CN Rockfall Hazard Risk Management System: Experience, Enhancements, and Future Direction

2005 International Conference on Landslide Risk Management
18th Annual Vancouver Geotechnical Society Symposium
Vancouver, B.C.
May 31 to June 2, 2005

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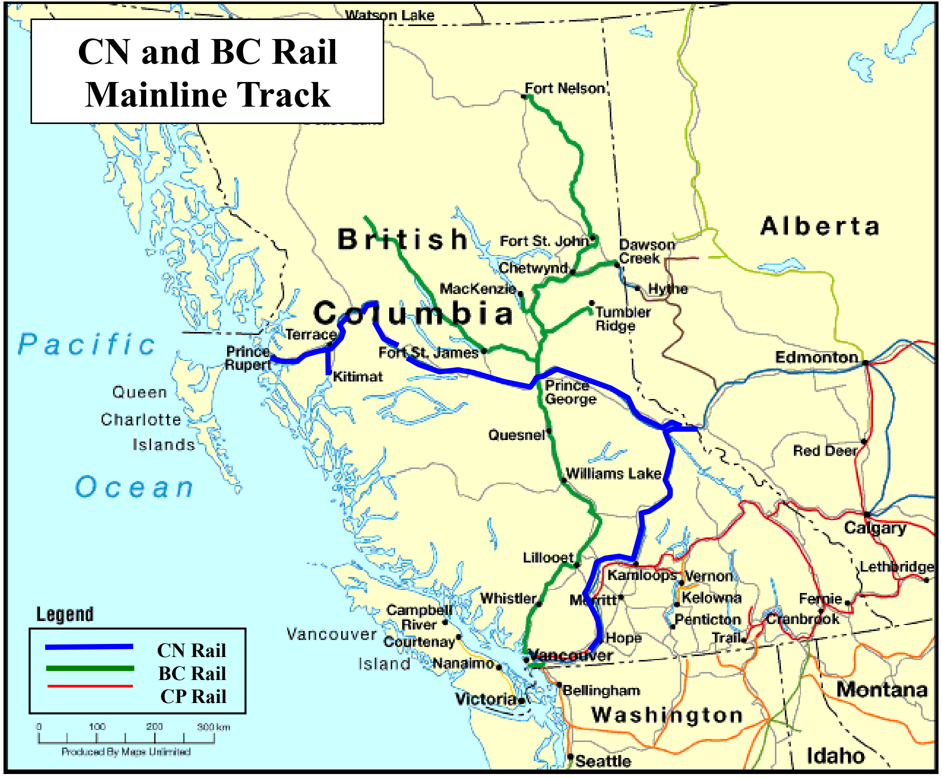
Abstract

Canadian National Railway (CN) operates main line tracks in BC that traverse mountainous terrain and are exposed to rockfall hazards. Between 1995 and 1997, CN, in collaboration with BGC Engineering Inc. and Oboni Associates Inc. (BGC, OA), developed and implemented a rockfall hazard risk assessment rating system (CN RHRA rating) on mainline track in mountainous terrain in Western Canada. The development and implementation of this rating methodology is documented in two previous papers (Abbott et. al. 1998a, 1998b). This paper provides an update to the 1998 papers with a review of the methodology and use of the rating system, and a discussion of additional modifications and enhancements to the rating system since implementation. This paper also outlines how the rating system has been incorporated into a fully developed risk management system for railway rockfall hazard that is consistent with the CSA standard Q850 "Risk Management Guideline for Decision Makers". The paper concludes with future development plans for the CN RHRA system.

1. Introduction

Canadian National Railway (CN) is one of the largest Class I railways in North America operating roughly 20,000 miles of mainline track between the Gulf of Mexico and Canada, and across Canada. In addition to two mainline tracks in the mountainous Canadian west coast province of British Columbia, CN also operates some 1,455 miles of the former BC Rail network (Figure 1). The rugged British Columbia terrain dictates that railways are typically located along the valley bottoms of major river systems with numerous adjacent rock cuts or steep natural rock slopes that are subject to considerable seasonal variability in temperature and precipitation. These features have made British Columbia the most active area on CN's system for rockfall hazard. Between 1995 and 1997, CN, in collaboration with BGC Engineering Inc. and Oboni Associates Inc. (BGC, OA), developed a rockfall hazard risk assessment rating system (CN RHRA rating) and implemented it on mainline track in mountainous terrain in Western Canada. This paper reviews the methodology of the CN RHRA, describes enhancements to the system based on nearly 10 years of development and use, and outlines how the rating system has been incorporated into a fully developed risk management system for railway rockfall hazard. The paper concludes with a discussion of possible future system enhancements.

