RAILWAY INVESTIGATION REPORT
R98V0148

REAR-END TRAIN COLLISION

CANADIAN PACIFIC RAILWAY
TRAIN NO. 839-020 AND TRAIN NO. 463-11
MILE 78.0, SHUSWAP SUBDIVISION
NOTCH HILL, BRITISH COLUMBIA
11 AUGUST 1998

Transportation Safety Board
of Canada

Bureau de la scurit des transports

du Canada

Railway Investigation Report

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Synopsis

On 11 August 1998, at approximately 1810 Pacific daylight time, Canadian Pacific Railway train No. 463-11 collided with the rear-end of Canadian Pacific Railway train No. 839-020 at Mile 78.0 of the Canadian Pacific Railway Shuswap Subdivision, near Notch Hill, British Columbia. One car on train No. 463-11 and two cars on train No. 839-020 derailed. There were no injuries.

Section 3 of this report contains the Board's findings as to causes and contributing factors and other findings. The Board has identified two safety deficiencies related to the backup safety defences for signal communication and the impact of noise on the communication of safety-critical information between crew members on locomotive cabs. The safety recommendations issued by the Board to address the two identified safety deficiencies are presented in Section 4.

Ce rapport est également disponible en français.

1.0 Factual Information

1.1 The Accident

On 11 August 1998, train No. 463-11 (train 463), a Canadian Pacific Railway (CPR) westward freight train, departed Revelstoke, British Columbia, at Mile 0.0 of the Shuswap Subdivision at approximately 1454 Pacific daylight time (PDT)[1]. At approximately 1810, train 463 was rounding a right-hand curve approaching Mile 78.0. Upon observing the last car on CPR train No. 839-020 (train 839), which was stopped at Mile 80.2 to allow an eastward train to pass, both crew members on train 463 immediately initiated emergency brake applications. Train 463 struck the tail-end car of train 839.

1.2 Injuries

There were no injuries reported.

1.3 Damage

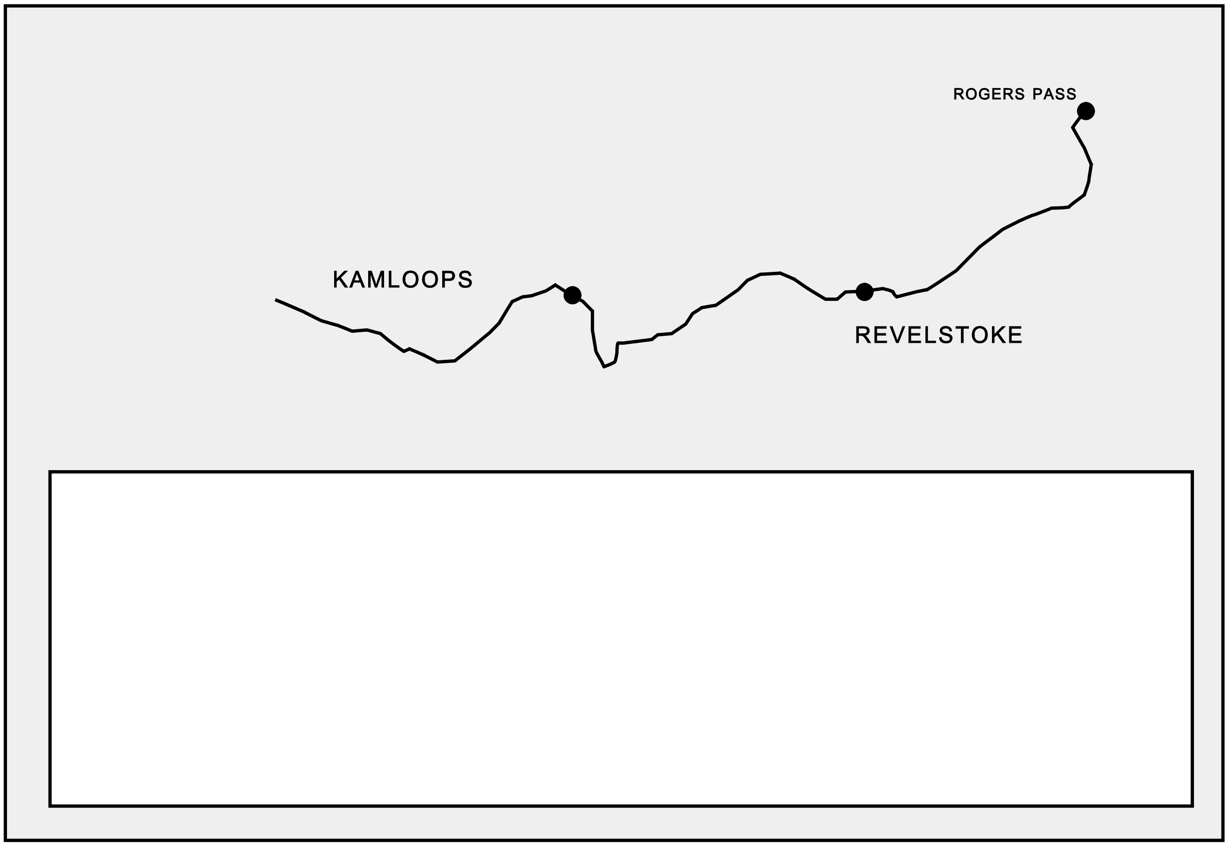
The last two cars on train 839 (loaded with coal) sustained minor damage.

