investigation into the 18 January 2002 CPR derailment near Minot, North Dakota (NTSB report RAR-04-01) concluded the cause to be the result of the joint bars and 100-pound rail having fractured under the previous train or as the accident train passed over the joint. The NTSB also determined that CPR inspection procedures before the accident were inadequate to properly inspect and maintain joints, and those inadequate procedures allowed undetected cracking in the joint bars to grow to a critical size.

There is no protection from these types of defects on non-signalled track. Even if the track had a signal system, detection would not be assured. The track circuit will not fail unless the rail or joint bars completely break apart. For example, the circuit will not be interrupted if the rail breaks out within a joint and the joint bars remain intact, or if the rail break occurs on a tie plate. However, the railway signal industry is working with a major United States railway to develop a broken rail detection system in non-signalled track. Constantly powered track circuits require expensive commercial power or large solar arrays and battery backup. New technology has the ability to reduce power consumption (a critical issue in railway signalling) by the track circuit when the track status is not required, allowing the system to be powered by a single solar panel. The unit can be activated through the rail by data radio or other means.

The most common method of inspecting joint bars is visual from a moving hi-rail vehicle. While this type of inspection may find an obviously fractured, separated joint, small joint bar fatigue cracks are impossible to see. To adequately visually check joint bars, an inspector must conduct an up-close, on-the-ground inspection. A secondary benefit of an on-the-ground inspection is that the inspector can assess the rail joint gap as well as look for bent or loose bolts. In today's fast-paced railway operating environment, these types of inspections are considered

[17] R01W0025, R01W0032, R04E0001, R01E0017

[18] R03T0064, R04C0014, R04T0027, R04W0064, R04E0027, R04T0015, R04T0016, R04C0031, R00E0126

impracticable and are rarely done by railway inspectors. CN is working with other Class 1 railways in North America and the FRA to come up with visual inspection frequencies for all types of joint bars including glued joints in CWR territories.

Although rail-bound or hi-rail ultrasonic/induction testing is generally effective in testing rails, there is no known production method for volume field testing of joint bars.[19] Joint bars can be tested ultrasonically with a hand-held transducer, and the NTSB noted in the Minot investigation that, although CPR had done this in the past, the practice was discontinued over time. Testing of joint bars using the magnetic particle or dye penetration method of inspection can also be done but all of these tests require time, effort and expense. The simplest way to avoid problems with joints is to eliminate them or ensure that they are properly installed and maintained according to the railways' standard maintenance practices.

New developments in equipment and changes in surfacing practices have made infrastructure maintenance more challenging in recent years. In the past, local maintenance forces had access to smaller machines to attend to spot surfacing problems as they emerged. However, equipment fleets have since been rationalized with many of the smaller surfacing machines replaced by fewer, larger, more productive machines. These machines are primarily used on major out-of-face tie, ballast and surfacing programs. As a result, completion of smaller, spot maintenance programs now depends much more on machine availability, which has occasionally resulted in surface problems going unattended longer than desirable.

Inadequately inspected and maintained rail joints represent a critical point of vulnerability, prone to defect development, failure and derailment. Current rail defect detection equipment or geometry cars are unable to identify joint bar defects.

2.3.4 Bolt Holes

Many fatigue cracks originate from bolt holes. Of the 1495 rail defects detected ultrasonically between 2001 and 2003 on the six CN subdivision included in this investigation, 1164 (or 78 per cent) were bolt hole cracks or breaks in the joint area. Of the 4813 rail defects detected between 1998 and 2003 on the seven CPR subdivisions included in this investigation, 1569 (or 35 per cent) were bolt hole cracks in the joint area.

When holes are drilled in rail, the drilling operation itself may result in rail failure. Excessive force and/or speed, in combination with a dull drill bit, may result in the formation of brittle martensite[20] and subsequent microcracks. If the rough and uneven edges around the hole are not removed, stress concentrations are introduced in an already highly stressed area, which can lead to crack initiation during service. This suggests that a smoother edge finish is desirable for all holes drilled in rail. Holes may be deburred, but chamfering[21] of holes drilled in rails in the field is not normally done. Railways recognize the threat posed by improperly drilled bolt holes and have improved the quality of bolt holes, using gas and hydraulic drills that automatically

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[19] A joint bar inspection system currently under development and testing will enable detection of cracked joint bars at speeds up to 50 mph.

