Railway Safety Technologies

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by

T.W. Moynihan, G.W. English

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Executive Summary

The objectives of this project were to:

- examine existing technologies and the potential of future technologies to enhance rail safety.
- examine whether or not the current legislation can readily adopt technology, and
- provide recommendations on the most promising technological developments.

The project drew upon information obtained through a literature review, contact with suppliers and interviews with selected stakeholders, including the Transportation Safety Board, Transport Canada (headquarters and regional personnel), Class 1 freight railways (CN, CPR), VIA Rail and an operator of shortline railways.

Technology and research findings have been used to advance the safety of Canadian railways in the past, and there will be ongoing opportunities to advance safety in the future. We believe that the Railway Safety Act (RSA) is not an impediment to the adoption of safety technology, but does not, in itself, facilitate technology development. The RSA allows safety regulations to be updated as changes in technology and knowledge make it desirable. However, the regulation development process has not been very successful in moving to performance based standards. The industry and regulator have not yet agreed on what a performance standard is, or what characteristics it should have. Close to twenty years after the RSA, Transport Canada is still perceived to be functioning in the compliance mode of the former Canadian Transport Commission.

Facilitation of technology development involves financial and manpower resources that have not yet been allocated. If Transport Canada wishes to have an influence on safety issues that are specific to the Canadian operational or physical environment, we believe it needs to invest in both research and personnel. We recommend Transport Canada allocate the resources necessary to fulfill the intent of the RSA.

Harmonization requirements and industry structure pose more of a constraint to equipment-related technology development than does the Railway Safety Act. There is more freedom to chart an independent course in the track area. We recommend that the present initiative to update the Track Safety Rules be used as an opportunity to interpret the intent of the RSA and update the process involved in regulation setting. By all accounts an excellent first step has been taken. The resources and priority allocation that are required to continue that process to a successful conclusion need to be allocated. Attaining the optimal balance of government’s safety oversight in support of public confidence, and industry’s freedom to efficiently manage/advance safety should be the objective. From our interview process, we found diametrically opposite viewpoints on some basic issues. We encourage both industry and government to approach the task with an open mind and recognition of the importance of getting it right after 15 years of experience with the existing TSR.
We concur with the majority of interviewees who indicated that research and development should be an integral component of Rail Safety Directorate’s (RSD) approach to fulfilling its mandate of providing safety oversight and advancing safety. We believe that the research program developed within Direction 2006 is an example of a joint industry-government initiative that was successful in advancing grade crossing safety and allowed Transport Canada to participate in, and contribute to, that advancement at an international level. We recommend Transport Canada implement a similar joint industry-government program in rail safety advancement and allocate sufficient financial and personnel resources such that, by 2010, the organizational structure and safety advancement targets for 2020 are set, and an initial five-year research program is outlined.

Rather than focus on specific technologies, we recommend that the following general guidelines be used in targeting future research efforts:

- There is more of a role for government to take leadership in developing technologies that do not offer significant operating savings, and where cross-functional boundaries exist.
- Selection of specific topics within these categories should recognize the potential constraints of cross-border harmonization.
- There are more opportunities to influence safety advancement in track and operations safety areas than in equipment related topics.
- Within equipment, the focus should be on providing leadership to address safety problems that are exacerbated in Canada’s operational and natural environment.
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1 INTRODUCTION

1.1 Background
The Railway Safety Act, which came into effect in January 1989, was designed to advance rail safety in Canada by giving the Minister of Transport responsibility for rail safety regulation; providing a modern regulatory framework, together with a streamlined regulation development and approval process; and providing railway companies with greater freedom to manage their operations safely and efficiently.

Since 2002, there has been an increase in railway accidents and main-track train derailments in Canada. In addition, Transport Canada officials have identified deficiencies with the Act during their day-to-day administration of legislative provisions.

There is a view that the current regulatory framework does not provide the full set of tools to effectively deal with railway accidents and main-track derailments. There is also a view that the current framework needs to be modernized and better aligned with safety legislation that applies to other modes of transport in Canada.

Accordingly, in December 2006, the government announced the Railway Safety Act Review to further improve railway safety in Canada and to promote a safety culture within the railway industry while preserving and strengthening the vital role this industry plays in the Canadian economy.

A four-member Railway Safety Act Advisory Panel (RSA Panel) was appointed by the Minister of Transport, Infrastructure and Communities to conduct independent study and analysis, undertake consultations, and prepare a report with findings and recommendations. Background studies and research were undertaken to help inform and provide the RSA Panel with additional information and analysis related to specific topics.

1.2 Objectives
The objectives of this project were to:

- examine existing technologies and the potential of future technologies to enhance rail safety.
- examine whether or not the current legislation can readily adopt technology, and
- provide recommendations on the most promising technological developments.

1.3 Scope and Methodology
This document has been prepared to provide the RSA Panel with a summary of existing technologies, and potential future technologies, employed to enhance safety within the railway industry. This report also identifies implementation issues associated with both the regulatory environment and the North American railway industry business model. This information has been obtained through literature review, contact with suppliers and through
interviews with selected stakeholders including the Transportation Safety Board, Transport Canada (headquarters and regional personnel), Class 1 freight railways (CN, CPR), VIA Rail and an operator of shortline railways.

1.4 Mainline Derailment Accident Distribution

An analysis of data for Canadian railway accidents which occurred between 1999 and 2006 revealed that track and equipment factors dominate all other causes of mainline derailments. As illustrated in Figure 1, track and equipment factors were identified in 63% of all main line derailments. Moreover, if one considers only those derailments where a contributing factor is cited (i.e. excluding the 29% where a cause was not assigned), equipment and track factors accounted for 89% of all mainline derailments.

Figure 1  Canadian mainline derailments by reported cause (1999-2006)

Within the 34% of equipment related mainline derailments, wheel failures were the dominant cause. Within the 29% of track related mainline derailments, geometry causes were the most dominant, followed by rail failure. The reader is referred to a companion report prepared for the RSA Panel by Transportation Research Ltd. entitled “Causes of Accidents and Mitigation Strategies”.

1.5 Report Layout

Based on the above relationships, equipment and track safety technologies are the focus of this technology review. This report is presented in six chapters and one appendix.

Chapter 2 discusses the role of institutional factors, including the Railway Safety Act in advancing safety technology.

Chapter 3 outlines safety technologies related to railway vehicles.
Chapter 4 discusses safety technologies related to track and infrastructure.

Chapter 5 presents additional safety technologies applicable to railway operations.

Chapter 6 presents observations and recommendations.
2 INSTITUTIONAL INFLUENCES

In the conduct of this study we interviewed personnel from industry (including CN, CPR, VIA, and an operator of shortline railways), the TSB and Transport Canada (including headquarters and regional personnel). We drew upon common themes in the interview responses to identify and shape the issues presented in this chapter. Where specific input from the interview process is cited, it is presented in indented italic font, rather than in quotations.

2.1 Technology Advancement under the Railway Safety Act

No interviewees questioned the adequacy of the *Railway Safety Act* in progressing Safety Technology, but some raised issues with execution of the Act, and most interviewees encouraged a raised R&D presence for Transport Canada (TC). The following responses reflect the general theme in relation to the question - Does the *Railway Safety Act* facilitate the adoption of safety enhancing technology?:

- Don’t see the present system as hindering adoption of a ‘magic bullet’; the problem is finding the magic bullet.
- Application of the Act requires Transport Canada facilitation – it should set targets and encourage railway adoption of technology.
- The Act does, but the cost of the application process and burden of proof required by a regulator that has demonstrated there is a high risk of no response once submitted is a major deterrent.
- The Act is OK but not adequately used. – e.g. Section 14 (demonstration projects) has never been used. TC needs to spend more and participate rather than monitor U.S. FRA safety R&D activities.

With respect to Transport Canada’s execution of the Act, the following comments capture the common themes in the responses from industry and Transport Canada staff:

- Fifteen years after the revised Railway Safety Act, HQ staff are still following the old CTC "compliance model" of safety oversight. HQ is not equipped to write regulations, it is only dealing with exemptions. They need the resources and knowledge to develop regulations.

  TC needs to have staff and resources to participate in and understand the issues and technologies being discussed. There needs to be a shift from a rules culture and associated personnel/qualifications to a performance based engineering level of qualifications and understanding. To help achieve the above, TC needs to have a more active R&D program and close interchange between the safety management and safety R&D personnel.

  TC should have personnel and facilities to evaluate technologies – now the railway must not only invest in the technology but undertake the risk assessment for TC.
Adopt the FRA approach to technology - FRA does its own R&D assessments and encourages new safety technology by offering tradeoffs against other rules. For example - installation of HWDs as a substitute for 1-a) brake tests.

TC should be more proactive in R&D, in safety benchmarking and encouraging the railways to take up new technologies.

Canadian initiatives are needed. There is no real activity going on in Canada. We need a safety group with funding to address safety issues.

There is an opportunity for TC to advance railway safety in cooperation with the industry under the existing Act if it approaches it with a vision to the future and a willingness to lead.

The Direction 2006 program and, particularly a couple of its research initiatives were cited as examples of how Canada can influence safety if it is willing to invest. One was the overall process and research study involved in the Canadian adoption of a two-level locomotive horn. TSB’s investigation of a trespass fatality raised an issue with the adequacy of the locomotive horn. TC responded by commissioning a research assessment in cooperation with the railways as part of the Direction 2006 initiative. The research confirmed the inadequacy of the existing horn placement on some locomotives at operating speeds and recommended a separate emergency horn (or setting) for high speed locomotives, a sound characteristic to elevate attention-getting, and positioning on the locomotive to best transmit the sound. The Railway Association of Canada (RAC) developed a wording for a new locomotive horn standard, which was adopted as part of the Locomotive Rules. The second Direction 2006 initiative that was cited in interviews was the research undertaken to demonstrate the safety advantages of LED technology in grade crossing warning lights. We note that in both cases the final regulation/standards were influenced by harmonization objectives. The constraints of harmonization are discussed in Section 2.4.

2.2 The Regulations Development Process

2.2.1 General Process

One common issue raised with respect to regulations dealt with the process itself; specifically the variation in the field interpretation of regulations. Some noted that any wording used in a regulation will be open to interpretation. Further, the lack of documentation on reasons for the adoption of a regulation, often limits the ability, at a future date, to assess the ongoing validity of a regulation or the adequacy of a new technology in replacing/modifying the original regulation. It was suggested that the very detailed background information provided within the regulation setting process in the U.S. FRA’s “Notice of Proposed Rulemaking” went a long way in reducing the scope for misinterpretation of the reason for, and intent of, a specific regulation. Transport Canada officials noted that the financial and manpower resources that are allocated in the U.S. FRA rulemaking process are orders of magnitude beyond what TC’s Rail Safety Directorate has
at its disposal. Adoption of such an approach by Transport Canada would require a significant increase in allocated resources.

One interviewee suggested that the process had deteriorated into a bargaining process, where industry submits unreasonable phrasing knowing that what ever they submit will initially be modified or rejected by TC staff. While more cooperative development of safety regulations was a common desire, there was pessimism since experience had shown that agreed wording that was cooperatively developed came back after formal submission with changes that were never agreed upon or in some cases even discussed.

Others suggested that TC’s regional inspectors had too much power in being able to interpret regulations as they wished, regardless of the original intent. Many raised the issue of TC’s organizational structure Regions/H.Q from other perspectives. We note that TC’s organizational structure issues are the focus of another RSAR report.

Some indicated that TC was not willing to stay within the framework of safety evaluations in considering new technology. One interviewee’s comment that “safety decisions should be based on safety merits and ignore the manpower side” reflects the sentiment of a number of industry-side interviews.

2.2.2 Equipment Regulations

The only issues raised with respect to equipment regulations were the need to rank the various regulations according to safety impact, and industry’s desire to have wayside inspection technologies assessed from a framework of offsetting visual regulatory inspections. The larger issue on the development/adoptions of equipment-based technologies is the need for North American harmonization, which is discussed later in Section 2.4.

2.2.3 Track Regulations

Numerous issues were raised with respect to Track Safety Rules, and some of these are the subject of a separate RSAR paper (Cause and Mitigation). North American harmonization is less of a constraint on the track side than on the equipment side, but domestic harmonization presents a hurdle. The domestic railways have different operating environments — differing equipment usage, different severities of curvature, gradient and environment. As a result, different track maintenance standards evolved and agreement on “safety-minimum” track standards was difficult to achieve when the Canadian TSR was first drafted in 1992. While positions varied on the type/extent of change desired, there was a common view from both TC and the industry that the Track Safety Rules need to be updated:

Canadian Track Safety Rules need to be modernized so they are relevant to the contemporary railroad operating environment and current level of technology.

Railways need minimum safety standards, to safeguard interchanged equipment and to preserve the public image/confidence in the industry. However, only an estimated 20% of existing defined defects under the Track Safety Rules are considered to represent a hazardous condition.
Allowable train speed is the only control parameter in the present TSR. Risk relevance was widely noted as a desirable attribute for all regulations, but particularly track:

Public perception is different than public safety. Need to measure real danger to public (e.g. severity based and cross modal based comparisons).