Figure 1. Route Map for CN in British Columbia



2. Review of the RHRA Methodology

Abbott et. al. (1998a, 1998b) documents the development, theory, and implementation of the RHRA system. This section reviews the rating algorithm, providing additional detail on the rating calculation. The purpose is to facilitate, by additional explanation and example, understanding of how the system works. This review also provides necessary background information for discussion of changes to the rating system.

Equation (1) provides the fundamental formulation of risk. Notes 1 through 4 provide the definitions used for the RHRA, which are consistent with Wong, et. al. (1998).

(1) Risk = Hazard Likelihood x Vulnerability x Consequence

Notes:

1. Hazard = Rockfall
2. Hazard Likelihood = Rockfall Frequency (RF)
3. Vulnerability = (Vspat * Vtemp * Vloss) = Derailment Hazard (DH) where:
    a. Vspat = probability of spatial impact (in our case, the likelihood of debris reaching the track);
    b. Vtemp = probability of temporal impact (in our case, the likelihood that a train strikes debris and expressed as Avoidance Factor (AF)); and,
    c. Vloss = probability of loss (in our case, derailment given impact with slide debris).
4. Consequence = Consequence Factor (CF) = severity of loss

The risk chain, with application of the RHRA terms, becomes Equation (2):

(2) Rockfall Derailment Risk (DRR) = Rockfall Frequency (RF) Score x Derailment Hazard (DH) Score x Consequence Factor (CF),

With expansion of the Derailment Hazard term and substitution of Avoidance Factor for Vtemp, equation 2 becomes Equation (3):

(3) DRR = RF x (Vspat * AF * Vloss) x CF

Most of the data collection and calculation effort in the rating system involves determining the Vspat and Vloss terms of Equation 3. Together, these terms are called Derailment Risk (DR), a measure of the probability of a derailment given the presence of a certain volume of rock on the track at a specific location. Substituting DR for Vspat and Vloss gives Equation (4).

(4) DRR = RF x (DR x AF) x CF

It is important to note that the analysis determines the risk to trains that encounter rockfall debris on the track. The analysis does not measure the risk of a train being hit by a rockfall.

DR is a function of the potential for rockfall release, the likelihood that a rockfall will reach the track, and the likelihood that the rockfall on the track will have a geometry that is hazardous to trains. Equation (6) provides the formulation of the DR term.

(6) $DR = \varphi\, [P_{Vn} * (P_T|Vn) * (P_F|Vn,Pn) * (P_D|Vn,Pn)]$ (3)

<u>Where:</u>

- P_{Vn} equals the relative probability of a given source volume of rock being present on the slope.

- $P_T|Vn$ equals the likelihood of source volume “n” detaching from the slope and reaching the track.

- $P_F|Vn,Pn$ equals the probability of a specific fragment size reaching the track. This is an estimate of the amount of debris fragmentation that will take place.

- $P_D|Vn,Pn$ equals the probability of derailment given a certain volume of rock of a certain particle size distribution reaches the track.