[20] Martensite is hardened brittle steel.

[21] Chamfering is a process by which a bevelled surface is added to the bolt hole as it emerges from the rail web.

feed hardened, round bits (not flat) that produce a machined, much cleaner hole, reducing potential stress risers created by burrs. CN's Recommended Method (RM) 3700-0, Drilling Holes in Rail, details proper drilling techniques to protect against the harmful effects created by unsuitable drilling practices. Appendix 9 of CPR's SPC 14 specifies that bolt holes shall be chamfered to remove any burrs and sharp edges, but this standard is intended for rail suppliers, not field drilling.

Fatigue cracking is most common in the first hole in from the rail end, where the greatest stress exists. This condition is aggravated during low temperatures, or if the joint is subject to impact loading or is poorly supported. Detection of fatigue cracking around bolt holes requires ultrasonic inspection. There is a continuing risk of fatigue cracking around rail bolt holes because there are no requirements for chamfering field drilled holes.

2.4 *Railway Track Safety Rules*

Since 1992, federally regulated railways in Canada have been governed by the TSR. The purpose of these rules is to ensure the safe operation of trains on standard-gauge track owned by, operated on, or used by a railway company. They are not intended to replace or circumvent good track maintenance practices, as specified in railways' SPCs.

Tracks are classified according to maximum allowable train operating speeds, not tonnage or type of traffic. The track geometry defect limits of the TSR are based on train speed rather than track strength, although Part II, subparts F II(c) and F IV(a) use tonnage to determine track and rail inspection frequencies. Railways set train speeds according to their operational needs and must maintain the track according to the TSR for that class of track, regardless of train axle loading or tonnage being moved over that portion of track.

Before the implementation of the TSR, CN's standards for constructing new main tracks or upgrading existing main tracks were governed by its SPC 1301. These standards were based on a speed tonnage rating (STR) formula that considered passenger, freight, and express tonnage and maximum speeds found in CN's SPC 1300:

$$STR = (P \times 1.01^{Sp}) + (F \times 1.01^{Sf}) + (E \times 1.01^{Se})$$

P, F and E are annual passenger, freight, and express tonnage, and Sp, Sf and Se are speed factors based on train speed. The higher the STR, the higher the construction and upgrade standard. Construction and upgrade standards were based on these criteria, but with the adoption of the TSR in 1992, the STR formula became obsolete. CN's SPC 1300 became obsolete after 1998. Construction and upgrade standards are now based on speed and TSR track class with no consideration for tonnage or axle loading.

Although the STR formula considered tonnage, it did not accurately reflect the effects of HAL and speed because the base (1.01) and speed factor exponents in the STR formula were the same for passenger, freight, and express trains. In addition, the speed factors increased linearly with respect to train speeds while the relationship between speed and the effect of heavy axle tonnage is not necessarily linear. On well-maintained track with good ballast and surface conditions, increasing axle loads would not necessarily result in an exponential-like increase in dynamic loading. However, on track where ideal geometry does not prevail and poorly supported joints exist, increased axle loading will result in a non-linear or exponential-like increase in dynamic loading even under newer, better-designed cars.

CPR does not have an SPC specifically for track construction standards. Rail weights and types are found in SPC 09 Rail and depend on track categories, tonnage, and TSR class of track. Standards for rail, fastenings, ties, and ballast are found in separate SPCs covering these components.

Reducing train speed and/or lowering the track classification allows deferral of infrastructure upgrade programs and/or increased maintenance and is effective at reducing impact loading and track degradation in the short to medium term. Long-term handling of bulk unit train traffic at reduced speed over secondary main lines that just meet the standards presents potential safety risks, particularly should track infrastructure upgrades and/or increased maintenance not be implemented. TC indicated in 2004 that its Track Safety Rules Working Group will consider factors of HAL, tonnage, and frequency of train traffic in its ongoing review of the TSR.

Over the longer term, handling bulk unit trains at reduced speed over secondary main lines that just meet the standards for lower track class maximum operating speeds presents long-term safety risks should track upgrades and/or increased maintenance not be implemented.

Current TSR may be insufficient to ensure safety because of a lack of consideration of the adverse effects of increased train traffic and HAL on secondary or feeder track systems over the long term.