On train 463, lead locomotive CP 5503 (type SD40-2) and trailing locomotive SOO 6604 sustained minor damage. The first truck of car DTTX 75914, a multi-platform car located immediately behind the locomotives, derailed to the north side of the north track and sustained major damage. The empty containers being transported on the multi-platform car were destroyed.

1.4 Occurrence Location

The Shuswap Subdivision extends from Revelstoke (Mile 0.0) westward to Kamloops, British Columbia (Mile 128.5). It is a single main track except between Mile 2.0 and Mile 6.1, Mile 69.0 and Mile 80.2, and Mile 103.8 and Mile 128.5, where there is double main track. A hot box detector (HBD) is located at Mile 77.5, which scans the wheel bearings of passing trains and emits a radio message indicating their condition.

[1] All times are PDT (Coordinated Universal Time (UTC) minus seven hours) unless otherwise stated.



Maximum permissible speed for freight trains on the north main track between Mile 77.2 and Mile 80.2 is 30 mph. Train 463 had experienced a Sense and Braking Unit (SBU) failure and was restricted to a maximum speed of 25 mph.

Approximately 955 feet east of Mile 78.0, there is a five-degree right-hand curve.

1.5 Particulars of the Track

The track structure consisted of continuous welded rail, laid on nine-foot hardwood ties and secured with 10 spikes per tie. The ballast was crushed stone. All track components were in good condition.

1.6 Personnel Information

The locomotive engineer and the conductor on train 463 were qualified for their respective positions and met fitness and rest standards. This was the locomotive engineer's fourth trip since returning from vacation. He obtained, on average, seven hours of sleep on each of the three nights preceding the occurrence. The conductor had been on leave for four days before the occurrence and obtained approximately eight hours of sleep each of those nights.

The locomotive engineer entered service as a trainman in 1971 and became a locomotive engineer in 1975. He had worked on the Shuswap Subdivision for the past 10 years. The conductor began his employment with Engineering Services in 1991 and transferred to the running trades, becoming a conductor in 1997. He had worked in that capacity on the Shuswap Subdivision on seven trips since qualifying for that position. Due to the seniority rules that he was working under, he had been laid off work four times during the year. The time off work accounted to a total of nine months.

1.7 Train Information

1.7.1 Train 839

Train 839 consisted of 3 AC4400 locomotives and 114 loaded coal cars. It weighed approximately 16,700 tons and was about 6,900 feet in length.

1.7.2 Train 463

Train 463 consisted of 2 SD40-2 locomotives, 19 loaded cars and 5 empty cars. It weighed approximately 2,900 tons and was about 1,500 feet in length.

1.8 Method of Train Control

1.8.1 General

The Shuswap Subdivision is controlled by the Centralized Traffic Control System (CTC) as authorized by the Canadian Rail Operating Rules (CROR). CTC is a system of block signals where train movements are supervised from a central office location by a rail traffic controller (RTC). Train movements are governed by these signal indications. The RTC and train crews communicate by radios. Under normal operating conditions, there is no requirement for the RTC or for the train crews to communicate a train's location to other trains. However, in this instance, the crew members would have been governed by CPR's Special System Instruction to Rule 90 (see Appendix A) and Rule 119 (see Appendix B) which require them to continuously monitor the standby channel in order to be aware of the movement of other trains in the vicinity.

The CTC system does not automatically ensure positive train separation; it provides signal indications which can allow trains to operate within the same block. There is no system in CTC to alert a train crew of areas of restrictions or the presence of other rolling stock. The design of the system is such that trains are given a series of signal indications that require trains to take action relative to the signal displayed. The system relies on the identification and calling of the signals by the crew per CROR Rule 34.

CROR Rule 34(b) states that:

> Crew members within physical hearing range must communicate to each other, in a clear and audible manner, the indication by name, of each fixed signal they are required to identify. Each signal affecting their train or engine must be called out as soon as it is positively identified, but crew members must watch for and promptly communicate and act on any change of indication which may occur.

CROR Rule 34(c) states that:

> If prompt action is not taken to comply with the requirements of each signal indication affecting their train or engine, crew members must remind one another of such requirements. If no action is then taken, or if the locomotive engineer is observed to be incapacitated, other crew members must take immediate action to ensure the safety of the train or engine, including stopping it in emergency if required.

1.8.2 Train Line-Up

A train line-up, which is updated several times per day, is made available to train crews. Line-ups indicate the names of crews assigned to future train movements and provide a rough indication of the timing of the trains. The current train line-up procedure is not a line-up of all train traffic for actual train operation purposes, but information for crews concerning trains that are scheduled to operate thus ensuring that crews can be properly rested for their next assignment. Train line-ups are not intended for use as a train schedule or as an authority for train movement. However, train crews use them informally to determine the sequencing, timing, and approximate location of other trains.

Before departing Revelstoke, the conductor on train 463 obtained a copy of the train line-up. The line-up had just been updated and started with train 463. It did not contain information on the preceding trains.

1.9 The Collision

As train 463 approached Tappen (Mile 70.5), the locomotive engineer heard the HBD transmission as train 839 passed the site at Mile 77.5. The conductor did not recall hearing the transmission.

Westward train 839 had stopped on the north track at Mile 80.2 to allow an eastward train to pass. Its tail end was located at Mile 78.0, approximately 7,000 feet west of signal 767N.