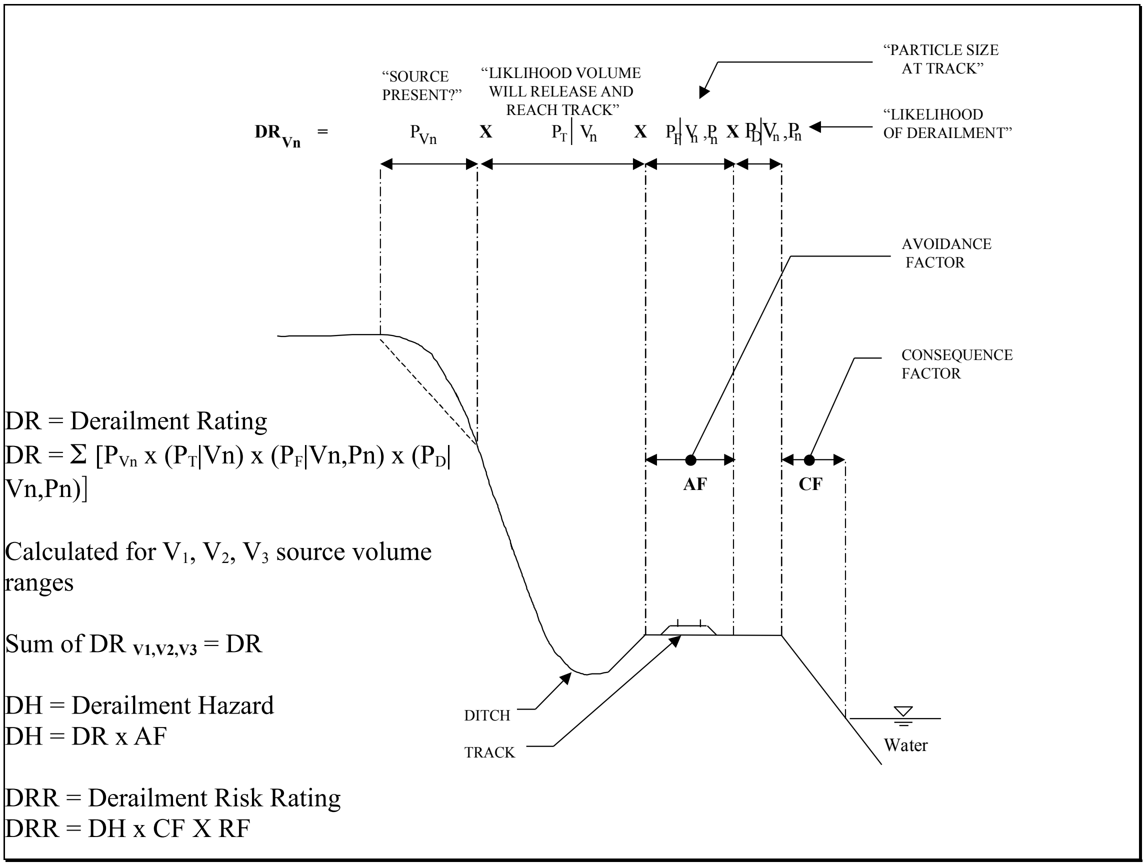
As the risk that a rockfall poses to trains varies with the volume of the rockfall, three different source volume sizes are considered and summed to obtain the DR value. The first term of Equation (6), P_{Vn}, represents the relative probability of a source volume of rock belonging to one of three categories: $V_1<1m^3$, $1m^3<V_2<3m^3$, and $V_3>3m^3$. A source volume, Vn, is defined as a volume of rock that is bounded by joints, bedding or other planes of weakness that could fail during any one event. As P_{Vn} is a relative measure, the summation of P_{V1} through P_{V3} will always be unity for a given slope segment.

Figure 2 provides a schematic illustration of the DR calculation in Equation (6). Table 1 provides general definitions of each term and a tabular illustration of the DRR calculation. Figure 3 is an example output of the DH rating showing the data entry fields that require completion during the rating process. For additional detail on the formulation of the DR and DH terms, the reader is referred to Abbott et. al. (1998a).

Table 1 – Structure of Derailment Risk Calculation with General Definition of Terms

DH	DR X	P_{Vn} X	Relative probability of a source volume of rock belonging to one of three categories: $V_1<1m^3$, $1m^3<V_2<3m^3$, and $V_3>3m^3$. The whole slope area in an interval is proportioned among the three volume ranges.
		$P_T \mid V_n$ X	For each source volume, the likelihood it will release and reach the track. A function of: Geology – favors stability or not; Mitigation (e.g. bolts) – effective or not; Barriers (e.g. ditch, bench) – effective or not.
		$P_F \mid V_n,P_n$ X	The relative probability of the largest particle dimension from the source volume falling into one of three categories: $P_1<0.3m$, $0.3m<P_2<1m$, and $P_3>1m$. Similar to P_{Vn}, it is a relative measure and the summation of $(P_F \mid Vn,P_1)$ through $(P_F \mid Vn,P_3)$ is always unity. This term recognizes that for similar source volumes, cobble size rock on the track from a fall of more closely jointed rock mass is less hazardous than large boulders from a fall of more widely jointed rock mass. Example: <0.3m = 0.15 is worse than <0.3m = 0.70m >0.3m, <1.0m = 0.70 >0.3m, <1.0m = 0.15 >1.0m = 0.15 >1.0m = 0.15
		$P_D \mid V_n,P_n$	Probability of a derailment given a certain volume of rock of a certain particle size distribution has reached the track. Primarily considers: a) lateral deflection space: is there room for the train to push the rock aside? b) concentration of debris: concentrated debris is worse than scattered; c) particle shape: slab shaped particles are more likely to wedge under a locomotive and derail it; d) high impact energy: assumed to break the rail and the central traffic control circuit (CTC), sending a warning through the signals system.
	AF	TSF X	Train Speed Factor: Function of train kinetic energy (i.e. proportional to the square of posted track speed). Trains are more likely to derail at higher impact speeds
		SDF	Slide Detector Fence factor. Presence of this rockfall warning device lowers the likelihood that a train will strike rockfall debris.
X CF			Consequence factor: function of proximity of site to water body and severity of slope to water. Four levels (A through D) each with numeric value between 0 and 1.0.
X RF			Rockfall Frequency: four ranges considered, each with a numeric scalar value between 0 and 1.0.
= DRR			