3.0 Findings

1. The statistical analysis demonstrates that annual bulk tonnage traffic is strongly correlated with the rail defect rate at a statistically significant level, while overall tonnage is not.

2. Where rail weight is less than 130 pounds, increased bulk unit train tonnage significantly increases rail defects, resulting in a higher risk of broken rail derailments.

3. Although railways recognize the accelerated rate of track degradation associated with bulk unit train tonnage on secondary main lines, the occurrence record indicates that an appropriate balance between increased track degradation and timely infrastructure maintenance and/or renewal has not been achieved.

4. Although railways are responsible for putting measures in place to keep the track safe and in compliance with the *Railway Track Safety Rules* (TSR), the TSR may be insufficient to ensure safety because they do not consider the adverse effects of overall increased traffic and specifically bulk unit train tonnage on secondary or feeder track systems over the long term.

5. Inadequately inspected and maintained rail joints represent a critical point of vulnerability since they are prone to defect development and failure. Inspections of rail joints using current rail defect detection equipment or geometry cars are unable to identify joint bar defects.

6. There is a continuing risk of fatigue cracking around rail bolt holes because chamfering of field drilled holes is not carried out.

7. While rail defect testing reduces the risk of broken rail derailments, the detection of all internal rail defects is not within the capacity of the defect testing methods currently in use.

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board authorized the release of this report on 25 May 2006.

*Visit the Transportation Safety Board's Web site (**www.tsb.gc.ca**) for information about the Transportation Safety Board and its products and services. There you will also find links to other safety organizations and related sites.*

Appendix A – Summaries of Table 1 Occurrences

Note that the data provided for some of these occurrences (that is, Class 4 occurrences) are based on a preliminary investigation only. Others (that is, Class 3 occurrences) were subjected to a full Board investigation. Therefore, the information available may not be consistent across all occurrences.

R03E0091 (12 October 2003), Derailment of 19 Cars on Canadian Pacific Railway (CPR) Train 269-11 at Mile 46.9 of the Aldersyde Subdivision

Eight of the cars contained anhydrous ammonia and seven contained fuel oil, but no product was released. The train was travelling at track speed, that is 45 mph. Weather was partly cloudy, windy with an ambient temperature of 15°C. The primary cause was sections of broken out rail that created a 38-foot gap in the high rail of a four-degree left-hand curve. Rail was 1974 Algoma 115-pound continuous welded rail (CWR). High wheel impacts produced by the 15th car behind the locomotives were a significant contributing factor to the rail failure. The last rail flaw detection test before the derailment was done 30 July 2003. No internal defects were recorded within 10 miles of the point of derailment (POD). The next test was scheduled for the week of October 13.

On the Aldersyde Subdivision, 47 per cent of the rail was 1974 115-pound CWR and 53 per cent was 100-pound, 72-foot jointed rail with standard spiking and anchor pattern. There was a mix of 11-inch and 14-inch double-shouldered plates. Ballast was in poor condition. Traffic on the Aldersyde Subdivision in 2003 was 13.0 million gross tons (MGT), a 15 per cent increase since 2001, with 7 per cent unit train traffic. Rail defects per 100 miles tested decreased from 19.69 in 1999 to 11.42 in 2002, but increased to 16.52 in 2003.

R03E0092 (15 October 2003), Derailment of 14 Cars on CPR Train 863-017 at Mile 40.4 of the Taber Subdivision

Derailed cars included six residue cars of molten sulphur and eight empty coal cars. Track speed was 40 mph with a 25 mph temporary slow order in place due to poor ballast conditions. The primary cause was determined to be a broken rail due to a 15-inch vertical split head, and head and web separation. The rail was 1953 Dominion 66-foot jointed, 100-pound head free on tangent track relaid[22] in the 1980s. The rail was ultrasonically tested one week before the accident. The defect was detected, but misinterpreted by the operator.

Rail on the Taber Subdivision was 100-pound and 115-pound jointed rail with standard anchoring and spiking. Ten-inch single-shouldered plates were used on rail under 100 pounds, and 14-inch double-shouldered plates were used on rail under 115 pounds. Ballast grade was fair to good on the east end of the subdivision and poor on the west end of the subdivision. Approximately 17 miles of CWR and 48 miles of plates were scheduled for installation in 2004. In addition, 31.4 miles of CWR were scheduled for installation in 2005 and 50 miles in 2006.