At approximately 1810, train 463 was rounding the curve approaching Mile 78.0. The visibility around this curve was reduced by the presence of a cluster of trees on the north side of the track. The measured line of sight to the tail end of the train was 380 feet. Upon observing the last car of train 839, both crew members on train 463 immediately initiated emergency brake applications. Train 463 struck the rear car of train 839. At the time of the collision, the crew of train 839 had disembarked the locomotive to inspect an oncoming eastward train. The crew on train 463 made an emergency broadcast at this time.

Westward trains travelling on the north track, between Mile 69.0 and Mile 78.0, are governed by the following block signals: 723N at Mile 72.3, 745N at Mile 74.5 and 767N at Mile 76.7.

Given proper signals operation, the presence of train 839 would have resulted in the following signal indications (as identified in Figure 2):

- Signal 723N - “Clear Signal” indication (Proceed)
- Signal 745N - “Clear to Stop” indication (Proceed, preparing to stop at next signal)
- Signal 767N - ‘”Restricting Signal” indication (Proceed at restricted speed[2])

The crew members on train 463 stated that they communicated the indication of signal 767N with each other.

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[2] A speed that will permit stopping within one-half the range of vision of equipment, also prepared to stop short of a switch not properly lined and in no case exceeding SLOW SPEED. Slow speed is a speed not exceeding fifteen miles per hour.

The conductor observed and called a “Restricting Signal” indication and noticed that the locomotive engineer was looking in the direction of the signal. The conductor did not hear the locomotive engineer call the signal indication he observed. The locomotive engineer observed and called a “Clear to Stop” indication but did not hear the conductor acknowledge this indication. Neither the conductor nor the locomotive engineer requested clarification of the signal indication observed nor did they challenge each other’s identification of the signal.

The crew was exposed to a high noise environment as the train was proceeding up Notch Hill at throttle eight, the maximum throttle position; both the conductor and the locomotive engineer were wearing ear plugs. As it was an exceptionally hot day, and the locomotive was not equipped with air conditioning, the crew had opened the windows.

The crew on train 463 did not have any radio communication with train 839 and could not recall hearing any other radio communications by other crew members in the area.

There is no form of voice recorder in locomotives. Without such a device, the exact nature of the voice communications in the cab cannot be determined.

1.10 Weather

Train 463 passed signal 767N at approximately 1810, at which time the sun would have been approximately 20 degrees above the horizon. The weather data for the area revealed that there was some smoke haze due to forest fires in and around the Salmon Arm area. However, both crew members reported that there was no smoke haze or other form of climatic condition obscuring the visibility of either signal 767N or Mile 78.0. The ambient temperature was 30 degrees Celsius.

1.11 Recorded Information

The event recorder data indicated that the emergency brake application occurred at a recorded distance of 78.040 miles (approximately 300 feet in advance of the tail end of train 839) while the train was travelling at a recorded speed of 21.9 mph. At a recorded distance of 78.098 miles from Revelstoke, the train came to a stop. The speed at the time of impact was 16 mph.

1.12 Other Information

1.12.1 Post-Accident Signal Testing

Block signal 767N was checked by railway officials immediately after the accident and was functioning as intended.

1.12.2 Signal Visibility Simulation

A simulation was performed several days after the occurrence with a work train. The simulation indicated that, when viewed from the conductor's position, signal 767N was initially visible from a distance of 2,500 feet, it then disappeared from view because of the track curvature, and reappeared at approximately 1,500 feet. Through the locomotive engineer's window, the signal first became visible at approximately 900 feet.

1.12.3 Crew Management

Locomotive engineers and conductors may elect the type of service they are interested in—single subdivision run, extended run (not applicable on the Shuswap Subdivision) and spare board—based upon seniority. For each type of service, there is a pool for locomotive engineers and one for conductors.

Each crew member works his/her turn on a rotating basis, first-in first-out, subject to mandatory rest and hours of service. In cases when it is not possible to fill a position for a type of service from a pool, names are chosen from the spare board, where the most junior employees are listed.

1.12.4 Company Supervision and Performance Monitoring

CPR enforces compliance with the CROR through a monitoring program conducted at both the local and the national levels.

At the local level, railway officers ride alongside train crews, and monitor and advise crews of any observed non-compliance. Officers also administer proficiency tests to ensure that crews understand and apply rules satisfactorily. Performance reviews are conducted at least once every three years on each locomotive engineer by a road manager or manager of operations. One of the skills evaluated is compliance with and understanding of key rules such as CROR Rules 34 and 90.

At the national level, CPR has three full-time "rules experts." As part of their duties, these individuals also ride trains. The rules experts prepare reports detailing the findings of their inspection rides. These reports are used to take remedial action.
For instance, CPR instituted a rule awareness program seven years ago, entitled "Rule of the Week." This program aims at increasing awareness amongst train crews about rules which have been revised, and those identified as problem areas (through inspection rides and other channels such as incident reports). Rule 34 has been the topic of "Rule of the Week" on several occasions over the last seven years.

Additionally, CPR supervisors and safety and health committees monitor and take corrective action on safety hazard reports which are filled out by train crews who observe hazardous locations/conditions.

1.12.5 Regulatory Overview

Transport Canada (TC) Rail Safety Directorate is the railway safety regulator. Its mission statement is to "develop and administer policies, regulations and services for the best possible railway transportation system."

The Rail Safety Directorate is divided into five regions. Each region prepares a plan at the beginning of each year which includes a projected target of on-site train crew inspections or "train rides" for that year. The number of trains which will be ridden in a given year is based upon examination of a number of factors, such as accident and incident reports, past audits, and random examination of train data recorder downloads.

