U.S. Department
of Transportation

Federal Railroad Administration

Human Factors Root Cause Analysis of Accidents/Incidents Involving Remote Control Locomotive Operations

Office of Research
and Development
Washington, DC 20590

DOT/FRA/ORD-06/05

Final Report
May 2006

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 2006	Final Report October 2002–December 2004

4. TITLE AND SUBTITLE Human Factors Root Cause Analysis of Accidents/Incidents Involving Remote Control Locomotive Operations	5. FUNDING NUMBERS
6. AUTHOR(S) Stephen Reinach and Alex Viale	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Foster-Miller, Inc. 350 Second Avenue Waltham, MA 02451-1196	8. PERFORMING ORGANIZATION REPORT NUMBER DFRA.020175 TO 7
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Railroad Administration Office of Research and Development 1120 Vermont Ave. NW MS-20 Washington, DC 20590	10. SPONSORING/MONITORING AGENCY REPORT NUMBER DOT/FRA/ORD-06/05
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION/AVAILABILITY STATEMENT This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.	12b. DISTRIBUTION CODE

13. ABSTRACT

This report presents findings from a human factors root cause analysis (RCA) of six train accidents/incidents—collisions, derailments, and employee injuries—that involved remote control locomotive (RCL) operations in U.S. railroad switching yards. Descriptive data from participating railroads were collected on all Federal Railroad Administration reportable RCL accidents/incidents from May 1 to October 31, 2004. RCA were performed on six RCL accidents/incidents (case studies) to examine some of the factors that contributed to the events in further detail. RCA data collection and analysis tools were developed based on a modified version of the Human Factors Analysis and Classification System (HFACS-RR) to provide a theoretical foundation to the RCA. HFACS-RR identifies 23 unique categories of accident/incident contributing factors among five different levels of a system. Participating railroads reported a total of 67 RCL accidents/incidents: 29 collisions, 25 derailments, and 13 employee injuries. RCA were conducted on three collisions, two derailments, and one employee injury. A total of 36 probable contributing factors were identified among the 6 RCA, and 33 of these were concentrated among 6 HFACS-RR categories: technological environment (8), skill-based errors (7), the organizational process (6), inadequate supervision (5), decision errors (4), and resource management (3). Loss of remote control operator (RCO) situation awareness was a significant factor in five of the six accidents/incidents. Based on an analysis of all of the contributing factors, several key safety issues emerged: loss of RCO situation awareness, insufficient training, inadequate staffing and pairing of inexperienced crewmembers, and inadequate practices and procedures governing RCL operations and the use of RCL technology, including pullback protection. This report suggests recommendations for future research to enhance RCL operations safety.

14. SUBJECT TERMS Remote control locomotive operations, portable locomotive control, railroad safety, remote control device, root cause analysis, accident/incident investigation	15. NUMBER OF PAGES 184
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

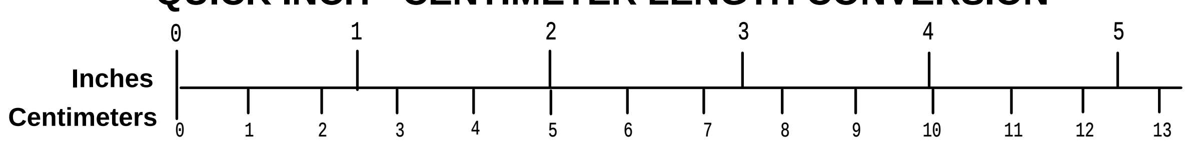
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

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Preface

U.S. Class I railroads began implementing remote control locomotive (RCL) operations starting in January 2002. Operating environments include yards, industrial spurs and sidings, and some main tracks and sidings/spurs. Remote control operators (RCOs) must adhere to all relevant operating rules in effect during their RCL operations and may have additional responsibilities depending on the operating environment. Some of these responsibilities may include communication with a yardmaster or dispatcher, minor train handling on ascending and descending grades, car handling, and communication with other crews operating in the vicinity of the RCL. RCOs on Class I railroads are generally switchmen who receive special training to become RCOs, although a small minority of RCOs are also qualified locomotive engineers who have experience operating a locomotive. Traditionally, switchmen were never trained to operate a locomotive.

The Federal Railroad Administration (FRA) Office of Research and Development Human Factors Program and FRA Office of Safety initiated a program of research into RCL operations to ensure that RCL operations are as safe as possible. FRA sponsored three separate studies: a comparative risk assessment of RCL and conventional yard switching operations; focus groups with RCOs; and a root cause analysis (RCA) of RCL-involved train accidents and incidents (hereto simply referred to as accidents/incidents). Accidents/incidents are collisions, derailments, and employee injuries that involve the operation or movement of on-track equipment and that meet certain reporting criteria or thresholds. This report describes the results of the RCA of RCL-involved accidents/incidents. This research was aimed at shedding light on some of the safety issues involved in RCL operations in railroad yards by analyzing a handful of accidents/incidents in depth.

Given the expansive nature of railroad yard switching operations, the recency of RCL operations, and the limited number of accidents/incidents that were analyzed, however, this study was not able to address all safety issues that exist for RCL operations. For example, one shortcoming is that the timeframe in which data were collected (May 1–October 31, 2004) may have precluded study of certain aspects of RCL operations, such as the impact of severe inclement weather (e.g., snowy, slippery, very cold weather and attendant need for additional clothing, and thick gloves) and long hours of darkness.

Furthermore, given the rapid changes that are occurring in RCL operations around the United States, care must be taken in interpreting the results. An operating practice or rule in effect in 2004 may be eliminated the following year. It is important to keep in mind that information on railroad operating procedures, rules, instructions, and other practices that provided source data for the RCA was based on what was in effect at the time of the accident/incident. It is possible that the railroad subsequently changed a rule or instruction that was discussed in the analysis.

Although some regional and shortline railroads participated in the study by providing RCL accident/incident data, they represent only a small segment of all U.S. RCL operations. Consequently, the study's focus was on U.S. Class I railroads, where a majority of U.S. RCL operations exist. As a result, this study does not address aspects of RCL operations that are unique to shortline and regional railroads. Furthermore, because the study was limited to yard operations, this study does not address RCL operations outside of yards.

The study was designed to shed light on RCL operations in yards, and in particular, to enable an examination of those factors that contributed to known RCL accidents/incidents, at all levels of the system, from the operating crewmember through organizational decisions. The study, however, does not assess the relative importance or influence of any of the contributing factors that were identified in the six accidents/incidents. Rather, all were considered equally important and valid. The only differentiating factor that was used was to provide an indication of the researchers' confidence in the finding, based on the data that were available at the time of the data collection. To aid the analysis, a number of heuristics were developed to aid the prioritization of different data sources when information was conflicting or unclear.

Lastly, it is important to understand that RCA, and accident/incident investigation more generally, is part science and part art. The researchers tried to apply scientific rigor wherever possible, including use of a formal human error taxonomy and a structured RCA process to guide data collection and analysis. As is the case with all accident/incident investigations, however, analysis is somewhat subjective in the end and based on the investigators' knowledge of the subject matter. An example is deciding when to stop analyzing a particular accident/incident. It was not possible to be exhaustive in the identification of accident/incident contributing factors. Accident/incident investigation and analysis lies on a continuum. The intention with this study was to dig a bit deeper, and with a different (systems) perspective, than perhaps past investigations conducted by the railroads or FRA. Had another perspective been used, no doubt a different set of conclusions may have been drawn.

Acknowledgments

This report presents the results of a first-of-its kind RCA of accidents/incidents involving RCL operations in U.S. railroad yards. FRA Office of Research and Development Human Factors Program and FRA Office of Safety sponsored this research under Contract DTFR53-01-D-00029.

The contents of this technical report reflect the authors' understanding of the facts and circumstances that contributed to the RCL accidents/incidents under study. Neither FRA nor stakeholder representatives who assisted or participated in the research are responsible for any of the report's content or findings.

The authors would like to express thanks in particular to Dr. Thomas Raslear, FRA Office of Research and Development, for supporting this work, and Mr. John Conklin, FRA Office of Safety, for providing subject matter expertise and answering a myriad of technical questions throughout the project.

A special thanks are also owed to the following FRA Office of Safety staff for their assistance and counsel in various stages of this project to ensure that it was successful: Mr. Alan Nagler, Office of Chief Counsel; Ms. Cynthia Gross, Office of Safety; and Mr. George Gavalla, former Associate Administrator for Safety.

The authors would also like to thank Dr. Frederick Gamst, who provided invaluable technical and logistical insight throughout the research project as subject matter expert. Dr. Gamst provided factual and timely answers to numerous railroad and RCL operation technical questions, and he always made time to discuss any and all facets of the project.

Special thanks to Dr. Steven Hursh, who conducted the operator alertness analysis for each of the six RCL accident/incident case studies, and provided the write-ups describing the results of each analysis.

We would like to give a special thanks to the representatives from the railroad carriers and railroad labor unions who participated in this study by attending the stakeholder meeting, providing data on RCL accidents/incidents that occurred on their properties from May 1 to October 31, 2004, and for facilitating the RCA process by providing access to their employees, facilities, and members during the 6-month study period. The authors thank the following individuals for their participation:

- Mr. Larry Breeden–Union Pacific Railroad
- Mr. Ray Cobb–International Brotherhood of Electrical Workers
- Mr. Tim DePaepe–Brotherhood of Railway Signalmen
- Mr. John Drake–CSX Transportation
- Mr. Robert Harvey–Brotherhood of Locomotive Engineers and Trainmen
- Mr. Ted Hegemo–Montana Rail Link
- Mr. John Irwin–Norfolk Southern Railroad
- Mr. Robert Keane–Canadian National Railroad

- Mr. Charles Lynch–Florida East Coast Railroad
- Mr. John Quilty–BNSF Railway
- Mr. Richard Marceau–United Transportation Union
- Mr. Dennis Marzec–Kansas City Southern Railroad
- Mr. Rod McCorkle–Canadian Pacific Railway

In addition, thanks to the following instrumental individuals for their assistance in ensuring the study was successful:

- Mr. Jeffrey Moller–Association of American Railroads
- Mr. Matthew Reilly–American Short Line and Regional Railroad Association

The authors would also like to thank Dr. Gerald Weeks, National Transportation Safety Board, for his technical support and guidance during the conduct of the research. Dr. Weeks provided valuable advice regarding accident/incident investigation data collection methods and analysis.

The authors would like to thank several individuals from Foster-Miller, Inc. for their assistance. First, thanks to Ms. Judith Gertler for acting as an occasional sounding board for ideas and for reviewing a draft manuscript. And thanks to Ms. Susan McDonough for providing program administration and editing support.

Thanks to each of the RCOs, yardmasters, other yard crewmembers, and local carrier officers with whom we spoke during the course of each RCA. Their expertise, professionalism, and willingness to share information with us were critical to the success of the study and are a testament to their genuine interest and concern for railroad safety.

Finally, thanks to all of the participating railroads and unions for giving the authors an opportunity to explore and study a world with which few are familiar, yet by which everyone is affected.

Executive Summary

In an effort to reduce operating costs and increase safety and efficiency, U.S. Class I freight railroads have begun to implement remote control locomotive (RCL) operations in and around railroad switching yards. U.S. railroads are permitted to use RCL operations as long as they follow all relevant Federal Railroad Administration (FRA) safety regulations. RCL operations consist of three components: (1) the locomotive (the RCL), (2) an onboard control computer (OCC) that interfaces with the locomotive's controls (and usually mounted somewhere inside or on the RCL), and (3) a portable remote control device (RCD; also frequently referred to as a belt pack, operator control unit, or simply box). A remote control operator (RCO) wears the RCD, usually by means of a vest.

Although the technology has been around for decades, the safety implications of using these devices in the U.S. railroad industry and of reducing crew size in switching operations remain unknown. FRA has begun to collect RCL operation-related train accident/incident data, including information on collisions, derailments, and employee injuries. Due to the recent implementation of RCL operations on a large scale in the United States (beginning in early 2002) and the more recent FRA requirement to report the involvement of RCLs and RCOs in train accidents/incidents (effective May 1, 2003), however, this data collection process will require several years before adequate data are available to analyze.

To better understand the safety implications of RCL operations, FRA Office of Research and Development Human Factors Program and FRA Office of Safety initiated a multi-study program of research into RCL operations in early 2002, just as RCL operations began on a large scale in the United States. FRA sponsored three separate studies: a comparative risk assessment of RCL and conventional yard switching operations; focus groups with RCOs to identify safety issues and best practices; and a root cause analysis (RCA) of RCL-involved train accidents/incidents (hereto referred to as accidents/incidents)—collisions, derailments, and employee injuries involving the operation or movement of on-track equipment and that meet certain reporting criteria or thresholds, during RCL operations. This report describes the results of the RCA of six RCL-involved accidents/incidents that occurred between May 1 and October 31, 2004.

The specific objectives of this research project included the following:

- Understand the circumstances that contribute to RCL-involved accidents/incidents—collisions, derailments, and employee injuries—in railroad yards.
- Identify individual, organizational, technological, and situational factors that contribute to RCL operations safety.
- Determine the applicability and validity of a selected human error taxonomy to railroad operations.

This research was supported by all of the stakeholders: FRA, railroad management, and labor unions. To obtain stakeholder buy-in, a meeting was conducted at FRA

Headquarters in December 2003. Representatives from the railroad industry, labor unions, FRA, and National Transportation Safety Board (NTSB) were invited to participate in the meeting. During the meeting, the research objectives, study design, and data collection methods were laid out and discussed, and stakeholder issues were addressed. All seven U.S. Class I freight railroads—Union Pacific Railroad (UPRR), BNSF Railway (BNSF), CSX Transportation (CSX), Norfolk Southern Railroad (NS), Kansas City Southern Railway (KCS), Canadian National Railroad (CN), and Canadian Pacific Railway (CPR)—and two regional railroads, Montana Rail Link (MRL) and Florida East Coast Railroad (FECR), subsequently agreed to participate (CN's and CPR's participation was limited to their U.S. operations). Several labor unions, including the United Transportation Union (UTU) and Brotherhood of Locomotive Engineers and Trainmen (BLET), also agreed to participate.

After conducting the stakeholder meeting, RCA data collection methods and materials were developed, and a process for the RCA was formalized. RCA is a method of accident/incident investigation (i.e., data collection) and analysis that enables investigators or researchers to identify individual, organizational, technological, and situational factors that contribute to an accident/incident. A guiding principle behind RCA is that accidents/incidents are not solely caused by *one* event; rather, *multiple* factors play a role in every accident/incident. RCA is a process used to methodically and objectively shed light on these contributing factors, many of which are otherwise difficult to find.

The Human Factors Analysis and Classification System (HFACS) was selected to provide the theoretical backbone to the RCA, given its logical structure and scientifically valid approach to human error within systems. Historically, HFACS has been used mostly to analyze data available from existing accident/incident investigations. However, HFACS was designed to also guide accident/incident investigations to support collection of human factors-related information in the first place. Some Federal agencies, such as the U.S. Coast Guard and the U.S. Department of Defense, have begun to experiment using HFACS to support accident/incident investigations as well as analysis (Wiegmann and Shappell, 2003; A. Carvalhais, personal communication, October 11, 2005).

HFACS, based on a well-known and accepted model of human error, depicts errors at four different levels, beginning with the operator and moving upward in the organization. For each level, HFACS identifies a number of second-level categories. Some second-level categories are further divided into third-level categories. HFACS contains a total of 19 unique categories of contributing factors. HFACS was initially developed and used as a classification system for organizing aviation accident investigation findings. Since HFACS was initially developed for the aviation domain, some minor changes were made to HFACS to optimize its relevancy to the railroad industry. Among these were changes to the terminology and the addition of a fifth level. The new HFACS-RR (Railroad) levels were operator acts, preconditions for operator acts, supervisory factors, organizational factors, and outside factors. The new HFACS-RR taxonomy contains a total of 23 unique categories of accident/incident contributing factors.

The use of a theoretically-driven RCA approach, based on a modified version of HFACS, ensures that the contributing factors identified during an investigation go beyond what happened to why an error occurred. Researchers used the RCA philosophy combined with the HFACS-RR structure to guide data collection and analysis for the six RCL accidents/incidents. A number of data collection tools were developed, including interview questionnaires, a checklist of items to request from the railroad, and a series of decision trees designed around the HFACS-RR taxonomy.

Between May 1 and October 31, 2004, participating railroads were asked to notify the researchers within 24 hours (h), or the next business day, of the occurrence of all FRA-reportable collisions, derailments and employee injuries that involved the movement of on-track equipment and that involved RCL yard operations. Collisions and derailments that involve the operation of on-track equipment and that meet certain reporting threshold are types of train accidents, while employee injuries that involve the movement of on-track equipment that meet certain reporting thresholds are a type of train incident, per FRA reporting definitions. During this 6-month data collection period, six of these accidents/incidents were examined in greater detail using the RCA methods and paper-based tools developed for this study. Selection criteria and guidelines were established to aid in identifying six accidents/incidents to examine in greater detail.

When an accident/incident was selected for RCA, the researchers worked with the participating railroad point-of-contact to arrange to travel to the accident/incident site as soon as possible, generally within 1-2 days (d) of notification. Separately, researchers contacted the point-of-contact from the union that represented the crewmembers involved in the accident/incident to help begin to arrange interviews with the crewmembers. Interviews were conducted privately with crewmembers; railroad officers were not present.

Researchers spent 2-3 d onsite collecting interview data and railroad-provided records, logs, and reports for each RCL accident/incident. Due to privacy concerns, medical-related data were not collected. Usually at least one followup telephone conversation was required to collect additional data or clarify an issue. Accident/incident data were de-identified to protect the identities of the individuals and railroads that participated since the focus of the study was on the entire railroad industry and overall RCL operations, not a particular practice at one railroad or by one individual.

Analysis of each RCA accident/incident case study was structured in a hierarchical fashion, whereby first, the top-level contributing factors were identified. Then, for each top-level contributing factor, a number of more specific contributing factors were identified. In addition to including a brief explanation for why the contributing factor was considered important and relevant, each lower-level contributing factor was mapped to an unique HFACS-RR category. An assessment was made in terms of the researchers' confidence in each contributing factor based on the data that supported each finding. No effort was made, however, to assess the relative importance of one contributing factor over another. Thus, all factors were considered equal with regard to their contribution to the accident/incident.

Participating railroads and unions were given an opportunity to review each accident/incident case study in which they were involved. Comments were either incorporated into the report, or if disagreement still existed between the researchers' findings and those of the reviewer, the alternative viewpoint is included in the case study beneath the original finding. For alternative viewpoints, authors' responses to the railroad or union comments are also provided.

Participating railroads reported a total of 67 RCL accidents/incidents from May 1 to October 31, 2004. Of the 67 accidents/incidents, 54 were collisions or derailments (train accidents), and 13 were employee injuries not associated with a reportable collision or derailment (i.e., train incident). Train accident cause code data for collisions and derailments were available for 44 of the accidents; 64 percent of these were associated with human factors cause codes. Analysis of all 67 accidents/incidents by time-of-day reveals that almost half of the 67 accidents/incidents—30—occurred between midnight and 8 a.m., roughly corresponding to third shift work. The greatest number of accidents/incidents in any one month occurred in August, when 16 accidents/incidents were reported (24 percent of the total number of accidents/incidents). These data should be interpreted with caution, however, since exposure data were not collected.

There were three collisions, two derailments, and one employee on-the-job injury among the six accidents/incidents that were further examined. Forty-six contributing factors were identified for the six case studies; of these, 36 were probable contributing factors and 10 were possible contributing factors. Two to thirteen contributing factors were identified for each accident/incident.

Analysis of the 36 probable contributing factors revealed the following key themes:

- Loss of situation awareness was a major factor in five of the six accidents/incidents. Further analysis suggests that RCL technology facilitated this loss of situation awareness in four of these five accidents/incidents by enabling RCOs to control their cuts of cars away (i.e., remotely) from the point of movement.

- Six HFACS-RR categories (26 percent) were associated with 92 percent of the 36 probable contributing factors. The HFACS-RR categories were the technological environment, skill-based errors, organizational process, inadequate supervision, decision errors, and resource management.