It makes the most sense to relate regulations to the consequences of an event—derailments could be tolerable when they have no consequences with respect to employees, the environment or public security and safety (and therefore would essentially involve only an additional operating cost to the railroad).

Track Safety Standards need to take on a more risk-based structure and the regulations must foster technology and innovation by allowing continuous revision as warranted by technological change.

However, the same unison of vision was not present for other aspects of the revision process. The regulator’s focus is on compliance:

TC intends to ensure that any ambiguity with respect to managing train speeds, track inspections, and maintenance of track above minimum standards is removed. This will be a very significant change to the current rules.

Another issue is the interpretation of certified or qualified personnel. The fact that track deficiencies are not being found (defects noted above and missing components cited below) via inspection indicates that either poorly trained personnel or inadequate inspection resources are being used.

A principal stumbling block to “performance based” rules or regulations is the lack of clarity on what “performance based” means. The requirements of the regulation, rule or standard, whether performance based or detailed physical specifications, must be apparent to the persons being regulated and the regulator, so that upon reading them it is clear whether someone is or is not in compliance. A performance standard should be “prescriptive” in terms of precisely what performance is required.

The current Track Safety Rules are ambiguous, as they contain many general statements that are open to interpretation (or misinterpretation). The Track Safety Rules need to specify measures that are both relevant and quantifiable, requiring that railroads use modern tools to properly assess track and operational capabilities and limits. However, such changes may be viewed by the railroads as being too “Prescriptive”, implying that the regulator is telling them how to operate aspects of their business.

While the railways’ focus is on freedom to manage:

There is no need for regulatory limits. Include track safety standards under the ‘safety management system’ umbrella and assess its effectiveness in the audit procedures. The smaller railways interchange with majors and can be influenced to adopt the same standards.

The Act should encourage technology but not force it on railways. New technology must be an option for shortlines, not part of a regulatory requirement.
2.3 Technology Advancement and Economics

2.3.1 Industry Level
Economic aspects were present at two levels – 1) the overall industry and 2) related to the particular circumstances of shortlines. Comments relevant to the industry as a whole included the following:

*The regulator’s position of adding regulations based on R&D rather than substituting old with new has led to an expectation of higher operating costs associated with safety R&D. It is more difficult to get management support in this environment.*

*Much of the safety technology has been around for years but awaits economic justification. There is a need to increase the cost of unsafe practices (e.g. fines).*

There are also some organizational structure issues within railway companies that impact safety technologies. While advances have been made by the industry in recognizing the system’s level aspects and functional interdependencies, resources are still primarily allocated at the departmental level within the railway. It is difficult to introduce a technology that has costs in one departmental area and realizes savings in another. Many safety technologies and the underlying research and development initiatives fall into the cross-departmental category.

2.3.2 Shortline Specific
A number of issues were raised with respect to shortlines, but no safety concerns were raised. Larger shortlines do not have an issue with equipment standards; each has its own certified inspectors. The smaller shortlines are in fact “short” and equipment is not on the property for long distances. Equipment is inspected and maintained by the Class 1 railways that the shortlines interchange with.

*Most shortlines are “short” – the interchange with Class-1s gives the cars adequate coverage. If it is a former Class 1 line and the Class 1 benefits from the line, it will consider offering assistance.*

Track is a bigger issue – many shortlines inherited track that had been allowed to deteriorate before it was spun off and many shortline operators do not have the capital to restore track. Nonetheless, safety performance is not seen as a problem since shortlines operate with shorter trains at lower speeds than do Class 1 railways, which mitigate the consequences should a derailment occur. In some cases a shortline railway will opt to allow its tracks to deteriorate and simply reduce the operating speed limits accordingly. This can continue to the point that an exemption must be obtained, or the speed limits become too low to sustain a financially viable operation. At that point, very substantial investments are required in order to adequately refurbish the track. Financial assistance to perform the necessary upgrades may be obtained from the provinces or Class 1 railways if maintaining the tracks is felt to be in their interest.

There was some concern raised with the exemption process. Some suggested that there should be measurable standards for exempted track rather than having specific standards
for Class 1 track with a 10 mph speed limit and nothing except exemption from standards for tracks that can not economically meet the Class 1 standards.

2.4 Harmonization Constraints

The North American railway industry is dominated by U.S. carriers, suppliers and regulators — a situation that presents efficiencies, but also constraints. It is a major factor in equipment technology (due to interchange agreements), but is also a factor in infrastructure and operations technology, and in regulation setting itself. The potential market for railway safety technology is small. Research and development of safety initiatives are largely undertaken in partnership with industry and/or government. In this regard, the U.S. FRA has an annual budget of $35 million compared with Transport Canada’s $0.5 million. The industry’s tithing commitment to R&D undertaken by the TTCI allows a voice in direction but that voice is proportional to its contribution.

Once developed, commercially viable technologies need to have approved North American standards or specifications before a firm will commit to supplying it. This standards approval process is dominated in both size and precedence by the U.S. railways and suppliers. Finally, if the technology involves potential regulatory change, the Canadian Act allows change but the U.S. Act does not – harmonization limits the scope of change that can be realized in Canada.

The harmonization issues are complex. Some of the perspectives involved in the development of wayside detector technologies are discussed in the following subsection.

2.4.1 Wayside Detectors Example

In North American interchange service, the establishment of performance thresholds can be a difficult issue, requiring agreement among all those affected. The problems are most prevalent in the equipment area where interchange agreements are a key element of efficient operations among all North American railways. We illustrate the relevant issues with respect to wayside detection systems.

Some wayside detection technologies, such as Wheel Profile Monitoring, can be configured to provide measurements in a form completely analogous with those obtained by manual inspections and therefore existing interchange rules may be applied. However, in the case of Trackside Acoustic Detectors (TADs) or Wheel Impact Load Detectors (WILDs), a defect may be detected while it is still “developing” into a condemnable magnitude. In the case of truck performance monitors, undesirable performance problems may be identified, which are not linked to any defined defect.

In the case of wheel impact loads, where the high cyclic loads increase rail damage, an operating railroad might desire a lower impact load threshold for removal of a car than would the owner of a car who would bear the financial cost of the wheelset replacement.

The AAR has more recently implemented rules which permit operating railroads to remove wheelsets from service that have been flagged by a Trackside Acoustic Detection System (TADS) as having a bearing defect. However, in addition to exceeding an alarm threshold
level, the bearing damage must be independently verified using either hand rolling or through teardown inspections.

Truck Performance Detectors (TPDs) may flag cars which, upon further inspection, do not have obvious defects. In an examination of “bad actor” cars (i.e. those exhibiting poor truck performance) flagged by a TPD, TTCI investigators found approximately 60% had AAR billable defects such as broken springs, worn wedges or damaged side bearings, while another 20% of the cars alarmed due to high L/V ratios. However, there were no obvious defects found in the final 20% of the cars and the investigators noted that these cars continued to display poor performance when returned to service.

Private-car owners have reported increased removal rates of some car components - in the order of 3 to 5 times above those prior to the implementation of advanced wayside detection systems into the AAR Interchange Rules. To private-car owners, who own approximately 64% of cars and are ultimately responsible for the maintenance of their own car fleets, this represents a significant cost increase. In addition, private-car owners who have invested in modern cars incorporating premium components and materials in order to maximize load carrying capacity in heavy-haul high-mileage operation have reported that premium parts are sometimes being replaced with standard quality parts more typically stocked by an operating railroad’s car shops. While the standard quality parts fully meet AAR specifications they can reduce the car’s performance and value.

Moreover, it is permissible within the AAR interchange rules for an operating railroad to replace new wheels, axles and bearings on a car that has been condemned by registering an impact load of 90 kips or greater with refurbished minimum-thickness wheels, a used axle and reconditioned bearings without any requirement to reimburse the car owner for the difference in value even though the railroad may refurbish and then subsequently re-use those higher quality parts. It has been estimated by the AAR’s Technical Advisory Group that the railroads are seeing 97% of the financial benefit associated with the implementation of advanced wayside detection technologies while private-car owners have only a 3% benefit.

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4 For example, the TTX Company, for example, maintains a fleet of over 210,000 intermodal, autorack and general use cars which they lease to various North American railways.
3 EQUIPMENT RELATED SAFETY TECHNOLOGIES

Equipment-related factors associated with mainline derailments may be grouped into several categories based on the major equipment subcomponent identified as being the root cause after investigation. Figure 2 illustrates the distribution of equipment related causes of mainline derailments occurring on CN Rail and CPR, respectively, as inferred from accident data for the years 1999 through 2006. All together, these equipment-related factors account for 34% of the mainline derailments with assigned cause occurring over that time frame. Approximately one half of all equipment-related causes were assigned to axles and wheels while roughly another quarter were due to body and coupler factors. The balance was split between truck factors and brakes. While the distribution of equipment-related factors is in general quite similar between both railroads, the notable difference in reported percentages of brake related factors assigned may be due to use of different reporting guidelines as many wheel defects may in fact be initiated by improper brake adjustment or operation.

![CN Equipment Factors in MLD](image1)

![CP Equipment Factors in MLD](image2)

Figure 2  Equipment subcomponent factors for mainline derailments (1999-2006).

All Class I and major shortline railways use some form of wayside detection in their operations to routinely examine the condition of rolling stock operating over their track. The most mature examples include hot box detectors and dragging equipment detectors which have been in use in North America since the 1960s. The capability and range of conditions which may be detected and monitored using automated wayside installations continues to expand as new inspection technologies are invented and then developed into mature and reliable instrumentation.

While preventing derailments due to equipment failures remains an underlying principle, improvements in the accuracy and precision of detection technologies facilitates increased attention to condition monitoring of equipment. Railroads may avoid operating costs by recognizing the early signs of equipment failure so that necessary maintenance may be scheduled before operations become interrupted, or in the worst case a derailment occurs.
Modern communication technology and information processing make it possible for railroads to accumulate histories and assess trends in their equipment’s performance degradation.

3.1 Technologies Targeting Wheel Causes

Many technologies have been implemented by railways to avoid development of significant wheel problems mainly due to excessive heat build up during braking and the high surface stresses which develop during rolling contact. The primary technologies are discussed in the following subsections.

3.1.1 Wheel Impact Load Detectors

Wheel Impact Load Detectors (WILD) are used to infer the presence of a wheel defect such as being out of round, having a flat spot or other tread defect. These systems function by detecting the high impact loads which occur when the defective area of a wheel comes into contact with the rail. High impact loads contribute to increased wear and tear of equipment and track and may result in rail fracture or catastrophic wheel failure. Commercially available systems typically use strain gauges and/or load cells to measure the magnitude of transient wheel loads as a train rolls by in revenue service and are configured to flag loads which exceed a threshold value. These are mature detection technologies which have been widely adopted by the North American railroad industry and have now been integrated into a system wide network of calibrated detector sites which evaluate measurements against established thresholds to detect the presence of wheel defects and characterize their magnitude. Typical examples of installed systems include the Salient System’s WILD and Teknis WCM. Also GE Transportation markets their MATTILD Defect Detector which measures the deflection of a laser beam and converts into an equivalent wheel load.

AAR Interchange Rules have been adopted which formalize the criteria, or detection thresholds, for equipment repair based upon direct measurements made by some wayside detectors. Most notable are the changes adopted in 2004 and 2005 which set out several impact load thresholds to be applied to Wheel Impact Load Detector (WILD) measurements and define the acceptable repair actions. The lowest threshold establishes a “window of opportunity” where a single wheel generates an impact load between 65 and 80 kips (a kip is equivalent to 1000 pounds). At this level, the car owner may be given sufficient notice to enable the scheduling of a repair action in the most cost effective manner. The next threshold establishes an “opportunistic repair” category where a wheel generates an impact load reading of at least 80 kips but less than 90 kips and an operating railroad may change out the wheelset if the car is moved on to a designated repair track for any other reason. The third threshold designates a wheel as “AAR condemnable” when it generates an impact load reading of 90 kips or greater and the railroad may send the car to a repair track at any time for repair and subsequently charge the repair costs to the car owner according to the AAR PriceMaster pricing schedule. A “final alert” threshold level of 140 kips or more

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requires the operating railroad to change the wheel and also allows the railroad to set its own fee to be charged to the equipment owner for the repair.

3.1.2 Hot and Cold Wheel Detectors
Hot Wheel Detectors (HWD) and Cold Wheel Detectors (CWD) are used to automatically evaluate the temperature of wheels as a train rolls by. These modern relatives of earlier Hot Box Detectors (HBD) precisely measure temperatures at high operational speeds using digital processing of infrared images. A hot wheel temperature can indicate that a vehicle is moving without its brakes being fully released and the wheel may have been damaged due to a build up of internal stress. A cold wheel temperature measured at a location where a train is normally braking may be used as an indication of a brake system malfunction. These are mature technologies currently being used by railways. When combined with axle counters and radio based annunciation technology, a train crew can be automatically notified about specific wheels in their consist exhibiting unusual temperatures immediately after passing by the detector site. Inclusion of automated equipment identification facilitates central car tracking which may be used to flag wheels for investigation.