The Pacific Region has two full-time "train riders" reporting to a chief, who also rides when there is an opportunity. One of the functions of the train riders is to ensure compliance with the CROR, including Rule 34. All areas of non-compliance or issues of concern identified while riding trains are noted. A report is sent to the appropriate company supervisor who then has 14 days to respond and to take remedial action. The information is recorded in the "Train Operations Monitoring" database. The database provides TC with both administrative tracking (for example, how often trains are ridden and the number of crews ridden with) as well as a means of analyzing recorded deficiency data.

1.12.6 Related Occurrences

This is the second rear-end collision to take place at Mile 78.0 of the Shuswap Subdivision in the last 10 years. In 1992, there was a rear-end collision (TSB report No. R92V0061) involving a work train (Extra 5580) and a freight train (Extra 5801). Extra 5801 was stationary awaiting a meet at Notch Hill; its tail end was at Mile 78.0. The crew members on Extra 5580 misinterpreted the "Restricting Signal" indication at signal 767N as a "Clear Signal" indication, and proceeded through the signal under the assumption that the track was unoccupied. They observed the stationary train as they rounded the five-degree right-hand curve immediately before Mile 78.0, and placed the train into emergency. The impact caused extensive damage to a locomotive on Extra 5580.

1.12.7 Noise and Speech Intelligibility

1.12.7.1 Noise in the Locomotive Cab

Engines are the largest source of noise in locomotive operations. The noise level and spectrum vary with speed and engine load. Additional sources of noise are internal brake air venting in older cabs, the horn, and wheel/rail noise. Open windows, especially in reflective areas like tunnels and along mountain slopes, will increase noise. Another noise source comes from vibrations which loosen locomotive cab components, causing them to resonate. Maintenance can also have an impact on locomotive cab noise. Engines in less-than-ideal condition will run rougher and noisier. Mountings wear and loosen and can create new vibration or decrease vibration damping which in turn can create or worsen noise.

While noise exposure is most often considered in the context of the potential for hearing loss, it can affect crew performance in other ways. Vigilance tasks and low stimulus environments which typify part of the locomotive engineer's and conductor's jobs may be considered monotonous. Noise produces a consistent, increasing, and statistically reliable fatigue effect, especially when experienced during such tasks.

Noise also has an impact on speech intelligibility. Speech intelligibility considerations require even lower noise levels than pure health considerations. MIL-STD-1472D[3] recommends a 75 decibel (dBA)[4] limit for areas requiring communication at up to five feet and recommends a 65 dBA limit for operational areas requiring direct communication at up to five feet.

The use of hearing protection can complicate communications.[5] When the level of ambient noise exceeds 75 dBA, a speaker wearing hearing protectors will typically reduce his/her vocal effort by about 3 decibels (dB) compared to the unprotected speaker.

1.12.7.2 Assessment of Speech Intelligibility

The TSB conducted an evaluation of speech communication among train crews to assess the impact of noise on locomotive crew communication. The principles and techniques used in this evaluation are contained in ISO 9921-1, *Ergonomic Assessment of Speech Communications - Part 1: Speech interference level and communication distances for persons with normal hearing capacity in direct communication (SIL method)*. The relevant acoustical characteristics of the noise are summarized in terms of a single-valued index known as the speech interference level (SIL). The SIL is the arithmetic average of the sound pressure levels of the interfering noise in dB, in the four octave bands centred on the frequencies 500, 1,000, 2,000, and 4,000 hertz (Hz).

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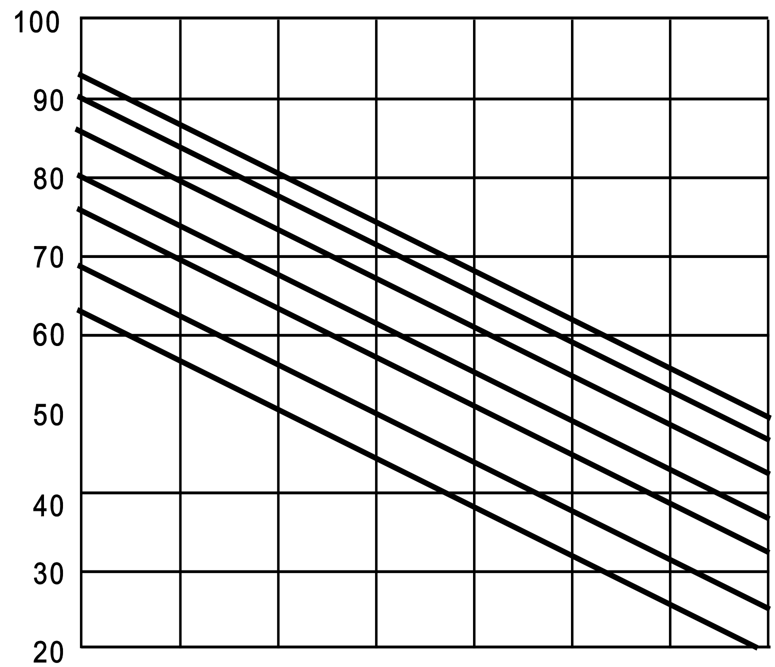
3 U.S. Department of Defence (1989). *Human Engineering Criteria for Military Systems, Equipment and Facilities* (MIL-STD-1472D).

4 The A-weighted sound level (dBA) weighs the measured sound pressure signal in much the same way as the human ear; it is insensitive to low-frequency sound (below 1,000 Hz), quite sensitive to high-frequency sound (between 1,000 Hz and 10,000 Hz) and then insensitive above 10,000 Hz.