- Eight probable contributing factors were associated with the technological environment. Four of the eight contributing factors were related to an RCO's control of a movement from a physical location away from the RCL and/or cut of cars. Three contributing factors (all were associated with one accident/incident) focused on the failure of the pullback protection system technology as part of the overall RCL system. In addition, one contributing factor was associated with the physical characteristics of the RCD itself.

- Seven skill-based errors were identified among the 36 probable contributing factors, and included failures of attention or memory.

- Organizational process was identified 6 times among the 36 probable contributing factors, and all 6 were related to inadequate practices and procedures governing RCL operations and the use of the RCL technology, including the pullback protection system.

- Inadequate supervision was identified 5 times among the 36 probable contributing factors; 4 of the 5 were related to some aspect of RCO training.

- Four decision errors were identified among the 36 probable contributing factors; half related to decisions made with regard to controlling a cut of cars.
- Three probable contributing factors were associated with resource management issues. One was related to staffing while the other two were equipment-related.
- Two specific factors that were identified—inadequate staffing and pairing inexperienced crewmembers—may be significant RCL safety issues in the future given the increase in railroad traffic, an aging workforce, and the influx of newly hired railroad employees.

Separately, analysis of operator work schedule history and sleep habits information suggests that two RCOs may have been operating with compromised alertness; however, these were possible contributing factors rather than probable contributing factors.

Based on analysis of the 36 probable contributing factors for the 6 RCL accidents/incidents, the following 4 critical safety issues were identified:

- *Loss of RCO situation awareness*. Loss of RCO situation awareness was identified as a factor in five of the six RCL accidents/incidents analyzed.
- *Insufficient RCO training*. Insufficient training was identified as a contributing factor among the RCL accidents/incidents. Improved training may be able to mitigate some of the skill-based and decision errors that were identified.
- *Inadequate staffing and pairing of inexperienced crewmembers*. Though these factors were identified as contributing to only one of the six RCL accidents/incidents analyzed in the study, given the current industry shortage of switchmen and engineers, these may be significant safety issues in the future, especially when combined with insufficient training.
- *Inadequate practices and procedures governing RCL operations and the use of the RCL technology, including the pullback protection system*. Inadequate practices and procedures were identified as contributing factors in several RCL accidents/incidents. Given that operating rules and practices govern most of railroading, inadequate practices and procedures can have significant consequences.

Lastly, several future research and development studies are recommended to address these safety issues, including the following:

- Analyze FRA RCL accident and incident data.
- Develop RCO training best practices.
- Develop RCO training objectives.
- Develop RCL operations best practices.

1. Introduction

This report describes the results of a human factors RCA of six train accidents/incidents that involved RCL operations in U.S. railroad switching yards. Train accidents include collisions and derailments that involve the operation of on-track equipment and that meet certain reporting thresholds set by FRA (FRA, 2003). Train incidents include employee injuries that involve the movement of on-track equipment and that meet certain reporting criteria (FRA, 2003). The report refers to train accidents and train incidents together as accidents/incidents. Section 1 provides an introduction to the study. Section 1.1 presents the background to the study, including a description of RCL operations. Section 1.2 presents the study's objectives, and Section 1.3 describes the overall approach used in the RCA. Section 1.4 discusses the study's scope, and Section 1.5 describes the report's organization.

1.1 Background

In an effort to reduce operating costs and increase safety and efficiency, U.S. Class I freight railroads have begun to implement RCL operations in railroad switching yards. RCL operations consist of three components: the locomotive (the RCL), an OCC (see Figure 1) that interfaces with the RCL's controls (and usually mounted somewhere inside or on the RCL), and a portable RCD (also frequently referred to as a belt pack, operator control unit, or simply box; see examples in Figure 2 and Figure 3). An RCO wears the RCD harnessed to a vest (see Figure 4). In RCL operations, typically only one or two crewmembers (one or both are RCOs) switch cars, commanding the locomotive to move via inputs to the RCD rather than radio or hand signals to a locomotive engineer onboard the locomotive. The RCO in control of the move is often referred to as the A or primary RCO, while the second RCO is referred to as the B or secondary RCO. The A operator has all of the RCL functions available to control the RCL, while the B operator has access to a limited set of safety-related redundant functions, such as the locomotive's horn and emergency brake application.

When an RCO wants to send a command to the RCL (e.g., to slow down), the RCO manipulates hand controls on the RCD. The RCD, in turn, transmits these inputs via radio frequency to the OCC. The OCC then actuates locomotive commands by interfacing with the RCL and sending the instructions to the RCL. Figure 5 illustrates the basic concept of RCL operation. An RCO on the ground can now directly control the locomotive rather than communicate movement directions to a locomotive engineer stationed onboard the locomotive. Consequently, RCL operations have led to reduced crew size; typically one to two crewmembers make up an RCO crew generally compared to three crewmembers in a conventional yard switching crew.

Proponents of RCL operations suggest that controlling the locomotive from the ground (i.e., the switch or coupling location) affords the individual in control of the locomotive the best vantage point (see Figure 6). Proponents further argue that these devices reduce or eliminate miscommunication errors between a locomotive engineer in the locomotive cab and a switchman on the ground. Opponents of the technology have raised a number of safety concerns, including inadequately trained operators, the added mental and physical stress of wearing and operating the RCD, and electromagnetic radiation emissions.

Figure 1. Example of an OCC

Figure 2. Front view of an RCD
(Courtesy of Cattron-Theimeg, Inc. 2004. Reprinted with permission.)

Figure 3. Top view of an RCD
(Courtesy of Cattron-Theimeg, Inc. 2004. Reprinted with permission.)

Figure 4. RCO

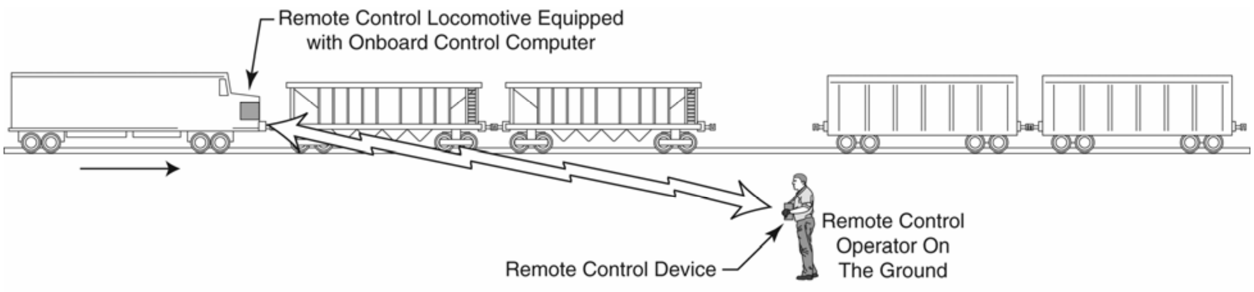

Figure 5. Basic illustration of RCL operation

Figure 6. Example of RCO making coupling

CN, one of two Canadian Class I freight railroads, began implementing RCL operations in North America as early as 1989 (CN, 2000). In addition, a number of regional and short line railroads in the United States experimented with RCL operations in the 1990s. According to FRA, 22 railroads in the United States began using RCL operations between 1995 and 2000 (FRA, 2000). Railroads in other countries, as well as other industries in the United States, such as mining and steel, have also used the technology for a number of years. Despite the varied uses of RCL operations in the United States and Canada since 1989, none of the large U.S. Class I freight railroads had implemented RCL operations as of 2000.

In an effort to provide guidance and assist the U.S. railroad industry and encourage railroads, RCL suppliers, and labor unions to work cooperatively, FRA held a technical conference in 2000 to discuss RCL operations and safety. Consequently, in February 2001, FRA published RCL operation guidelines (FRA Safety Advisory 2001-01; FRA, 2001). These voluntary guidelines provided general direction in four areas of RCL operations: equipment design, operating procedures, operator training, and data collection. These guidelines also clarified which FRA regulations pertain to RCL operations. These include qualification and certification of RCOs (49 CFR § 240), and daily and periodic inspection of RCL equipment (49 CFR § 229), including the RCD.

As a result of these guidelines and a subsequent agreement between the U.S. Class I freight railroads and one of the operating craft unions, U.S. Class I freight railroads began to implement RCL operations starting in early 2002. Operating environments include yards, industrial spurs and sidings, and, most recently, some main tracks and sidings/spurs. RCOs must adhere to all relevant operating rules in effect during RCL operations and may have additional responsibilities depending on the operating environment. Some of these responsibilities may include communication with a yardmaster or train dispatcher, minor train handling on ascending and descending grades, car handling, and communication with other crews operating in the RCOs' vicinity. A majority of the RCOs on U.S. Class I railroads are switchmen[1] who receive 80 h of additional training on the RCD and RCL operations to qualify as an RCO, though a small number of RCOs on U.S. Class I and some regional railroads are also qualified locomotive engineers who have experience operating a locomotive.

To obtain a sense of the scale of implementation, five U.S. Class I railroads—UPRR, BNSF, CSX, NS, and KCS— were asked to provide some fundamental statistics on their RCL implementation. Four of the five railroads—UPRR, BNSF, NS, and KCS—provided data. As of August 31, 2004, these four railroads had converted or generated 1126 RCL job assignments. A job assignment is defined as one job for one shift; thus, for example, if an RCL trim job at a particular yard works three shifts per day, then this would count as three RCL assignments. Among these four railroads, 179 railroad yards across the country have at least one RCL job assignment. Lastly, each of the 4 railroads had converted anywhere from 6 to 50 percent of all yard job assignments to RCL, indicating a significant difference in RCL implementation strategies among the 4 railroads. Table 1 presents statistics from each individual railroad.

Table 1. RCL implementation data from select U.S. Class I freight railroads as of August 31, 2004

Railroad	Number of yards with one or more RCL job assignments	Total number of RCL job assignments	Percent of all yard jobs converted to RCL
BNSF	57	388	45
KCS	7	42	31
NS	34	86	6
UPRR	81	610	50
Total	179	1126	N/A

[1] The term switchmen in this report generically refers to all train service employees. Depending on the particular railroad, these employees are variously referred to as switchmen, groundmen, trainmen, conductors, brakemen, yard foremen, or helpers. The title depends on the railroad and the particular function of the position. For example, in some railroads, a switchman responsible for a road train is called a conductor, while the same switchman in charge of a yard job is called a yard foreman. Both positions are in train service. These titles are used interchangeably in this report.

Although the technology has been around for decades, the particular safety implications of using these devices in the U.S. railroad industry, and of reducing crew size in switching operations, remain unknown. FRA collects accident/incident data, including accidents/incidents involving RCL operations. It will take several years before adequate RCL-related data are available to analyze, however, since RCL operations began on a large scale in the United States starting only in early 2002. Furthermore, railroads were only required to identify the involvement of RCLs and RCOs in accidents/incidents beginning May 1, 2003 (FRA, 2003).

To better understand the safety implications of RCL operations, FRA Office of Research and Development Human Factors Program and FRA Office of Safety initiated a multi-study program of research into RCL operations in early 2002, just as RCL operations began on a large scale in the United States. FRA sponsored three separate studies: a comparative risk assessment of RCL and yard switching operations; focus groups with RCOs to identify safety issues and best practices; and an RCA of RCL-involved accidents/incidents. This report describes the results of the RCA of RCL-involved accidents/incidents.

1.2 Objectives

Ultimately, the goal of the research was to assist FRA in its mandate to ensure the safety of those who work on, and use, the U.S. rail network. The specific objectives of this research project included the following:

- Understand the circumstances that contribute to RCL-involved accidents/incidents in railroad yards.
- Identify individual, organizational, technological, and situational factors that contribute to RCL operations safety.
- Determine the applicability and validity of a selected human error taxonomy to railroad operations.

1.3 Overall Approach

This research study involved an examination of a generally sensitive topic—chiefly, accident/incident causation. In the U.S. railroad industry, only those party to an investigation are usually privy to the facts surrounding the accident/incident. Depending on the nature of the accident/incident, parties (and their representatives) may include some combination of railroads, labor, FRA, and the NTSB. Occasionally other government agencies with jurisdiction over the accident/incident may also participate, for example, a local police department. Researchers to date, though, have not been permitted to investigate the causes or contributing factors of railroad accidents/incidents in depth, even when conducting FRA-sponsored research.

This study is a first-of-its-kind study because researchers were allowed to conduct their own independent data collection and RCA of RCL-involved accidents/incidents in the United States. This research was necessarily supported by all of the stakeholders: FRA, railroad management, and labor unions. To obtain stakeholder buy-in, a general meeting was conducted at FRA Headquarters in December 2003. Representatives from the following organizations were invited to participate in the meeting:

- FRA Office of Research and Development

- FRA Office of Safety
- FRA Office of Chief Counsel
- UPRR
- CSX
- NS
- BNSF
- KCS
- CN
- CPR
- FECR
- MRL
- Amtrak
- American Short Line and Regional Railroad Association
- Association of American Railroads (AAR)
- BLET
- UTU
- Brotherhood of Railway Signalmen (BRS)
- International Brotherhood of Electrical Workers (IBEW)
- NTSB

During the meeting, the research objectives, study design, and data collection methods were laid out and discussed, and stakeholder issues were addressed. All seven Class I freight railroads[2], MRL, FECR, and all four labor unions subsequently agreed to participate in the study.

The overall technical approach used to carry out the study involved the following steps:

1. Conduct a stakeholder meeting to share the study's goals and methods and solicit stakeholder feedback, suggestions, and participation.
2. Develop RCA data collection methods and approach.
3. Collect descriptive data on FRA reportable collisions, derailments, and employee injuries (accidents/incidents) that involved RCL operations for a 6-month (mo) period, from May 1 to October 31, 2004.
4. Conduct indepth RCA case studies of six accidents/incidents.

Section 2 provides more detail regarding the methods used. Though RCA data were only collected on six accidents/incidents, it is important to understand that the focus of the research

[2] CN and CPR's participation was limited to their U.S. operations.

was not on what any one railroad or employee did as a practice. The activities identified and discussed as part of the RCA are expected to occur throughout the railroad industry, even though the six accidents/incidents are not a scientifically representative sample of all railroad operations.

Another unique aspect to this study was that before submission to FRA for approval, each railroad and labor union that was involved in each of the six RCA case studies was given an opportunity to review and comment on a draft of the case study. Reviewer comments were either incorporated into the final report as edits, or, if an issue could not be resolved, then the reviewer's dissenting viewpoint was included in the report along with a response by the study authors.

1.4 Scope

This study was limited to RCL-involved accidents/incidents that occurred in U.S. railroad yards from May 1 to October 31, 2004. Accidents/incidents included collisions, derailments and employee-on-duty injuries that meet certain reporting thresholds as set by FRA (FRA, 2003). One shortcoming is that this timeframe may have precluded certain aspects of RCL operations from being studied, such as the impact of severe inclement weather (e.g., snowy, slippery, very cold weather and attendant need for additional clothing and thick gloves) and long hours of darkness.

Furthermore, given the rapid changes that are occurring in RCL operations around the United States, care must be taken in interpreting the results. An operating practice or rule in effect in 2004 may be prohibited or not observed the following year. It is important to keep in mind that information on railroad operating procedures, rules, instructions, and other practices that provided source data for the RCA was based on what was in effect at the time of the accident/incident. It is entirely possible that the railroad subsequently changed a rule or instruction that was discussed in the analysis.

Two other methodological limitations that restricted the scope of the study included the following: researchers were not permitted to obtain any medical-related information from participating railroads about any employee, including results from drug and alcohol testing, medical history, or railroad-related medical exams; and RCL crewmember, conventional yard switching crewmember, and yardmaster interview data were limited to voluntary participation of the individual railroad employees. If an individual elected not to participate, data from that individual were not collected.

It is important to also recognize that the approach used in this study to identifying contributing factors to RCL-involved accidents/incidents was one of many different possible approaches to investigating accidents/incidents. The conclusions from this study are based on a systems approach to accident/incident data collection and analysis, and they are limited to the researchers' abilities to take the data that are collected and integrate it with their own knowledge of RCL operations to make sense of the data for each accident/incident that was studied. It is quite likely that a railroad or FRA, conducting its own investigations on the same accidents/incidents, may focus on different concerns and consequently draw a different set of conclusions. For example, FRA may look for issues surrounding a railroad or employee's compliance with Federal regulations, while a railroad may focus on operating and safety rule violations. Each is a valid approach, and each offers something different to the overall base of knowledge of RCL operations.

Due to the fact that only six accidents/incidents were examined in depth using RCA methods, this study could not possibly address all potential risks associated with RCL operations. The study was designed to shed light on RCL operations and, in particular, to enable an examination of those factors that contributed to known RCL accidents/incidents where an RCO was directly and immediately involved, at all levels of the system, from the operating crewmember through organizational decisions. This report does not examine RCL accidents/incidents where an RCO was not directly or immediately involved, for example where a broken rail caused a derailment of an RCL.

1.5 Organization of the Report

This report is organized into several sections. Section 2 discusses the methods used in conducting the RCA. Section 3 summarizes data from all RCL accidents/incidents that were reported over the 6-month data collection period. Sections 4-9 present the results of the individual RCA case studies that were conducted on six different accidents/incidents. Section 10 presents the results of an analysis of the data from the six RCL accident/incident case studies. Section 11 presents the key findings from the study and includes some recommendations for future research. Section 12 presents a list of references used in the conduct of this study. Five appendices are also included. Appendix A presents a copy of the background questions that were asked of each interviewee. Appendix B-D present the three questionnaires that were used to guide interviews with RCOs, other yard employees, local officers, and upper level officers. Appendix E presents a copy of a checklist that was developed to aid researchers in collecting appropriate, adequate, and consistent railroad materials to support each RCA. Lastly, the report includes a list of abbreviations and acronyms.

2. Methods

Section 2 presents the methods used in the study. This section first provides a short description of RCA, the overall philosophy behind the study. The next subsection describes a taxonomy of human error called HFACS. A slightly modified version of HFACS (HFACS-RR) provided the backbone and structure to both the data collection and analysis. Next, data collection procedures are discussed, including collection of descriptive information on all FRA-reportable RCL accidents/incidents that occurred in participating railroad yards, as well as the indepth RCA data collection. The data analysis procedures are described next. The study includes a separate subsection describing the fatigue analysis method. Lastly, the format for the case studies is presented to aid review of each case study.

2.1 RCA

RCA is a method of accident/incident investigation (data collection) and analysis that enables investigators or researchers to identify individual, organizational, technological, and situational factors that contributed to an accident/incident. RCA is a qualitative approach to understanding accidents/incidents that complements quantitative analysis of large descriptive accidents/incident databases. A guiding principle behind RCA is that accidents/incidents are not solely caused by one event; rather, multiple factors play a role in every event. RCA is a process used to methodically and objectively shed light on these contributing factors; many of which are otherwise difficult to find or not identified in larger accident/incident databases.

An important element of RCA is its nonpunitive nature. An operator is often blamed for an accident/incident because the operator is associated most recently in time and most closely in space with the last event that goes wrong before an accident/incident occurs, such as pressing the wrong button or missing a red signal. This punitive approach to accident/incident investigation, referred to as the bad apple theory by Dekker (2002), seeks to fix the problem by blaming an employee. Taken to its extreme, the employee is removed from service or fired. Thus, the problem appears to be fixed. However, given that no real systemic problems have been remedied, other employees are likely to repeat the exact same unsafe act for which their coworker was just disciplined. Human error is much more complex. In fact, as Petersen (2003, p. 28) notes in a discussion of human error, “Human errors at lower levels of the organization are symptoms of things that are wrong in the organization at higher levels.” Furthermore, James Reason, a leading expert in the field of human error theory, notes,

> …human error is a consequence not a cause. Errors…are shaped and provoked by upstream workplace and organizational factors. Identifying an error is merely the beginning of the search for causes, not the end. The error, just as much as the disaster that may follow it, is something that requires an explanation. Only by understanding the context that provoked the error can we hope to limit its recurrence (Reason, 1997, p. 126).

Since errors “are shaped and provoked by upstream workplace and organizational factors,” a basic tenet of RCA is that it seeks to identify a broad range of factors that may have contributed to an accident/incident, from an individual operator’s action or inaction, to a senior-level executive decision that may have occurred several years before the accident/incident.