[22] The term "relay" refers to the practice of re-laying used continuous welded rail with residual service life that has been taken from principal main track.

Traffic on the Taber Subdivision in 2003 was 15.7 MGT, a 43 per cent increase since 1999, with 80 per cent unit train traffic, transporting mainly bulk commodities such as coal, grain, sulphur, and potash. Rail defects remained relatively stable between 1999 (30.46 per 100 miles tested) and 2001 (30.75), decreased in 2002 (20.40) then increased in 2003 (39.44).

R03C0101 (24 October 2003), Derailment of 16 Cars on CPR Train 269-21 at Mile 10.75 of the Moyie Subdivision

Track speed through the area was 25 mph; the train was travelling at 27 mph. The weather was clear and the temperature was 9°C. Derailed cars included one residue non-dangerous commodity tank car and one residue tank car that last contained sodium hydroxide. There was no loss of product from the tank cars. The primary cause of the derailment was a break in the high rail within the body of a six-degree left-hand curve due to a transverse detail fracture extending from the gauge corner of the high rail. The rail was 136-pound RE CWR manufactured by Algoma between 1980 and 1985. The last ultrasonic test before the derailment was on September 19, with no defects noted in the area. In the area of the POD, the rail flaw detector car showed an intermittent response typical of poor rail head surface condition, and no further action was taken by the rail test operator.

Rail on the Moyie Subdivision was a combination of 100-pound, 130-pound, 132-pound, and 136-pound rail with CWR on most curves and jointed rail on tangent track. Standard anchoring was used with double-shouldered plates and five spikes per plate on most curves, and single-shouldered plates and two spikes per plate on tangent track. Ballast was fair to poor. Approximately nine miles of rail were relaid between 2001 and 2004. Two miles of relay rail were planned for 2005 and 2006. Traffic on the Moyie Subdivision in 2003 was 16.0 MGT, a 33 per cent increase since 1999 with 26 per cent unit train traffic. Rail defects per 100 miles tested decreased from 17.61 in 1999 to 9.15 in 2001, increased to 26.76 in 2002, and then decreased to 20.13 in 2003.

R04E0001 (01 January 2004), Derailment of 28 Loaded Grain Cars on Canadian National (CN) Train A44351-01 at Mile 58.90 of the Camrose Subdivision

The northbound train was proceeding at 40 mph, slowing for a 25 mph permanent slow order between Mile 49.2 and Mile 58.4. The primary cause of the derailment was a broken rail in a joint on tangent track. The rail break was likely due to a bolt hole crack. The rail was 1949 Algoma 100-pound, 39-foot jointed (four bolt joints) rail with a 7 mm head loss. Ties were No. 1 hardwood in good condition, 14-inch double-shouldered tie plates with five spikes per plate, and anchors boxed every second tie. Ballast was crushed rock in fair–to–good condition.

The rail was 100 pounds of primarily CWR with the remaining rail 39-foot jointed, anchored every second tie. Ties were softwood except for hardwood on curves greater than four degrees with 11-inch double-shouldered plates and 14-inch double-shouldered plates on some curves, two spikes per plate with pin spiking on higher-degree curves. There were 20 to 30 per cent defective ties on average. Ballast was crushed rock in good condition. Over 16 miles of partly worn CWR had been installed and 15 200 electric flash butt welds done since 2001 to eliminate jointed rail. A total of 14 000 anchors, 3600 ties, 6000 spikes, and 4.52 miles of gauging were done, and 2600 cubic yards of ballast were placed. Train traffic in 2003 was 10.5 MGT, which was a 40 per cent increase since 2001. There was 21 per cent unit train traffic, mainly northbound sulphur and grain.