5 J. Multer, R. Rudich, and K. Yearwood (1998). *Human Factors Guidelines for Locomotive Cabs*. DOT/FRA/ORD-98/03. U.S. Department of Transportation.

The necessary voice effort for reliable communication increases with the distance between the talker and the listener and with increasing SIL. Figure 3 shows the relationship between SIL for satisfactory communication and maximum distance between the speaker and listener, for seven levels of speaker vocal effort[6].



6 This diagram does not take into account ambient noise levels and the impact of hearing protection.

1.12.7.3 ISO 9921-1–Definition of Normal Hearing

In audiometric measurements, sound levels at various frequencies are standardized against a reference zero, the nominal hearing threshold. An individual's hearing threshold is the lowest sound pressure level which can be detected by that person, and is expressed as a deviation from the nominal hearing threshold. Individuals with hearing loss will have larger deviations than normal hearing persons.

Normal hearing is defined in ISO 9921-1 as the median threshold deviations for males up to 70 years of age (otologically normal persons) from the nominal hearing threshold. ISO 9921-1 specifies the maximum deviations from the threshold values as 6, 7, and 12 dB at the respective frequencies of 500, 1,000 and 2,000 Hz.

1.12.7.4 Running Trades Hearing Requirements

The entrance and retention standards for running trades personnel are detailed in Canadian Transport Commission General Order No. 0-9, *Railway Vision and Hearing Examination Regulations, C.R.C., c. 1173* and in the *Railway Vision and Hearing Examination Regulations Amendment CTC 1985-3 RAIL*.

The entrance requirements limit employment of individuals who have a hearing loss (deviation from the nominal hearing threshold) greater than 20 dB at frequencies of 500, 1,000 and 2,000 Hz. The employee retention requirements stipulate that running trade employees cannot have a hearing loss of 40 dB, except in assignments in which the hearing loss does not prevent the proper and safe performance of the assignments.

1.12.7.5 Speech Intelligibility—General Simulation

Over the course of five days, noise level measurements were taken during separate trips on the Mountain Subdivision and the Shuswap Subdivision of the CPR. In order to capture different noise environments, nine trains with three locomotive types and consists were sampled in a variety of topographic conditions. A minimum of three locomotives of each type were tested. SILs were calculated and their ranges are presented in Table 1, for the different locomotive types, on an ascending grade of 1 to 1.4 per cent, with a throttle setting of eight, both with windows open and windows closed.

Locomotive Type	Windows Closed (SIL)	Windows Open (SIL)
SD40-2	73 - 74 dB	73 - 78 dB
AC4400	68 -74 dB	73 - 74 dB
SD90-MAC	54 - 61 dB	65 - 70 dB

Table 1 - Speech interference levels for various locomotive types, on an ascending grade, with windows closed and open.

The maximum distance at which two individuals can effectively voice communicate can be determined using Figure 3, after correcting for ambient noise levels (dBA) and hearing protectors. The ranges are presented in Table 2.[7]

Locomotive Type	Windows Closed	Windows Open
SD40-2	0.6 - 0.7 m	0.4 - 0.6 m
AC4400	0.5 - 0.9 m	0.5 - 0.6 m
SD90-MAC	1.2 - 2.4 m	0.7 - 1.3 m

Table 2 - Maximum distance, in metres (m), at which effective voice communication can take place

1.12.7.6 Speech Intelligibility Evaluation—Occurrence Simulation

The conditions that prevailed at the time of the occurrence were simulated on a train with similar characteristics to that of the occurrence train (intermodal train with two SD40-2 locomotives, throttle eight, similar speed range 15-25 mph, windows open, locomotive engineer's and conductor's seats approximately 2 m apart). Samples were taken at five-minute intervals as the train progressed through the Shuswap Subdivision. The results obtained were consistent with the values presented in Table 2.

[7] Frequency differences in the ambient noise level can affect the distance at which effective voice communications can be made.

1.12.8 Survey of Conductors and Locomotive Engineers

A voluntary survey was conducted to assess the extent to which train crews are calling signals. A total of 27 survey forms were distributed and all were completed. The questionnaires were distributed in Southern Ontario (Toronto and Sarnia) and in British Columbia (Vancouver and Revelstoke) to both CPR and Canadian National (CN) crews.

When train crews were asked whether signals were being called in the industry, 20 stated that "Clear Signal" indications were not always being called and 7 stated that "Other than Clear Signal" indications were not always being called. Similar responses were obtained when crews were asked whether their co-workers were calling signals; 20 stated that their co-workers were not calling "Clear Signal" indications and 10 were not calling "Other than Clear Signal" indications. When asked whether they personally called signals, 15 responded that they did not call "Clear Signal" indications and 1 reported not calling all "Other than Clear Signal" indications.[8]

The results of this survey were also corroborated by field observations made by TSB investigators where only 20 per cent of crews were calling signals consistently.

[8] It is normal to expect a reduction between the values reported for co-workers and self-reported values, as respondents are less likely to personally admit to regulatory infractions.

2.0 Analysis

2.1 Introduction

The safety of a train is dependent upon the level of situational awareness[9] that the crew is able to achieve together as a team. Fundamental factors for maintaining optimal situational awareness are the ease, effectiveness, and completeness of communication among the train crew members and also between the train crew members and their broader operational environment (e.g. radio transmissions from other trains, RTCs and HBDs, and other information such as train line-ups).