RCA examines both active and latent factors. Active factors are those decisions, conditions, or other aspects that are closest in time and physical space to the accident/incident, and have traditionally been most often cited as the cause of an accident/incident, for example, an operator's errant press of the wrong button on an RCD. On the other hand, latent factors (decisions or conditions) often exist for years and may never be identified as a safety issue unless they are explicitly examined, for example, poor (human factors) design of equipment or an unsafe operating practice.

RCA is based on the tenet that the immediate act that precedes an accident/incident is simply the last step in a series of events that led to the accident/incident. RCA focuses on unwinding the tape to explore all of the factors that led to the accident/incident. To do this, individual, organizational, technological, and situational factors are examined. Each of these factors can be, and often is, at least partly responsible for providing a situation conducive to the accident/incident's occurrence. RCA yields complex and rich information regarding the likely contributors to an accident/incident and can lead to a more complete understanding of organizational safety.

2.2 HFACS

2.2.1 HFACS

One particularly successful human error classification system is the HFACS (Wiegmann and Shappell, 2003). HFACS is based on James Reason's generic error modeling system (GEMS; 1990), also commonly known as the Swiss cheese model of error. The Swiss cheese model depicts errors as arising from holes in the organization's defenses against accidents at various levels of an organization, beginning with the operator and working all the way back to organizational decisions and conditions. Active failures by the operator combine with latent conditions or factors upstream in the organization to lead to an accident/incident. Accidents/incidents occur when all of the active and latent holes line up. Accidents/incidents are prevented when the holes do not line up because of defenses in one or more of the layers.

HFACS was originally developed as a classification system to help analyze U.S. naval aviation mishaps. HFACS has subsequently been broadened to include commercial and general aviation domains as well. HFACS models error at four different levels, beginning with the operator and moving upward in the organization. The four levels mirror Reason's Swiss cheese model of error. The four levels of HFACS are unsafe acts (Reason's active failures—the operator activity that occurs closest in time and space to an accident/incident), preconditions for unsafe acts, unsafe supervision, and organizational influences. These three latter levels relate to Reason's latent factors or conditions, and they often exist for years before they contribute to an accident/incident. For each level, HFACS authors have identified a number of second-level categories. Some second-level categories are further divided into third-level categories. A total of 19 unique categories of contributing factors exists. Figure 7 provides an overview of HFACS, and conveys both the structure of HFACS and the unique categories of contributing factors. HFACS applies Reason's Swiss cheese model of human error to an accident/incident classification system and provides a theory-driven structure to accident/incident investigation findings. For a discussion of the definitions of each unique category, see Wiegmann and Shappell (2003).

The use of a theoretically-driven RCA approach ensures that the accident/incident contributing factors identified during an investigation go beyond what happened to why an error occurred. Furthermore, such an approach allows for the relationship between contributing factors to be more readily identified, for example, some types of errors may be linked to other types of contributing factors. Classifying errors based on their underlying theoretical nature allow for global trends to be identified across error forms, which on the surface may appear to be totally different. For example, an RCO's accidental activation of the wrong button on an RCD and a slip/trip/fall by an RCO may both be linked to the inability to manage one's attention. Consequently, and perhaps most importantly, corrective actions can be more readily identified to prevent errors and accidents/incidents from recurring, since the data collected during the investigation highlight the underlying systemic problems that contributed to the events in the first place.

Historically, HFACS has been used mostly to analyze data available from existing accident/incident investigations. However, HFACS was designed to also guide accident/incident investigations to support collection of human factors-related information in the first place. Some Federal agencies, such as the U.S. Coast Guard and the U.S. Department of Defense, have begun to experiment using HFACS to support accident/incident investigations as well as analysis (Wiegmann and Shappell, 2003; A. Carvalhais, personal communication, October 11, 2005).

HFACS was selected to provide the theoretical backbone to the RCA, given its logical structure and scientifically valid approach to human error. Furthermore, HFACS, as a classification system, is diagnostic, reliable, and comprehensive (Wiegmann and Shappell, 2003). This is critical since the taxonomy must accommodate a wide range of railroad operational situations and circumstances that can lead to accidents/incidents. HFACS was developed initially for the aviation domain. As a result, some minor changes were made to HFACS to optimize its relevancy to the railroad industry. Section 2.2.2 discusses these minor changes.

2.2.2 HFACS-RR

To ensure the best fit between HFACS and the railroad industry, and to increase its acceptance within the railroad industry, several minor changes were made to HFACS. The overall HFACS tree structure remains—the only changes that were made were additions to the structure, and a few changes to some of the terms used in the original HFACS (e.g., rule violations was changed to contraventions since contraventions is a more apt description of the event and is less provocative than rule violations). The modified HFACS taxonomy was labeled HFACS-RR (railroad). An advantage of the original HFACS is that it uses generic terms and descriptors that are applicable to a range of industries and activities. Although others have made minor alterations to HFACS to suit their particular application, for example, to address air traffic control (HFACS-ATC; Scarborough and Pounds, 2001) and military activities (Canadian Armed Forces, or CF-HFACS; see Wiegmann and Shappell, 2003), most of the original HFACS taxonomy was retained in HFACS-RR to preserve the original structure to facilitate future comparisons between data collected in this study and HFACS-based accident/incident analyses in other industries.

To begin, the names of the top HFACS level were changed to become more neutral. For example, unsafe acts of operators was changed to operator acts. Table 2 presents the original and modified terms.

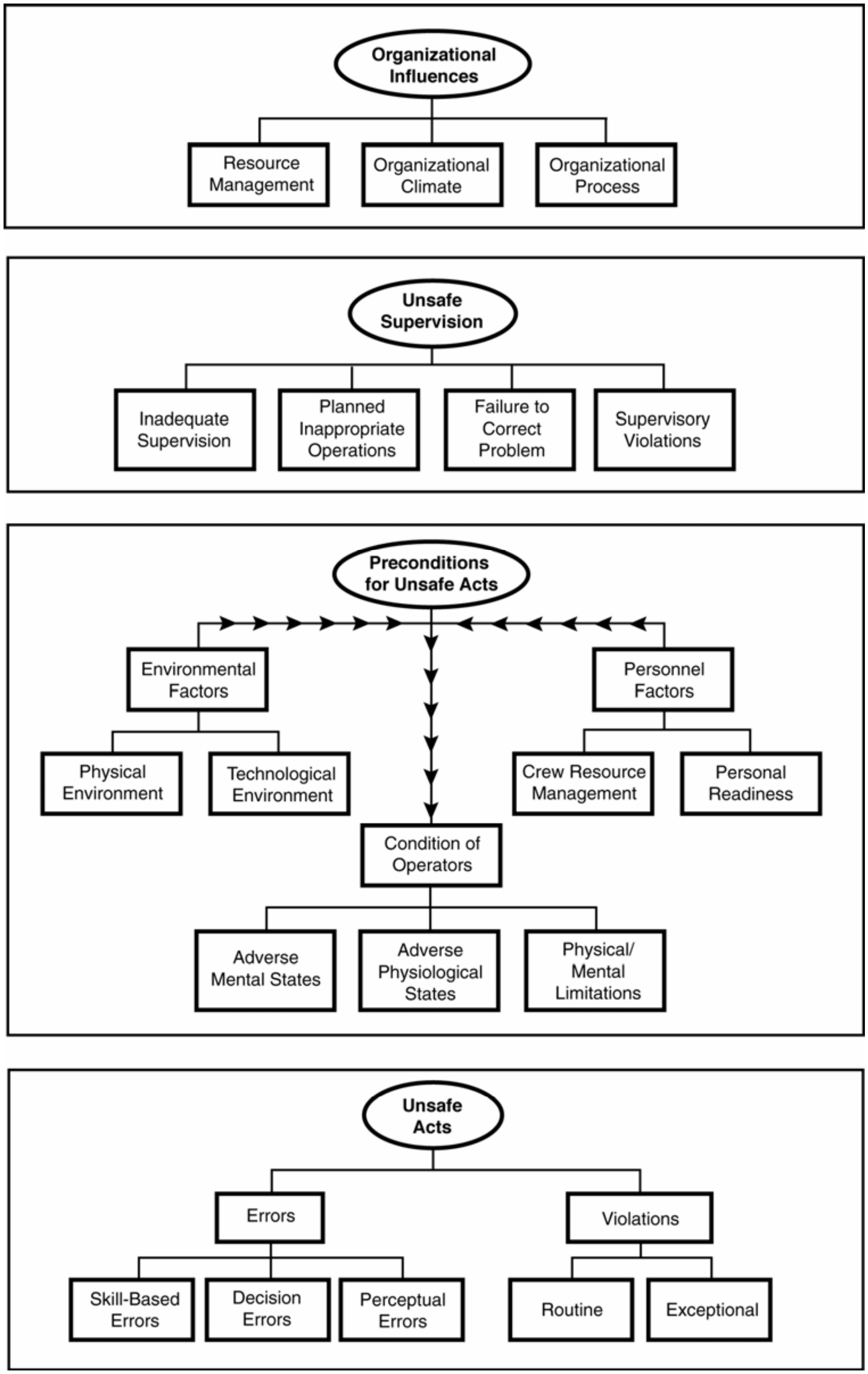

Figure 7. Original HFACS taxonomy (Wiegmann and Shappell, 2003)

Table 2. Original four HFACS and new HFACS-RR top-level categories

Original HFACS top-level category	Modified HFACS-RR top-level category
Unsafe acts of operators	Operator acts
Preconditions for unsafe acts	Preconditions for operator acts
Unsafe supervision	Supervisory factors
Organizational influences	Organizational factors

A new, fifth level named outside factors was also added to the HFACS-RR taxonomy. Outside factors include the regulatory environment and the economic/political/social/legal[3] environment in which railroads operate. Outside factors cover those influences outside the railroad or organization that affect how the organization operates and its decisions.

Other changes to the original HFACS taxonomy (and contained in the new HFACS-RR taxonomy) include the following:

- The term violations was replaced with contraventions throughout the HFACS taxonomy to avoid stigma and biases associated with violations. Violations in the railroad industry are often associated strictly with (operating, safety) rules. Contraventions are more general short-cutting and rule-bending, and they may not necessarily be tied to violating a specific rule.
- Added a third subcategory under operator acts/contraventions called acts of sabotage. Acts of sabotage are related to the investigation only as much as the act is in response to a problematic organizational factor that is identified.
- Added a new, fourth subcategory under the organizational factors category, called organizational contraventions. This subcategory addresses upper level management and executive contraventions and short-cutting of existing organizational (i.e., internal) procedures or processes, and externally imposed municipal, State and Federal regulations. This category parallels supervisory contraventions and contraventions of the operators themselves.

Figure 8 presents the new HFACS-RR taxonomy with these modifications incorporated. The new HFACS-RR taxonomy contains a total of 23 unique categories of accident/incident contributing factors. Though not formally included in the original HFACS or HFACS-RR diagrams, several of the unique categories can be further classified (see Wiegmann and Shappell, 2003). The following HFACS-RR categories were further classified, when possible, in each of the six RCA case studies:

- Skill-based errors were further categorized into attention failures, memory failures, and technique errors.
- Decision errors were further categorized into procedural errors, poor choices, and problem-solving errors.

[3] The legal environment includes other-than-regulatory laws that affect railroad operations.

- Resource management was further categorized into human resources, equipment and facility resources, and monetary/budget resources.
- Organizational climate was further categorized into organizational structure, organizational policies, and organizational culture.
- Organizational process was further categorized into organizational operations, organizational practices and procedures[4], and organizational oversight.

Figure 9 reconfigures the five HFACS-RR levels according to their flow of influence. Influence flows from the outer levels toward the inner levels. That is, outside factors can influence all other HFACS levels (organizational factors, supervisory factors, preconditions, and operator acts); organizational factors can influence supervisory factors, preconditions, and operator acts; supervisory factors can influence preconditions and operator acts; and lastly, preconditions can influence operator acts. This taxonomy pictorially shows how (remote control) operator acts can be influenced by a number of contexts—preconditions, supervisory factors, organizational factors, and outside factors.

Researchers used the RCA philosophy combined with the HFACS-RR structure to guide data collection and analysis. A number of data collection instruments were developed to aid researchers in collecting accident/incident-related data. These instruments, including questionnaires, a checklist of items to request from the railroad, and a series of decision trees designed around the HFACS-RR taxonomy, aided researchers in collecting and analyzing RCL-related accident/incident data. The next section discusses these materials more fully.

2.3 Data Collection Procedures

Participating railroads were asked to notify the researchers within 24 h, or the next business day, of all FRA-reportable accidents/incidents—specifically, collisions, derailments, and employee injuries—involving RCL yard operations that occurred between May 1 and October 31, 2004. Railroads were asked to notify the researchers regardless of the cause of the accident/incident and even if the remote control equipment was not considered at fault. When an accident/incident occurred, the researchers asked the railroad to provide the following information:

- Carrier name
- Carrier point-of-contact name and telephone number
- Nature of accident/incident (i.e., collision, derailment, or employee injury)
- Brief description of accident/incident
- Location of accident/incident (yard name, city, and state)
- Date and time the accident/incident occurred

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[4] Wiegmann and Shappell (2003) originally discuss procedures under the organizational influences/organizational process subcategory. Procedures were changed to practices and procedures in HFACS-RR since many of the activities undertaken in a railroad switching yard or environment involve practices, which may be defined as more broad methods of operation than procedures, which are more specifically prescribed methods.

- Name of crewmembers involved in accident/incident and union(s) that represents crewmembers

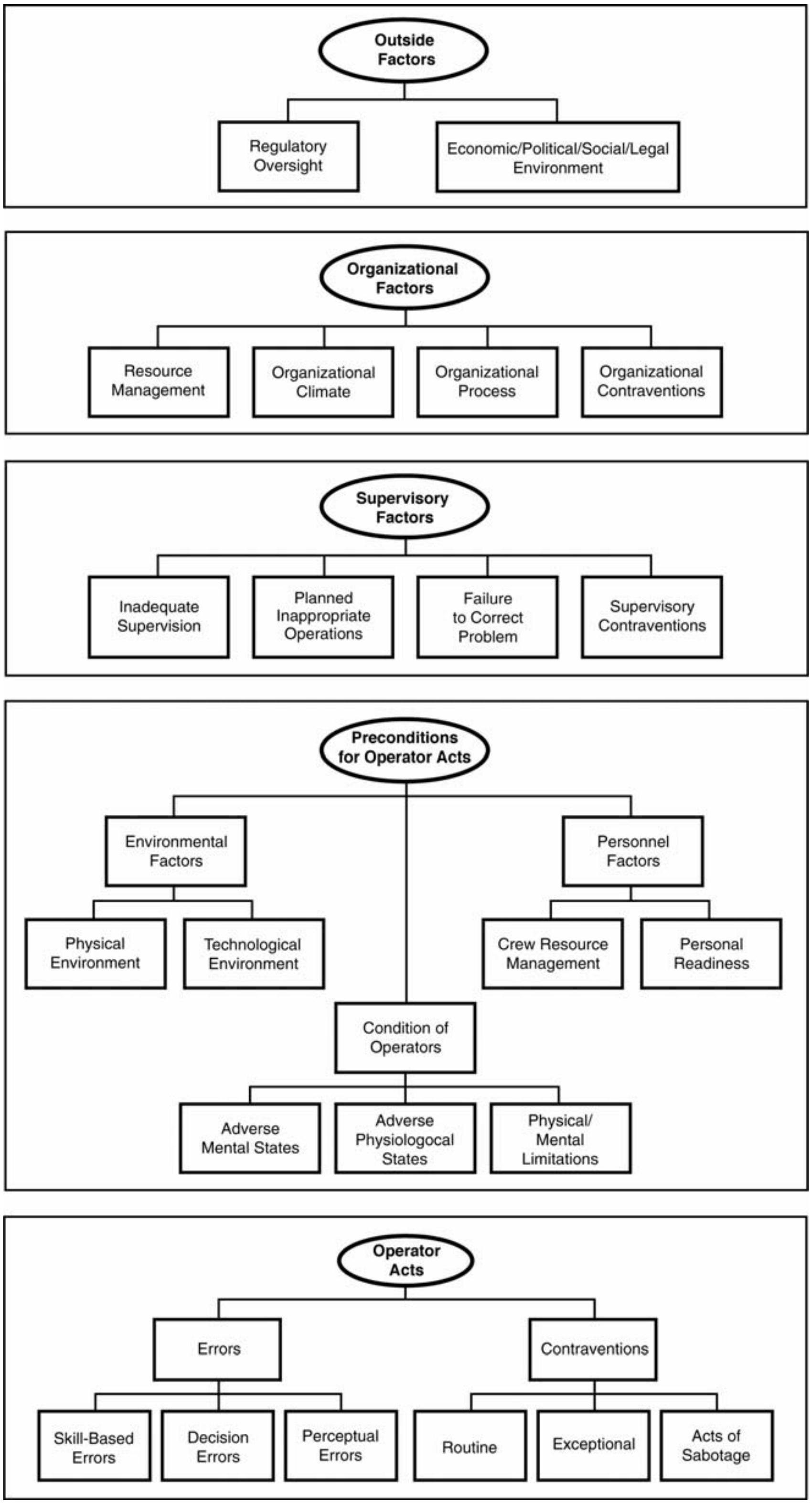

Figure 8. HFACS-RR taxonomy

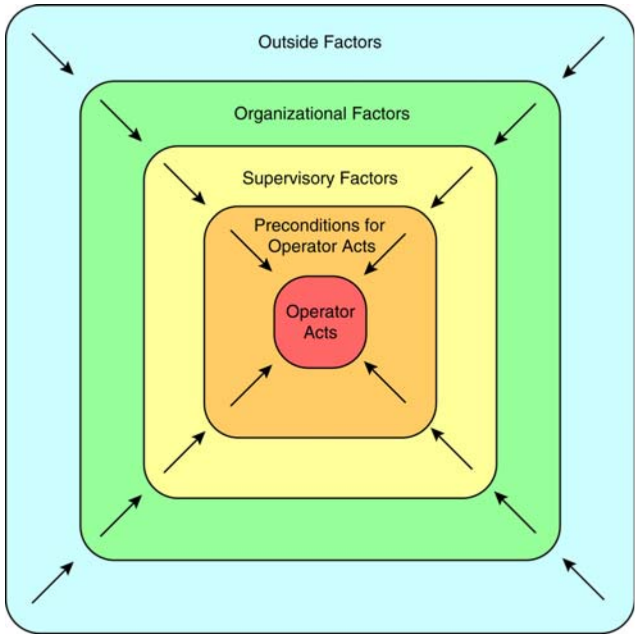

Figure 9. Concentric influence of HFACS-RR levels

Data were logged into a computer database. It is important to recognize that differences exist among each of the participating railroads in terms of RCL operations. In fact, differences often exist in how RCL operations are performed among different yards within a given railroad. These differences are based on which RCL supplier is chosen, what optional and customized RCL features are selected, differences in operating rules, and differences in operating cultures and norms, among others. To tap into this wide array of RCL operations experience, and to ensure fair and objective selection of accidents/incidents to examine further, several criteria and guidelines were established to help select which RCL accidents/incidents were examined in greater detail using RCA. The criteria and guidelines were exercised to the extent possible, given that the accidents/incidents were not controllable. Selection criteria and guidelines include the following:

- Accidents/incidents had to occur in participating U.S. railroad yards, including large terminals and smaller satellite yards, including hump and flat switching operations. Industry jobs are also considered part of a yard, since the major activity involved with an industry job is switching cars, the same as that which occurs in yards themselves.
- Accidents/incidents had to involve qualified (i.e., certified) RCOs. Accidents/incidents involving student RCOs were not included.
- Transfer jobs and other jobs where the main function is moving a train from point A to point B were not included as candidate case studies.
- Accidents/incidents should be unique to RCL operations; that is, they likely would not have occurred under conventional operations.
- Look at a breadth of different potential human factors issues.
- Look at a breadth of different circumstances and kinematics.
- Examine at least one accident/incident that occurred in a remote control zone (RCZ).

- Examine at least one accident/incident that occurred with a one-person RCL crew.
- Examine no more than two accidents/incidents from any one railroad.
- The data collection timeframe must work within researchers' schedules.

When an accident/incident was selected as a case study, the researchers worked with the participating railroad point-of-contact to arrange to travel to the accident/incident site as soon as possible, generally within 1-2 d of notification. Separately, the point-of-contact from the union that represented the crewmembers involved in the accident/incident was contacted to help begin to arrange interviews with the crewmembers. Interviews were conducted privately with crewmembers; railroad officers were not present. Interviewees, however, had the option of bringing someone with them (e.g., their local chairman).