Figure 2 – Schematic Illustration of Derailment Rating (DR) Calculation



DR = Derailment Rating
DR = Σ [P_{Vn} x (P_T|Vn) x (P_F|Vn,Pn) x (P_D|Vn,Pn)]

Calculated for V_1, V_2, V_3 source volume ranges

Sum of DR $_{V1,V2,V3}$ = DR

DH = Derailment Hazard
DH = DR x AF

DRR = Derailment Risk Rating
DRR = DH x CF X RF

The strengths of the system are:

- It utilizes the fundamental formulation of risk in a "risk chain", so that ratings can be properly influenced by any one component of the chain. This is considered a fundamental requirement of risk analysis.
- It has proven repeatable by different, properly trained, personnel.
- It can be rapidly applied in the field.
- It is not a static system. It includes parameters that allow the rating to change if work is done to mitigate the hazard.
- It recognizes that different source volume sizes, and different particle sizes at track level, have different likelihoods of causing a derailment. This is an important distinction, as most slopes will have a higher likelihood of small rockfall than larger rockfall. By being able to distinguish the hazard from each particle size range in the ratings, it is possible to focus the risk rating on the most hazardous particle size.
- The protocol for annual inspection of rock slopes prioritizes slopes and assigns rating frequencies between annual and once every 10 years. This is important as it provides a defensible means of minimizing the number of rock slopes that require inspection in a given year.

1.0 RHRA Implementation and Use

Development and database programming of the RHRA occurred in 1995 and 1996, and the system was implemented in the field on CN mainline track in British Columbia in 1997. Site data was collected on paper forms, which were subsequently entered into a desktop database. At this stage of development, the consequence model was not defined numerically, but was rated on an alphabetic scale from "A" (least consequence) to "D" (worst consequence) according to the perceived severity of the potential derailment (a function of grade side slope, proximity to railway or public infrastructure, and potential for environmental damage). Also, rockfall frequency for each rated site was assigned during the rating based on assessment of the rock mass dilation and evidence of rockfall at the site.

The system provided DH values, and a graph of DH versus rockfall frequency for rated sites was used to assign inspection frequency. Threshold values of DH and rockfall frequency were used to assign sites to inspection frequencies of annual, less than 3 yearly, less than 5 yearly, or less than 10 yearly. Sites were prioritized for work based on qualitative consideration of the derailment hazard value, the inspector's observations of rockfall frequency, and the rated derailment consequence. Following each annual cycle of inspections, potential work sites were re-prioritized.

At the end of 1997, the rating system consisted of a desktop database with a few standardized database reports, and the graphing process that was used to prioritize inspection sites. In the spring of 1998, the database began to be used to direct rockfall hazard management work consisting of annual inspections, prioritization of work sites and work completion. With the implementation complete, work concentrated on enhancements to the system, and building the system into a fully integrated risk management program for rockfall hazard.

4.0 RHRA Effectiveness and Analysis Modifications

4.1 Effectiveness

CN now has eight years of experience using the RHRA Derailment Hazard value to help prioritize inspection frequency and work priorities. The system has been found to be consistent and repeatable, and facilitates objective comparison of the hazard between sites in different terrain.