The analysis will focus on the factors which have an impact on the protection of train movements in CTC territory: track visibility, the mental models of crew members, noise in the locomotive, authority gradient, and company supervision and regulatory overview.

2.2 Track Visibility

This occurrence and the 1992 rear-end collision referred to in Section 1.12.6 highlight the importance of track visibility in train operations. The track curvature immediately before Mile 78.0 and the stand of trees to the north side of the track reduced the distance of visibility. Once the signal at Mile 76.7 was misinterpreted as being a "Clear to Stop" signal indication, under the assumption that the track was unoccupied, the crew did not reduce the train speed. There was not sufficient time for the train crew to avert the collision. Due to the track layout and the reduced distance of visibility, this location is particularly vulnerable to collisions because it is a regular meet location where trains are often stationary and are difficult to see.

2.3 Crew Mental Models

At the level of the individual, situational awareness can be thought of as the mental model that a person has of a given situation at a particular time. Mental models develop from cues in the immediate situation and environment (e.g. location, speed, presence of hazard) as well as information from education, training and experience.

Train crews often make use of informal information to shape their mental models, and in the absence of a complete set of cues for a given situation, fragmentary information may be combined with mental expectations and integrated into the mental model.

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[9] Situational awareness in this context is the accurate perception of the factors and conditions that affect a locomotive and its crew during a defined period of time. More simply stated, it is "knowing what is going on around you."

The train line-up obtained by the crew members did not specify the trains in advance of their train, and as a result, the crew members had no indication of the separation between their train and train 839. The HBD message heard approximately 25 minutes before the collision confirmed to the locomotive engineer that, while there was a train ahead, it had already passed the HBD at Mile 77.5 and was long gone. There was no other communication heard by the crew on train 463 which would have alerted the locomotive engineer to the fact that train 839 had stopped for a meet. The position of the sun (low on the horizon) made it difficult for the locomotive engineer to discern the indication of signal 767N clearly. Often, when ambiguity exists, external information, either partial or complete, is employed by an individual to assist in better defining the mental model. As a result, the locomotive engineer believed that the block ahead was unoccupied and that signal 767N was displaying a “Clear to Stop” signal indication.

While the locomotive engineer believed that the signal was displaying a “Clear to Stop” indication, the conductor, who had not heard the HBD message and who had greater visibility of the signal, believed that the signal was indicating a “Restricting Signal” indication.

2.4 Calling of Signals

Protection of movements in CTC territory rely on the locomotive engineer identifying signals, interpreting the signal indication, and taking appropriate action. The conductor acts as a second line of defence by independently identifying and interpreting the signals and communicating this to the locomotive engineer. By communicating the signal to each other, the crew members have an opportunity to reassess a potentially misidentified signal.

It was identified in the survey and through TSB investigators’ observations that the calling of signals is not being performed consistently. The survey identified that many crews do not call “Clear Signal” indications, presumably because of the redundant nature of clear signals (the vast majority of signals encountered are clear) and the fact that a clear signal identifies a situation not requiring any immediate action.

Lack of calling signals extends beyond “Clear Signal” indications as some crews are also not calling “Other than Clear Signal” indications. This inconsistency in calling signals defeats the basic premise of redundancy, the double check by the second crew member, built into the protection of train movements. As a result, the locomotive engineer will not be able to confirm if the signal is actually a “Clear Signal” indication or if the conductor did not call an “Other than Clear Signal” indication, and the locomotive engineer has to rely solely on his/her own interpretation of the signal. Where the locomotive engineer has misinterpreted the signal as a “Clear Signal,” a conductor’s failure to call a signal may reinforce the locomotive engineer’s mental model that the signal is clear.

2.5 Noise in the Locomotive Cab

The study revealed that, in the SD40-2 locomotive, for individuals with normal hearing, the maximum distance at which effective voice communications would have been possible is 0.6 m. Given that the seats are approximately 2 m apart, this would make verbal communication between crew members impractical. Furthermore, the definition of normal hearing as defined in the ISO standard is more restrictive than the accepted hearing standard, General Order No. 0-9.

As a result, running trade personnel may have greater hearing impairment than accounted for in the ISO standard. This means that the effect of noise may be more pronounced in train crews than predicted by the method detailed in the ISO standard.

Noise in the locomotive cab exacerbates the potential confusion from inconsistently called signals. When a signal is called in the presence of noise, and not heard, this apparent "lack of calling" may be misinterpreted as confirmation of a "Clear Signal" indication.

The crew was exposed to a high noise environment as the train was proceeding at throttle eight and the windows were open. In order to deal with the high noise levels, the conductor was wearing ear plugs which made it even more difficult for the crew members to communicate. As the train approached signal 767N, each crew member identified, interpreted and called out the signal indication, but neither heard the other's message. This reinforced the locomotive engineer's mental model that the signal was clear and that the block was unoccupied, and he proceeded past the signal at 21.9 mph without reducing speed.

Different individuals can develop different mental models of the same situation. Communication between crew members is essential if they are to harmonize their mental models and come to a common understanding. Because locomotive cabs are not equipped with cab voice recorders, there is no way of ascertaining exactly how the signals were communicated.

2.6 Authority Gradient

The conductor was relatively inexperienced, with only seven trips on this subdivision compared to the locomotive engineer who had 25 years' service, the last 10 years of which had been on this subdivision. New conductors can be expected to rely on the experience of the locomotive engineer to assist them in performing their duties. It can be intimidating for newly trained conductors to assert themselves when they are paired with locomotive engineers who have many more years of experience.