As previously mentioned, wheel defects develop gradually due to high contact stresses which occur during rolling contact and are manifested by shallow surface cracks which often develop further into shells and spalls on the tread surface. The normal wear process also results in changes to the surface profile of the wheel which alters the location of contact between the wheel and rail and may lead to higher contact stresses being developed. Wheels are periodically inspected and will be re-profiled to remove surface defects found to exceed established size thresholds, thus restoring the contour of the running surface to its original shape. Using higher quality “clean” steels in the fabrication of wheels helps to reduce the rate at which defects develop. Technologies used to address contact stress related problems of wheels include:

3.1.3 Tread Conditioning Brake Shoes
Tread conditioning, or grinding, brake shoes are special brake shoes designed to continuously grind the wheel tread surface during braking. Over time this removes a thin layer of material which has sustained damage. These brake shoes have been found effective in controlling the development of shells when installed on equipment identified by WILDs as exhibiting the early signs of defect development.

3.1.4 Over and Unbalanced Load Detectors
Over/unbalanced load detectors are used to identify a wheel which is more heavily loaded than are the other wheels of a rail car. A heavily loaded wheel will be subjected to higher contact stress, and therefore accelerated rate of damage, and will subject the rail to a higher load. Lateral unbalanced loads can lead to poor performance on track geometry that would otherwise be adequate, resulting in car-track interaction derailments. Endwise unbalance or overloading can lead to suspension component failure and in the extreme, full axle failure. Accordingly, it is advantageous to maintain a balance between wheel loads. These detectors operate on similar principles as do impact load detectors but are configured to
resolve and compare the static vertical loads of each wheel of a car. This functionality can be integrated into a WILD system.

3.1.5 Wheel Profile Monitoring
Wheel Profile Monitoring (WPM) systems are currently available which use digital image processing techniques to measure a wheel’s profile. These systems can be used to compare the actual wheel profile with the profile of a new wheel and make key measurements including flange height, flange thickness and rim thickness. Examples of commercially available systems include: ImageMap’s WheelSpec; AEAT/Alstom’s Tread View; and LynxRail’s ATEX. There are approximately seven such systems currently installed on North American railroads and the use of this technology is expected to grow in the future.

The Fully Automated Car Train Inspection System (FactIS™) is a machine vision inspection technology developed in Australia by Lynxrail and marketed in North America by TTCI. It uses high-speed digital cameras and strobe lights installed adjacent to tracks to capture images of wheels and brake shoes as a train passes by at normal track speed. These images are stored and then analyzed for existence of defects in near real time by the local electronic systems. The system analyzes captured wheel profiles to determine each wheel’s flange width and height, rim thickness, amount of tread hollow and also calculates the distance between the back wheel faces on each axle. The images of brake shoes are used to measure top and bottom shoe thickness. The system will also flag uneven shoe wear.

3.1.6 Automated Wheel Crack Detection
Automated wheel crack detection systems use ultrasonic waves traveling through a wheel to detect the presence of internal cracks and inclusions. Most systems require the use of an acoustic coupling medium, often water, to bridge the gap between acoustic transducers and the wheel surface. The transducers generate ultrasonic waves which propagate (grow) through the wheel. The presence of a defect causes signal attenuation and/or reflections which are picked up by the transducers. Such systems are normally implemented only for examination of high speed passenger equipment in maintenance facilities, but we note that they are not currently used by VIA Rail. Focused lasers have been successfully used to generate ultrasonic waves in wheelsets which are then detected by air-coupled ultrasonic transducers (i.e. non-contact). The prototype TTCI Dynamic Detection Station is an example of such a Laser Air-coupled Hybrid Ultrasonic Technique (LAHUT). That system was demonstrated to successfully test moving wheelsets at very low speeds but has not yet been developed into a detection system suitable for widespread implementation.

3.2 Technologies Targeting Axle/Bearing Causes
Failures due to overheated bearings (and to a less extent, cracked axles) are significant causes of mainline derailments. Forged steel axles are used in passenger service to provide superior failure resistance. Also, design changes are being explored to improve the performance of axles used in heavy haul service. The primary technologies used, or under development, to detect axle and bearing faults include:
3.2.1 Hot Box Detectors
Hot Box Detectors (HBD) are used to detect abnormally hot wheel bearings, a symptom of impending failure. These are quite mature technologies which have evolved since first installations in late 1950s and early 1960s. The earliest sensors detected infrared radiation using thermally sensitive resistors while modern systems use digital processing of infrared images to allow higher operating speeds and achieve more precise temperature measurements. Today, Class 1 railways have extensive networks of HBDs installed throughout their entire network at intervals of 30 miles or less.

3.2.2 Onboard Hot Bearing Detectors
Onboard hot bearing detectors are installed on passenger cars and locomotives to continuously monitor axle bearings for abnormal levels of heat build up. This provides an additional level of security above that provided by the use of wayside hot box detectors, as bearing failure can occur very quickly once heated up to normally detectable temperature levels. The train crew can immediately stop a passenger train before a failure occurs if a hot bearing is detected.

Remote Tracking of On-Board Condition Monitoring Sensors
VIA has indicated that it would like to upgrade its onboard monitoring systems to report to a central site for continuous monitoring. The system would avoid human error in reporting and/or interpreting onboard sensors. It would also allow technical personnel to diagnose some problems remotely by monitoring trends and looking at reporting history for the sensor location.

Implementation of onboard monitoring in passenger equipment is facilitated by the existence of electrical train-line wiring which runs the entire length of the train. Currently, North American freight trains do not have an electrical train-line which makes implementation of onboard monitoring more expensive. Use of Electronically Controlled Pneumatic (ECP) brakes, discussed in a later section of this report, within the industry in the future will make the inclusion of onboard monitoring systems feasible since an electrical train-line would need to be implemented.

Onboard sensors and remote monitoring have also been assessed for freight trains. In June of 1999 the FRA initiated a five year research program to develop and demonstrate onboard condition monitoring systems for use on freight cars. Science Applications International Corporation (SAIC) and Wilcoxon Research (WR) developed prototype systems over the next two years which were tested on a test car provided by the Norfolk Southern Corporation.8 The system was then installed on five hopper cars in the fall of 2003 which were used for revenue testing on Norfolk Southern tracks in Alabama during 2004.

The on-board condition monitoring system incorporates sensors to monitor the bearings, wheels, trucks and brakes using a vehicle-mounted supervisory computer which

Rail Safety Technologies communicates within the train using a wireless LAN technology and with remote computers over the internet via cell phone technology. Figure 3 illustrates the remote communications concept used while Figure 4 depicts the monitoring sensor configuration installed on each car. Accelerometers are mounted on each bearing adapter to measure vertical accelerations which are then digitally processed to identify signal characteristics typical of bearing damage, wheel defects and derailed wheels dragging along the ties and ballast. Thermocouples are installed on the inboard and outboard bearings of each axle to sense bearing temperature. A tri-axial accelerometer – one that measures accelerations in the vertical, lateral and longitudinal directions – is installed on the centre sill above the bolster of each truck. Lateral accelerations are processed to detect truck hunting, vertical accelerations provide an indication of track quality and large longitudinal accelerations indicate undesirable train action during braking. The electronics systems on each freight car are powered using an innovative generator built into the bearings.

**Figure 3** FRA On-Board Condition Monitoring System (OBCS) Configuration.9

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9 Source: http://www.fra.dot.gov/us/content/926
3.2.3 Trackside Acoustic Detectors

Trackside Acoustic Detectors (TADs) are a more recent development than Hot Box Detectors. These systems use microphones and digital signal processing techniques to detect sounds which are characteristic of bearing defects. These detectors are very sensitive and able to predict bearing failure long before they become hot enough to be detected by a Hot Box Detector. It has been estimated that at least 35% of hot bearing failures should be detectable using current acoustic detection capabilities.\(^{11}\) Examples of commercially available systems include: RailBAM® by VIPAC\(^{12}\) and TTCI’s Trackside Acoustic Detection System (TADS®). Several systems are currently in use within North America. As illustrated in Figure 5, a typical wayside installation consists of multiple microphones installed in cabinets in close proximity to both sides of the railroad track. The electronic processing equipment is housed close by in a structure providing climatic protection.

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\(^{10}\) Source: http://www.fra.dot.gov/us/content/1446


3.2.4 Automated Axle Crack Detection
The incidence of derailments due to broken axles has been increasing in recent years as the North American railroad industry continues to expand the use of heavy axle loads. For example, in the late 1990s there were 4 derailments due to broken axles in the U.S. while 4 to 5 years later the numbers increased to approximately 20. The AAR is investigating new axle design possibilities and developing improved crack detection methodologies. TTCI is currently developing a prototype in-track system which uses a Laser Air-coupled Hybrid Ultrasonic Technique (LAHUT) to detect cracks in railroad axles while in motion. This work follows up on successful laboratory experimentation which demonstrated the viability of this approach.\(^\text{13}\) In this system, a laser pulse is used to generate ultrasonic surface waves which travel from the mid-point of the axle outwards towards both wheels where two air-coupled ultrasonic transducers are positioned to detect the source pulse and any additional echo which would be produced when a surface crack is present.\(^\text{14}\) This work is still in progress and is not likely to be implemented in the near term.

![The trackside acoustic detector system](image)

3.3 Technologies Targeting Truck Causes
Undesirable truck performance can lead to a derailment either due to truck hunting (an unstable lateral oscillation which may result in violent car body motion), or poor curving performance, which leads to the development of unnecessarily high lateral forces. This typically occurs in equipment with worn or failed suspension components, or may also be


\(^{15}\) Source: A. J. Reinschmidt, IBID.
due to inadequate lubrication of centre bowls. Technologies which have been implemented to detected poor truck performance are presented in the following subsections.

3.3.1 Truck Performance Detectors

Truck Performance Detectors (TPD) are wayside systems used to identify poorly performing trucks by measuring a wheelset’s angle of attack. Some systems are also able to identify truck hunting by detecting lateral oscillations using multiple measurement stations.

Examples of commercially available systems include: Wayside Inspection Devices’ *TBOGI & TBOGI-HD*, Salient Systems’ Hunting Truck Detector, LynxRail’s *ATEx* and Progressive Rail Technologies’ Truck Performance Detector (TPD) and Truck Hunting and Tracking Error Detector.

Salient Systems’ Hunting Truck Detector (HTD) measures lateral forces exerted on rail by hunting trucks and evaluates a Hunting Index. When installed in conjunction with their WILD system it facilitates comparison of simultaneous lateral and vertical force measurements to identify conditions which may promote wheel-climb derailments.

TTCI tested LynxRail’s system which uses pairs of proximity sensors and found them to be viable but at that time the algorithms used to calculate carbody end RMS acceleration needed improvement.

The Progressive Railroad Technologies’ Truck Performance Detector (TPD) system uses strain gauges installed on the rails to measure lateral and vertical forces at multiple locations. Their recommended configuration is to install detectors on a reverse (or “S”) curve with an intermediate section of tangent track. At least two instrumented cribs are installed on the entry curve, another two in the intermediate tangent section and at least another two on the exit curve. This allows both a comprehensive assessment of the angle of attack adopted by the trucks during curving and also determines how well the truck realigns after passing through the entry curve.

These truck hunting detector technologies are sufficiently mature that a number of railways have already installed them on their rail networks. The AAR is now working to develop performance based thresholds which will be applied to measurements made by these detectors in order to initiate repair actions under AAR interchange rules. This will expand upon the set of performance based thresholds already used in conjunction with WILD measurements. Figure 6 depicts a truck performance detector test site which incorporates automated equipment identification, truck hunting detection and a wheel profile measurement system.

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17 http://www.salientsystems.com/prod_hunting.html

19

Research & Traffic Group
3.3.2 Truck Condition Monitoring

Using digital imaging technology it is possible to automatically verify the presence and integrity of various truck components and to make some key measurements. These can include examination of brake shoes, springs, friction wedges, column spacing, side frame buttons, bearing end-cap bolts and side bearings. Railroads in North America are now using these technologies on a limited basis and several manufacturers provide customized systems to meet particular inspection needs. Examples of such systems include: Progressive Rail Technologies’ Truck Inspector\textsuperscript{25} as well as LynxRail which offers modules with truck inspection capabilities as part of its Automated Train Examination (ATEx) systems.

3.4 Technologies Targeting Coupler and Brake Systems

Railway operations have evolved to include longer trains, heavier axle loads, high performance locomotives, and energy saving train handling practices that have required mitigating strategies to maintain safety performance. Some of those strategies involve technologies that are described in the following subsections.