Once onsite, the researchers met with the local officer in charge, generally a Terminal Superintendent, Terminal Manager, or Director of Terminal Operations. Generally, the first half-day involved becoming familiar with the details of the accident/incident and reviewing the site and any equipment involved. Over the course of the next 1-3 d, the researchers then interviewed local officers (e.g., superintendent or trainmaster), the RCOs involved in the accident/incident, and others familiar with the accident/incident (e.g., a yardmaster on duty at the time). A set of background questions (see Appendix A) was developed to help collect demographic information about interviewees. Several very general sets of questionnaires were also developed to aid data collection (see Appendix B-D). The particular questions that were asked depended on the circumstances surrounding the accident/incident and the individual being interviewed; not every question was asked of every interviewee. The questionnaires were developed based on the HFACS-RR human error framework. The questionnaires were meant to provide a broad starting point from which researchers could select appropriate and relevant questions that pertained to the actual accident/incident. Interviews with railroad employees (non-officers) were conducted privately, and they were compensated for their time. In some instances the researchers interviewed the participating railroad point-of-contact, either onsite or by telephone.

Additionally, researchers requested copies of relevant records, reports, logs, and other carrier-maintained materials for review. A checklist was developed to aid the researchers in collecting applicable materials (see Appendix E). Generally, the researchers collected the following data:

- OCC (remote control) or locomotive event recorder data
- Work schedule history for the 30 d before the accident/incident
- Operational efficiency test information
- Copies of relevant operating and safety rules, special instructions, bulletins, and notices
- Training materials and histories
- Yard diagrams
- Copies of the initial carrier accident/incident report, including crew statements (where available)

Depending on the accident/incident, the researchers requested additional data, such as radio transcripts, equipment diagrams and photographs, which the participating railroads provided.

After the site visit, the researchers reviewed the material and wrote up the RCA in a case study. Often it was necessary to follow up with one or more interviewees to ask additional questions or clarification (e.g., to corroborate a fact, assumption, or finding). Participating railroads and unions were also encouraged to contact the researchers at any time with any questions during the six months of data collection.

2.4 Data Analysis Procedures

Accident/incident data were de-identified to protect the identities of the individuals and railroads that participated since the focus of the study was on the entire railroad industry and overall RCL operations, not a particular practice at one railroad or by one individual. To this end, the following procedures were followed to assure the anonymity of those who participated:

- Dates and locations of each of the six accidents/incidents, as well as all reports of RCL-involved accidents/incidents, are not reported, or are the names of the railroads where the accidents/incidents occurred, or the names of the employees involved in the accident/incident or that provided data.
- Removed insignia, paint scheme, and other identifiers in all photographs.
- Photographs were reproduced in black and white.
- Identifying information was not recorded on any interview notes. Each interviewee was assigned a random identification number or letter.
- Information was treated as confidential during data collection and analysis. Information provided by a railroad was not shared with employees, and information provided by employees was not shared with the railroad.

A number of decision criteria and heuristics were also developed over the course of the study to aid researchers in resolving conflicting information and ensure consistency in analysis across all six accidents/incidents. Decision criteria that were developed include the following:

- Experience will be discussed in terms of how long an individual has been qualified for a particular position (e.g., RCO).
- If conflicting information exists between what an RCO says he did with regard to the RCL and/or RCD and what the event recorder data show in terms of RCO input, data from the event recorder will take precedence unless reason exists to believe that the event recorder is incorrect or inaccurate.
- If conflicting statements occur between interviewees, first try to call back each crewmember to clarify. If this is unsuccessful, try to discuss at a level where both statements can be valid. For example, if it unclear how a particular crew YYY made a move, but it is known that the crew used the AA lead, simply say “YYY used the AA lead.”
- If an interviewee provides inconsistent information, call back to clarify. If this does not help, utilize other sources of data to verify interviewee data.
- Written crewmember statements taken immediately after the accident/incident will take priority over verbal recall later during interviews if inconsistencies arise, except if evidence exists to support the later recall, discounting the written statement(s).

- When a discrepancy occurs between information from the initial face-to-face interview and a follow up interview, use the earlier information, unless overwhelming evidence exists that supports the later information, since the face-to-face interview was conducted nearer in time to the accident/incident. When confronted with conflicting information from one source, assume information provided closer in time to the accident/incident is more reliable based on a presumption that factual knowledge of the accident/incident decays over time.
- When a discrepancy occurs between crewmember self-report data provided on the researchers' background demographic data form and data provided by the carrier based on their records, data from the railroad's records will be used.
- When a discrepancy occurs between an initial railroad accident/incident report and later record, use the later (more recent) record since this record is expected to contain more up-to-date and accurate information. However, if the initial report is the only source of data, then it is acceptable to use this record as a source of information, assuming nothing contradicts the information.
- If multiple speed values exist for one event recorder time stamp (e.g., two speed recordings for 06:33:33), use the lowest value if it is known that the RCL is decreasing speed, or use the highest value if RCL speed is known to be increasing.
- Meteorological data at the time of the accident/incident will be gathered from www.weatherunderground.com. When determining temperature and temperature time stamps are on both sides of the accident/incident time (e.g., an accident/incident occurred at 1 a.m., and readings are for 12:30 a.m. and 1:30 a.m.), use the reading closest to the accident/incident time. If the accident/incident time is exactly half-way between reading times, use the average value of the two readings, rounding to the odd whole number if necessary. For example, if temperature readings are 63° F and 65° F, and time of accident/incident is exactly half-way between, use 64° F. If readings are 70° F and 75° F, take 73° F (72.5° F, rounded to the odd is 73° F).
- If work schedule data includes two notification times, use the later time. It will be assumed that the crew caller did not contact the RCO in the first notification time nor did he/she leave a message; otherwise a need for a second call would not have existed.

Lastly, rather than using the term, causal factors, the term contributing factors was used to denote the myriad of factors that played a role in setting up and contributing to each accident/incident. The term contributing factors was preferred over causal factors because causal factors connotes an immediate presence in terms of time and space relative to the accident/incident. Given the organizational/systems focus, it was important for the terminology to convey this more general perspective to accident/incident investigation and analysis.

2.5 Operator Alertness Analysis

Operator sleep deprivation and time-of-day induced variations in alertness can lead to lapses in attention, slowed reactions, and impaired reasoning and decisionmaking that have been shown to contribute to accidents/incidents and errors in a host of industrial and military settings. Collectively, these effects have been described as fatigue or impaired alertness. What is significant in terms of railroad operations is the observable behavior of alertness–that is, attention to and appropriate responses to one's surroundings rather than the less exact term fatigue that has various meanings for different people. Within the railroad industry, some accidents/incidents appear to reflect impaired alertness since appropriate actions were not taken in the presence of signals to take action. Impaired alertness may be traced to a number of variables; for this study, the focus is on two main causes: the amount of sleep a person has had in the recent past and the time of day the accident/incident occurred.

The average person needs about 8 h of sleep per day to maintain full alertness. Sleep induced impairments in alertness fall into two main categories. The first kind of problem occurs when a person does not get sufficient amounts of sleep each day, extending over a series of days. This produces what is called a sleep debt, a difference between the average amount of sleep actually obtained and the amount of sleep the person needs to maintain alertness. This may be caused by poor management of off-duty time to obtain sleep, excessive work and associated work demands (commuting, deadheading) that limits the amount of time to get sleep, and poor quality sleep caused by bad timing (trying to sleep during the day), a bad environment (trying to sleep in an uncomfortable or noisy environment), or a sleep disorder (such as sleep apnea). All of these factors can cause an accumulated sleep debt that can impair alertness. The second kind of sleep problem occurs when a person has been awake more than 16 h since his/her last major sleep episode, called acute sleep debt. Normally, people sleep 8 h a day and are awake16 h a day. Once a person's awake period exceeds 16 h, he/she experiences an increasing pressure to go to sleep and this is reflected in a gradual loss of alertness and an increased potential for lapses, brief periods when the person loses contact with his/her environment. Problems from acute sleep debt can occur even when a person has been generally getting 8 h of sleep per day. A classic example of acute sleep debt can occur when a person awakens in the morning at 6 a.m. after sleeping regularly from 10 p.m. to 6 a.m. while on vacation and does not take any naps before going to work in the evening, say after 6 p.m. Work starts 12 h after awakening; if the work period is 8 h, the person will have been awake for 20 h at the end of the shift and may experience an acute impairment of alertness during the last half of the work period.

The time of day can induce problems with alertness because peoples' bodies have a biological rhythm that modulates alertness. For people who are adjusted to daytime work, they are generally most alert during the hours from 8 a.m. to 8 p.m. and experience impaired alertness between 12 a.m. and 6 a.m. This is called the circadian rhythm and is a property of many biological systems, including the brain. The exact timing of the rhythm can be changed by environmental factors. For example, when one travels to a new time zone, it can take many days for the rhythm to realign to the new time for sleep and wakefulness. If a person shifts from a day job to a night job, sleeping during the day, it will take many days or weeks for that person to adjust to that new routine. During the period of adjustment the person will experience impaired alertness called circadian desynchronization.

The two causes of impairments to alertness, sleep debt and time of day, are additive. A person working at 4 a.m. will be more impaired if also sleep deprived compared to a person at that same time who has been getting plenty of sleep and has been awake for only a few hours.

In summary, a number of variables can impair alertness, including chronic sleep debt, hours since awakening, time of day, and circadian desynchronization, and these variables add together. To estimate the amount of alertness impairment a person might experience, a way to combine all these factors must exist. Scientists have developed what are called sleep models or mathematical simulations of how these factors combine physiologically to cause reduced performance and impaired alertness. With a sleep model, a scientist can take information about a person's sleep history and the time of day of sleep and work and calculate how all these factors may combine to produce variations in brain function that is manifested as changes in cognitive speed, reaction time, attention to the environment, and judgment, i.e., alertness.

During the past 5 yr, the U.S. Air Force has sponsored the development of a model of human sleep regulation and circadian variation, as well as a scheduling tool based upon the model, which has been used to minimize aircrew fatigue and impaired alertness. The software was developed by SAIC and NTI and is called the Fatigue Avoidance Scheduling Tool (*FAST*™). This alertness forecasting system has been developed and tested by NTI under a small business innovative research (SBIR) grant from the U.S. Air Force and has been enhanced by SAIC under a contract with FRA. Fatigue predictions are derived from the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE™) model invented by Dr. Steven Hursh of SAIC. The SAFTE™ model has received a broad scientific review and the U.S. Department of Defense considers it the most complete, accurate, and operationally practical model currently available to aid operator scheduling. At the *Fatigue and Performance Modeling Workshop* held in 2002, of the six fatigue models evaluated from around the world, the most recent version of SAFTE™ had the lowest error of all models evaluated (Hursh et al., 2004). The U.S. Department of Transportation is in the third phase of a project to validate and calibrate the model for avoiding excessive fatigue in transportation operations.

FAST allows easy entry of proposed schedules and generates graphical predictions of performance along with tables of estimated effectiveness scores for objective comparison. High effectiveness scores signify that the person has a short reaction time, high mental speed, and a low tendency to have lapses in attention–or, in short, is mentally alert. Low effectiveness signifies that the person has impaired alertness, which includes longer than normal reaction times, slowed mental processing speed, and an elevated tendency to have a lapse in attention. The tool may be used for retrospective analysis of alertness related factors that may have contributed to an accident/incident or error. In this mode, information on the work and sleep schedules of operators before the event may be entered into the tool, a projection of performance effectiveness, and a prediction of the likelihood of a lapse, at the time of the event is determined. In combination with other information, this analysis can project the combined effects of time of day and sleep history as a contributing factor to safety-related events. Pilot data collected so far validate that low levels of effectiveness based on *FAST* predict an increased risk of accidents.

The *FAST* tool was used in this study to determine whether or not impaired alertness due to one or more of the factors discussed above may have contributed to any of the six RCL-involved accidents/incidents. *FAST* was selected for several reasons. The basic model (SAFTE) has undergone considerable testing and validation against available human performance data. The *FAST* scheduling tool has been used by the U.S. and Canadian Air Forces to evaluate fatigue in long duration transport operations, training exercises, and accident investigations. For example, the U.S. Air Force used *FAST* to evaluate the benefits of strategic naps to maintain sustained operations during 45 h nonstop bombing missions. FRA uses *FAST* to analyze railroad operations for the effects of shift schedules and acute sleep deprivation on possible human factors errors and accidents. The software is user friendly and available for government and commercial applications, leveraging the over $2.6 million development investment by the U.S. Air Force and Army. Multiple schedule windows can be used to compare alternatives as an aid to scheduling decisions or when comparing alternative scenarios. FAST includes an algorithm based on a major study of railroad engineers that computes likely sleep patterns under a given work schedule. This aids in the prediction of effectiveness when sleep histories are not available.

When using *FAST* it is recognized that impaired alertness is a continuous process that ranges from fully alert to minimally alert or asleep. No specific value of effectiveness or alertness signifies unsafe behavior. The level of alertness that is required for a specific situation depends on many factors: the demands of the job, the basic skills of the individual, the environmental conditions, the presence of safe guards, and the intrinsic motivation of the situation. Within *FAST*, effectiveness varies from 0-100 percent. The average person working from 9 a.m. to 5 p.m. during the day and getting 8 h of sleep at night will have effectiveness scores at work that range from 90-100 percent. Any value below 90 percent signifies some level of impairment compared to the average day worker; however, any operation that involves work at night will inevitably involve workers who are performing safely with effectiveness scores below 90 percent. So how much below 90 percent is considered problematic? Using the *FAST* model, Dr. Hursh has observed that effectiveness ranges from 65-90 percent during a day following a missed night of sleep. The U.S. Air Force has adopted a rule of thumb that says do not attempt flight operations with more than a single night of sleep deprivation (i.e., below 65 percent), and make every effort to maintain effectives in the upper half of the range between 65-90 percent (i.e., above 77.5 percent).

Furthermore, comparisons of the effects of alcohol and sleep deprivation on reaction time have suggested that an effectiveness score below 77.5 percent is roughly similar to the effects of alcohol consumption (blood alcohol level above 0.05 percent blood alcohol content, or BAC). Hence, the Air Force guide will be followed; an effectiveness estimate at or below 77.5 percent will be considered potentially problematic. Of course, these estimates are only a guide for several reasons: certain information that would improve the accuracy of the estimate are not available, such as actual sleep histories from RCOs (self-reported estimates of sleep histories were collected, but actual sleep history was not collected); the model assumes that all employees have an average sleep need of 8 h, which is only an estimate and not necessarily true of any given individual; and information was not collected on possible RCO sleep disorders. Because of these limitations, if the model revealed impaired alertness, it was always treated as a possible contributing factor rather than a probable contributing factor.

The process of evaluating an accident with *FAST* was straightforward. For each accident/incident, the work schedule and sleep habits of the RCO closest in time and physical proximity to the accident/incident was entered into *FAST*. The sleep algorithm within *FAST* was used to estimate probable patterns of sleep based on interview information about the typical sleep habits of the individual, such as the regularity and predictability of the work schedule, usual bed time, usual duration of sleep, the use of optional naps to augment major sleep episodes, commuting times, and any time typically reserved for personal affairs (see Appendix B for sleep habits questions that were asked of RCOs). When important information about a person's history was lacking, several possible scenarios (e.g., a best credible case and worst credible case) were considered. When effectiveness estimates were below 77.5 percent, the RCO's compromised alertness was considered to be a possible contributing factor of the accident/incident under study. Otherwise, compromised alertness was not considered to be a contributing factor in the accident/incident and noted in the exclusions section of each accident/incident analysis.

2.6 Case Study Format

To ensure that each case study was written in a consistent fashion, an outline was developed to structure each accident/incident case study. The outline, presented below, consists of five major sections (note that section numbers here do not correspond with header sections in actual case studies):

1. Summary
2. Circumstances before the accident/incident
    - 2.1. Meteorological conditions
    - 2.2. Personnel
    - 2.3. Yard layout
    - 2.4. Preceding events
3. The accident/incident
    - 3.1. RCL event recorder-based timeline
    - 3.2. Injuries
    - 3.3. Damage
    - 3.4. Train information
    - 3.5. Actions of RCL crewmembers
4. Analysis
    - 4.1. Exclusions
    - 4.2. Analysis of accident/incident
5. Corrective actions

Section 2.3, "Yard layout," of each case study includes a simplified yard diagram to help the reader understand the circumstances and follow the description of events leading up the accident/incident. Yard diagrams are not to scale and only depict portions of the yard that are relevant to the accident/incident. To provide consistency in reading each of the six yard diagrams, North is always oriented up.

Section 4.2, "Analysis of accident/incident," is structured in a hierarchical fashion, whereby first, the top-level contributing factors are identified. Then, for each top-level contributing factor, a number of more specific contributing factors are identified. In addition to including a brief explanation for why the contributing factor was considered important and relevant, each lower-level contributing factor is mapped to the most specific HFACS-RR category that is possible, given the data that are available. For example, a distracted RCO's action may be categorized as an operator act/skill-based error/attention failure.

Separately, an assessment was made in terms of the researchers' confidence in each contributing factor (i.e., finding) based on the data that support each finding. The U.S. Navy similarly assigns a level of confidence for each of its naval aviation mishap causal finding (U.S. Navy, 2003). A contributing factor was considered to be a probable contributing factor or a possible contributing factor. Probable contributing factors are those factors that researchers are reasonably confident contributed, in some way, to the accident/incident, either directly or indirectly, immediately or remotely, proximally or distally. Confidence is based on the degree to which data or information are consistent from one source to the next, verification from a second source, and the source of the data (e.g., event recorder is expected to be more reliable than interviewee recall). They are also based, although to a lesser extent, on engineering judgment. Possible contributing factors are those factors that appeared to contribute to the accident/incident based solely on interview data or the researchers' understanding of the accident/incident, but these factors lack additional data to corroborate or support this conclusion. Whether a contributing factor is assessed to be probable or possible is a reflection of researchers' confidence in the conclusion, not the degree of influence that the factor had on the accident/incident. Similar to the U.S. Navy mishap investigation process (U.S. Navy, 2003), no effort was made in the RCA to assess the relative importance of one contributing factor over another—all factors are considered equal with regard to their contribution to the accident/incident.

Participating railroads and unions were given an opportunity to review each case study for which they were involved. For example, if a case study involved the Acme Railroad and the Brotherhood of Railroad Operators, then both Acme Railroad and Brotherhood of Railroad Operators were permitted to review a draft of the case study. Reviewers were asked to focus their feedback on the accuracy of the information and ensure that the information in the case study was sufficiently de-identified. Based on stakeholder feedback, the final case study was either revised to reflect the new information or the alternative viewpoint was included in the case study next to the unchanged finding. A brief explanation why each alternative viewpoint was not incorporated into a finding is also included for completeness. Lastly, as part of each case study, railroads were asked to share what corrective actions they planned to make, or had made, to prevent re-occurrence of similar accidents/incidents on their properties.

3. FRA-Reportable RCL Accidents/Incidents at Participating U.S. Railroad Yards: May 1–October 31, 2004

Section 3 is further divided into two sections—discussion of the overall set of RCL accident/incident data collected over the 6-month period (Section 3.1) and discussion of the six RCL accidents/incidents that were examined in greater detail using RCA (Section 3.2). Sections 4-9 present results of the indepth RCA of each of the six case studies.

3.1 Overview of RCL Accidents/Incidents from May 1 to October 31, 2004

Data on all FRA reportable[5] train accidents and incidents—collisions, derailments, and employee injuries involving the operation or movement of on-track equipment—that occurred in yards and that involved RCL operations were collected from participating railroads for a 6-month period, from May 1 to October 31, 2004. A total of 67 RCL accidents/incidents were reported in this 6-month period. Data provided by participating railroads were not verified or validated with FRA accident/incident databases. However, at the end of the data collection period, participating railroads were asked to verify their own data to ensure accurate information.