There were at least two opportunities for the conductor to challenge the locomotive engineer. The first was when the conductor did not hear the locomotive engineer call back the signal indication. The second was when the locomotive engineer did not reduce speed upon passing signal 767N. When there is an authority gradient, the difference in levels of authority between crew members, the more junior crew member is less likely to communicate concerns, notwithstanding the principles advocated by crew resource management (CRM) training. The concept of the authority gradient is universal, and has been demonstrated in the other transportation modes.

In the aviation domain, the authority relationship between an aircraft captain and the first officer has been cited in many accidents and incidents. Research has shown that there is an optimum "trans-cockpit authority gradient" to allow an effective interface between pilots on a flight deck (Edwards, 1975). The gradient may be too flat, such as with two equally qualified individuals occupying the two seats, or too steep, as with a dominating chief pilot and a junior and unassertive first officer. In such cases, a reduced performance may result with a chance of error going undetected and uncorrected. A study[10] in the United Kingdom of 249 airline pilots confirmed the importance of this aspect of flight deck communication. Nearly 40 per cent of the first officers surveyed said they had on several occasions failed to communicate to the captain their proper doubts about the operation of the aircraft. Reasons appeared to be a desire to avoid conflict and a deference to the experience and authority of the captain.

The current emphasis by airlines and aviation regulatory agencies on CRM training has created a substantial improvement in cockpit discipline and performance. The "trans-cockpit authority gradient" should be relatively flat as a result of CRM development. The marine industry has adopted bridge resource management (BRM) training for ships' officers and a similar improvement in accidents or incidents attributed to communications irregularities can be anticipated.

The current railway practice of crew pairing from the spare board will pair senior and junior crew members at random, and therefore, the importance of CRM training within the railway industry should be developed as a safety initiative to eliminate the "authority gradient" factor.

2.7 Company Supervision and Regulatory Overview

[10] J. Wheale (1983). "Crew coordination on the flight deck of commercial transport aircraft," Flight Operations Symposium. Irish Airline Pilots Association/Aerlingus. Dublin. pp. 19-20. October 1983.

While individuals may support the goal or objectives that a rule is directed toward, if they do not think that the means by which the rule achieves this end is relevant, they will exhibit a reduced willingness to comply[11]. Based upon informal discussions with train crews, and replies obtained through the TSB survey questionnaires, it is evident that train crews acknowledge the importance of the communication of signals in achieving the end goal of safe operations. However, train crews reported that communicating all signals was actually not necessary, as the real issue for safety was communicating signals which were "Other than Clear Signal" indications, as these were the critical signals to prevent occurrences. As a result, not all train crews are calling all signals consistently. This then results in the loss of a consistent safety barrier, which yields a potential confusion between crew members as to signal indication.

The monitoring method used presently by TC and by the railway is ineffective as there is no means of assessing the level of compliance to Rule 34 without being in the locomotive cab with the crew. The problem is that train crews will typically call signals in the presence of a company supervisor or TC inspector because of the sanctions that not calling signals would precipitate. As verbal communication is impaired by the noise level in the locomotive cab, the calling of signals could be achieved through means other than voice communication, resulting in safer train operations.

[11] Dave T. Miller. *Psychological Factors Influencing Compliance*. Final Report for the Federal Statutes Compliance Project. Department of Justice, Ottawa.

3.0 Conclusions

3.1 Findings as to Causes and Contributing Factors

1. The signal at Mile 76.7 was misinterpreted as being a "Clear to Stop" signal indication; consequently, the train crew did not reduce the train's speed and was unable to avert the collision.

2. On the SD40-2 locomotive, at throttle eight and with the windows open, the resulting noise made it impractical for the locomotive engineer and conductor to voice communicate effectively from their respective seating positions.

3. The train line-up, the hot box detector message, and the ambiguity caused by the glare due to the sun's position confirmed the locomotive engineer's mental model that the block ahead was unoccupied.

4. Neither the conductor nor the locomotive engineer challenged each other's identification of signals; the authority gradient between the two crew members probably prevented the conductor from challenging the locomotive engineer and expressing his concerns.

3.2 Findings as to Risk

1. The risk of collision at Mile 78.0 is increased because it is a regular meet location where trains are often stationary and are difficult to see due to the track layout and the reduced distance of visibility.

2. The inconsistency among crew members in calling signals defeats the basic premise of redundancy built into the protection of train movements and introduces potential confusion as to the signal indication.

3. Effective voice communication between crew members, from their respective seating positions in SD40-2, AC4400, and SD90-MAC locomotives, is not always possible.

3.3 Other Findings

1. The informal nature of train line-ups may lead train crews to develop incorrect mental models regarding their position relative to other trains.

2. Within the current operating procedures, noise in the locomotive cab exacerbates the potential confusion from inconsistently called signals.

3. Current verbal communication is impaired by the noise level in the locomotive cab. The calling of signals could be more effectively achieved through other communication methods and/or enhanced voice communications.

4. The monitoring method used presently by Transport Canada and by the railway is ineffective as there is no means of assessing the level of compliance to Rule 34 without being in the locomotive cab with the crew.

4.0 Safety Action

4.1 Action Taken

The Service Area[12] has increased its focus on Canadian Rail Operating Rules (CROR) Rules 34 and 90 through traditional train rides and proficiency tests. The crew was provided a refresher course on rules application.

The details of the rear-end collision were reviewed during the four-hour fall safety meeting in 1998 to develop a heightened awareness of the incident and highlight the importance of rules compliance. In addition, front-line supervisors increased attendance at the Revelstoke booking-in room in order to discuss the incident with crews going on and off duty.