3.4.1 Distributed Power

Distributed Power (DP) describes an operational practice, supported by radio frequency communications technology, by which locomotives are located away from the head end of a train and remotely controlled by a locomotive positioned at the head end. This is predominately used in long trains which operate over territory having significant grades in order to reduce the maximum in-train forces which must be transferred through a car body’s frame, draft gear and coupler. Without distributed power, all traction required to overcome the accumulated grade, rolling and aerodynamic resistances for each car in the entire

\footnote{Source: FRA website http://www.fra.dot.gov/us/content/926}
consistent must be generated at the head end and the coupler force at the front of the first car will be equivalent to that total resistance in order to maintain speed. In large consists it is possible to generate draft (tensile) coupler forces which exceed a car component’s maximum strength capability and a pull-apart will occur with possible risk of derailment. Also, during dynamic breaking through curves, extreme buff (compressive) forces can induce lateral wheel loads sufficient to roll the high rail or lead to a wheel climb derailment. By moving some of the tractive effort farther back in the train, the same total accumulated tractive effort can be provided but at substantially lower peak coupler force.

Another benefit of distributed power is that the brake signals can be transmitted via radio signal to the remote locomotives and initiate braking forces more evenly throughout the train. Other technologies that address the limitations of railway brake systems are discussed in the following section.

The use of distributed power is not a new concept and railroads first began using the technique in the 1970s. It requires all locomotives within a consist using distributed power to be equipped with special remote control equipment which coordinates the application of throttle and dynamic braking under the control of a single locomotive. The additional equipment required for each locomotive costs in the order of $115,000 USD including installation labour.

3.4.2 Track/Train Systems Design Tools
Software applications are available, such as Applied Rail Research Technologies Inc.’s ASSET/DP, which help railways to identify critical locations and optimize superelevation in curves, thereby limiting track forces at critical locations. The software considers the railway’s mix of trains, locomotive placements in train and range of attainable train speeds at those locations. The analysis can lead to recommendations on placement of distributed power and design of superelevation to reduce lateral track forces.

3.4.3 Improved Braking Systems Performance
3.4.3.1 Freight Train Brake Systems Background
The roots of conventional freight railroad air brake systems extend back to the mid 1870s when George Westinghouse devised the plain triple valve, which uses the pressure state of a normally pressurized air brake pipe running the entire length of a train to automatically control the application and release of a train’s brakes. The plain triple valve controls the charging of a vehicle mounted air reservoir, directs air from the reservoir into a brake cylinder used to apply braking force and exhausts air from the brake cylinder into the atmosphere to remove the braking force.

In contemporary train air brake systems, each vehicle is equipped with a two compartment air reservoir which supplies air pressure to the brake cylinders under the control of an air brake valve. Compressed air is supplied from a locomotive to charge these air reservoirs via a brake pipe running the entire length of the train and is maintained at a nominal

http://www.arrt-inc.com/software.html
pressure of 90 psi in North American freight service when the brakes are not being applied. The train’s brakes are activated by reducing the air pressure in the brake pipe at the locomotive thus inducing a pressure wave which can theoretically travel along the train at up to the speed of sound. As the air brake valve on each car senses this pressure drop, it disconnects the brake pipe which normally charges the air reservoir and then routes air from the reservoir into the brake cylinder to apply a braking force. The air pressure applied to the brake cylinders, and therefore the resulting brake force, is proportional to the magnitude of the pressure drop in the brake pipe.

This process of brake application continues sequentially with each car in the train as the pressure wave propagates through the brake pipe and it may take up to two minutes for the brakes to become fully applied at the last car of a mile long train. The delay in brake application due to the time required for wave propagation causes high buff (compressive) loads to build up in the front of the train as the cars at the rear of the train run in on the more quickly braking cars nearer the front of the train.

Train brakes are released by increasing the air pressure supplied to the brake pipe by the locomotive; however, it is not possible to partially release the air brakes in conventional systems used on freight trains. In freight trains, the only option is to fully release the brakes and then attempt to re-apply using a smaller pressure reduction, although sufficient time will be required to recharge the air reservoirs.

Emergency train braking provides a higher braking ratio than service braking and is achieved by quickly reducing the brake pipe pressure by a greater amount than that used in normal service braking. Modern air brake valves are capable of differentiating the rate of pressure decrease during an emergency application and will direct air into the brake cylinders from an emergency air reservoir which is maintained separately from the auxiliary air reservoir used in service braking. This arrangement helps to ensure that braking capacity is maintained for an emergency stop if the service air brake reservoirs become depleted. Emergency braking in the entire train is also triggered by a sudden loss of brake pipe pressure such as would occur when the brake pipe connection between two cars is severed during a pull apart or a derailment.

3.4.3.2 Remote Brake Application Systems
Improvements in both the speed of the brake-application signal to the rest of train, and the dynamic forces development in front-end brake initiation can be gained by having remote applicators. The distributed power systems previously described achieve this by having some locomotives positioned part way in the train. Both traction and brake forces are distributed by this technology.

In long trains where tractive effort is not a concern, remote brake application can be realized more economically. The lowest cost devices use the existing end-of-train communication

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21 An automatic brake valve was designed in the 1920s which facilitated graduated brake release but was found to be unreliable when used in long freight trains, and was ultimately only adopted for use in passenger trains.
link to initiate emergency and full-service brake applications from the rear of the train at the same time they are applied at the front. Additional initiation points can be provided in mid-train at additional cost. The electrical power for these units can be provided by small air-turbine generators that charge batteries when the train is moving and/or wind is blowing.

3.4.3.3 **Electronically Controlled Pneumatic (ECP) Brakes**

In the 1990s, electronically controlled pneumatic (ECP) brakes were devised by brake system suppliers to alleviate the problems associated with the time required for propagation of the pneumatic braking and release signals, air pressure recharging delays after a brake release and their inability to provide a graduated brake release capability. In an ECP brake system, the brake pipe pressure is maintained constant to continually recharge the air reservoirs and electronic controllers mounted on each car are used to operate electro-pneumatic air brake valves which regulate the transfer of air into, or venting out of, the brake cylinders. The individual car air brake controllers are connected to a 230 volt dc electrical train line which provides power for actuation and also carries serially encoded control messages from a master air brake control unit housed in the head end locomotive and returns status messages from individual car controllers back to the master unit. Using this system, the brakes on each car can be simultaneously controlled thus avoiding unnecessary dynamic train force build up and afford much smoother braking. Also, the electronic controllers are equipped to sense brake cylinder pressure and can decrease or increase the pressure applied to the brake cylinders from the air reservoirs in response to the electrical control signal without limitation.

ECP brake systems may be implemented as stand-alone or overlay systems depending on the equipment used. Stand-alone ECP brake systems assume that all cars and locomotives are equipped with ECP brake equipment and are not compatible with contemporary fully pneumatic systems. Overlay ECP brake systems offer the flexibility of dual-mode operation where a car may use ECP brakes in a compatible consist while also being capable of operating using conventional automatic air brakes on systems using brake pipe reductions as the control signal. ECP brake systems preserve the emergency brake application function such that emergency brakes can be quickly applied by reducing the brake pipe pressure and air for the brake cylinders is drawn from the emergency portion of the car mounted air reservoir.

Several railroads (BNSF, CR and CP) began limited testing of ECP braking systems on selected high mileage unit trains in 1995 and the Quebec Cartier Mining Railway (QCM) began converting their iron ore trains in 1998 to use ECP braking systems.\(^\text{22}\)

The main benefits of using these systems include:

- reduction in stopping distances of 40-60%,
- reduced energy consumption,

• reduced wheel and brake shoe wear,
• savings in delay and cost due to reductions in required brake inspections, and
• reductions in train-handling related collisions and derailments.

While commercial systems are now offered by several air brake suppliers, the North American railroad industry has been slow to adopt this technology. Closed system operators like QCM realize the benefits from the investment made in a highly utilized car fleet. However, the industry as a whole interchanges freight cars throughout North America, with the cars experiencing widely ranging utilization rates. The capital cost of converting the whole fleet is very high and the economic return for some low utilization cars is very low. Also, the substantial investment costs involve many equipment owners, while the benefits accrue mostly to the operating railroads.

Installation costs have been estimated to be $40,000 USD per locomotive and $4,000 USD per car and the cost to equip the entire U.S. fleet would be on the order of $6.8 billion USD. Full implementation would take many years and would require cost sharing between equipment owners and railroads as well as financial incentives, development of specifications and rule making support.

The U.S. FRA is vitally interested in having this technology implemented and in March of 2007 issued waivers to BNSF and Norfolk Southern which provides partial relief from performing some brake inspections on ECP equipped trains. The railways would begin by applying the technology to their owned-equipment in company-dedicated services like coal unit train operations. As discussed earlier (chapter 2), several interviewees indicated this type of proactive leadership by the regulator, with regulatory change to improve the operating cost savings would be welcomed in Canada.

3.4.4 Car Body Condition Monitoring

Various types of wayside detectors are used by railways to identify abnormal car equipment conditions. Early examples are Dragging Equipment Detectors (DED) which used mechanical paddles installed on ties to sense dragging hoses, derailed wheels or other equipment hanging unacceptably low below cars. Other systems are implemented using directed light sources, or laser beams, which are interrupted by dragging equipment and need to be coordinated with axle counting capability to scan only between trucks. New systems using high speed digital imaging technologies, such as offered by Progressive Rail Technologies, are also being offered which have the capability to analyze the height of brake hoses and measure coupler heights. Low hanging brake hoses are problematic as they can become disconnected which will initiate an undesired emergency braking application and may lead to a derailment if the train is moving at high speed.

3.5 Accident Analysis and Consequence Mitigation Technologies

3.5.1 Next-Generation Tank Car

While railroads are actively deploying various wayside technologies in order to reduce the overall frequency of main line derailments, there is also a significant effort currently underway to redesign tank cars with the objective of reducing the potential consequences should a derailment involving a tank car occur. The Next-Generation Rail Tank Car Project is a joint industry-government initiative in the U.S.A. which aims to have a prototype next-generation car to carry Toxic Inhalation Hazards (TIH) developed by the spring of 2008 and with first introduction into service by 2010.26 The industry partners in this venture include DOW Chemical, Union Pacific Railroad and Union Tank Car. This generation 1 design is projected to exceed the current AAR Tank Car Committee Performance Specification to provide between 5 and 10 times the level of safety and security.27 Generation 2 and 3 tank cars will be subsequently developed to carry chlorine and other environmentally sensitive chemicals and DOW Chemical expects to have 50% of their fleet renewed by 2013 with the balance replaced by 2018. However, changeover of the overall North American fleet will take a significantly longer period of time in the absence of any regulatory inducement.

Typical “normalized” pressure tank cars have 500 psi pressure vessels manufactured of heat treated TC-128 steel which are wrapped with 4-8 inches of fiberglass insulation and then cased in a thin 11 gauge steel outer jacket. While thick steel is used, these cars are susceptible to puncture by coupler impacts during a derailment. The performance improvements of the next-generation tank cars will be achieved by adapting a variety of technologies and concepts used for accident protection in other forms of transportation.

A range of technologies are being considered for the next generation tank cars. Crumple zones to remove energy from an impact through sacrificial deformation. These would likely be implemented as 2 foot thick, multi-layered head shields attached to each end of the main pressure vessel. The tank can be constructed with a structural outer wall in place of the thin outer jacket and tougher/stronger steel materials may be used without significant cost premium. These include a low-sulfur content version of the standard TC-128 steel and different alloys such as HPS-70 and HPS-10 which offer from 3 to 10 times greater tensile strength. More efficient insulating materials may be used to achieve longer fire protection of the contents in a more compact layer thus preserving additional space for use in crumple zones. Also, shear pins or deformable mounts may be used to attach the internal pressure vessel within the outer shell which will act to lower the impact forces imparted on the inner vessel by allowing small amounts of movement.

The valves used for loading and unloading a tank car’s contents typically project out of current-generation tank cars are therefore quite vulnerable to damage during a derailment.

In the next-generation tank cars these will be either recessed into the tank car itself or designed to be removable so that releases due to valve damage may be avoided.

The risk of rupture due to coupler impacts can be reduced by using “push-back” couplers which are designed to retract when subjected to high force. Also, the risk of puncture can be reduced by eliminating sharp edges and corners where possible.

Accelerometers and on-car data recorders may be installed on the next-generation tank cars to record acceleration profiles which can be analyzed during a post accident reconstruction effort. Additional information could be recorded from GPS receivers on each car to provide supplementary positional information.