R04C0002 (05 January 2004), Derailment of 15 Cars on CPR Train 266-02 at Mile 76.4 of the Crowsnest Subdivision

Track speed was 35 mph and the train was travelling at 30 mph. Temperature at the time was -31°C. All derailed cars were empty except for one residue liquefied petroleum gas tank car and one loaded phosphoric acid car. The primary cause of the derailment was a broken high rail in transition between five- and six-degree curves. Eleven pieces were recovered, and TSB examination determined that there were transverse defects in 12 of the 14 fractures, all in the gauge corner of the rail head, varying in size from 5 to 50 per cent of the cross-sectional head area. The last ultrasonic test, which had been done 03 October 2003, indicated a possible transverse defect near the POD, but the rail ultrasonic operator decided that the defect was less than 10 per cent and took no action because the rail surface was poor (significant checking and shelling). Rail was 1982 Algoma 115-pound partly worn CWR cascaded from the CPR main line in northern Ontario.

Rail was 100-pound jointed from Mile 7.9 to Mile 10.3, with single-shouldered plates. The remainder was 115-, 132-, and 136-pound CWR with 14-inch double-shouldered plates, except for 11-inch double-shouldered between Mile 48 and Mile 77. Anchoring and spiking patterns were standard. The ballast was rated as in good condition. Traffic in 2003 was 20.1 MGT, a 53 per cent increase since 1999, with 58 per cent unit train traffic. Rail defects per 100 miles tested increased from 2.14 in 2000 to 11.79 in 2002, levelling off to 11.53 in 2003.

R04C0014 (26 January 2004), Derailment of 11 Intermodal Service Cars on Southward CPR Train 104-26 at Mile 46.1 of the Red Deer Subdivision near Didsbury, Alberta

Permissible track speed was 55 mph and the train was travelling at 21.7 mph. The weather was clear at -29°C, and a 35 mph cold weather slow order was in effect at the time. The primary cause of the derailment was broken rail/joint bars in the west rail. Fatigue cracks had developed from bolt holes in the south rail end of the joint. Well-developed fatigue defects were present on the fracture surfaces of both joint bars. Poor joint inspection and maintenance were contributing factors in this derailment. Rail was 1983 Algoma 115-pound CWR on tangent track with six- hole joint bars. The last ultrasonic test, 10 November 2003, identified a defective plant weld immediately north of the POD (not considered causal).

Rail on the Red Deer Subdivision is mainly 100-pound jointed with some 115-pound CWR. Overall traffic on the Red Deer Subdivision varied little between 2000 (25.0 MGT) and 2003 (26.4 MGT) with 14 per cent to 20 per cent bulk traffic.

R04C0031 (22 February 2004), Derailment of 22 Intermodal Platforms on Westbound CN Train Q11531-19 at Mile 37.21 of the Oyen Subdivision

Track speed was 40 mph and the train was travelling at 34 mph. Weather was clear and calm, at -6°C. The primary cause of the derailment was a broken rail due to a vertical split head in a joint near a crossing. Rail was 1956 RA Dominion 100-pound, 78-foot jointed rail (four bolt joints) on tangent track. No rail defects were recorded in the area on the last previous ultrasonic rail test done on 17 June 2003.

Oyen Subdivision traffic in 2003 was 5.1 MGT, with 70 per cent intermodal and 30 per cent other freight, mainly grain. Maximum loading permitted on the Oyen Subdivision is 268 000 pounds.

R04E0027 (04 March 2004), Derailment of 20 Cars on Westbound CPR Train 575-03 at Mile 86.03 of the Red Deer Subdivision near Penhold, Alberta

Derailed cars included five residue cars of anhydrous ammonia, two residue cars of propylene and one residue car of sodium aluminate. The weather was clear and calm with a temperature of -18°C. At the time of the derailment, the train was travelling at 39.2 mph. The posted subdivision speed at the POD was 45 mph; however, there was a slow speed order of 40 mph in effect in the area due to excess cross-level variation (not considered causal). The last rail flaw detector test was conducted between Mile 67.3 and Mile 95.6 on 13 February 2004, with no defects found. The train derailed as it passed over a rail joint in tangent track that had broken and separated. Two joints at both ends of a buffer bar were involved. All joint bars failed at their approximate middles with the fracture surfaces of the bars showing pre-existing fatigue fractures extending from the top fishing surfaces. The joint bars were weakened by these fatigue defects due to the poorly supported and unsecured condition of the joint and adjacent rails.