4.2 DH Calculation Modifications

The few changes to the DH calculation that have been made include:

- Updating database train speed tables and slide detector fence locations as changes occur;
- Defining minimum slope geometry for ratings to avoid cluttering the system with small, very low rated slopes.
- Disabling the calculation for High Impact Energy as it was considered non-conservative in its current "on/off" formulation. In the original RHRA formulation, any rockfall from greater than 8 m height above the rail was assumed to be High Impact Energy, and considered to have a greater likelihood of completely breaking a rail. Where the track has Centralized Track Control (CTC), breaking a rail breaks an electrical current triggering a warning to the trains and the track controller of an unsafe track condition. This effectively provides a warning to approaching trains of an unsafe track condition. In the DH calculation, selecting High Impact Energy applied a reduction factor to the $P_D|V_N$,Pn term, and lowered the overall DH rating. This concept was based on the likelihood of a rockfall breaking a rail being a function of the energy of the rock. As it is an "on/off" factor, it did not account for situations where a rockfall could damage the grade sufficiently to make it impassable (e.g. by pushing the track out of alignment, or by knocking the head off a rail) without breaking the rail completely. It also did not consider the relative strength of the rail to the size of potential rockfall particles, or the particle strength (e.g. would the rockfall particles be large enough to have enough energy to break a rail, and would they be strong enough to break the rail, rather than be broken themselves). While a valid concept, High Impact Energy needs to be a function of these factors. Until this development has been advanced, the factor has been turned off in the calculation.

4.3 Derailment Risk Calculation

4.3.1 Background and Discussion

The RHRA database calculates a derailment hazard (DH) value. This is a measure of the likelihood of a certain volume of rockfall release with an anticipated particle size distribution at track level causing a derailment should a train encounter the debris. This alone is a very useful tool for allocating rockfall mitigation work. However, the numeric DH value does not consider how often such rockfall are possible, or consider the likely consequences to the train after derailment. Without these factors, the rating assesses the potential for train derailment should a rockfall occur, but is not a rating of rockfall risk to trains. The rockfall rating database does include information on rockfall frequency (both estimates during ratings, and accumulating factual data collected by track maintenance personnel), and consequence (rated with four levels of severity) but inclusion of these parameters in a risk calculation was not done during the initial implementation of the system. As discussed in Abbott et. al. (1998a), these parameters were not included as the rockfall frequencies in the initial ratings were estimates whose accuracy was uncertain. The intent was to collect rockfall incident data, which could be used in a Bayesian analysis to improve confidence in the rockfall frequency estimates. With this greater confidence, rockfall frequency and consequence would then be used to complete a risk rating.

While this approach to refining rockfall frequency estimates is valid in theory, in practice it is difficult. Potential inconsistencies can introduce bias to the data analysis.

Other difficulties with the use of actual rockfall data to calibrate rockfall frequency estimates are the potential low frequency of rockfall at many sites, and the episodic nature of rockfall. For the relatively small site length of a rated rock slope, a very long period of rockfall incident records is required to capture long-term rockfall trends. For example, on a long-term average, if a slope experiences one rockfall every 10 years, a period of record spanning decades would be required to develop confidence in this frequency. At the same time, a 20 year return period frequency rain on snow event at the site might trigger several simultaneous rockfalls. Again, a long-term period of record is required to determine the actual average rockfall frequency.

While the limitations of the rockfall frequency estimates were recognized, CN and BGC staff believed there was merit in examining whether a risk calculation was reasonable with the available data. It was also recognized that during the eight years of systematic inspections of the rock slopes, inspection staff have made repeated observations of rockfall frequency, refining the original estimates.

4.3.2 Risk Rating Calculation

While the continued long-term objective is to use actual rockfall incident data to calibrate the rockfall frequency estimates, for the past two years, a simplified system of risk calculation has been used to aid in prioritizing high risk sites. The analysis uses scalar equivalents (values between 0 an 1) for each of the rockfall frequency estimates and consequence estimates, and multiplies the DH rating by these scalars to determine a derailment risk rating (DRR). Table 2 summarizes the scalars selected. These scalars were selected after a trial period, and are still under review. Trials were made by comparing a list of rated sites sorted by descending DRR value against a list of priority work sites selected by a combination of DH value, inspector recommendations, and qualitative assessment of consequence. The sorted DRR ratings using the scalars selected provided a good correlation with priority work sites selected by the more manual method.

Table 2 - Summary of Consequence and Frequency Scalars for Derailment Risk Rating

Rockfall Frequency		**Consequence**	
Rating Categories	**Risk Calculation Scalar**	**Rated Value**	**Risk Calculation Scalar**
<Monthly (More than 11 per year)	1.0	D	1.0
<Yearly (1 to 11 per year)	0.8	C	0.7
<10 Yearly (1 per year to 1 per 10 years)	0.6	B	0.4
>10 Yearly (<1 per 10 years)	0.6	A	0.2

Actual rockfall frequency estimates are not used as the scalar values in the DRR calculation. Not using the actual estimated rockfall frequency (e.g. <Monthly = More than 11 rockfall per year) is a reflection of the lower confidence in the rockfall frequency estimates, given the relatively short period of record. It was felt that rockfall frequency estimates should have some weight in a risk rating, but not the weight available from the potential approximately hundred-fold range of actual estimates of rockfall frequency (>11 rockfall per year to <0.1 rockfall per year). Also, the factors selected recognize the lower confidence in rockfall frequency estimates for the lowest frequency (e.g. >10 yearly) by not lowering the factor for this frequency less than the factor for the next higher frequency category (<10 yearly).