3.5.2 Electronic Data Recorders

Electronic data recording equipment is currently required to some extent in all but highway modes of transport. Table 1 summarizes the status of Canadian regulatory requirements for electronic data recorders in each mode. Transport Canada has recently adopted the FRA ‘air-equivalent’ criteria for the survivability of data recorders used on locomotives which specifies required performance with respect to impact and fire resistance. The balance of this section provides details on the required data storage content and crashworthiness of locomotive data recorders. Information related to electronic data recording equipment used in other transportation modes may be found in Appendix A.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Data Recorder</th>
<th>Voice Recorder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail</td>
<td>Required, recent TC adoption of FRA ‘air-equivalent’ criteria for survivability (impact+ high intensity/short duration fire)</td>
<td>Not required, under review</td>
</tr>
<tr>
<td>Marine</td>
<td>TC has proposed adoption of IMO requirement (only for international vessels)</td>
<td>IMO data requirement includes one or more bridge microphones</td>
</tr>
<tr>
<td>Air</td>
<td>Required (international spec)</td>
<td>Required (international spec)</td>
</tr>
<tr>
<td>Road</td>
<td>No Proposed Regulation – new engine computers record basic data (engine-rpm/speed/brakes)</td>
<td>No Proposed Regulation</td>
</tr>
</tbody>
</table>
Locomotive Event Recorders

Event recorders are currently used on all mainline locomotives to continuously record speed, throttle settings and other information. Typically these data have been recorded on magnetic tape and can be accessed by railroads for operational and/or maintenance purposes. Additionally, these data are used by investigators to provide valuable insight into the circumstances leading up to collisions and derailments. Transport Canada has indicated that the recently revised U.S. FRA regulations will be applied in Canada. The fundamental data elements recorded by existing locomotive event recorders, as specified by the U.S. FRA,\(^\text{28}\) include:

- Train speed
- Selected direction of motion
- Time
- Distance
- Throttle position
- Applications and operations of the train automatic air brake
- Applications and operations of the independent brake
- Applications and operations of the dynamic brake, if so equipped
- Cab signal aspect(s), if so equipped and in use

Recently, in response to U.S. FRA regulations adopted on June 30, 2005, rail event recorders have been redesigned with new electronics technologies to produce FRA certified crashworthy Event Recorder Memory Modules (ERMMs). These new recorders use a much more robust solid state memory technology. These certified crashworthy ERMMs recorders are to be supplied on all new locomotives ordered after October 1, 2006 as well as retrofitted on any older locomotives operated in the lead position of a consist by October 1, 2009.

These new regulations also specify an expanded set of data elements which must be recorded. These are to include:

- any emergency brake applications initiated either by the engineer or by an onboard computer
- any loss of communications from the End of Train (EOT) device
- messages related to the ECP (electronic controlled pneumatic) braking system
- EOT messages relating to “ready status,” an emergency brake command, and an emergency brake application, valve failure indication, end-of-train brake pipe pressure, the “in motion” signal, the marker light status, and low battery status
- the position of the switches for headlights and for the auxiliary lights on the lead locomotive
- activation of the horn control
- the locomotive number
- the automatic brake valve cut in
- the locomotive position (lead or trail)

• tractive effort
• the activation of the cruise control
• any safety-critical train control display elements with which the engineer is required to comply

The new ERMMs are designed to preserve all required data elements for a period corresponding with the previous 48 hours over which the locomotive electrical systems were in operation. However, older locomotive event recorders (installed prior to November 3, 1993) are only required to maintain data for the previous 8 hours over which the locomotive was moving.

The FRA requires that a certified ERMM be mounted “for its maximum protection” and suggests, although does not absolutely require, that they be mounted behind the collision posts somewhere above the platform level and below the top of the collision posts. To obtain crashworthiness certification, suppliers must demonstrate that their ERMMs meet or exceed all requirements set forth in one of two alternate survivability performance criteria as summarized in Table 2 and Table 3.

The TSB has expressed its reservations about using existing air-mode survivability standards in the railway environment. Air crashes typically involve intense heat for short durations whereas railway crashes can involve lower intensities but for much longer durations.
### Table 2  FRA Event Recorder Memory Module Survivability Criteria - Option A

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Duration</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire, High Temperature</td>
<td>750 °C (1400 °F)</td>
<td>60 minutes</td>
<td>Heat source: Oven.</td>
</tr>
<tr>
<td>Fire, Low Temperature</td>
<td>260 °C (500 °F)</td>
<td>10 hours</td>
<td></td>
</tr>
<tr>
<td>Impact Shock</td>
<td>55g</td>
<td>100 ms</td>
<td>1/2 sine crash pulse</td>
</tr>
<tr>
<td>Static Crush</td>
<td>110kN (25,000 lbf)</td>
<td>5 minutes.</td>
<td></td>
</tr>
<tr>
<td>Fluid Immersion</td>
<td>#1 Diesel</td>
<td>Any single fluid, 48 hours.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>#2 Diesel</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Salt Water</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lube Oil</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fire Fighting Fluid</td>
<td>10 minutes, following immersion</td>
<td>Immersion followed by 48 hours in a dry location without further disturbance.</td>
</tr>
<tr>
<td>Hydrostatic Pressure</td>
<td>Depth equivalent = 15 m. (50 ft.)</td>
<td>48 hours at nominal temperature of 25 °C (77 °F).</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3  FRA Event Recorder Memory Module Survivability Criteria - Option B

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Duration</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire, High Temperature</td>
<td>1000 °C (1832 °F)</td>
<td>60 minutes</td>
<td>Heat source: Open flame</td>
</tr>
<tr>
<td>Fire, Low Temperature</td>
<td>260 °C (500 °F)</td>
<td>10 hours</td>
<td>Heat source: Oven</td>
</tr>
<tr>
<td>Impact Shock—Option 1</td>
<td>23gs</td>
<td>250 ms</td>
<td></td>
</tr>
<tr>
<td>Impact Shock—Option 2</td>
<td>55gs</td>
<td>100 ms</td>
<td>1/2 sine crash pulse</td>
</tr>
<tr>
<td>Static Crush</td>
<td>111.2kN (25,000 lbf)</td>
<td>5 minutes</td>
<td>Applied to 25% of surface of largest face</td>
</tr>
<tr>
<td></td>
<td>44.5kN (10,000 lbf)</td>
<td>(single &quot;squeeze&quot;)</td>
<td></td>
</tr>
<tr>
<td>Fluid Immersion</td>
<td>#1 Diesel</td>
<td>48 hours each.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>#2 Diesel</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Salt Water</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lube Oil</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fire Fighting Fluid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrostatic Pressure</td>
<td>46.62 psig (= 30.5 m. or 100 ft.)</td>
<td>48 hours at nominal temperature of 25 °C (77 °F).</td>
<td></td>
</tr>
</tbody>
</table>
4 TRACK RELATED TECHNOLOGIES

Track-related factors associated with mainline derailments may be grouped into several categories based on the major aspect identified as being the root cause after an investigation. Figure 7 illustrates the distribution of track related causes of mainline derailments which occurred on CN and CPR, as inferred from accident data for the years 1999 through 2006. All together, these track-related factors account for 29% of the mainline derailments with an assigned cause occurring over that time frame. Review of these data shows that geometry defects are the most frequent cause of track-related derailments, followed closely by rail problems.

Figure 7 Track Subcomponent Factors for Mainline Derailments (1999-2006).

<table>
<thead>
<tr>
<th>CN Track Factors in MLD</th>
<th>CP Track Factors in MLD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other 13%</td>
<td>Other 14%</td>
</tr>
<tr>
<td>TOISw 7%</td>
<td>TOISw 11%</td>
</tr>
<tr>
<td>Geom 43%</td>
<td>Geom 44%</td>
</tr>
<tr>
<td>Rail 37%</td>
<td>Rail 31%</td>
</tr>
</tbody>
</table>

4.1 Technologies Targeting Track Geometry Causes

4.1.1 Track Geometry Measurement

Automated track geometry measurement equipment is routinely used by railways to very precisely measure the geometric features of track such as rail surface, crosslevel, alignment, curvature, superelevation and gauge. These measurements are generally made at one foot intervals. Many systems are also capable of measuring the profile of each rail and will quantify the amount of rail head wear as well as determine the rail cant. The systems are typically capable of analyzing all measurements necessary to evaluate the track’s geometry with respect to the thresholds defined within the applicable track standards and will automatically generate a list of all exceptions, or deficiencies, of the measured track with respect to those standards.

Both major railways in Canada currently operate fully manned track geometry vehicles across their rail networks on a consistent basis throughout most of the year. These vehicles consist of full sized passenger coaches and auxiliary vehicles which are pulled by a
locomotive at full track speed. The measuring instrumentation is mounted to the undercarriage of these cars and communicates with on board computers which process all measurements and report any defects, or deficiencies, found in real-time. The defects are categorized into the three levels of urgent, near urgent and priority. Urgent defects represent measurements exceeding those specified within the Canadian Track Safety Rules, while near urgent and then priority defects are associated with measurements which are approaching but still below those thresholds. Track maintenance supervisors of the track subdivision being tested travel aboard the track geometry car and review all defects as they are reported, assigning work crews to immediately attend to any urgent defects found.

The rail coach based track geometry cars operated by the Canadian railroads have undergone significant evolution, with the major measurement systems having been replaced by modern technology within the past several years. They now use inertial based systems and laser-optical measurement devices to quantify the vehicle’s motion and then resolve the track’s geometry. Previously, the track geometry was inferred from measurements of truck yaw and required sufficient distance between the rail car’s trucks. These system upgrades have been provided by ImageMap, although there are several other manufacturers offering similar equipment such as ENSCO, Inc. which has recently provided systems for the U.S. FRA.

The modern inertial-based track geometry measurement systems are very compact and therefore suitable for installation on both self-propelled railroad vehicles and smaller hi-rail vehicles. Both ENSCO and Plasser American Corp. are suppliers of turn-key self-propelled track geometry measurement vehicles. The Holland Company LP builds and operates a fleet of heavy hi-rail vehicles for track geometry testing. Both the self-propelled and hi-rail systems may be provided at a lower capital-cost and operated at lower cost than the full-sized rail-coach based systems. These more compact measuring vehicles are disadvantaged in that they are not capable of measuring the track geometry under the heavily loaded conditions facilitated by the full-sized geometry car consists pulled by locomotives. Moreover, the maximum operating speed of hi-rail based systems is in the order of 30 mph\(^2\) which falls significantly below the maximum speed limits for most mainline track. Nonetheless, these systems offer a significant advantage in terms of measurement accuracy and thoroughness when compared with visual inspection alone.

The simplification, miniaturization and reliability of contemporary inertial-based track geometry systems has now reached the point where it seems practical for railroads to consider implementing autonomous track geometry measuring systems. Units such as ImageMap’s Unattended Geometry Measurement System (UGMS) and ENSCO’s Autonomous Geometry Evaluation and Notification for Track (AGENT)\(^3\) are available commercially in North America. These units provide the same accuracy of measurement of the fundamental track geometry parameters as do the systems operated by technical staff, although they do not measure rail profiles. These systems can be mounted on locomotives,

\(^{29}\) http://www.hollandco.com/track-testing/railroad-testing/equipment-specifications

\(^{30}\) http://www.ensco.com/trans/products/autonomoussystems/remotetrackgeometrysystem
or other rail cars (with suitable provision being made for powering the system) without interfering with the normal operation of the vehicle. Global Positioning System (GPS) receivers are integrated with other inertial tracking techniques to provide an absolute position reference for the measured track geometry. The measured track geometry is retained in local storage and then periodically relayed using wireless communication technologies to a central office for further processing and action. Installing autonomous track geometry measurement systems on revenue service equipment offers railroads the capability of frequently assessing their track geometry without the service delays and expense associated with operating dedicated track geometry vehicles. ImageMap UGMS systems are currently being used in revenue service by Network Rail in the UK. North American railroads are exploring this technology.

The convenience and low cost of present technologies make them a candidate to assist local crews on visual inspections and/or a means of achieving a higher automated test frequency. Transport Canada’s Pacific Region has purchased Andian Technologies’ *Solid Track* geometry measurement system. The compact system (see Figure 8) can be accommodated within a hi-rail vehicle. Pacific Region has one system for use by its inspectors so that they can better assess geometry conformance with the regulations.

**Figure 8** Andian Technologies’ *Solid Track* geometry measurement system.

4.1.2 Gauge Restraint Measurement
Gauge Restraint Measurement Systems (GRMS) are used to quantify the lateral strength of the rail and crosstie fixation. While traveling along the track, these systems use a hydraulically actuated split-axle to apply known lateral forces (on the order of 10000 to 15000 pounds) to the rail heads while measuring the loaded gauge. The lateral track stiffness can then be assessed using the known applied load and the difference between the track gauge measured both while laterally loaded and without the lateral load applied. Once determined, the lateral track stiffness may be used to extrapolate the extent of gauge widening expected in response to operational loads. In operations, large lateral loads can develop in tangent (i.e. straight) track and are exacerbated in curves. They arise from individual car dynamic action, from compressive longitudinal forces due to thermal expansion of rails and/or from traction forces during train braking. A wide gauge derailment can occur if the rails are spread too far apart when one rail is subjected to high lateral forces.

A GRMS may be incorporated within a track geometry measurement system, however the maximum track geometry testing speed will be more limited (between 30 and 50 mph depending on equipment) when the GRMS axle is applying lateral loads. CPR currently operates two rail-coach-based track geometry testing consists, one of which is outfitted with a retractable GRMS. ENSCO and Plasser American Corp. produce GRMS systems. Also, the Holland Company’s line of TrackSTAR heavy-hi-rail units incorporate a GMRS.