Appendix B – Supplemental Statistical Analysis Information

Selection of Canadian Pacific Railway Subdivisions

Those Canadian Pacific Railway (CPR) subdivisions not having an annual tonnage greater than 10 million gross tons (MGT) and a majority of rail weight under 130 pounds, according to data provided by CPR, were excluded from the final sample. The Hardisty, Wilkie, Estevan, and Sutherland subdivisions were excluded due to low MGT. The Cranbrook, Moyie, and Nelson subdivisions were excluded because a majority of the rail weighed more than 115 pounds. The Crowsnest Subdivision was also excluded because nearly all bulk traffic was borne by 132- or 136-pound rail. Although only 26 per cent of Crowsnest Subdivision rail is over 115 pounds, that heavy rail is entirely located between Mile 77.2 and Mile 101.1, where it bears nearly all of the bulk unit train traffic on that subdivision. The bulk coal cars travel south from the open-pit mines of the Elk Valley coalfield, then west and north through the Cranbrook Subdivision and on to the port facility of Roberts Bank on the west coast, so that the lighter rail located east of the open-pit coal mines of the Crowsnest Pass region bears very little of the bulk unit train traffic.

Variables

The following variables were averaged across 2002 and 2003:

- Overall tonnage – annual MGT;

- Bulk unit train tonnage – derived by multiplying the percentage of bulk unit train traffic (supplied by the railway) by overall MGT;

- Rail defect rate – annual rail defect count per mile of track;

- Surface roughness index – supplied by CPR.

Table 4. Selected CPR Subdivisions

Subdivision	Average MGT	Average Bulk MGT	Average Rail Defect Rate	Average SRI
Taber*	15.10	11.78	1.09	95.65
Weyburn*	28.50	10.97	0.93	49.75
Macleod*	12.45	0.93	0.19	52.75
Aldersyde*	12.40	0.93	0.50	60.50
Red Deer*	25.70	3.64	0.48	55.00
Leduc*	18.55	2.19	0.12	42.90
Cranbrook	37.90	15.96		
Moyie	15.20	3.57		
Crowsnest	18.85	10.57		
Hardisty	3.50	0.81		
Wilkie	3.85	0.69		
Nelson	15.70	3.95		
Estevan	3.25	1.20		
Sutherland (Lanigan to Saskatoon)	9.40	5.90		

* denotes subdivision selected for statistical analysis

Rail defect rates and surface roughness index values are reported only for those subdivisions that met the selection criteria.

Appendix C – Rail Testing

Railways rely heavily on testing rail for defects. The testing methodology used by all rail testing contractors is basically the same. The only differences are data processing speed, presentation of information, vehicle setup, and roller search unit (RSU) carriage construction. Over the years, Sperry Rail Service has developed and used RSUs that combine different transducer angles to achieve the best inspection possible. Fluid-filled wheels are used to house and couple the transducers to the rail. A liquid couplant consisting of a thin film of water mixed with glycol or calcium facilitates the transmission of ultrasonic energy from the transducers into the rail.

In the A-scan system, there are two wheels with nine transducers per rail—five transducers in one wheel and four in the other. Each rail has nine transducers: one zero-degree or vertical-looking probe, one forward-looking and one rear-looking transducer nominally aligned at 45 degrees (actually at 37 degrees), and six 70-degree probes. In the newer B-scan system, two additional "side-looking" modified 70-degree probes look at each rail head at a lateral angle for vertical separations for a total of 11 transducers on each rail. These arrays of probes result in a test of all the rail cross-section with the exception of the outside base edges. Because the B-scan ultrasonic testing technology permits a greater volume of rail to be tested and smaller defects to be detected, flaw detection is improved by approximately 50 per cent.

At Sperry Rail Service, there are two primary inspection units: a rail-bound vehicle that uses both ultrasonic and electromagnetic (induction) technologies to identify defects, and an ultrasonic-equipped hi-rail truck. In the past, induction equipment has been too large for hi-rail vehicles, but Sperry Rail Service has recently developed an induction system that operates on a hi-rail platform. The vehicles will test rail between 6.5 and 13 mph, and vehicles operating at higher speeds are under development.

The data from the inspection equipment are fed to the operator inside the car and visually presented on monitors. Six channels display the ultrasonic and induction signals and where exceptions occur relative to track features such as joints and crossings. If the operator considers an indication suspect, the test vehicle is stopped and backs up to the point of examination. The operator gets out and hand tests the rail with an ultrasonic test set mounted on the rear of the car. If a defect is confirmed, it is marked and a rail work crew following the Sperry Rail Service car changes the rail or otherwise protects it.