Each accident/incident was uniquely categorized by event type as a collision (any impact with on-track equipment or object, and may include a subsequent derailment or injury), derailment (one or more cars or RCLs derail not due to a collision with on-track equipment or object), or employee-on-duty injury involving the movement of on-track equipment (not associated with an FRA-reportable collision or derailment). Collisions can include hard couplings that result in equipment damage, derailment, or injury. The first two events—collisions and derailments—are types of train accidents according to FRA (see FRA, 2003), while the last event is a considered a type of train incident. Together, these three event types are discussed simply as accidents/incidents. Table 3 presents a summary of the 67 RCL accidents/incidents by FRA category, event type, and associated injuries. An employee injury associated with a reportable collision or derailment is still considered a casualty, but it is classified as a train accident due to the reportable collision or derailment which preceded the injury.

For collisions and derailments (i.e., train accidents), participating railroads were asked to identify the train accident cause code. Train accident cause code data were provided for 44 of the 54 collisions and derailments, and missing for 10. In 3 of the 44 cases where train accident cause code data were provided, 2 train accident cause codes were reported. In each case, the first cause code listed was considered the primary cause while the second cause code was treated as the secondary cause[6, 7]. Of the 44 collisions and

[5] FRA-reportable accidents/incidents for the 2004 calendar year include train accidents—collisions and derailments—associated with $6700 or more in damage or incidents—employee injuries that required medical attention beyond first aid treatment. For further definitions of FRA accident/incident categories and FRA reporting thresholds, see FRA, 2003.

[6] Analysis of the three secondary cause codes shows that all three were human factors related. In each case, the primary cause code was also human factors related.

[7] Where one cause code is provided, it is the primary cause code.

derailments for which train accident cause code data were provided, 28 were associated with human factors cause codes (64 percent), 6 were associated with signal and communication cause codes (14 percent), 5 were associated with mechanical and electrical cause codes (11 percent), and 5 were associated with track, roadbed, and structures cause codes (11 percent). Among these 44 collisions and derailments, 7 train accident cause codes were cited more than once and accounted for 25 of the 44 collisions and derailments (see Table 4).

Table 3. RCL accidents/incidents by type

FRA Category	Event Type	Number of Accidents/Incidents	Number of Accidents/Incidents with Associated Injuries
Train accident	Collision	29	1
	Derailment	25	0
	Subtotal	**54**	**1**
Train incident	Injury[8, 9]	13	13
	Subtotal	**13**	**13**
	Grand Total	**67**	**14**

Table 4. Most frequently cited primary train accident cause codes

FRA Train Accident Cause Code	Description	Number of Accidents
H307	Shoving movement, man on, or at leading end of movement, failure to control	7
H306	Shoving movement, absence of man on, or at leading end of movement	5
H310	Failure to couple	3
H312	Passed couplers (other than automated classification yard)	3
H607	Failure to comply with restricted speed or its equivalent not in connection with a block or interlocking signal	3
H702	Switch improperly lined	2
S011	Power switch failure	2

[8] Includes one fatal injury.

[9] Five injuries were the result of non-reportable collisions (4) or derailments (1).

Analysis of all 67 accidents/incidents by time-of-day reveals that almost half of the 67 accidents/incidents—30 (45 percent)—occurred between midnight and 8 a.m. (see Figure 10), which roughly corresponds to third shift work. Some possible explanations for this finding include operator fatigue and visibility of the equipment. Examination of all 67 accidents/incidents per month reveals that the largest number of accidents/incidents—16, or 23.9 percent—occurred in August. Figure 11 presents accident/incident frequency data per month for the 6-month data collection period. Caution is warranted when trying to interpret time-of-day and monthly accident/incident data, however, since exposure data were not collected to provide a normalized accident/incident rate per time period or month.

Participating railroads were also asked to indicate whether or not each accident/incident occurred in an RCZ. Twelve accidents/incidents occurred within an active RCZ while 46 accidents/incidents did not occur in an RCZ. RCZ information was not provided for nine accidents/incidents.

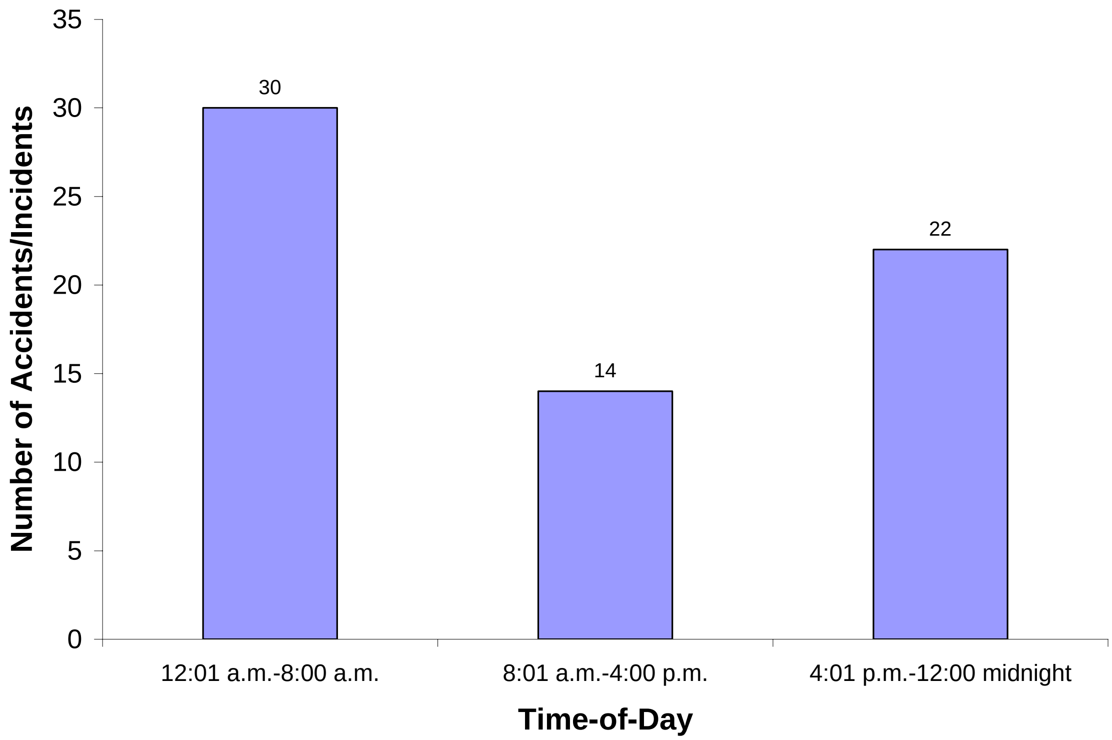

Figure 10. RCL accidents/incidents by 8-hour time period

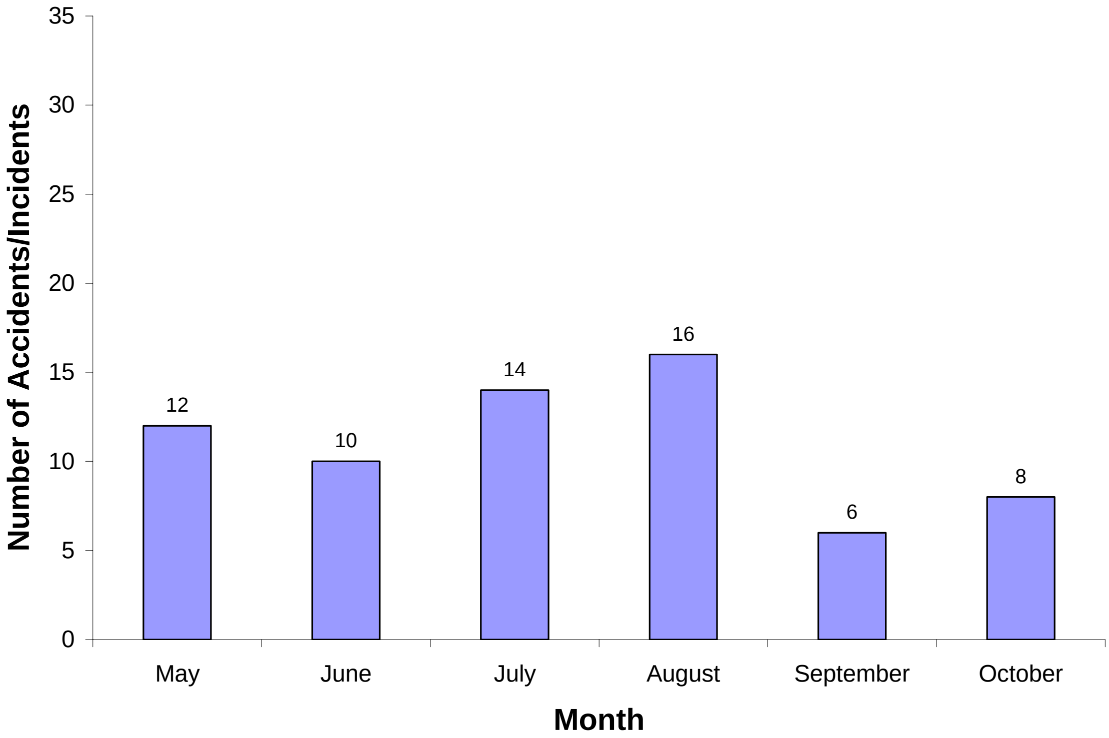

Figure 11. RCL accidents/incidents by month

3.2 Overview of Six RCA Case Studies

During the 6-month data collection period, researchers selected six RCL accidents/incidents to examine in greater detail using the RCA methods that were developed. To assist researchers in being objective in selection of the accidents/incidents, criteria and heuristics were developed. Though these criteria and heuristics were described in Section 2.3, they are reiterated here for convenience:

- Accidents/incidents had to occur in participating U.S. railroad yards, including large terminals and smaller satellite yards, and including hump and flat switching operations. Industry jobs are considered part of a yard, since the major activity involved with an industry job is switching cars, the same as that which occurs in yards themselves.
- Accidents/incidents had to involve qualified (i.e., certified) RCOs. Accidents/incidents involving student RCOs were not included.
- Transfer jobs and other jobs where the main function is moving a train from point A to point B were not included as candidate case studies.
- Accidents/incidents should be unique to RCL operations; that is, they likely would not have occurred under conventional operations.
- Look at a breadth of different potential human factors issues.
- Look at a breadth of different circumstances and kinematics.

- Examine at least one accident/incident that occurred in an RCZ.
- Examine at least one accident/incident that occurred with a one-person RCL crew.
- No more than two accidents/incidents from any one railroad will be examined.
- The data collection timeframe must work within researchers' schedules.

The result was that researchers conducted an RCA approximately once per month between May 1 and October 31, 2004.

Table 5 presents a summary of the six RCL accidents/incidents that were further examined through RCA.

Table 5. RCA accident/incident case study information

	FRA Category	Event Type	Time-of-Day (Local Time)	Did Accident/Incident Occur in Active RCZ?
RCL1	Train accident	Collision	6:30 a.m.	No
RCL2	Train accident	Collision	1:09 a.m.	No
RCL3	Train accident	Collision	3:45 a.m.	Yes
RCL4	Train incident	Injury	8:30 p.m.	No
RCL5	Train accident	Derailment	4:00 p.m.	No[10]
RCL6	Train accident	Derailment	2:06 a.m.	Yes

The next six sections present the results of the six RCAs. Accident/incident descriptions and analyses reflect the researchers' best understanding, at the time of data collection, of the circumstances that contributed to the accidents/incidents, and are based on data voluntarily provided by the employees and railroads. It is important to understand that the researchers could not exhaustively study each and every accident/incident. Several reasons exist for this: the researchers are not trained, formal accident/incident investigators; they do not have access to the resources of such investigative bodies as NTSB; and they are dependent on the voluntary participation of the railroads and employees, and thus, certain types of data were not available for review. Rather, the six RCA case studies begin to provide insight into some of the factors that contribute to RCL accidents/incidents across the entire railroad industry.

[10] The RCZ was initially activated but later de-activated when the crew operated with cars on the leading end of the movement. Thus, when the accident occurred, the RCZ was not active.

4. Case Study 1

4.1 Summary

At 6:30 a.m. local time, job 111, a southward RCL pulling a cut (a.k.a. string or draft) of cars on the middle lead track, collided with a northward RCL hump operation, job 222, at the far crossover between the middle lead and hump lead (see Figure 12) tracks. The northward hump operation was occupying the hump lead and the middle lead at the far crossover. Initial impact caused minimal damage. However, continued northward movement by the 222 job caused additional raking damage to the 111 locomotive, as well as the derailment of three of 222's cars. No injuries occurred.

4.2 Circumstances Before the Collision

4.2.1 Meteorological Conditions

At the time of the accident the temperature was 68° F, conditions were overcast to mostly cloudy, with calm winds and 10 miles of visibility. Sunrise was at 6 a.m. local time, about a half hour before the accident.

4.2.2 Personnel

<u>Job 111</u>

The foreman and helper of the 111 job went on duty at 11:58 p.m. the night before the accident. They had been on duty for about 6.5 h before the collision.

- *Foreman/A Operator*

  The foreman was 36 yr old. He had been qualified as a switchman for 84 mo. He had also been qualified as a yardmaster for 1 yr. He had been qualified as an RCO for 1 mo. His last rules examination was approximately 7 wk prior to the accident and resulted in satisfactory performance.

- *Helper/B Operator*

  The helper was 29 yr old. He had been qualified as a switchman and hostler for 29 mo. He had been qualified as an RCO for 8 mo. His last rules examination was approximately 8 mo prior to the accident and resulted in satisfactory performance. The helper had been off duty 35 h and 36 min prior to going on duty.

<u>Job 222</u>

The foreman and helper of the 222 job went on duty at 11:05 p.m. the night before the accident. They had been on duty for about 7.5 h before the collision.

- *Foreman/A Operator*

  The foreman was 33 yr old at the time of the accident. He had been qualified as a switchman and hostler for 82 months and qualified as an RCO for 7.5 mo. His last rules exam was 3 mo prior to the accident and resulted in satisfactory performance.

- *Helper/B Operator*

  The helper was 33 yr old. He had been qualified as a switchman for 41 mo, 23 mo as a hostler, and 8 mo as an RCO. His last rules exam was 14 mo prior to the accident and resulted in satisfactory performance.

<u>Tower yardmaster</u>

The yardmaster went on duty at 10:30 p.m. the night before the accident. He had been on duty for about 8 h at the time of the collision.

- The yardmaster was 33 yr old. He had been qualified as a yardmaster for 24 mo. He had been qualified as a locomotive engineer for 60 mo` and as a switchman for 48 mo. He had been qualified as an RCO for 6 mo. His last rules exam was 14 mo prior to the accident and resulted in satisfactory performance. This individual alternated among the different jobs for which he was qualified.

4.2.3 Yard Layout

The accident occurred at the south end of the yard (see Figure 12). At the south end three lead tracks exist. One, the hump lead, is used primarily for humping. The middle and outside lead tracks are used to bring trains in and out of the yard, and they are used as necessary to build trains for the intermodal facility. Two crossovers connecting the hump lead to the middle lead exist. One is the regular crossover (see Figure 13), and the other is the far crossover. In addition, two crossovers exist to the north of the office that connect the outer and middle lead tracks. The retarder crossover, one of these latter two crossovers, also allows access to the intermodal facility (see Figure 14). The outer and middle leads provide access to the receiving and departure (RD) tracks, while the hump lead provides access to the bowl classification tracks. Further south a highway-rail grade crossing is occasionally traversed by the switch crews using this end of the yard.

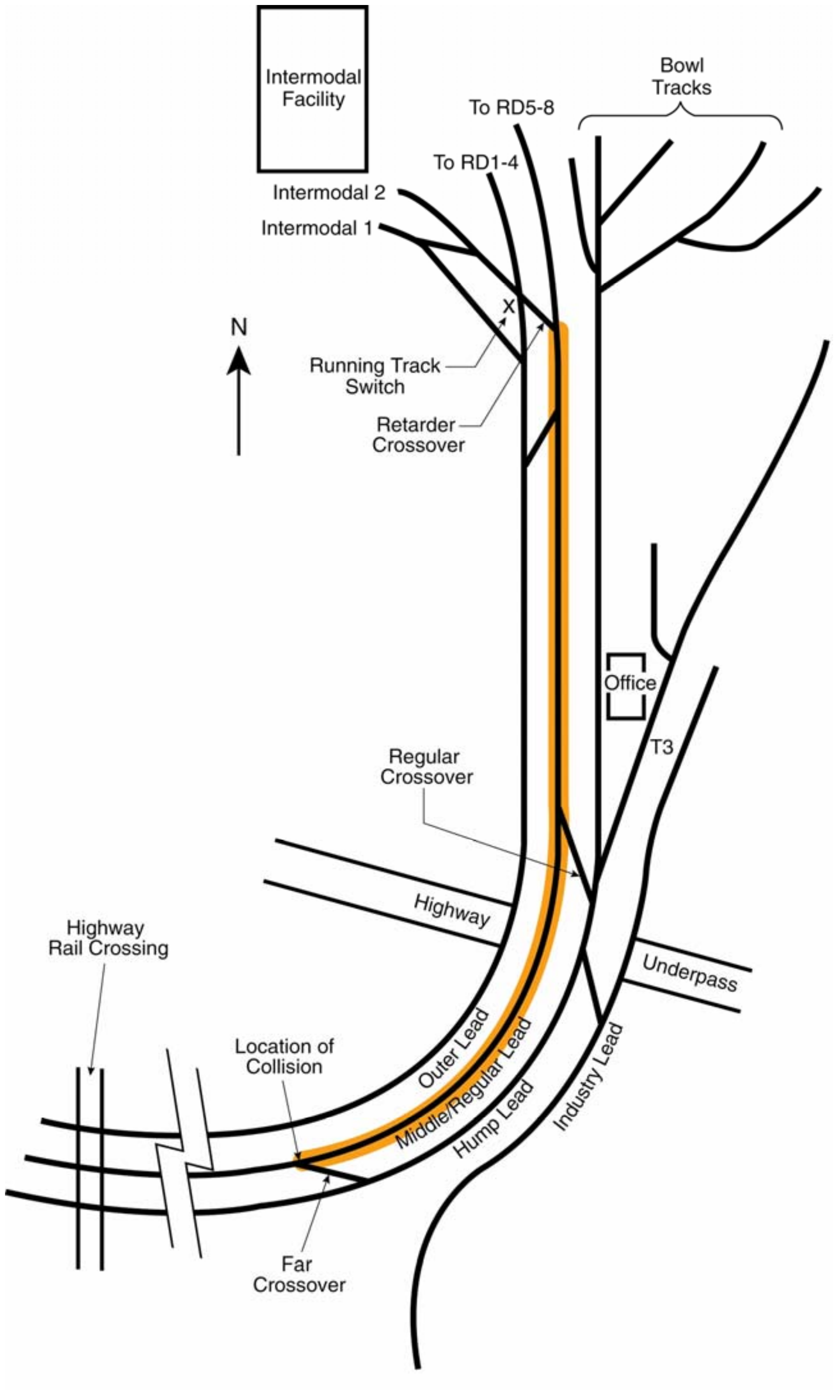

Figure 12. RCL1 south end of yard with job 111 southward path highlighted

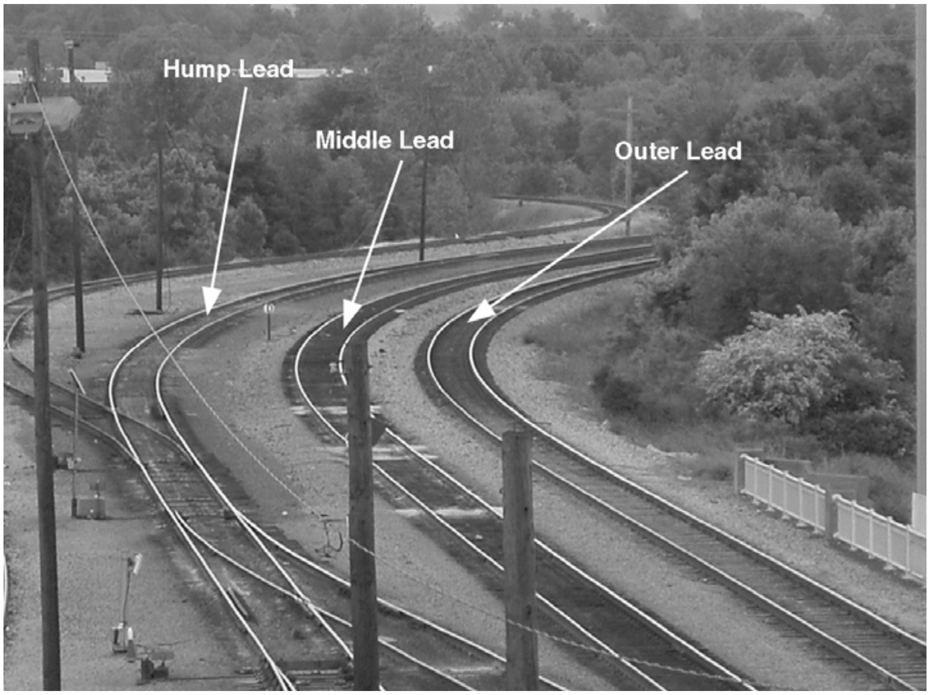

Figure 13. RCL1 southward view of outer, middle, and hump lead tracks and regular crossover in the foreground