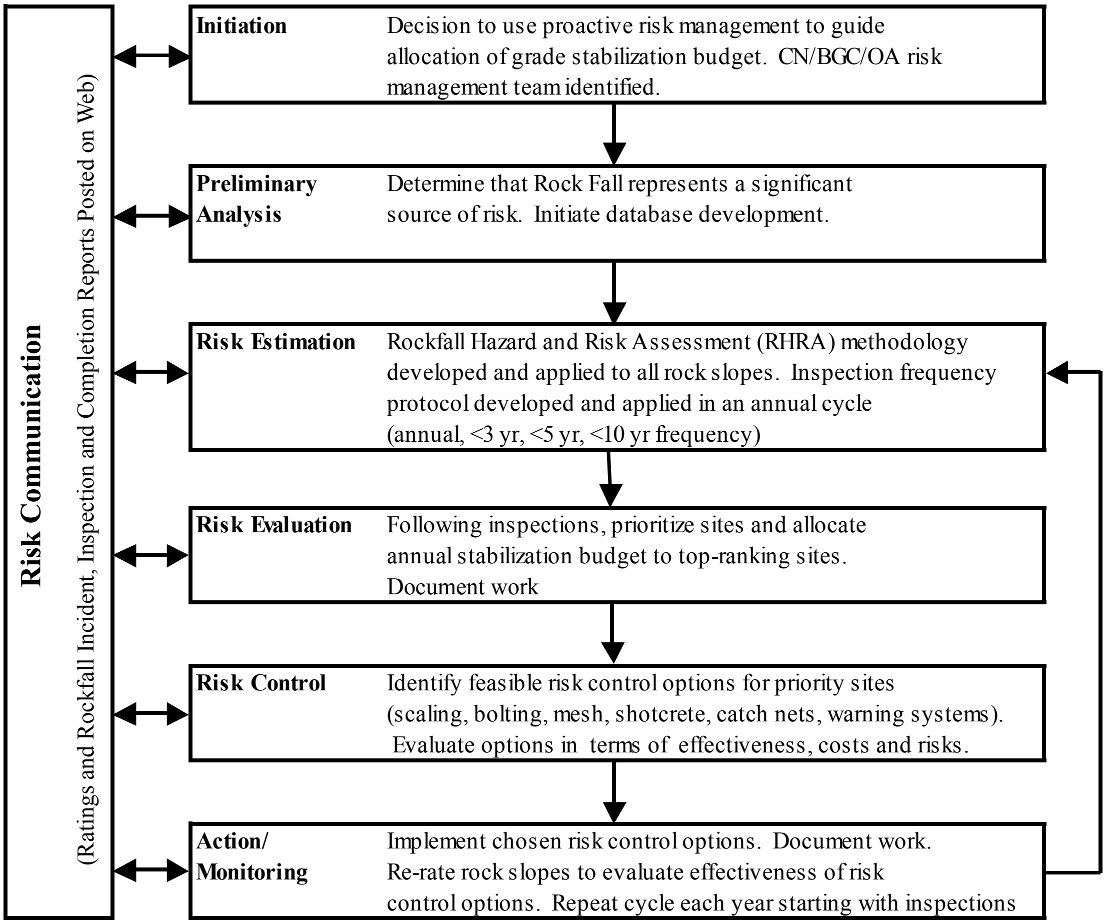
The scalar factors for the derailment consequence were given a greater total range than those for rockfall as consequence parameters such as shoulder width, side slope, and proximity to water and structures can be quantified.

As prioritization of mitigation has always qualitatively considered the rockfall frequency and derailment consequence, use of the DRR values has not lead to a re-prioritization of mitigation efforts. Use of the DRR values has helped to quantify the risk, which provides a more transparent assessment of priorities.