Canadian Pacific Railway (CPR) has developed a crew resource management (CRM) training program which is currently being delivered to new hire running trade employees. Work is ongoing to deliver this program to existing employees. The Association of American Railroads is working on adapting this program for generic use by all North American railroads. The Norfolk and Southern is using CPR material as a basis for a CRM training video, which is now available to all railroads.

Transport Canada (TC) is aware of possible non-compliance to Rule 34(b) by railway employees and intends to initiate a concentrated effort across Canada to assess compliance with the rule. Depending on the results of this assessment, TC will take remedial action as necessary.

4.2 Action Required

4.2.1 Signal Communication

The Board recognizes the concerted effort by the railway company and the regulatory body to address the issue related to the communication of signals between crew members. Railway company programs such as the "Rule of the Week" are positive steps towards the reduction of risks associated with the communication of signals. The Board looks forward to the results of TC's review of the current state of compliance to Rule 34, and this program will likely heighten awareness of this issue amongst crews. However, the Board is concerned that the effectiveness of the program will likely be both temporary and incomplete. The current practice suggests that many crews do not consider compliance with the current Rule 34 to be necessary for safe

[12] There are two Canadian Pacific Railway Service Areas in British Columbia: the Vancouver Service Area and the B.C. Interior Service Area which incorporates 14 subdivisions, including the Shuswap Subdivision.

operation. The widespread practice of not calling signals effectively removes the backup safety defence available from the second crew member in ensuring accurate signal interpretation, thus increasing the risk of accidents.

Various measures could be considered to address this safety deficiency. One option would involve a shift to a non-verbal recordable electronic means of communicating signals which would also provide a record of crew actions thereby facilitating company or regulatory monitoring. An additional option would involve replacement of the current rule with another more suitable backup defence that could alert crew members if their actions are not consistent with the signal indication. A wide-ranging review of both the extent of the problem and various potential solutions could achieve a significant improvement in rail transportation safety. Therefore, the Board recommends that:

> The Department of Transport and the railway industry implement additional backup safety defences to help ensure that signal indications are consistently recognized and followed.

R00-04

4.2.2 Locomotive Environment

The effective and safe operation of a railway is largely dependent upon accurate and timely communications. Communication on railway locomotives is currently based on unaided voice communication. Noise in the locomotive cab, particularly in older locomotives, impedes the exchange of safety-critical information through voice communication between the crew members. Therefore, the Board recommends that:

> The Department of Transport assess the impact of noise on voice communication in locomotive cabs and ensure that crew members can effectively communicate safety-critical information.

R00-05

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board authorized the release of this report on 28 November 2000.

Appendix A - CPR System Special Instruction to Rule 90

Voice communication - additional requirements

1. In addition to the requirements of Rule 90, voice communication must be made at the following times and places:

   a) Before departure from location where crew receives operating authority, stating:

      - name of the station from which the train is departing;
      - location train is first restricted by limit of operating authority (item 3), item 4, 6, 7 or 8 of clearance.

   b) In OCS [Occupancy Control System], unless otherwise specified by subdivision footnote, before passing station mile signs enroute, stating:

      - name of the station;
      - location train is first restricted by limit of operating authority (item 3), item 4, 6, 7 or 8 of clearance.

   c) Between one and three miles from locations where protection of impassable or slow track has been provided by GBO [General Bulletin Order] or DOB [Daily Operating Bulletin].

   d) Between one and three miles from locations where instructions from a foreman are required, as specified by Rule 311, 567.1 or 618.

   e) In OCS, immediately before a train or engine enters or leaves a main track through a hand operated switch, stating:

      - switch location
      - position, switch is to be left in
      - clearance number, when switch is left in reversed position

      Note: Not applicable when switching.

      Examples as follows:

      "5820 West, East Siding Switch Mirror may be left in reversed position, clearance No 231. OUT"; or

      "5820 West, West Siding Switch Mirror must be restored to normal. OUT."

2. When all crew members are located in the operating cab of the lead locomotive:

- a crew member will make such announcement on the Standby radio channel designated in the time table.

3. In the application of Rule 90:

- a crew member located in other than the operating cab of the lead locomotive must voice communicate with a crew member located in the operating cab of the lead locomotive.

Appendix B - Rule 119 of Canadian Rail Operating Rules

CONTINUOUS MONITORING

(a) When not being used to transmit or receive a communication, mobile radio receivers (and portable receivers when practicable) must be set to the appropriate standby channel and at a volume which will ensure continuous monitoring.

(b) the volume of a radio receiver should be kept at a level which will avoid annoyance to the public in passenger cars and station facilities.

Appendix C - Glossary

B.C.	British Columbia
BRM	bridge resource management
CN	Canadian National
CPR	Canadian Pacific Railway
CRM	crew resource management
CROR	Canadian Rail Operating Rules
CTC	Centralized Traffic Control System
dB	decibel
dBA	A-weighted sound level
DOB	Daily Operating Bulletin
GBO	General Bulletin Order
HBD	hot box detector
Hz	hertz (cycles per second)
ISO	International Organization for Standardization
m	metre
mph	mile per hour
OCS	Occupancy Control System
PDT	Pacific daylight time
RTC	rail traffic controller
SBU	Sense and Braking Unit
SIL	speech interference level
TC	Transport Canada
TSB	Transportation Safety Board of Canada
UTC	Coordinated Universal Time