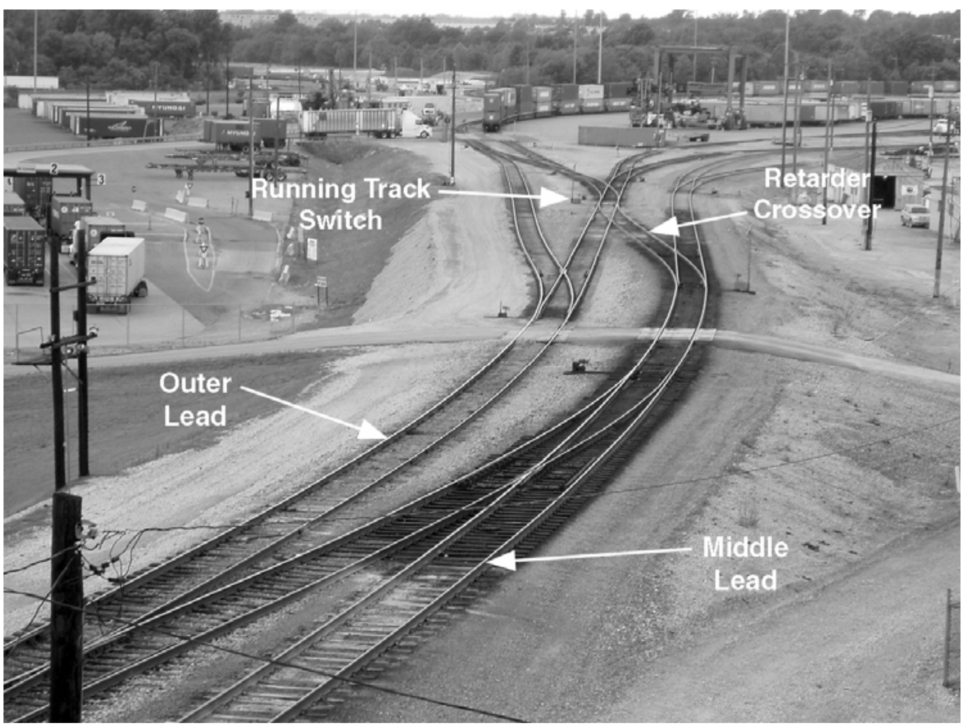

Figure 14. RCL1 northward view of middle and outer lead tracks with retarder crossover in the background

4.2.4 Preceding Events

Before the accident, job 111 was instructed to pull a cut of cars out of RD5 to enable an inbound train to pull into RD5 before the train crew's Hours of Service expired. Job 111 was instructed to take their cut up the middle lead, use the far crossover to access the hump lead to hump the first half of the cut of cars, and shove the last half of the cars into RD8 using the turnout from the bowl to the RD tracks. Ordinarily, the regular crossover is used to go from the middle lead to the hump lead to set up a hump operation. However, occasionally (one estimate was 1 in 20 times) it may be necessary to bring a cut over from the middle lead to the hump lead using the far crossover. Use of the middle lead and far crossover were necessary since another crew, 222, was using the hump lead. The 111 crew pulled up the middle lead past (clear of) the far crossover, lined the far crossover to access the hump lead for a northward move to the hump, waited for 222 to enter track T3 (to eat lunch) and clear the hump lead, and began shoving northward on the hump lead. They did not reline the far crossover for straight movement.

After lunch, 222 came back out onto the hump lead and used the regular crossover to pull a cut of cars out of RD4 to bring them to the hump. 111 then went to lunch in T3. After lunch, the 111 foreman received a switch list from the yardmaster and conducted a job briefing with his helper to discuss their next move. They were instructed to get a cut of cars from RD2 and bring it southward up the middle lead and shove northward to the intermodal tracks via the running track switch (see Figure 14).

222 was busy humping cars on the hump lead at the time the 111 crew received their assignment. The yardmaster asked 222 to back up to allow 111 to depart T3. 111 came out T3, then traveled northward on the hump lead through the regular crossover to the middle lead, then relined the regular crossover straight, and went down the middle lead into RD2 to pick up their cut of cars. The 222 crew resumed humping on the hump lead.

After humping their cut of cars, 222 was instructed to pull a large cut of cars, about 6300 ft, out of RD4 through the retarder crossover to the middle lead through the regular crossover to the hump lead and, once clear of the regular crossover, to begin humping northward on the hump lead. 222 picked up their cut of cars and began their southward move. 222 came up the middle lead, crossed over to the hump lead at the regular crossover, traveled southward along the hump lead, and crossed back over to the middle lead via the far crossover. 222 continued their southward move across both leads using both crossovers. Eventually 222 cleared the regular crossover. They then reversed direction and began humping northward, occupying both the middle and hump leads and far crossover.

At the same time, 111 began to pull its cut of 1500-1700 ft of double-stacked intermodal containers on flat cars (a.k.a. COFC, pigs, or piggybacks) southward from RD2 across the retarder crossover and out the middle lead. A train was parked further up on the outer lead, preventing 111 from using this track. The helper (operator B) rode inside the locomotive while protecting the point. The foreman (operator A) rode the cut out of RD2 and dismounted at the running track switch to be in position to line the switch for the reverse move into the intermodal tracks.

4.3 The Collision

As 111 pulled their cut southward up the hill using the middle lead and the rear of the cut of cars came closer to clearing the running track switch for the reverse move into the intermodal track, 111 foreman began incrementally reducing the speed of his cut of cars from the 8 miles per hour (mph) setting to Hump-Slow (approximately 1.6 mph). As the cut of cars reduced speed, it struck cars from 222 that were moving northward on the middle lead through the far crossover to the hump lead (see Figure 15 for the location of the accident). The 222 foreman stopped their movement shortly after the initial collision. The 222 foreman then resumed northward movement, causing additional raking damage. 111 also began to move northward, either because 222's movement shoved 111 northward due to contact from the collision or because gravity pulled 111 back down the hump crest hill. Moments later, the 222 foreman again stopped the movement. The 111 cut of cars also stopped. The 222 crew then investigated and discovered the collision.

111's speed was 2.61 mph upon impact, when the RCL event recorder shows a low pipe pressure event, likely due to a break in the air hose at the front of 111's locomotive as it impacted with a car from 222. The low pipe pressure event caused the RCL system to initiate an emergency brake application and brought 111 to a stop. According to the event recorder, 222 was traveling between 1.8-2.0 mph at the time of impact.

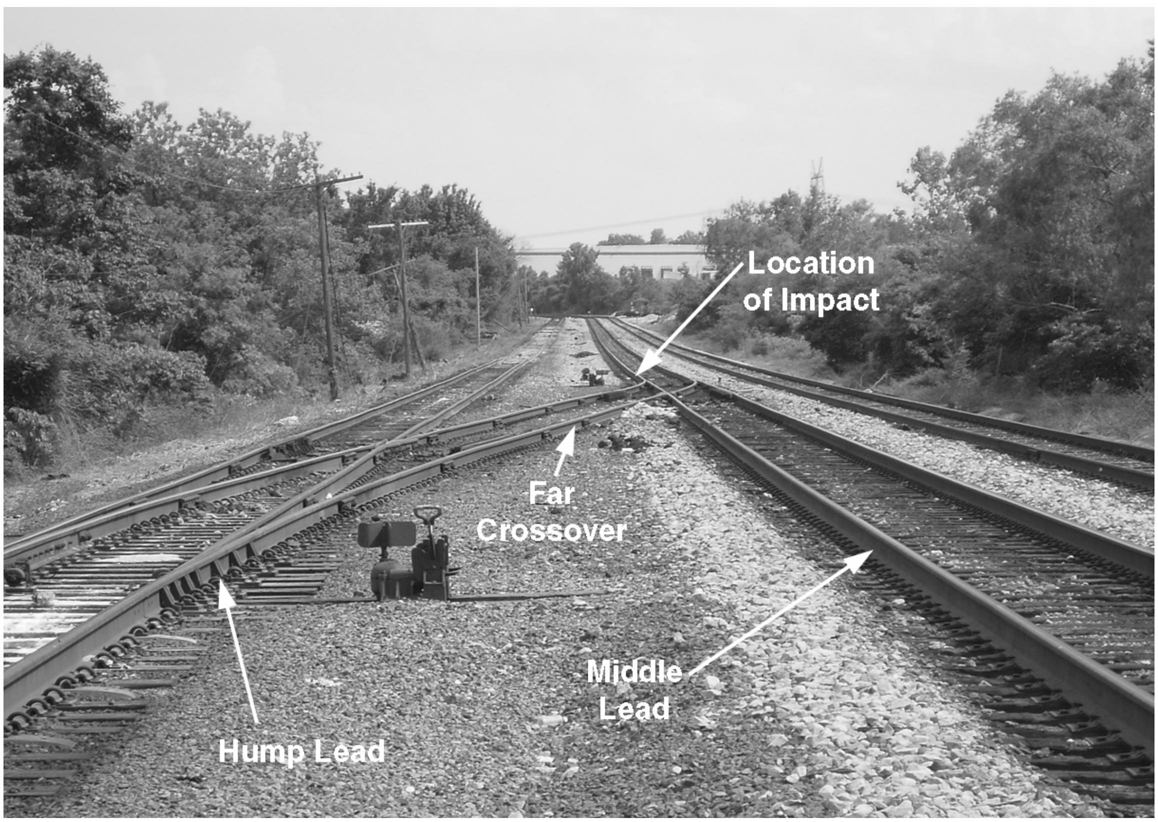

Figure 15. RCL1 southward view of collision location

4.3.1 RCL Event Recorder-Based Timeline

Table 6 provides a timeline of information from the 111 RCL OCC event recorder download.

Table 6. RCL1 OCC event recorder download data

Time	Event	Additional details
06:32:02 a.m.	Operator adjusts speed from 8 mph to 4 mph; speed 8.04 mph; odometer 1858.	RCL traveling in southward direction.
06:32:08 a.m.	Operator adjusts speed to 2.25-Hmp[11]; speed 6.93 mph; odometer 1927.	
06:32:11 a.m.	Operator adjusts speed to 1.75-Hmp; speed 6.15 mph; odometer 1960.	
06:32:20 a.m.	RCL records a low pipe pressure event; speed 2.61 mph; odometer 2019.	Likely point of impact.
06:32:22 a.m.	Low pipe pressure fault. System initiates emergency brake application. System applied and maintained full independent brake and emergency train brake; speed 1.81 mph; odometer 2025.	
06:32:25 a.m.	Speed 0.00 mph; odometer 2029.	111 stops.
06:32:54 a.m.	Speed -0.43 mph; odometer 2028.	111 travels in northward (opposite) direction.
06:33:01 a.m.	Speed -0.24 mph; odometer 2025.	
06:33:02 a.m.	Speed 0.00 mph; odometer 2025.	111 comes to a second stop.

4.3.2 Injuries

No injuries occurred.

4.3.3 Damage

The initial impact likely caused minimal damage. When 222 resumed movement northward, however, it caused raking along the leading left edge of 111's locomotive, resulting in damage to the 111 locomotive (see Figure 16) and the derailment of three of job 222's cars. Two of the three derailed cars were damaged (see Figure 17).

[11] Hmp refers to a preset RCL speed, in mph, used primarily for humping operations. Hump speeds are usually minimal, somewhere between 1 and 4 mph. Thus, 2.25-Hmp refers to a hump speed setting of 2.25 mph.

Figure 16. RCL1 damaged 111 RCL

Figure 17. RCL1 damage to box car

Actions of the 222 Crew

During their southward pull move, the helper, riding the point, noticed the far crossover switch position oriented for the middle lead and may have notified his foreman that they were going out the middle. However, no other communication or action was taken. Once the cut of cars cleared the regular crossover, the crew relined both ends of the regular crossover straight, reversed direction, and began to shove their cut northward to begin humping along the hump lead.

Actions of the 111 Crew

The helper gave an initial car count of 20 at the beginning of the southward move up the middle lead. It is unclear whether or not any additional car count information was given and, if so, whether or not the helper gave an updated car count 10 car lengths into the original count or a new car count after the initial 20 car lengths. Railroad operating rules specify that radio communications for backing and shoving movements must specify the direction and distance and must be acknowledged when distance specified is more than four cars. Further, movement must stop within half the distance specified unless additional instructions are received. As the rear of the cut approached the running track switch, the 111 foreman began to slow the movement down in preparation of stopping clear of the running track switch. The 111 foreman adjusted the speed selector to Hump-Slow.

Just before he was going to stop the movement, the 111 foreman reported that he heard his helper say, “That’ll do.” The RCL then went into emergency on its own and stopped the movement.

Actions of the Yardmaster

The yardmaster had asked 111 to use the far crossover for an earlier move. After 111’s use of the far crossover, the yardmaster said that he was going to tell the crew to line the switch back. However, the yardmaster reported that he heard over the radio that the 111 crew was stopping to line a switch. The yardmaster assumed this communication was referring to the relining of the far crossover. Believing the far crossover was lined back for straight movement on the hump lead, the yardmaster tended to other duties.

4.4 Analysis

The analysis section is organized into two sections. The first section identifies exclusions—those factors that were examined but not considered to be a contributing factor. The second section presents and identifies the HFACS-RR analysis.

4.4.1 Exclusions

The investigation team considered the following exclusions and factors and dismissed them as contributing factors. They are included here for completeness.

- Because movement of the 111 job was in a southward direction, the position of the sun, rising in the east, probably did not produce glare that could have negatively impacted the foreman's ability to see the 222 job.
- Weather did not appear to contribute to the collision.
- The operating crews and the yardmaster appeared to be familiar with this area of the yard.
- The crewmember of the 111 job, the B operator of the 222 job, and the yardmaster did not appear to be sick. The 222 A operator was not interviewed.

4.4.2 Analysis of Accident

Two basic elements existed that led to the collision. They are the double crossover move by the 222 crew, which errantly placed 222 on the middle lead track, and inadequate situation awareness by the 111 helper at the point of 111's movement to prevent the collision. The remainder of this section provides a human factors analysis of these two elements. The helper's loss of situation awareness is discussed first.

> <u>Railroad Comment 1</u>: Do not agree with the statement that the double crossover move by the 222 crew was a basic element leading to the collision. The cause of this accident was entirely the fault of the crewmember on the point of movement for failure to comply with rules related to stopping within half the range of vision. Rules are provided that cover crossover moves. No violation of this rule occurred before or subsequent to the accident.
>
> <u>Railroad Comment 2</u>: Due to switches not lined or equipment fouling tracks, all movements are made at a speed which requires being prepared to stop short of switches not properly lined or equipment fouling the movement.
>
> <u>Authors' Response</u>: The fact that the 111 crew failed to follow a rule requiring that they stop short of equipment fouling the movement does not explain why the rule was violated nor why the collision occurred; it explains what happened. The RCA focused on *why* the collision occurred, including why the 222 crew occupied the far crossover and middle lead track at the time of the collision.

Loss of RCO Situation Awareness

The 111 helper gave an initial car count to his foreman, in control of the move, as they began their southward movement. It is unclear what followed in terms of whether or not a car count update occurred. The 111 foreman began to slow the movement down as the rear of the cut of cars neared the running track switch that needed to be cleared for reverse movement. However, no subsequent inputs were made by the helper or the foreman placing the RCL into emergency to avoid the collision. It was the initial impact between the 111 RCL and a car from 222 that caused the 111 RCL to go into emergency and apply the brakes. The lack of RCD input by the helper suggests that the helper had lost situation awareness allowing 111 to strike 222, which was fouling 111's path at the intersection of the middle lead and far crossover. A number of factors likely contributed to the helper's loss of situation awareness, which are discussed below.

HFACS analysis:

- Helper failed to attend to (notice) cars fouling path. The helper, riding in the cab of the RCL, failed to attend to, or otherwise notice, the cars fouling his path and consequently was unable to stop the cut before it collided with the 222 job. It is unclear, however, precisely why the RCO did not attend to the cars fouling his path. *Operator acts/skill-based error/attention failure.* **Probable contributing factor.**

> Railroad Comment: Both operators had responsibility for this movement. Operator B (helper) was required by rule to communicate direction and distance of the move from the cab of the locomotive. Operator A (foreman) was required by this same rule to stop the movement within half of the last transmitted distance received from operator B. This process was not followed by either employee; however, operator A should have stopped before the cut moved 10 cars as no further communication occurred. Additionally, operator B had the capability to place the locomotive in emergency from either the remote control transmitter or due to the fact the operator was in the locomotive cab.
>
> Authors' Response: It is understood that, according to operating rules, both operators had a responsibility for the movement. However, identification of responsibility for the movement alone does not explain *why* the collision occurred. Further, based on the data collected, it is not clear what communication occurred between the two crewmembers of job 111. Regardless of responsibility or communications, data collected suggest that the helper failed to attend to the cars in the path of his movement. Possible explanations for this failure follow below.

- Helper's alertness was likely compromised at the time of the collision. According to the results of the FAST analysis, the 111 helper had a calculated effectiveness of 66.7 percent and a likelihood of lapse about six times the rate of a well-rested person. This level of effectiveness is below the level of effectiveness that might be expected of a person with a blood alcohol level of 0.08 that produces an effectiveness of about 70 percent. This compromised effectiveness and alertness is the result of the combined effects of three fatigue factors. First, the helper was carrying an accumulated sleep debt from prior work and restricted sleep of 9.8 h. A sleep debt of 8 h is considered problematic. Second, the helper had less than 2 h of sleep in the prior 24 h based on the prior work history and the helper's self-reported sleep habits. Less than 8 h of sleep is considered problematic. Third, the collision occurred near the typical circadian nadir (lowest point) at 6:30 a.m. The hours between midnight and 8:00 a.m. are considered problematic. *Preconditions* *for operator acts/operator conditions/adverse physiological state.* **Possible contributing factor.**

- Operating practice allowed the foreman to control the move at the rear, which likely reduced the helper's situation awareness by making point protection task passive. The foreman of job 111 was in control of the move at the rear of the movement, while the helper rode inside the RCL cab to provide point protection. This was an accepted practice when it was necessary to clear a switch at the rear of the movement. In contrast, RCOs were required to be at the point when in control of the move during humping operations and during couplings. Since the helper was not actively controlling the RCL on the head end, the helper's task, that of monitoring the track ahead to protect the point, was passive. This passivity likely degraded the helper's vigilance, at least to some extent, and likely contributed to the helper's loss of situation awareness. *Organizational factors/organizational process/organizational practices and procedures.* **Probable contributing factor.**

Double Crossover to Unintended Track

Before the accident, the crew of 222 pulled about 6300 ft of cars on the middle lead, through the regular crossover to the hump lead, and then through the far crossover back to the middle lead. The helper on the 222 may have told his foreman about the move back up the middle, but no further communication or action was taken. Based on interviews, a double crossover move like this one is rare and is usually a mistake, though it does happen occasionally. Since 222 was pulling such a heavy cut, had they tried to stop their movement to shove back northward out of the far crossover and resume southward movement along the hump lead to correct their move, they may not have been able to restart because of the ascending grade from the RD tracks to the crest. According to interviews, if 222 had not been able to resume, they would have had to shove all the way back down and retry the move. An alternative would have been to continue southward with their move but notify the yardmaster so that he could instruct other crews to work around 222's double crossover move. Earlier in the morning, 222, on the hump lead, had backed up southward to let 111 out of T3 after lunch, but 222 did not back up far enough to become aware that the far crossover was lined for the middle lead. These factors are discussed below.