5.0 Rockfall Risk Management Program and Tools

Implementing a risk analysis system is only one part of a risk management program. Figure 3 illustrates the full cycle of risk management that includes: risk estimation (analysis: inspections and ratings), risk evaluation and risk control (prioritization and planning), and action (work completion and documentation). The process is an annual cycle, and returns to re-estimation and inspection following work completion. For CN's rockfall risk management program, procedures, documentation, and tools for completion of each task have been standardized. As part of the professional requirement for quality management, the program includes review and sign-off procedures for documentation, and database security features that document the origin of changes to data. These processes, and the tools that have been developed to facilitate ease of use of the system, are described below.

Figure 3 – RHRA Risk Management Cycle (after CAN/CSA-Q850-97)



Risk Communication

(Ratings and Rockfall Incident, Inspection and Completion Reports Posted on Web)

Initiation	Decision to use proactive risk management to guide allocation of grade stabilization budget. CN/BGC/OA risk management team identified.
Preliminary Analysis	Determine that Rock Fall represents a significant source of risk. Initiate database development.
Risk Estimation	Rockfall Hazard and Risk Assessment (RHRA) methodology developed and applied to all rock slopes. Inspection frequency protocol developed and applied in an annual cycle (annual, <3 yr, <5 yr, <10 yr frequency)
Risk Evaluation	Following inspections, prioritize sites and allocate annual stabilization budget to top-ranking sites. Document work
Risk Control	Identify feasible risk control options for priority sites (scaling, bolting, mesh, shotcrete, catch nets, warning systems). Evaluate options in terms of effectiveness, costs and risks.
Action/ Monitoring	Implement chosen risk control options. Document work. Re-rate rock slopes to evaluate effectiveness of risk control options. Repeat cycle each year starting with inspections

5.1 Data Management

When the rockfall management system was first implemented, it consisted of:

- a desktop database that contained the rating parameters for each rated interval, and calculated the DH ratings, and a separate database for rockfall incident records. A few standard reports were available from the DH database;
- a procedure for graphing DH versus rockfall frequency to determine the frequency of inspection for sites; and
- an inspection report and work completion report format, with reports prepared in a word processor.

Since 1997 we have:

- Automated the generation of inspection lists based on DH, rockfall frequency, last inspected date, and whether a site had work activity since the last inspection.
- Developed database resident inspection and work completion reports that include digital photographs and can be printed as required.

- Developed an Internet site (web site) for viewing and printing rock slope management information (ratings, inspection reports, work completion reports, and rockfall records). This web site makes the rockfall management data accessible from any computer with Internet access. The data is searchable by subdivision and mileage range, and can be sorted by DH and DRR value. Initiating a search causes a table of site mileages to be compiled according to the sorting parameters that contains hyperlink connections to each of the available report types for the rated sites within the search interval.
- Assigned each rated rock slope a unique filing number. All work on an interval is linked to this number, and paper and digital files for an interval use the same number.
- Developed a web based natural hazard incident reporting form. This includes a rockfall report form that is completed on-line, and a graphing module for users to study rockfall incident records by subdivision, mileage range, or time of year using a specified date range. The reporting procedure includes protocols for email notification of event submission to the CN senior geotechnical engineer, and on-line review, editing, and acceptance of records by the CN senior geotechnical engineer. Review, with the reviewer's identification, is required before the incident is included in the database. Qualified reviewers are restricted to senior CN and BGC geotechnical staff.

5.2 Implementation – New Ratings and Revised Ratings

The original rating database did not include photographs or GPS locations for sites. The database has since been modified to accept both, and general arrangement photographs and GPS locations are now required parts of new ratings. Both these measures make it easier to locate the cut slope during inspections.

The original database could not accept overlapping mileage intervals. This meant that for locations of through-cuts, the person completing the rating would have to choose the worst cut side to rate. This limitation has been remedied by adding a rating field for the side of the track.

A handheld computer application was developed for field entry of rating data and field editing of rating data. This system eliminates paper completion of rating forms, or paper based mark-up of existing ratings in the field, and the potential data entry errors transferring rating information from field forms to the database. Current rating information for the subdivision of interest is loaded into the handheld computer for field use, and on return to the office, the handheld computer database synchronizes with the main database to update records that have been changed or added. The system comprises:

- HP IPac handheld computers;
- A handheld computer version of the Microsoft Access database;
- Rating forms (screens) and fields with a similar layout to the paper form;
- Incorporation of GPS locations into the record if desired. GPS locations are collected directly into the rating form using a Bluetooth wireless connection to a GPS unit;
- The ability to enter photograph numbers and captions into a rating record. This facilitates synchronization of digital photos with rating records;
- A digital log of who is entering or adjusting the rating, of changes to existing ratings and the reason for the change;

- Error checking algorithms that confirm all required fields are properly completed, and especially that new or edited ratings (for the same track side) do not overlap on other rated intervals; and
- As the system is a fully functional database, it also provides rating calculations for review as soon as a rating is completed or altered.