Selecting an appropriate frequency for rail testing is a complex task involving many different factors including temperature, traffic density, rail sections, and accumulated tonnage. The *Railway Track Safety Rules* (TSR) specify an annual test of rail for internal defects of all track in classes 4 through 6 over which the annual gross tonnage is 25 million tons or more and in Class 3 track over which passenger trains operate. Both Canadian National (CN) and Canadian Pacific Railway (CPR) recognize the value of frequent testing and exceed this requirement, particularly during the colder winter months when rail is more brittle and susceptible to defect growth.

The number and types of rail defects form a database used by the railways in the development of rail replacement programs and to give an overall sense of the defect history of a subdivision. CN's rail defect severity program calculates total rail defect severity or rail defect indices (RDI) across a subdivision. The program assigns a severity value for each defect based on the type of defect. Fatigue defects such as vertical split head, head and web separation, transverse defect, and horizontal split head have higher values than defects due to wear such as battered end, curve wear, flowed rail, and shelly rail. The sum of all severities for a five-mile window is calculated and plotted on a rail severity plot. The plot allows for enhanced planning and prioritizing of rail replacement programs, which are then included in the railway's overall capital renewal plan where the requirement for rail competes with other corporate capital demands. Approved rail programs are nearly always less than what has been requested, resulting in local supervisors placing their allotment in the highest risk locations.

At CPR, defective rails are replaced or protected as required by its Standard Practice Circular (SPC) 27. According to SPC 09, Section 4.2, rail is replaced through a whole curve at wear limit A (wear limits for planning rail relay where there is evidence of fatigue), rather than C (maximum wear limits at which rail must be removed from track). Rail is considered to be fatigued when there is evidence of one rail defect of a fatigue type within the past 12 months or two rail defects within the past 24 months. CPR has no hard standard on the number of defects occurring in tangent track that would automatically trigger a change-out. This is done on a case-by-case basis, depending on the nature of the defects.

CPR's SPC 09, Section 8.0, provides rail replacement guidelines based on the TSR class of track. New or relay continuous welded rail (CWR) is the guideline for all tonnage classes of secondary main lines and above; however, the actual decision concerning the rail to be used may be influenced by availability of rail, costs, and future prospects of the line.

Sperry Rail Service has taken the following steps to ensure that operators are sufficiently trained to reliably identify rail defects:

- The company employs a training program in which an operator progresses from driver to assistant to chief, which lasts between one and three years including on-the-job training. Before proceeding to the next level, the operator receives 40 hours of formal training in ultrasonic testing and must demonstrate competence according to a standard recognized by the American Society for Nondestructive Testing (ASNT).

- Rail test results are monitored and any in-service failures occurring within 30 days of a test are investigated and successive inspections on a given track are compared to identify any defects missed. An operator who has not identified defects that were present is given feedback and/or remedial training.

- Although Sperry Rail Service seeks to maximize miles tested each day, the chief is responsible for the conduct of the test and the pace of the task. Since rail testing contracts are based upon hours worked, not miles tested, operators can take the time required for hand testing and visual inspections, and can stop the car to redo a section if deemed necessary.

Sperry Rail Service, CN, and CPR have adopted the American Railway Engineering and Maintenance of Way Association (AREMA) Recommended Minimum Performance Guideline for Rail Testing. The performance guideline specifies the minimum acceptable performance in terms of the percentage (reliability ratio) of actual in-track defects that can be expected to be located in a single test by a test car maintained in reasonable condition and operated by an experienced operator in service over a typical mix of track conditions. Since 100 per cent accuracy in testing is not within the capabilities of current technology and equipment, the performance guideline also specifies the number of valid defects in track that are not reported or are otherwise missed. For example, AREMA testing performance standards specify a reliability ratio of 75 per cent for bolt hole cracks ½ inch to 1 inch in length for Category I track. Detection of smaller cracks is not assured. Reliability ratios depend on size of defect and category of track. Category I track includes all main track with annual tonnage equal to or exceeding 3 million gross tons (MGT) per year, or with train speeds equal to or exceeding 40 mph. Category II track includes all sidings and track with annual tonnage less than 3 MGT per year, and with train speeds less than 40 mph.