4.1.3 Real-Time Track Performance Evaluation
Contemporary track geometry evaluation is primarily concerned with the measurement of various individual geometrical parameters of the track which are then compared against established threshold values. Any measurements exceeding an established threshold are flagged as an exception and the track condition is repaired. The defect conditions and threshold values now in use have been developed and accumulated over the years by the railways and regulatory bodies as problems associated with the operation of particular pieces of equipment arose. For the most part, each geometrical defect condition is considered as a separate entity and the regulations don’t consider the significant role which some wavelengths or combinations of geometrical perturbations may play in stimulating undesirable car response.

Much research throughout the last decade has been directed towards identifying and analyzing high-risk geometry conditions which can not be manually detected. This approach considers the dynamic response of a range of vehicles of particular interest while operating over the measured track geometry features and identifies track locations where the predicted car behavior is indicative of an elevated derailment risk. Computing technology is now sufficiently advanced to support real-time evaluation of track geometry on-board automated track geometry measurement vehicles.
Transport Canada, CPR and CN have contributed to the development and participated in the evaluation of one such system LVSafe\textsuperscript{32,33} developed by TranSys Research Ltd. Other approaches that have been undertaken include TTCI’s PBTG\textsuperscript{34} program and ZetaTech’s TrackSafe\textsuperscript{35} program.

The LVSafe system has been successfully implemented as a prototype system on-board CN and CPR’s track geometry cars. The model predicts the wheel forces of multiple cars at a range of speeds as expected to respond to track geometry conditions. High lateral/vertical force ratios can lead to wheel-climb derailments; thus, where such events are predicted for any car/speed combination, the location is flagged as a high risk condition. CPR has integrated the LVSafe software system with its existing defect printout system; but has not yet been able to build a business case to go the next step of handing out the new defined defects to its field maintenance forces.

4.1.4 In-Situ Rail Stress Measurement

Track buckling and pull-aparts occur less frequently than other track geometry defects but have a higher potential for significant derailment consequences and are normally associated with extreme temperature conditions. Buckling occurs when the compressive stresses in the rail steel induced by thermal expansion at high ambient temperatures produce large forces which exceed the track structure’s ability to withstand and a portion of the track moves sharply laterally to relieve the stress. Conversely, a pull-apart occurs when the internal tensile stress within the rails of a track as induced by thermal contraction during extreme cold ambient temperatures exceeds the rail steel’s strength, or that of a weld, and the rail parts.

Track engineers use Rail Neutral Temperature (RNT), the temperature at which installed rail has no temperature induced internal stress, as a baseline from which to assess the amount of longitudinal stress within rails. Nominally, this would be equivalent to the temperature conditions at which the rail was initially installed. However, normal rail wear and maintenance activities conducted to repair rail defects in cold weather may result in significant reductions in the RNT over time. Safely managing longitudinal rail stress is typically achieved by maintaining the RNT within specified limits.

Monitoring of internal rail longitudinal stress can be achieved using strain gauges which are applied at a known stress level. Naturally this is impractical to implement on a large scale. Currently accepted methods of determining the RNT require that the rail be either cut or unfastened over a length of at least 100 feet. Devices are available, such as Salient System’s Rail Stress Monitor, which when permanently affixed to rails and properly

\textsuperscript{33} TranSys Research Ltd, Performance Measures from Track Geometry Cars: A Vehicle Dynamic Response Predictor, Transport Canada publication TP 13921E, November 2002.
\textsuperscript{35} http://www.zetatech.com/software/TrackSafe/TrackSafe.html
calibrated at the time of installation provide reliable indications of the internal longitudinal stress state of the rail.

A new portable and non-destructive RNT testing system using the D'stresen rail vibration technique is currently being tested by TTCI investigators. This system, designed and patented by Brent Jury of New Zealand, has been under development and testing for the past seven years. It does not require a rail to be modified in any manner in order to conduct the required tests.

The D’stresen system evaluates the RNT by exciting the rail head with a known rotational vibration and observing how small amplitude vertical vibrations picked up by a “tune bar” temporarily attached to the rail head a short distance away vary with changes in rail temperature. The theory behind this technique assumes that the amplitude of tune bar vibrations increase linearly with changes in rail temperature as the neutral temperature is approached, at which point the vibration amplitude reaches its peak magnitude which is termed the “background number”. As illustrated in Figure 9, the linear rates of change in measured vibration amplitude is different depending on whether the rail is in compression or tension and may be calibrated for a rail by taking a number of readings at the same site over a wide temperature range.

If the system is to be used to make single stand-alone RNT evaluations, then the user must know the applicable maximum vibration amplitude (i.e. the background number at the RNT) and must also determine by other means whether the rail is in tension or compression.

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37 Source: David Read & Bill Shust, IBID.
Based upon the initial findings of the TTCI investigations conducted in Pueblo, Colorado and at several strain gauged sites on BNSF’s mainline in northern New Mexico the D’stresen system appears capable of determining RNT to within 10 degrees Fahrenheit.

4.1.5 Elastic Fasteners

Elastic fasteners, or tie clips, were developed to attach rail to concrete ties. They function to resist rotational and lateral movement of the rail in response to the lateral and vertical forces imparted by the wheels of a train. They also serve to resist longitudinal movement of the rail when subjected to uneven thermal stress or due to high traction or dynamic braking forces under the wheels of locomotives associated with operation on significant grades. The elastic fasteners are designed to be installed with a working compression such that positive contact with the rail is maintained and contact forces vary linearly about a nominal design value in response to the dynamic loading during wheel/rail contact. Thus, large step loadings likely to exceed the strength of the rail fasteners, and potentially causing failure, are avoided.

Over the past decade, railroads have adopted this technology for use with wood ties in tight curves as elastic fasteners provide a superior means of managing the force transmission from the rail to the tie. With rail spiked to wood ties, large cyclic lateral forces and rotational moments transmitted to the spikes tend to cause failure, over time, of the wood fibers adjacent to the spikes and the rail attachment loosens. Looseness in the attachment results in poor lateral rail restraint, and therefore poor gauge retention, and may also lead to shearing of spikes. Also, there is very little longitudinal restraint provided by the friction between the rail base and wood tie surface. Elastic fasteners are adapted to wood ties by spiking or screwing a steel tie plate to the tie and then using the elastic fastener to attach the tie plate to the rail base.

4.2 Technologies Targeting Rail Causes

Rail fracture is a dangerous event which is a leading cause of rail related derailments. Fracture occurs after sufficient propagation of cracks originating at: sites of manufacturing defects, such as inclusions; from rail head surface damage; from wheel burns; or from small rail head surface cracks which develop as a result of rolling contact fatigue. Figure 10 illustrates a rail fracture which occurred after a crack initiated at the site of an internal defect subsequently propagated over time due to gauge corner contact stresses. Rolling contact fatigue (RCF) is a mechanism caused by shearing within the surface layers of the rail head when subjected to many cycles of combined normal and tangential stresses which occur at the wheel rail interface.

Head checks, gauge corner cracks and squats are examples of defects initiated by RCF. Most cracks initiated by rolling contact fatigue do not propagate more than 1 or 2 mm diagonally (at 15° to 30° from horizontal) down into the rail head before turning more horizontally and culminating in surface spalling, a condition where patches of the rail head surface flake off. However, some of these cracks turn downward and propagate vertically into the rail head and eventually lead to a rail fracture when the structural integrity of the rail
is sufficiently weakened. Figure 11 illustrates the appearance of head checks on the rail head surface while Figure 12 illustrates how head checks propagate down into the rail head.

**Figure 10 Internal rail defect propagated from gauge corner contact stresses.**

Railroads devote significant resources to inspecting rail for the presence of surface and internal defects, primarily through the use of ultrasonic rail flaw detection. The Canadian Track Safety Rules mandate that all jointed and continuously welded rail (CWR) used in Class 4 through Class 6 track; all track carrying 25 or more million gross tonnes per year; and all Class 3 track over which passenger trains operate be tested at least once per year along its entire length for the presence of internal defects. However, in the case of newly installed rail, these inspections can be deferred for three years provided that the rails were inspected for internal defects using inductive or ultrasonic techniques prior to, or within 6 months of installation.

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4.2.1 Ultrasonic Testing Techniques

4.2.1.1 Conventional contact systems

The ultrasonic flaw detection technique involves introducing ultrasound - sound waves at frequencies above audible wavelengths - into the rail head which then propagate linearly through the rail steel until reflected entirely, or otherwise deflected, when encountering an internal defect or crack. The ultrasound waves are typically generated within a transducer held in close proximity to the rail head surface and transferred into the rail steel through an acoustic coupling medium such as water or other suitable liquid. Another ultrasonic transducer, also acoustically coupled to the rail surface, is used to detect echoes. Ultrasonic techniques are capable of detecting the presence of cracks and internal defects which can not be detected visually.

Much of the ultrasonic rail flaw testing being applied on North American railroads is contracted out by the railways to companies which offer specialized detection services. Sperry Rail Service, DAPCO Technologies, LLC (now owned by NORDCO Inc.) and Herzog Services Inc. are examples of companies which supply and operate self-propelled and/or hi-rail vehicles fitted with automated ultrasonic rail inspection equipment and staffed by skilled technicians. Testing normally proceeds at speeds between 15 and 20 mph and the vehicle is stopped when defects are detected so that the rail can be examined in more detail and appropriate action taken. Some railways use non-stop test procedures, where one or more following vehicles stop to investigate the defect locations in more detail.

Although conventional ultrasonic rail testing techniques are used very effectively, they can be problematic to apply in situations where the rail head’s surface condition is extensively damaged or significantly worn from its original profile thus making it difficult to maintain adequate acoustical contact with the rail head probes. Research has been conducted into using Electromagnetic Acoustic Transducers (EMATs) which use magnetic fields to generate ultrasonic wave forms within the rail head and also receive ultrasonic wave forms from the rail head across a small air gap. This work produced a prototype RailPro system installed in a hi-rail vehicle and used as a proof of concept demonstration; however, a viable commercial system did not materialize.

4.2.1.2 Non-contact systems

Research and development into using non-contact laser-to-air transducers for ultrasonic rail inspection is currently underway. Tecnogamma, an Italian developer of laser and vision systems has a prototype non-contact system. Since November 2004, it (in partnership with a number of other European companies and in cooperation with TTCI) has been developing a non-contact laser based ultrasonic rail flaw detection system called U-Rail. Their approach was demonstrated in North America during a Rail Ultrasonic Workshop held at the Transportation Technology Centre in Pueblo, Colorado in March of 2004. In this technique, focused laser light is used to generate bulk and surface ultrasonic wave forms within the rail and offers potential benefits over conventional surface-contacting ultrasonic methods by avoiding the difficulties of adverse rail head surface conditions and geometry. Moreover, by using this technique it should be possible to inspect the rail’s web and base in addition to the rail head. Completion and demonstration of a prototype marketable system was projected for the end of 2006; however, little information regarding commercial adaptation of this system can yet be found in the literature. Herzog, a major supplier of rail flaw detection equipment and services in North America, has recently been invited by TTCI to participate in this work. TTCI investigators indicate that this technology appears promising in overcoming testing speed limitations associated with the use of liquid filled Roller Search Units (RSU).

40 “Development of a Mobile Inspection System for Mobile Rail Integrity Assessment”, Ahmad Chahbaz, Tektrend International, June 2000, Transport Canada Publication No. TP 13611E.
41 http://www.u-rail.com/
42 http://www.laserinstitute.org/conferences/ilsc/advance?selection=1
Another laser-based rail flaw testing technique is currently under investigation by researchers at the University of California, San Diego.\textsuperscript{44} In their prototype system, a laser pulse is used to generate ultrasonic wave forms within the rail such that the waves travel longitudinally along the rail. Pulses are induced at one foot intervals and ultrasonic microphones mounted 12 inches away from the point of laser excitation and 2 inches above the rail head are used to monitor for reductions in the transmitted ultrasonic signal strength which would indicate the presence of significant cracks or internal defects. The researchers report that because the ultrasonic wave forms are induced within the rail head (i.e. below the surface), the presence of superficial surface cracking does not interfere with propagation of the ultrasonic wave as happens with conventional techniques which must transmit the ultrasonic signal through the rail head surface.

4.2.2 Eddy Current Testing Technique

Eddy current testing is an inherently non-contact technology which has been used extensively in industries such as aerospace and pipeline but until quite recently has not been applied to commercially viable rail testing. In this technique, the material to be tested is subjected to a magnetic field and the presence of surface cracks is inferred by observing the disruptions they induce in the magnetic field as measured by sensitive probes. A prototype mobile system for eddy current testing of rail, DYNATRAK II, was developed and tested in Canada.\textsuperscript{45} In that system, the eddy current probes were attached to a small carriage which was towed behind a hi-rail vehicle containing the electronic and power subsystems.