5.3 Inspection

The procedure followed to determine which sites require inspection each year has not changed (Abbott et. al., 1998a). However, all inspection photographs are now collected as digital images, facilitating entry into the database, and any re-rating of slopes is completed using the handheld system described above.

5.4 Work Prioritization

Prioritization of work was initially based on the DH values, with judgemental consideration of the rockfall frequency and consequence class. In the last two years, reliance has been growing in the use of the derailment risk (DRR) calculation values discussed previously.

5.5 Work Completion Reporting

Since 2000, work completion reports have been entered into the database, rather than prepared using a word processor. These consist of several database fields that form a one-page summary of the site conditions, access considerations, work completed, special considerations, and any further recommendations. Photographs with captions are included. Preparation of these reports follows a checklist that includes senior review before the reports become viewable and printable from the web site.

6.0 Future Development

Future revisions to the Rockfall Risk Management program are expected to focus on refinement to the algorithms, changes to data management procedures that make the data easier to view through the Internet, and changes that expand the ability of the system to accept data entry through an Internet portal. Specific areas of possible development follow.

<u>Rating Algorithm and Risk Management Methodology Changes</u>
Potential areas of future development include:

- Revisions to the High Impact Energy factor in the ratings to determine if it can be modified to improve its sensitivity to potential rockfall block size, and intact rock strength;

- Use of the derailment risk rating (DRR) values to govern rock slope inspection frequency. This would replace the process of graphing rockfall frequency versus derailment hazard (DH) value to determine inspection frequency.

- Increased reliance on the use of the derailment risk rating (DRR) values, combined with observations from inspections, as the principal method for prioritizing work sites.

- Continuing collection of rockfall incident data for use in future Bayesian updating of rockfall frequency in the ratings, and to target areas for review during annual inspections.. It is anticipated that, with a few more years of data collection, use of actual rockfall data to determine the rated rockfall frequency will be practical for at least the higher rockfall frequency sites.

- Work to refine the consequence model.

Expansion of Rated Slope Types

The RHRA is designed to rate derailment risk from railway cut slopes, and natural rock slopes, that can be seen from the track. There are many areas where the track is exposed to rockfall hazard from tree covered bluffs, or cliffs that are not visible from the track. CN and BGC have developed preliminary rating procedures to rate rockfall hazard from natural slopes using the RHRA algorithm. Development of this sub-system is ongoing.

There are also many potential rockfall source areas along CN track that are not rock slopes, such as erosional terraces in alluvial or pro-glacial deposits. As long as the source areas can be viewed from the track, these areas can be rated using the RHRA system. These sites were not rated during the initial implementation of the system, but will be included over the next few years.

Functionality and Data Storage

In general, we expect to continue to move towards a paperless system that fully functions over a web portal. We plan to:

- Revise the format of the inspection reports to make them more compact, and establish a web based portal for inspection report entry, with review and sign-off by the engineer of record; and
- Create a web based portal for entry of work completion reports, with protocols for review and sign-off by the engineer of record.

With the hand held computer system, we expect to include the ability to collect digital photographs directly into the database as they are taken. This will occur as the technology becomes more practical. We are also developing a program to help determine precise track locations by railway curve list mileage. This is a handheld computer application that uses the GPS to track location relative to a list of track mileage GPS locations. This tool is being developed as the track is a linear facility, making it possible to simplify two dimensional GPS coordinates into a one dimensional measurement system (track mileage) for ease of locating oneself or rating sites.

7.0 Conclusions

CN, in conjunction with BGC Engineering Inc. and Oboni Associates Inc. developed and implemented the rockfall hazard risk assessment program on CN mainline track in 1997. In the eight years since, CN has confirmed the utility and practicality of the rating calculations system, and expanded its use across North America. CN and BGC have also developed additional procedures around the initial rating process to include the full cycle of risk management activities (ratings, prioritization, work, documentation of work, and inspection/re-rating). Taken together with their integral quality management processes, the risk ratings and related management tools form a risk management procedure that meets the requirements of CAN/CSA-Q850-97. Enhancement of the management system is ongoing, and it is expected that other risk management rating systems (Porter et. al., 2005) will utilize the data management framework developed for rockfall risk management.

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