HFACS analysis:

- Poor RCO decision not to inform others of errant move to unintended track. It is unclear whether or not the 222 helper reported the double crossover move to his foreman in control of the move. If the 222 helper did inform his foreman about the move back to the middle lead, he did not receive any feedback from his foreman, and the helper did not try to communicate this information to his foreman again. Further, the helper did not inform the yardmaster of the double crossover back to the middle lead. Due to the fact that the yardmaster's instructions to 222 were to use the hump lead once past the regular crossover, not the middle lead, the decision not to ensure that the yardmaster was aware of their occupancy of the (incorrect) middle lead was a poor choice. *Operator acts/decision error/poor choice.* **Probable contributing factor.**

> <u>Railroad Comment</u>: Do not agree that the use of both crossovers was a contributing factor for the cause of derailment. This type of move could have been at the direction of the yardmaster, and no requirement would have existed for the yardmaster to notify the 111 crew. This is possible because rules exist related to stopping within half the range of vision. This basic yard movement rule requires all moves to be prepared to stop within half the field of vision.
>
> <u>Authors' Response</u>: Had the 222 crew occupied the hump lead as directed by the yardmaster, they would not have been in the path of job 111 along the far crossover and middle lead track. Thus, the double crossover move was a necessary, but not sufficient, factor that set up the conditions for the collision that occurred. Because the yardmaster believed the 222 crew was using (only) the hump lead, as directed, he instructed the 111 crew to use the (separate) middle lead. The RCA attempted to explore why the 222 crew occupied the far crossover and middle lead, as well as why this information was not communicated to others, such as the yardmaster.

- <u>Loss of yardmaster situation awareness</u>. During the previous move, the tower yardmaster intended to instruct 111 to reline the far crossover switch for straight movement. However, he misinterpreted a communication between 111 crewmembers discussing lining of a switch. The yardmaster believed the referenced switch being discussed by 111 crewmembers was the far crossover. He subsequently believed the far crossover was relined for straight movement. This loss of situation awareness was, at least in part, probably due to the yardmaster's large number of responsibilities. Monitoring radio traffic and keeping (mental) track of switch positions are only two of these responsibilities. Yardmaster responsibilities include communicating and coordinating with numerous train crews, other yardmasters and operators, and dispatchers, as well as strategically managing the flow of work in one or more sections of a yard. The large number of demands placed on the yardmaster places a significant workload, whereby monitored radio communications can be misunderstood, and awareness of the moment-by-moment switch positions and yard movements can be diminished or impaired. Furthermore, from his office in the hump tower, the tower yardmaster cannot visually confirm or check the status of the far crossover since this part of the yard, including the crossover switches, are beyond a curve (see Figure 18). *Supervisory factors/inadequate supervision.* **Probable contributing factor.**

Railroad Comment 1: Yardmasters are charged with the management and general operation of the yard they have jurisdiction over. They are not expected to know each and every move each engine makes in the yard. Yardmasters are not required to know the position of every switch in the yard. The yard crews manage these details. The yardmaster expects each of his engines and their crew members to work per the Operating Rules.

Railroad Comment 2: Field of View is not a factor. The view from the tower at this location is better than most. At some locations the yardmasters are located in buildings with no overhead view of their yard. Many use only cameras at strategic locations. While the yardmasters are charged with the management of the yard, it is not necessary they be able to see the entire yard and every moment.

Authors' Response: It is understood that the yardmaster has a number of responsibilities related to the management and general operation of the yard. It is also understood that the view of the yard from the yardmaster's office is better than at other yards. At this location, the yardmaster gives instructions to the yard crews regarding which lead tracks to use when making moves using these tracks. Thus, to some extent, the yardmaster does manage track occupancy within the yard. Given the intent of the yardmaster was to instruct 111 to reline the far crossover switch for straight movement during the previous move and his misinterpretation of a communication between 111 crewmembers regarding the intent of a crewmember to line a switch, it is reasonable to believe that the yardmaster was trying to keep apprised of the status of the lead tracks and crossovers in order to make subsequent assignments using the middle and hump lead tracks. However, for a variety of reasons, including the lack of direct line-of-sight to these tracks, the yardmaster's situation awareness was reduced. Had the yardmaster been aware of the switch position of the far crossover, it is reasonable to believe that the yardmaster would have communicated this information to the 111 and/or 222 crews, or instructed one of the crews to line the switch back for straight movement. Furthermore, had the yardmaster known that 222 was occupying the far crossover and middle lead, it is reasonable to believe the yardmaster would not have instructed the 111 crew to occupy the same track, or at a minimum, may have informed the 111 crew of the presence of 222 ahead of their movement. Thus, the authors cite the yardmaster's diminished situation awareness as a contributing factor, since, had the yardmaster been aware of the far crossover switch position or the exact location of the 222 crew, the collision would not have occurred due to yardmaster intervention.

Figure 18. RCL1 southward view from yardmaster's office (far crossover out of sight)

4.5 Corrective Actions

To prevent similar accidents/incidents from occurring in the future, the railroad has made, or is in the process of making, the following yard-specific corrective actions since the accident occurred:

1. The operator at the point of a move must always be in control of the movement.
2. Yardmaster communication protocol has been enhanced between yardmaster and operating crews to require yardmasters to provide information to switching crews on any potentially conflicting moves, such as another crew that is using the same lead but further up.
3. Northward and southward movements on the hump end of the yard (where the accident occurred) are required to operate with train air to increase braking ability.

5. Case Study 2

5.1 Summary

At 1:09 a.m. local time, a two-person RCO job was instructed to pull a cut of cars westward to receiving track 4, cut off the engine, attach the engine to the west end of a cut of about 60 cars in adjacent receiving track 3, and then shove the cut eastward to hump the cars. The foreman (B operator) remained in the hump office to operate the hump computer and manual retarders. The helper (A operator) pulled the cut of cars into R4, uncoupled his engine, continued westward out a lead track, and then reversed direction into R3 to couple up to the cars in R3. After making the initial coupling between locomotive and cars, the RCL pulled westward to confirm that the coupling was successful (to give it a stretch). The RCO then set-and-centered the RCL to bleed off the air on several cars and release the handbrakes on several cars. The RCO was then vanned eastward to the hump, where he verified the positions of the switches on the east end of the receiving tracks, and initiated RCL movement. He started the move at about 2 mph, increased the speed to 4 mph, then 8 mph, expecting to see his cut of cars coming to him. The RCL moved westward instead of eastward, away from the hump, and impacted a departing train on the north running track. The collision resulted in damage to the RCL and the derailment of four cars on the departing train, as well as damage to the track, nearby switch, and signal. The collision was due to the helper's loss of situation awareness, in particular, to his cut of cars and their direction of movement.

5.2 Circumstances Before the Collision

5.2.1 Meteorological Conditions

The temperature was 64° F with southeast winds between 11.5 and 13.8 mph. Heavy thunderstorms had occurred earlier that evening, but conditions at this time were between partly cloudy and clear. Visibility was 10 miles.

5.2.2 Personnel

<u>RCL Crew</u>

The RCL crew went on duty at 11:00 p.m. the evening before the collision and had been on duty for a little over 2 h at the time of the collision.

- *Helper/A Operator*

  The helper was 28 yr old. He worked as a maintenance-of-way employee for 6 mo prior to qualifying as a switchman. He had been qualified as a conductor for 7 yr, 5 yr 6 mo as a yard switchman, and 16 mo as an RCO. In the last 12 mo, he has had 59 efficiency tests, of which 14 were RCO tests. He received passing scores on all but two tests; neither of which were RCO-related. His last efficiency test was less than 2 mo before the collision. His most recent annual performance monitoring observation was 15 mo prior to the collision. His last biannual rule examination was 11 mo prior to the collision. He was working on the extra board at the time of the collision and rotated among several yard jobs, including the bowl/trim job and the hump job. He had been off 16 h before going on duty.

- *Foreman/B Operator*

  The foreman was 41 yr old. The foreman had been qualified as a switchman for 7 yr 10 mo and qualified as an RCO for 1 yr 6 mo. His last biannual rules exam was 2 mo prior to the collision, and he had his annual performance monitoring observation less than 2 mo before the collision. In the last 12 months, he has had 138 efficiency tests[12], of which 133 were RCO tests. He received passing scores on all tests but one, which was not RCO-related. His last efficiency test was less than 1 month prior to the collision. This was the foreman's regular job. He had been off 16 h before going on duty.

Departing Train Crew

- *Utility Man*

  The utility man for the outbound train was 31 yr old. He had been qualified as a switchman for 8 yr. The utility man was assisting the departing train crew in setting out a bad order car. Though he was not working as an RCO at the time of the collision, the utility man had also been qualified as an RCO for 2 yr.

5.2.3 Yard Layout

On the west end of the yard, eight receiving tracks run east-west, where R1 is the northernmost receiving track. North and parallel to these tracks are departure tracks 1-4, where D1 is the northernmost track. The receiving and departing tracks merge together on the west end of R8 on what is referred to as the north running track. The receiving tracks feed to the hump via a ladder track to R2; R2 runs up to the hump. The classification yard is positioned to the east of the hump (see Figure 19). One set of overhead lights is near the highway-rail crossing at the west end of the receiving and departing tracks.

[12] The discrepancy between the number of efficiency tests between the foreman and helper is because the foreman works a regular job and therefore is routinely exposed to more efficiency tests. The helper works various jobs and therefore may not consistently be evaluated.

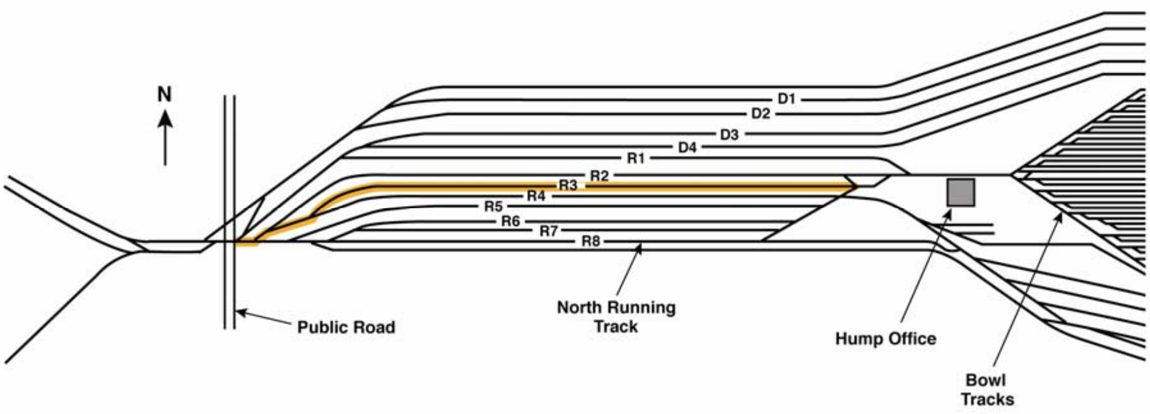

Figure 19. RCL2 west end of yard with RCL path highlighted

5.2.4 Preceding Events

Using locomotive 6331, the helper from the RCL job began the move by pulling a cut of cars out of bowl track 15 westward to R4. The helper cut the RCL off on the west end of R4 and then ran his light RCL westward out the north running track. The helper then lined a reverse switch eastward into R3 to tie on the west end of a cut of 62 cars for a shove move eastward to the hump. After coupling up to the standing cars in R3, the helper set his reverser to forward (the locomotive's F side was oriented westward) to stretch the cut to ensure that the coupling was successful. He stretched the cut and stopped. He then walked back to bleed the air out of those cars that still had air (the carmen leave the air in a few cars to help hold the cut). As the helper looked down at the RCD to set-and-center the controls to go in between the cars to release the hand brakes, he noticed that the reverser was in forward. The helper placed the reverser into neutral, made sure the speed selector was set to stop, and notified his foreman that he was going to go between the cars. After receiving confirmation from his foreman, the helper went between the cars to release the hand brakes. After releasing the hand brakes, the helper boarded a shuttle van that took him to the hump, where he planned to shove the cut eastward on R3, eastward on the east ladder track to R2 to the hump.

Separately, a departing train was just finishing setting out a bad order from D1 into R1 on the west side of the yard. It pulled westward on D1, split the cut, and pulled out across the highway-rail crossing. The train then received permission from the tower operator to shove back eastward into R1 and set the bad order out. The departing train then began pulling westward out of R1 with the intent of clearing R1 and shoving back into D1 to tie back on to the rest of its cars in preparation of departing the yard.

5.3 The Collision

Track R3 contained 62 cars, all on the west end of the track, leaving at most about 5-6 car lengths of travel on the east end of R3. The distance from the nearest car in R3 to the hump was about 25 car lengths. Once at the hump, the helper disembarked from the van, verified his eastward switch positions, placed the reverser into forward, and initiated movement of his cut of cars.

He began at 2 mph, and after not seeing the cut of cars after a moment, he increased the speed to 4 mph and then to 8 mph. He entered the hump office at this point, obtained his switch list, and looked out the window westward to see if he could see his cut coming toward him. After a short time, he said aloud to his foreman and a third employee in the office, “I should have seen the cars coming by now.” At that time the utility man on the departing train radioed the RCL crew to ask where they were headed with their RCL. The third employee (on light duty) looked at a video monitor that shows a camera view of the west end of the receiving tracks and said, “Well, there are your cars going westbound.” The helper quickly confirmed this and immediately set his RCD speed selector to stop.

At the same time, a utility man attached to the departing train, and positioned near R1 and D1, noticed the RCL starting to move westward on R3 but initially thought an engineer was on board (i.e., that it was a conventional crew). He thought the RCL was going to stop, but, as the RCL moved closer to the departing train on the north running track without slowing down, the utility man radioed his crew and told them to stop and prepare for a collision. The RCL struck the departing train on the north running track.

5.3.1 RCL Event Recorder-Based Timeline

Table 7 provides a timeline of information from the RCL OCC event recorder download.

Table 7. RCL2 OCC event recorder download data

Time	Event	Additional details
0:59:08 a.m.	Operator speed command of .80 Hmp in reverse	Operator shoves eastward to tie on to the cut of cars.
0:59:42 a.m.	Operator speed command of coast.	
0:59:45 a.m.	Operator speed command of stop.	
0:59:47 a.m.	Locomotive comes to a stop	RCL tied on to cars in R3.
0:59:48 a.m.	Operator places reverser into forward	Operator prepares to stretch the joint to ensure locomotive coupled to cut of cars.
0:59:50 a.m.	Operator speed command to 4 mph	
0:59:57 a.m.	Operator speed command to stop	Operator confirms tie-on with cars.
1:00:00 a.m.	Locomotive comes to a stop	
1:02:39 a.m.	Operator places reverser into neutral	Operator then releases hand brakes on cars.
1:06:28 a.m.	Operator places the reverser into forward	Operator prepares for movement to the hump.
1:06:34 a.m.	Operator speed command of 2 Hmp	
1:07:16 a.m.	Operator speed command of 4 mph	
1:07:19 a.m.	Wheel slip	
1:07:24 a.m.	Wheel slip	
1:07:52 a.m.	Operator speed command of 8 mph	
1:08:02 a.m.	Wheel slip	

Time	Event	Additional details
1:08:41 a.m.	OCU A RSC warning	The RCD vigilance alarm initiates
1:08:41 a.m.	Operator Command	Operator re-sets the vigilance alarm.
1:09:16 a.m.	Wheel slip	
1:09:18 a.m.	Wheel slip	
1:09:22 a.m.	Operator speed command to stop	Operator realizes westward movement.
1:09:23 a.m.	Wheel slip	
1:09:31 a.m.	Locomotive comes to a stop	

5.3.2 Injuries

No injuries occurred.

5.3.3 Damage

The accident resulted in damage to the RCL (see Figure 20) and the derailment of four tanker cars on the departing train (see Figure 21), as well as damage to the R1 track (see Figure 22 and Figure 23), nearby switch, and signal.

Figure 20. RCL2 damaged locomotive fuel tank

Figure 21. RCL2 damaged tank cars

Figure 22. RCL2 location of collision and damaged track (out of service indicated by flag on left rail)

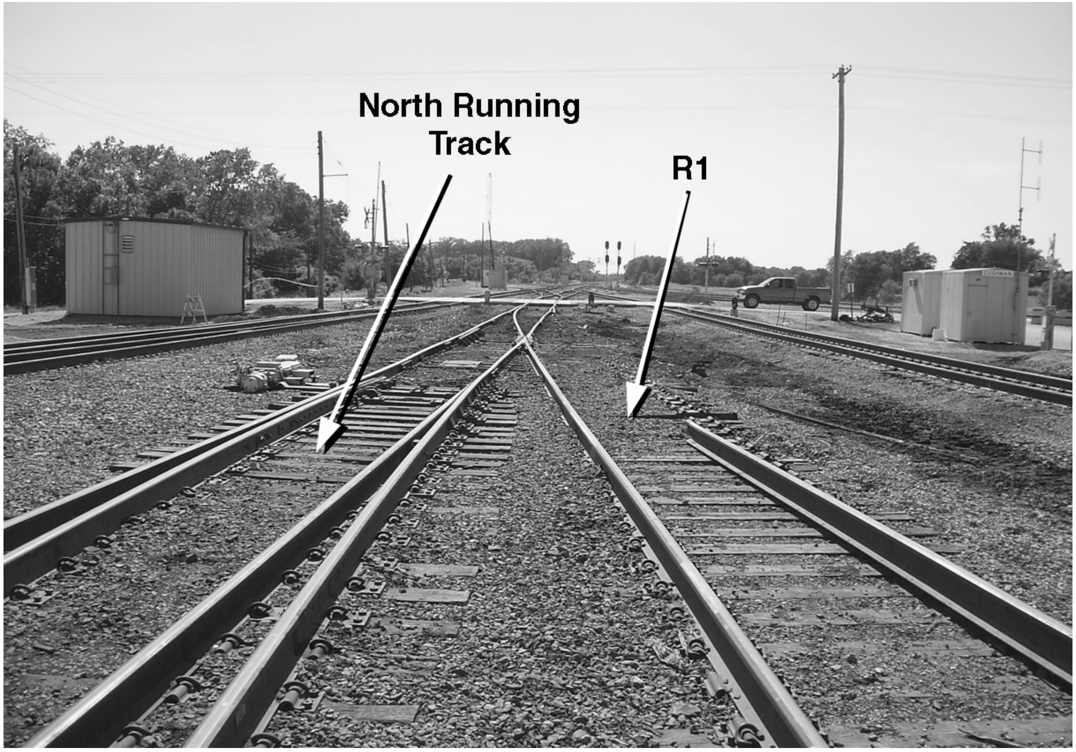

Figure 23. RCL2 closeup of damaged track (out of service)

5.3.4 Train Information

The locomotive used by the RCL crew had its short hood forward, denoted with an F stenciled on each side (see Figure 24). This meant that the short hood of the locomotive was always oriented in the forward (as opposed to reverse) direction of movement, so that forward on the reverser would move the RCL in the direction that the F was oriented—the short hood. Most locomotives at this yard are short hood forward, except yard switcher engines, which are long hood forward. Figure 25 depicts an example of a locomotive with its short and long hood labeled. As a general practice at this yard, locomotives used on the east end of the yard are oriented so that the short hood (forward) is facing eastward, while locomotives used on the west end are oriented with their short hood (forward) oriented westward.

Equipment was not tested because of damage to the locomotive and RCL equipment.

Figure 24. RCL2 view of short hood forward RCL with F highlighted

Figure 25. RCL2 example of short and long hood of locomotive

5.3.5 Actions of RCL Crewmembers

After cutting the RCL off on the west end of R4 and continuing westward out the north running track, the helper reversed eastward into R3 to tie on the west end of a cut for a shove move eastward toward the hump. The helper tied onto the west end of R3 and set the RCD reverser to forward to stretch the cut westward to ensure that the coupling had been made between the RCL and cut of cars. The helper stretched the cut westward and stopped. He then walked back to bleed off the air brakes of several cars on the west end of R3.