Appendix D – Transport Canada Inspections

Moyie Subdivision

Following a Transport Canada (TC) inspection of the Moyie Subdivision in October 2004, a TC Notice and Order was issued 29 October 2004 regarding high density or defective track ties, worn and defective rails, inadequate rail joint maintenance, and fouled and insufficient ballast. Both the Cranbrook and Moyie subdivisions were placed on special inspection status (more frequent and detailed TC inspections to be done).

Cranbrook Subdivision

A TC Notice and Order was issued 08 May 2003 regarding general poor tie conditions and high/broken fasteners on the latter portion of the subdivision, and increasing tonnage and heavier axle loads. Although some improvements were noted as a temporary measure, Canadian Pacific Railway (CPR) was advised on 29 October 2004 that the Notice would remain in effect due to poor rail joint maintenance, worn rail, inadequate turnout maintenance, and sub-standard track conditions in Cranbrook Yard.

Taber Subdivision

On 17 July 2002, TC inspected the track between Mile 55.69 and Mile 114.64. This inspection recorded fouled ballast conditions, defective tie clusters, tie and tie plate deterioration, ineffective anchoring, and general poor track conditions. TC wrote to CPR on 18 July 2002, requesting information on CPR's rail, tie and ballast program, both for work completed in 2001 and work planned for 2002. CPR was given 14 days to provide details of the corrective action it planned to take to address the track deficiencies identified during the July 17 inspection. CPR responded on 08 August 2002, outlining the immediate corrective action taken. However, there was no supplementary information regarding the long-term maintenance plans necessary to address the inspector's observations.

On 08 January 2003, another inspection was completed between Mile 32.5 and Mile 62.0. On 10 January 2003, TC identified concerns regarding the ongoing maintenance and accelerated track degradation due to the overall subdivision tonnage increases and increased car loading over the previous four years. TC requested that CPR provide it with details by 30 April 2003 of its plans to maintain the infrastructure of the Taber Subdivision to safely handle anticipated rail traffic. CPR responded on 28 April 2003, indicating that, for 2003, the maintenance plans on the Taber Subdivision would include relay rail installation, turnout upgrades, and broken tie plate replacement. In addition, CPR provided TC with its multi-year maintenance plan for 2004 to 2008. TC reviewed this information and expressed concerns regarding the tie program and the plan to address the sub-standard ballast conditions. CPR was requested to review TC's concerns and provide a follow-up.

On 22 September 2003, CPR advised TC that it was limiting train speed on the subdivision until it had the infrastructure upgraded with better rail, fastenings, ballast, and, where necessary, ties. CPR also indicated that TC's other earlier concerns could be addressed through appropriate revisions to the capital plan. There was no further information on what revisions were being contemplated for the capital plan.

Appendix E – Glossary

AAR	Association of American Railroads
AREMA	American Railway Engineering and Maintenance of Way Association
ASNT	American Society for Nondestructive Testing
CN	Canadian National
CPR	Canadian Pacific Railway
CWR	continuous welded rail
E	annual express tonnage
F	annual freight tonnage
FRA	Federal Railroad Administration
HAL	heavy axle loading
MGT	million gross tons
mph	miles per hour
NDT	non-destructive testing
NTSB	National Transportation Safety Board
p	statistical significance value indicating the probability that the relationship is due to chance
P	annual passenger tonnage
POD	point of derailment
r	correlation coefficient representing the linear relationship between two variables
r^2	coefficient of determination representing the strength or magnitude of the relationship between two variables
RAC	Railway Association of Canada
RSA	*Railway Safety Act*
RDI	rail defect indices
RM	Recommended Method
RSU	roller search unit
SII	safety issues investigation
SMS	safety management system
Se	speed factor for express trains based on train speed
Sf	speed factor for freight trains based on train speed
Sp	speed factor for passenger trains based on train speed
SPC	standard practice circular
SRI	surface roughness index
STR	speed tonnage rating
TC	Transport Canada
TQI	Track Quality Index
TSB	Transportation Safety Board of Canada
TSR	*Railway Track Safety Rules*
TTCI	Transportation Technology Center Inc.
WILD	wheel impact load detector
°C	degrees Celsius
$<$	less than
$\geq$	equal to and greater than
$\sqrt{n}$	root number of data points