BAM, the German Federal Institute for Materials Research and Testing, in conjunction with German Railways, has been actively researching the application of eddy current testing to in-situ rail and several systems are now being used in Europe. Speno International has recently integrated an eddy current rail testing system called the HC Grinding Scanner onto a rail grinding machine.\textsuperscript{46} Figure 13 shows the eddy current measurement system installed underneath a Speno grinding machine. This system is able to effectively detect and quantify the depth of head checking cracks using a set of four eddy current probes above each rail head. Eurailscout, a provider of rail testing services in Europe, owns and operates the self-propelled rail test vehicle UST 02\textsuperscript{47} which combines ultrasonic and eddy-current testing techniques to detect head checks, squats and welds. Their system operates at speeds up to 70 km/h.

\textsuperscript{44} http://www.jacobsschool.ucsd.edu/news/news_releases/release.sfe?id=558
\textsuperscript{47} http://www.railway-technology.com/contractors/infrastructure/eurailscout/
4.2.3  Joint Bar Inspection

Joint bars are typically visually inspected for any evidence of cracks, loose or missing bolts or other signs of movement. Inspections conducted on foot can be quite thorough although very time consuming, so this task is often performed by a track inspector traveling in a hi-rail vehicle. However, the vantage point from within a hi-rail vehicle is not ideal and those inspections are not as effective. Emerging technology seems promising for automating the visual joint bar inspection process. A prototype system mounted onto a hi-rail vehicle was jointly developed by the FRA and ENSCO, Inc. and field tested in 2005.49,50 At that time, the system exhibited a 60% false alarm rate while missing 15% of existing cracks, although it was noted that no centre cracks were missed. Figure 14 illustrates the main components and configuration of this system.

Figure 13  Eddy Current Measuring System Installed on Grinding Train.48

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The prototype system has undergone further development to improve detection effectiveness (reduce incidence of missing cracks) and extend its capabilities to include detection of missing bolts and nuts. Currently, the ENSCO Joint Bar Inspection System (JBIS) has been installed on hi-rail and track geometry inspection car platforms and is capable of operating at speeds in excess of 50 mph. The system automatically detects joint bars and captures a high-resolution image which is then digitally processed and stored for subsequent review. Using this technology, track maintenance personnel are able to inspect a 200 mile subdivision of continuously welded rail in roughly 2 hours from a workstation in their office rather than walking the track. CN is acquiring a new self-propelled track geometry car in 2007 which will incorporate a video-based automated joint bar inspection system.


4.2.4 Automated Tie Inspection
Traditionally railroad ties are inspected by workers who walk the tracks and visually inspect ties for problems such as excessive cracks, missing pieces and fastener condition. Digital imaging technologies are also very applicable for use in automating the railroad tie inspection process. As illustrated in Figure 15, the hardware and software algorithms implemented in digital imaging systems used for tie inspection are capable of segmenting the image and identifying key features and highlighting potential defects. Referring to that figure, the ends of each tie are highlighted in white, tie plates are highlighted in red and spikes are highlighted in green. All major cracks in the ties are outlined in grey and the system has also identified a missing piece from the right hand side of the top most tie in the image which it outlines in yellow.

Figure 15 Digital image of tie and spike condition.\(^{54}\)

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The Georgetown Rail Equipment Company (GREX) provides tie inspection services using their Aurora hi-rail based system capable of operating at 30 mph and inspecting both concrete and wooden ties over hundreds of miles of track in a single day.

4.2.5 Rail Grinding

Rail grinding is a maintenance process used by railroads for many years to refurbish the running surfaces of rail used in mainline track, switches and crossovers in order to prolong track service life. Wear at the wheel/rail interface which occurs during rolling contact and variability in the profile of the wheels of equipment traveling over the rails contribute to a gradual change in the shape of the rail head over time. These gradual changes in rail head shape lead to a shift in the location where the wheel surface contacts the rail head thus increasing contact stresses and the rolling contact fatigue which leads to the development of surface cracks which tend to propagate into surface defects such as shells or less frequently grow more deeply into the rail head and compromise the strength of the rail. Rail grinding is used to both reshape the rail head surface so that it matches the desired profile while removing the surface layer of fatigued material.

4.3 Technologies Targeting Ground Hazard Management

Canadian railroads have been constructed and now operate over vast territories of varying challenging terrain. For example, tracks wind their way along steep mountain slopes and cross rivers which often see a substantial seasonal variation in water flow. Being built in close proximity to such potentially unstable geographical features, railway tracks are exposed to natural hazards such as slides which result from the failure of uphill or downhill slopes and washouts which result when water causes the failure of a track’s ballast and substructure. Although these events occur relatively infrequently they represent a high potential of very severe consequences to the railways.

4.3.1 Slide Fences & Washout Detection

Where the natural hazards in particular locations are well known, the railways have installed and continuously monitor slide detectors or roadbed stability detectors. A typical slide detector has the appearance of a fence constructed adjacent to the tracks on the uphill side (see Figure 16) while a roadbed stability detector would be constructed on the downhill side. The presence of a hazard is detected when electrical conductors in the fence are broken or dislodged by moving materials and approaching trains are automatically warned by a signaling device. Installation and maintenance of these devices is both costly and time consuming because of the amount of construction work involved. It is therefore only practical to protect modest lengths of track using these detectors located in the most critical locations.

The railways continue to explore new technologies and methods which may be used to predict and/or detect ground hazards and to mitigate the consequences. In 2002, a Workshop on Slide and Washout Hazards was held in Kananaskis, Alberta, sponsored in

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55 http://www.georgetownrail.com/aurora.php
part by Transport Canada and other government agencies. The workshop provided a forum for industry, government and researchers to review current practices in managing the risks of natural hazards and to identify future needs and viable opportunities for further research and development initiatives. Shortly thereafter, a Railway Ground Hazard Research Program (RGHRP) was initiated.

*Figure 16  A Slide Fence on CN Rail.*

Much research work has been conducted under that RGHRP to examine techniques of building digital elevation models which can be used with computer models to analyze topographical features and assess locations with significant risk of landslides or rockfalls. Individual projects involved photogrammetry using digital cameras, use of terrestrial light detection and ranging radar (LiDAR), use of low altitude airborne LiDAR and using synthetic aperture radar interferometry (InSAR) from earth orbit. Such information and analyses can be used by railroads to direct the development of future hazard detection sites.

While slide fences are a proven detection method for landslides and rockfalls, other technologies continue to be explored such as using land based guided radar to detect

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57  "Digital Elevation Models Based on Terrestrial Photogrammetry", RGHRP Project 5.1 – GIS Based Models for Predicting Ground Hazard Events.
58  "Light Detection and Ranging (LiDAR) Survey of CN Rail Track near Yale, British Columbia", RGHRP Project 5.3 – GIS Based Models for Predicting Ground Hazard Events.
59  "Mobile terrestrial and low altitude airborne Lidar data assessment for Algoma Central Railway", RGHRP Project 6.3 - Develop GH mapping processes for rail corridors
60  "INSAR", RGHRP Project 9.1 - Hazard monitoring – event detection technology.
landsides and applying electromagnetic perimeter sensing technology to detect landslides and rockfalls. In the Electromagnetic Field Disturbance (EMFD) technique, investigators detected induced disruptions in a radio frequency signal carried through a co-axial cable when material falls within close proximity to the sensing cable. In a report evaluating 26 detection technologies on the basis of maturity, potential and applicability to the task of detecting railroad ground hazards, ground based radar interferometry and a fibre optic interferometry were identified as the two most highly ranked new technologies.

4.3.2 Fibre Optic Sensors
The fibre optic sensing technology concept identified was based on a Secure Pipe™ product commercially offered by Future Fibre Technologies Pty. Ltd. This technology, originally developed for the oil and gas industry, uses fibre optic cable buried at a depth of 1 to 2 metres to detect surface activity in the monitored area and is reported to be able to detect such activity with an accuracy of 150 metres along the buried cable’s length. Similar systems are currently used for perimeter protection of large areas such as military bases and also for border defense. In the railroad environment, the cable would likely be buried 15 to 30 centimetres below the surface of the ballast and could be run for many miles (the example used 40 kilometre detector lengths). Further testing of this type of system in the railroad environment would be required to confirm its sensitivity and ability to differentiate debris on the tracks from normal train operations. It appears, however, that interest in this technology for slide detection has waned in favour of different approaches.

4.3.3 Geo-Phones
Research in Canada is now turning towards implementing networks of low cost geo-phones for detection of slides. The initial stages of work are focused on data collection tasks and the development of pattern recognition software capable of discerning significant ground movement events.

4.3.4 Bridge Testing System
CN owns and operates a Bridge Testing System (BTS) which it characterizes as a mobile laboratory on wheels. The instrumentation in this truck is used to assess the strength and reserve capacity of bridge members. Recent improvements include addition of a wireless testing system. There is a possibility of further upgrading the system to support the long-term monitoring of fatigue-sensitive bridge components. CN indicates testing of between 10 and 12 bridge structures per year.

4.3.5 Ground Penetrating Radar
The traditional method used by railways to evaluate ballast and subgrade involves boring holes and inspecting the samples at regular intervals. It is easy to overlook defects in the track structure using this method. Ground penetrating radar may be used to examine the

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thickness and quality of a track’s ballast, sub-ballast and sub-grade with nearly complete coverage (the areas under ties may be poorly covered). While this technique seems to have only been experimented with in North America, it is extensively used in Europe (for example Germany, Austria, Switzerland, Hungary and Norway) for geotechnical survey of railway roadbeds. Early systems used bow-tie antennas placed just above the ballast and operation was limited to speeds below 30 kph. Also, antennas are prone to damage by track work (switch rails, etc). Higher inspection speeds are now possible using horn antennas which can be mounted approximately half a metre above the ballast where they remain safely above any track work. Zetica Rail in the UK have developed their Zetica advanced rail radar (ZARR) acquisition system specifically for use on railways. This system is designed to be interfaced into inspection equipment with antennae mounted beneath the vehicle and provision is offered for a tachometer pulse stream, GPS system and video technologies for accurate defect location. Zetica’s system is reported to reliably capture samples in 5 centimetre intervals at speeds of 100 km/hr.

CN is monitoring GPR as a potential future technology. CPR has tested the technology but, while it acknowledges that the system yields information on the subsurface condition, it has been disappointed in the usefulness of the information to its maintenance planning.

64 “Fast Inspection of Railway Ballast By Means of Impulse GPR Equipped with Horn Antennas”, http://www.ndt.net/article/v10n09/kathage/kathage.htm
5 OTHER TECHNOLOGIES (SIGNALS, CROSSINGS)

5.1 Positive Train Control

Positive Train Control (PTC) refers to a collection of automated processes and technologies which function collectively to: ensure adequate separation of trains, enforce track speed limits and temporary slow orders, and provide protection for work crews and equipment operating on the tracks. Positive Train Separation (PTS) provides a subset of the PTC functionality specifically concerned with maintaining safe distances between trains at all times.

Positive train control can be implemented either as an overlay system or as a more completely automated vital safety system. In the overlay implementation, computer systems installed on board locomotives are used to accurately track current location and to support data communication between the rail equipment and a central control facility, but continues to rely largely on the train crew to operate their train according to instructions and the conventional track signalling system. However, overlay systems are capable of positively enforcing stops when the system determines that the train will exceed its operating authority by passing through a track block boundary without permission.

A vital safety system is more completely automated and determines a train’s location very precisely so that adjacent tracks may be distinguished. Vital systems facilitate operating trains with moving blocks which minimize train separation to the distance actually required to stop specific trains safely before a collision can occur.

Forms of positive train control systems have been fully implemented in some mass transit and passenger service operations worldwide. Examples include AMTRAK’s Automatic Train Control (ATC) system, Advanced Civil Speed Enforcement System (ACSES) and Incremental Train Control System (ITCS). Systems, such as ATCS in the 1980s and others in the 1990s, were proposed for use in North American freight operations but progress has been limited to demonstration projects such as one on BNSF in 1997.66

The U.S. NTSB has had PTC on their most wanted list of transportation safety improvements67 since 1990 and the U.S FRA began action in 1997 by establishing a working group under the aspecies of its Railroad Safety Advisory Committee to examine implementation of PTC systems. The FRA has since published the rule "Standards for Development and Use of Processor-Based Signal and Train Control Systems" which became effective on June 6, 2005.

U.S. railroads are now beginning to introduce PTC systems into their operations on a limited basis. These include the Union Pacific Railroad (UP), Burlington Northern Santa Fe Railway (BNSF), Norfolk Southern Railway (NS) and the Alaska Railroad Corporation. Implementation in dark territory, that is tracks without a signaling system, offer a prime

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66 http://findarticles.com/p/articles/mi_m1215/is_n1_v198/ai_19077859
67 http://www.ntsb.gov/Recs/mostwanted/positive_train.htm
application since substantial productivity gains are possible although railroads are also targeting implementations on signaled territory.

It seems reasonable to expect that the implementation of PTC systems will continue to expand on individual railroads throughout North America as the collective industry experience with these systems grows and sufficient benefits accrue. However, it was reported in 2005 that the cost/benefit ratio of PTC system implementations falls well short of 1 which makes implementation difficult to justify. There are also issues around interoperability of PTC equipment which need to be fully addressed so that North American railways can continue to cross-travel where such agreements exist. The railroad industry is addressing these issues through working committees and many of the required standards have already been developed.

5.2 Switch Position Indicators in Unsignalled Territory

Derailments in dark (unsignalled) territory may occur when switch points are erroneously left in the wrong position for an approaching train who's crew is unable to safely stop the train once close enough to visually confirm the switch’s alignment. Despite operational procedures being put into place to safeguard against misaligned switches such as requiring personnel to contact the rail traffic controller when operating a manual switch, accidents still happen.

Technology used in rail yards, such as Rail Comm’s Switch Position Indicator, is available to provide a positive indication of switch alignment using lighted signals which are controlled by the switch position and visible to an approaching train from a safe stopping distance. Addition of annunciation technology, whereby an approaching train can radio the switch position indicator equipment and receive a message back indicating the switch alignment, provides an effective means of extending application to mainline operational speeds. Global Rail System's Fail Safe Audible Signal Power Activated Switch (FAS-PAS™) system combines both visual and audible indications of switch position. This system displays a green light in the direction of oncoming trains when the switch is correctly aligned and a red light when the switch is reversed. The engineer of an approaching train is also able to query the switch indication device for switch position using the standard on-board locomotive radio. FAS-PAS™ systems have been in use on segments of track on the NB Southern Railway since May of 2005 and Transport Canada has recently sponsored work to evaluate the reliability of this equipment under winter conditions.

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70 http://www.railcomm.com/products/switch_position_indicator.htm
71 http://www.globalrailsystems.com/
5.3 Grade Crossing Systems

Transport Canada and the railways explored a number of issues and new technologies under the auspice of Direction 2006, an initiative started in 1996 with the objective of reducing grade crossing accidents by 50%. Most grade crossing safety issues have a human factors focus, which is the subject of another study. We simply list some of the technologies assessed within the Research program of the Direction 2006 initiative. Many technologies deal with improving either the visible conspicuity or audible alerting capacity of approaching trains. The visible technologies include:

- Light Emitting Diode (LED) Signal Lights - to improve the conspicuity of automated crossings, when approaching off-centre from the warning lights' alignment.
- Rail Car Reflectorization to improve night time visibility of trains occupying a crossing with passive warning signs.

Lighting at the front of the locomotive is also used to improve conspicuity of an approaching train. We were asked to report on any research into strobe light effectiveness in this regard. The following summarizes the findings of a U.S. FRA evaluation, and is extracted from a study undertaken for Transport Canada within the Direction 2006 initiative: *Locomotive Horn Evaluation, Effectiveness at Operating Speeds*, [TranSys Research Ltd. 2003].

The U.S. FRA has conducted evaluations of strobe lights and other light systems to raise the conspicuity of a locomotive [Carroll, et al. 1995] and subsequently introduced a regulatory requirement. The experimental field tests compared the performance of a lone headlight with combinations of a headlight and each of the following:

- pulsing crossing lights that were aligned straight down the track,
- steady burning ditch lights that were outwardly aligned at 15 degrees, and
- dual strobe lights mounted on the top of the locomotive.

The following were among the principal findings:

- All three types of auxiliary lights outperformed the lone headlight by significantly increasing the distance a train can be detected and improving an observer's ability to estimate a train's arrival time at the crossing. For detection distance, the crossing light performed best, followed by the ditch and strobe lights.
- Although desirable effects can be achieved with pulsating strobe lights, particularly those lights operated in pairs, extensive use of strobe and oscillating-type lights on emergency vehicles has reduced their usefulness as a distinct warning of an approaching train. Further, strobe lights can tend to wash out against a light background and may not compete well for attention in a night time environment with a variety of light sources. Research in support of this proceeding indicates that crossing lights and ditch lights--the auxiliary lights most widely used by U.S. railroads--also appear to perform well under both experimental conditions and in revenue service.
With respect to estimation of time of arrival, the crossing lights were judged to result in the smallest estimation errors for actual arrival time intervals between 7 and 22 seconds. However, the ditch lights clearly aided estimation of arrival, as well. In the field tests, observers wore headphones to mask noise from the oncoming locomotive.

Improved Second Train Warning Systems, which assessed a number of visual systems to improve the understanding of presence and dangers of second trains to pedestrians at grade crossings.

Audible alerting systems were also assessed within the Direction 2006 initiative, including:

- Two-level horns, which were recommended to balance the noise concerns of residents, with the alerting benefits of a high-sound-level in emergency situations.
- Wayside-Horns - acoustic warning devices that are mounted at the crossing to provide an audible warning down the road rather than along the tracks and thereby reduce community noise concerns.

Other research topics included:

- Photo Enforcement - assessment of the safety impact of an automated photo enforcement system at an automated crossing with flashing lights but without a gate; and
- Low Cost Alternatives - an assessment of possible technologies to provide an incremental improvement in safety over low cost passive devices but at a much lower cost that the full automated crossing warning systems now available.
6 OBSERVATIONS AND RECOMMENDATIONS

The Railway Safety Act is not an impediment to the adoption of safety technology, but does not in itself facilitate technology development. The RSA allows safety regulations to be updated as changes in technology and knowledge make it desirable. However, the regulation development process has not been very successful in moving to performance based standards. The industry and regulator have not yet agreed on what a performance standard is, or what characteristics it should have. Close to twenty years after the RSA, Transport Canada is still perceived to be functioning in the compliance mode of the former Canadian Transport Commission. Facilitation of technology development involves financial and manpower resources that have not yet been allocated. If Transport Canada wishes to have an influence on safety issues that are specific to the Canadian operational or physical environment, it needs to invest in both research and personnel. We recommend Transport Canada allocate the resources necessary to fulfill the intent of the RSA.

Harmonization requirements and industry structure pose more of a constraint to equipment-related technology development than does the Railway Safety Act. There is more freedom to chart an independent course in the track area. We recommend that the present initiative to update the Track Safety Rules be used as an opportunity to interpret the intent of the RSA and update the process involved in regulation setting. By all accounts an excellent first step has been taken. The resources and priority allocation required to continue that process to a successful conclusion need to be set. The objective should be to attain the optimal balance of government’s safety oversight in support of public confidence, and industry’s freedom to efficiently manage/advance safety,. From our interview process, we found diametrically opposite viewpoints on some basic issues. We encourage both industry and government to approach the task with an open mind and recognize the importance of getting it right this time.

We concur with the majority of interviewees who indicated that research and development should be an integral component of RSD’s approach to fulfilling its mandate of providing safety oversight and advancing safety. We believe that the research program developed within Direction 2006 is an example of a joint industry government initiative that was successful in advancing safety and allowed Transport Canada to participate in, and contribute to, that advancement at an international level. Some of the research focused on topics not researched elsewhere and some addressed specific Canadian perspectives. There were also topics that could be considered to duplicate research efforts of other countries; yet these initiatives came to different conclusions and led to different actions in Canada than elsewhere. A model similar to Direction 2006 could be applied to the overall rail safety area. We recommend Transport Canada implement a similar joint industry-government program in rail safety advancement and allocate sufficient financial and personnel resources such that, by 2010, the organizational structure and safety advancement targets for 2020 are set, and an initial five-year research program is outlined.
Technology and research findings have been used to advance the safety of Canadian railways in the past, and there will be ongoing opportunities to advance safety in the future. Rather than focus on specific technologies, we recommend that the following guidelines be used in targeting future research efforts:

- There is more of a role for government to take leadership in developing technologies that do not offer significant operating savings, and/or where cross-functional boundaries exist.

- Selection of specific topics within these categories should recognize the potential constraints of harmonization.

- There are more opportunities to influence safety advancement in track and operations safety areas than in equipment related topics.

- Within equipment, there is more need to provide leadership in those safety technologies that address safety problems associated with Canadian operational and environmental differences.
APPENDIX A

Electronic Data Recorders
Air Transportation Electronic Data Recorders

The FAA requires all large commercial aircraft and some smaller commercial, corporate, and private aircraft to be equipped with a Flight Data Recorder (FDR) and a Cockpit Voice Recorder (CVR). These devices record information which investigators may use to infer the events leading up to an aircraft accident. The flight data recorder maintains a time history of information describing the operation of the aircraft such as its altitude, airspeed and heading. The cockpit voice recorder, as its name suggests, records the pilot’s voice, engine noise, alarms, landing gear noise and other sounds in the cockpit using a microphone usually installed above the instrument panel. All radio transmissions are also recorded. Older analog recorder units use one-quarter inch magnetic tape as a storage medium while the newer digital units use hardened memory chips. Both recorders are required to be installed in the most crash survivable location within the aircraft which is usually considered to be the tail section.

Table A-1 lists the main specifications for a FDR while Table A-2 lists the main specifications for a CVR.

Table A-1  Aircraft Flight Data Recorder Specifications

<table>
<thead>
<tr>
<th>Flight Data Recorder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time recorded</td>
</tr>
<tr>
<td>Number of parameters</td>
</tr>
<tr>
<td>Impact tolerance</td>
</tr>
<tr>
<td>Fire resistance</td>
</tr>
<tr>
<td>Water pressure resistance</td>
</tr>
<tr>
<td>Underwater locator beacon</td>
</tr>
</tbody>
</table>

Table A-2  Aircraft Cockpit Voice Recorder Specifications

<table>
<thead>
<tr>
<th>Cockpit Voice Recorder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time recorded</td>
</tr>
<tr>
<td>Number of channels</td>
</tr>
<tr>
<td>Impact tolerance</td>
</tr>
<tr>
<td>Fire resistance</td>
</tr>
<tr>
<td>Water pressure resistance</td>
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<tr>
<td>Underwater locator beacon</td>
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</tbody>
</table>
Marine Transportation Data Recorders

Many marine vessels on international voyages are required to be equipped with a Voyage Data Recorder (VDR) to assist with accident investigations.

Table A-3 summarizes the data elements to be stored by a marine VDR according to the IMO Performance Standard (Res. A.861(20)) and the IEC Information format (IEC 61996).

<table>
<thead>
<tr>
<th>A.861(20) REF</th>
<th>DATA ITEM</th>
<th>SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.4.1</td>
<td>Date &amp; time</td>
<td>Preferably external to ship (e.g. GNSS)</td>
</tr>
<tr>
<td>5.4.2</td>
<td>Ship’s position</td>
<td>Electronic Positioning system</td>
</tr>
<tr>
<td>5.4.3</td>
<td>Speed (through water or over ground)</td>
<td>Ship’s SDME</td>
</tr>
<tr>
<td>5.4.4</td>
<td>Heading</td>
<td>Ship’s compass</td>
</tr>
<tr>
<td>5.4.5</td>
<td>Bridge Audio</td>
<td>1 or more bridge microphones</td>
</tr>
<tr>
<td>5.4.6</td>
<td>Comms. Audio</td>
<td>VHF</td>
</tr>
<tr>
<td>5.4.7</td>
<td>Radar data- post display selection</td>
<td>Master radar display</td>
</tr>
<tr>
<td>5.4.8</td>
<td>Water depth</td>
<td>Echo Sounder</td>
</tr>
<tr>
<td>5.4.9</td>
<td>Main alarms</td>
<td>All mandatory alarms on bridge</td>
</tr>
<tr>
<td>5.4.10</td>
<td>Rudder order &amp; response</td>
<td>Steering gear &amp; autopilot</td>
</tr>
<tr>
<td>5.4.11</td>
<td>Engine order &amp; response</td>
<td>Telegraphs, controls and thrusters</td>
</tr>
<tr>
<td>5.4.12</td>
<td>Hull openings status</td>
<td>All mandatory status information displayed on bridge</td>
</tr>
<tr>
<td>5.4.13</td>
<td>Watertight &amp; fire door status</td>
<td>All mandatory status information displayed on bridge</td>
</tr>
<tr>
<td>5.4.14</td>
<td>Acceleration &amp; hull stresses</td>
<td>Hull stress and response monitoring equipment where fitted</td>
</tr>
<tr>
<td>5.4.15</td>
<td>Wind speed &amp; direction</td>
<td>Anemometer when fitted</td>
</tr>
</tbody>
</table>

Road Transportation Electronic Data Recorders

There are currently no legal requirements to use electronic data recorders on buses operated in Canada. In 1999 the U.S. NTSB recommended that all newly manufactured school buses and motor coaches (those manufactured after January 1, 2003) be equipped with electronic data recording devices. In 2004 the U.S. NTSB also recommended that all newly manufactured passenger vehicles be equipped with electronic data recording devices. Many vehicle manufacturers have incorporated some ability to store data within the engine control electronics of new vehicles which can provide some useful information for accident reconstruction. Also, GPS based vehicle location system used by truck and bus fleets can also provide some useful information.

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73 NTSB Safety Recommendations H-99-53 and H-99-54 to NHTSA, November 1999