The operator then obtained 3-point protection (setting the speed selector to stop and centering the reverser) and went between the cars to release the hand brakes. As the helper was setting the reverser to neutral, he observed that the position of the reverser was in forward. According to interview data, he noted to himself, “I just tied on, so east must be forward.” The helper forgot that he had stretched the cut westward after tying on to confirm that the coupling was made. After releasing the hand brakes, the helper then boarded a shuttle van and rode eastward to the hump in preparation for humping. The helper got out of the van, verified the switches located at the east end of the receiving tracks, and placed his reverser into forward, believing that forward would move the cut eastward, toward the hump (when in fact forward was oriented westward). The helper began to move the cut westward rather than eastward, starting with 2 mph, and after not seeing the cut of cars emerging from R3, he increased the speed to 4 mph and finally 8 mph using the speed selector. During this time, the helper walked into the hump office and picked up his switch list. The helper also asked his foreman if the RCL was forward to the hump and looked out the window for his cut of cars. The helper reportedly said out loud, “I should have seen the cars coming by now.” At that time the utility man on the departing train radioed the RCL crew to ask where they were headed with their RCL. The crew then looked into a TV monitor that showed a view of the west end of the yard and saw the westward moving cut of cars. The helper immediately stopped the RCL, but the cut of cars was unable to stop before colliding with an outbound train that was setting out a bad order before leaving.

5.4 Analysis

The analysis section is organized into two sections. The first section identifies exclusions—those factors that were examined but not considered to be a contributing factor. The second section presents and discusses the HFACS-RR analysis.

5.4.1 Exclusions

The investigation team considered the following exclusions and factors, dismissing them as contributing factors. They are included here for completeness.

- The helper indicated that he was familiar with this part of the yard, although he was on the extra board and therefore worked several different jobs. Although the foreman was not formally interviewed, this was his regularly assigned job.
- Weather did not appear to be a contributing factor.
- The helper did not appear to be sick. The foreman was not formally interviewed.
- The RCO’s alertness did not appear to be a contributing factor in this collision. Based on the work history and the A operator’s self-reported sleep habits, this person should have been well within normal well-rested boundaries of effectiveness at 95 percent and a low likelihood of lapses. Although the person did work the night before, the person reported a high level of sleep hygiene,

attempting to sleep for 5 h immediately after a night shift and taking a 1-2 h nap prior to subsequent night assignments. On days off, the person would delay sleep until late at night, sleeping 9 h and rising midmorning. In examining possible fatigue factors, the A operator had a mild accumulated sleep debt of about 5 h, 8 h of sleep in the prior 24 h, and was working early in the period of circadian downturn at 1:30 a.m. Only the time of day might suggest vulnerability, but this person was adapted to predominately night shifts, and it is presumed that his circadian peak was probably 2-3 h later than the typical day worker. Hence, the 1:30 a.m. work time was probably of little consequence. Taken together, no evidence exists from the work and sleep schedule to suggest a fatigue or alertness contribution to the collision. One cannot rule out, however, that some unusual event prevented the A operator from taking the daytime sleep that was reported as typical. Hypothetically restricting prior day sleep to 3 h immediately after the prior work shift would reduce effectiveness to 83 percent at the time of the accident, somewhat vulnerable to alertness difficulties with a lapse index about twice that of a well-rested person. However, no independent evidence exists to suggest that this was the situation on the day of the collision.

5.4.2 Analysis of Accident

One basic element led to the collision—a loss of situation awareness by the RCL helper in control of the move that (1) allowed his cut of cars to travel in the opposite direction as intended and (2) interfered with his ability to realize the error and recover in time to avoid a collision. The remainder of this section provides a human factors analysis of how the loss of RCO situation awareness contributed to the collision.

Loss of RCO Situation Awareness

The collision between the RCL and the departing outbound train occurred because the RCL helper initiated movement of his cut of cars westward away from the hump, rather than eastward toward the hump as intended. This unintended direction of movement and delay in becoming aware of the westward movement resulted from a reduction in, or loss of, the crewmember’s situation awareness. The result was that not only did the helper initiate movement in the wrong direction, but he was unable to detect the error and stop the RCL in time to avoid a collision with a departing train. A number of contributing factors facilitated this loss of RCO situation awareness. They are discussed below.

HFACS-RR analysis:

- <u>Failure to correctly recall previous movement</u>. When the helper looked down at his RCD to set-and-center the controls to (obtain 3-point protection to) release the hand brakes, he observed that the reverser was in forward. He incorrectly recalled his last move to be an eastward coupling of the RCL to the standing cut of cars. This set up the situation later for the helper to incorrectly believe that forward would bring the cut eastward. The helper forgot that he had stretched the cut westward after tying on to the cut (eastward), and that, in fact, forward orientation was for a westward direction. After riding the van to the hump office, he placed the reverser of his RCD in forward and errantly pulled the cut of cars westward and into the departing train. *Operator acts/skill-based error/memory failure.* **Probable contributing factor.**

- <u>Poor choice to initiate movement without being able to see the cut of cars</u>. The helper initiated his movement without being able to see his cut of cars and to positively confirm movement, enabling the cut of cars to move in the direction opposite that intended and delaying detection of this inadvertent direction of movement. *Operator acts/decision error/poor choice.* **Probable contributing factor.**

- <u>Misapplication of a good rule</u>. As a common practice, the F end of locomotives used on the east end of this yard often face eastward, while the F end of locomotives used on the west end of the yard are often oriented westward, so that forward on the reverser pulls out, or away from the bowl located in the middle of the yard. The helper misapplied a usually good rule by erroneously believing that F would bring him eastward (to the hump), as it often would when operating on the east end of the yard. The helper tried to confirm this belief with his foreman in the hump office. This misapplication was likely due, in part, to the fact that the helper worked on the extra board and thus alternated among the different jobs located on the east and west ends of the yard. The helper had also not worked the hump (west end) job much recently, possibly contributing to a stronger belief that forward would bring the locomotive eastward rather than westward. *Operator acts/decision error/procedural error.* **Possible contributing factor.**

- <u>Inability to determine or verify locomotive's F orientation</u>. Since the helper controlled the move far away from the RCL, he was unable to see the F markings on the RCL to verify the locomotive's orientation. *Preconditions for operator acts/environmental factors/technological environment.* **Probable contributing factor.**

- <u>No feedback to indicate the true direction of RCL movement</u>. The helper initiated a westward move of his cut of cars and was unable to detect this error due to a lack of feedback indicating the true (westward) direction of movement of his cut of cars. In addition to a lack of visual feedback based on his position at the hump (he was 25 car lengths away from the nearest car in his cut), inadequate lighting, and lack of formal procedure for using the west end camera, the helper lacked any type of kinesthetic or auditory feedback from the RCL or RCD that would inform him of his errant westward move. *Preconditions for operator acts/environmental factors/technological environment.* **Probable contributing factor.**

- <u>Unsafe operating practice permitting RCOs to initiate movement of a cut of cars without line-of-sight to the cut</u>. The helper, standing at the hump or inside the hump office, was unable to see his cut of cars when he initiated his movement. The helper was standing about 25 car lengths away from the first car and would not be expected to see his cut until the cut had traveled about 10 car lengths toward the hump. This is the distance that the first car would have to travel eastward out of R3 and up the ladder track toward the hump. *Organizational factors/organizational process/organizational practices and procedures*. **Probable contributing factor.**

- Inadequate lighting. Although a set of lights is mounted on a pole to illuminate the west side of the west end of the yard and lights on the east end of the yard, no lights are on the east side of the west end of the yard, near the hump office, to help crewmembers shove cars to the hump. The lack of adequate lighting in this part of the yard at night made it more difficult to see the RCO's cut moving in either direction in the track (see Figure 26 for a view from the hump and Figure 27 for a view from inside the hump office looking westward toward the receiving tracks). Rail cars that are dark, such as black tank cars, are especially difficult to see at this end of the yard. *Preconditions for operator acts/environmental factors/physical environment.* **Probable contributing factor.**

Figure 26. RCL2 view from hump pin puller position looking westward in daytime (left) and at night (right)

Figure 27. RCL2 view from hump office looking westward in daytime (left) and at night (right)

- Inadequate procedure for use of west side camera to monitor west end movements. Inside the hump office is a monitor to give crewmembers a view of the west side of the west end of the yard (see Figure 28), since this part of the yard is beyond line-of-sight. The camera is typically used when crews are making moves and operating in that part of the yard. However, at the time of the collision, there existed no explicit procedure to require operators to use the camera to verify eastward moves to the hump to protect against an unintended westward move. *Organizational factors/organizational process/organizational practices and procedures*. **Probable contributing factor.**

Figure 28. RCL2 eastward-looking camera view of west side of west end of receiving tracks from monitor located inside hump office

5.5 Corrective Actions

To prevent similar accidents/incidents from occurring in the future, the railroad has made, or is in the process of making, the following yard-specific corrective actions since the accident occurred:

1. The railroad is going to require RCL crews operating at the hump to place a flashing red strobe light on the eastern-most car of a cut of cars that is to be shoved eastward to the hump, to help crewmembers discern the direction of movement of their cut of cars at night. The crew will remove the strobe light when the car gets to the hump before it is humped.
2. The railroad developed a new instruction as part of a General Notice to formally require the use of the camera on the west end of the yard to protect against incorrect westward moves. The instruction reads:

> Effective immediately, before initiating movement from any of the Receiving Tracks–Eastward to the Hump Crest–the RCO Operator in control of the movement MUST notify the Hump Foreman in order to provide protection on the West End of the Receiving Yard via the camera at the West End….The Hump Foreman will then inform the RCO Operator of the direction of the movement.

6. Case Study 3

6.1 Summary

At 3:35 a.m. local time, after overriding an automatic pullback protection system in an RCZ, an RCL hump job consisting of a foreman, helper, and student RCO pulled their cut of 106 cars eastward on the east lead traveling about 5 mph, ran an absolute (stop) signal, and struck the side of a westward train traveling on the main track about 20 mph. The lead RCL sideswiped the 9th and 10th cars behind the locomotives of the westward train and derailed the next 8 cars. The lead RCL derailed and toppled over on its side, while the trailing RCL and first car derailed but remained upright. No injuries occurred. Damages were estimated to range from $500,000 to $1,000,000.

6.2 Circumstances Before the Collision

6.2.1 Meteorological Conditions

At the time of the collision, conditions were clear with approximately 10 miles of visibility. The temperature was 71° F, with southeast winds at 10 mph.

6.2.2 Personnel

<u>RCL Crew</u>

The RCL crew went on duty at 11:59 p.m. local time the evening before the collision occurred. The crew had been on duty for 3 h 36 m prior to the collision.

- *Foreman/A Operator*

  The foreman was 37 yr old. He had been qualified as a brakeman/switchman (including yard foreman and road conductor) and RCO for 11 wk and had worked as an RCO 31 times (i.e., 31 RCL starts) during these 11 wk. Management had conducted 33 efficiency tests on this RCO (19 RCL-related) since he qualified as a switchman and RCO; he passed all of them. His most recent efficiency test was one day before the collision. His most recent rule examination was 1 mo prior to the collision. He had been off 20 h and 57 m before going on duty the evening before.

- *Helper/B Operator*

  The helper was 22 yr old. He qualified as an RCO and switchman 6 wk prior to the collision but immediately returned to conductor school for a total of 4 wk—2 wk classroom and 2 wk road trips—and did not work an RCO job during these 4 wk. Thus, although qualified as an RCO for 6 wk, he had 1.5 wk (four previous starts as an RCO) experience as an RCO. Management had conducted 24 efficiency tests on this RCO (15 RCL-related) since he qualified as a switchman and RCO; the RCO passed all of them. His most recent efficiency test was 12 d before the collision. His most recent rule examination was 1 mo before the collision. He had been off 30 h and 47 m prior to going on duty the evening before.

- *Student RCO*

  Information on the student was not collected.

Hump Yardmaster

The yardmaster was 49 yr old. He had 25 yr of total experience in the railroad industry, the first 17 yr as a clerk and the last 8 yr as a yardmaster.

Road Train Crew

Information on the road train crew was not collected.

6.2.3 Yard Layout

The yard is laid out in an east-west[13] direction. The classification yard (the bowl) and receiving/departure tracks are located west of the hump, and three hump lead tracks are located to the east of the hump (see Figure 19). The three hump lead tracks are generally used to pull back cuts of cars in preparation for humping, to shove cars over the hump, and to enter and leave the yard via the main track. The main track runs parallel to the yard. The three hump lead tracks are referred to as the west lead (closest to the main track), east lead, and 49 lead. The west, east, and 49 lead tracks run westward toward the hump and eastward to the main track. Before connecting to the main track, all three leads converge into a single track (see Figure 30). Access to the main track is controlled by a signal (see Figure 31) from the carrier's dispatching center.

The receiving and departure tracks are located to the north and south of the bowl. Nine receiving and departure tracks are just to the south; among these is track 48, from which the RCL crew was pulling a cut of cars to hump just before the collision. Two crossovers, near the hump, allow access between the west and east lead tracks and the east and 49 lead tracks (see Figure 32). These crossovers enable cuts of cars to move between the receiving and departure tracks and the hump lead tracks.

6.2.4 Automatic Pullback Protection System

The west and east lead tracks are each equipped with an automatic pullback protection system, whereby passive transponders (a.k.a. pucks) are mounted between ties at various locations along each lead track, beginning about 750 ft east of the hump switch crossover and extending approximately 5950 ft east, where the last stop transponder is located (see Figure 33). RCLs are equipped with a radio frequency (RF) antenna mounted underneath the RCL to energize and receive a signal from each transponder as it passes over each one. The first transponder authorizes and commands a maximum speed of 10 mph, the next commands a speed of 9 mph, and so on, until the RCL reaches the last transponder, which commands the RCL to stop. The automatic pullback protection system provides

[13] The yard is not actually laid out in a precise east-west direction, but, to simplify the explanation, track locations are referenced as east or west of the hump.

positive stop protection (PSP), whereby the system is designed to prevent a cut of cars from traveling beyond a predesignated location along a track.

The pullback protection system can be cut out, or overridden, if necessary (e.g., if a cut extends longer than the pullback-protected track), by manually depressing two buttons onboard the RCL. When using the pullback protection system, an RCZ is established to span the distance between the switch clearance point near the hump to the last stop transponder, a distance of approximately 6700 ft. The morning of the collision the RCZ had been established, and the pullback protection system was in use.

An additional 500 ft safety zone exists beyond the last stop transponder and then another 200 ft clearance zone in which the west and east lead tracks converge. At the end of the 200 ft clearance zone, the west/east lead track begins to converge with the 49 lead track. The signal authorizing movement on the main track is located about 500 ft east of this track convergence point. Thus, an additional approximately 1200 ft of track extends past the stop transponder and the signal authorizing movement onto the main track.

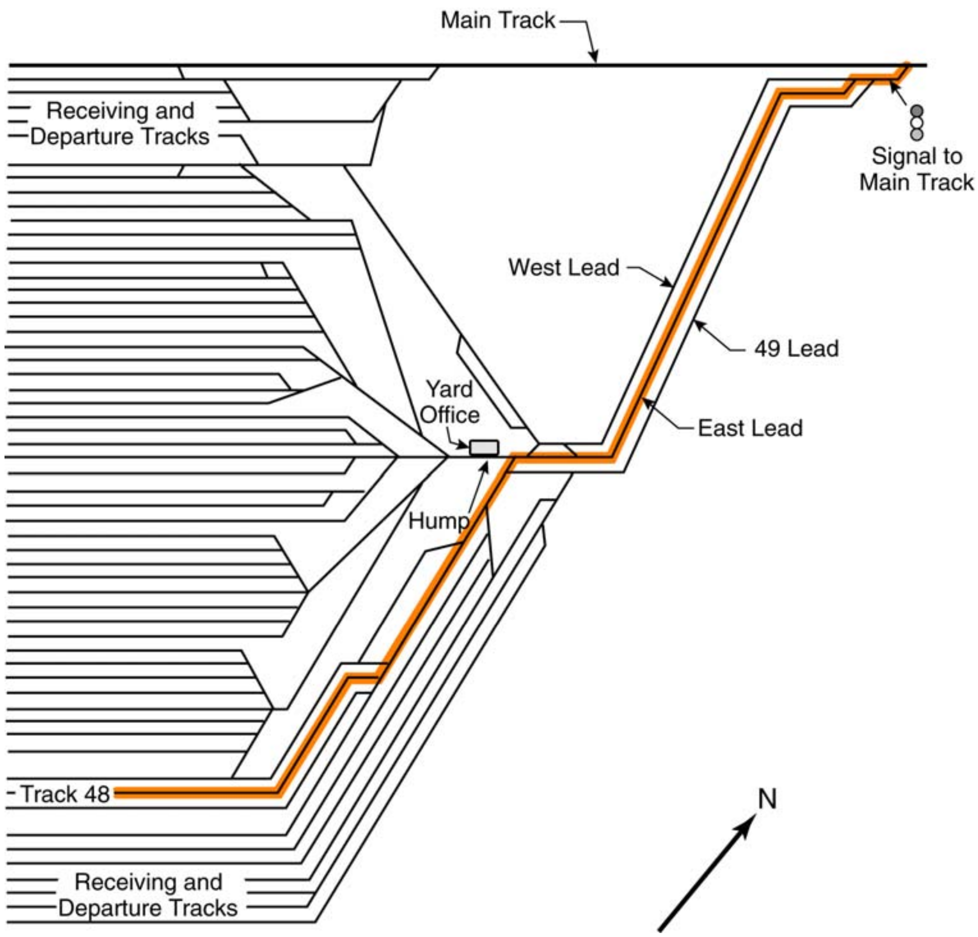

Figure 29. RCL3 yard layout with eastward path of RCL highlighted

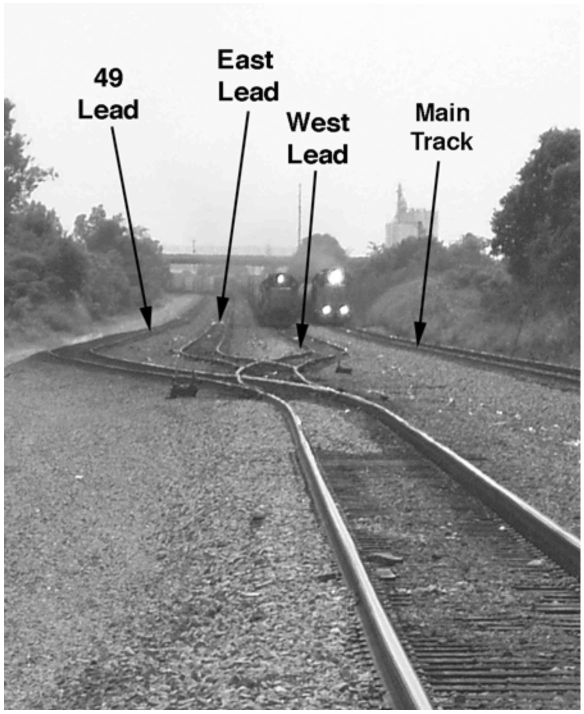

Figure 30. RCL3 view westward (toward the hump) of three lead tracks converging into one just before access to main track

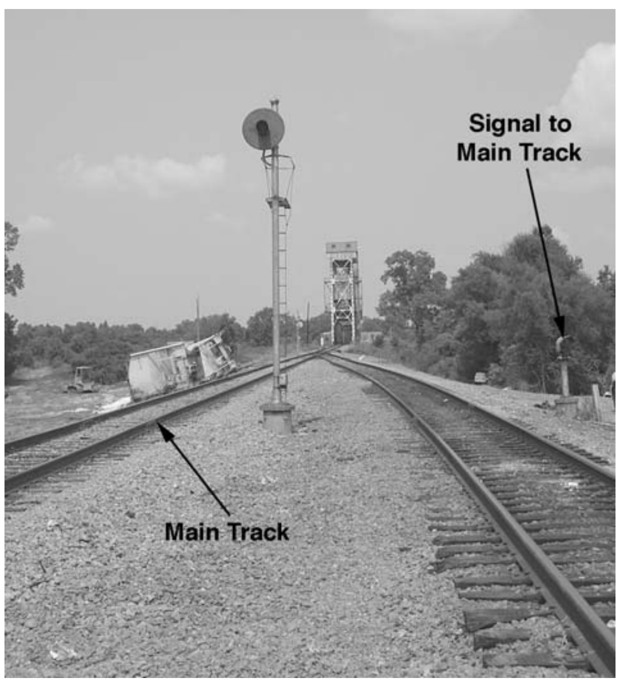

Figure 31. RCL3 view eastward (away from hump) of main track and yard lead track with signal to main track

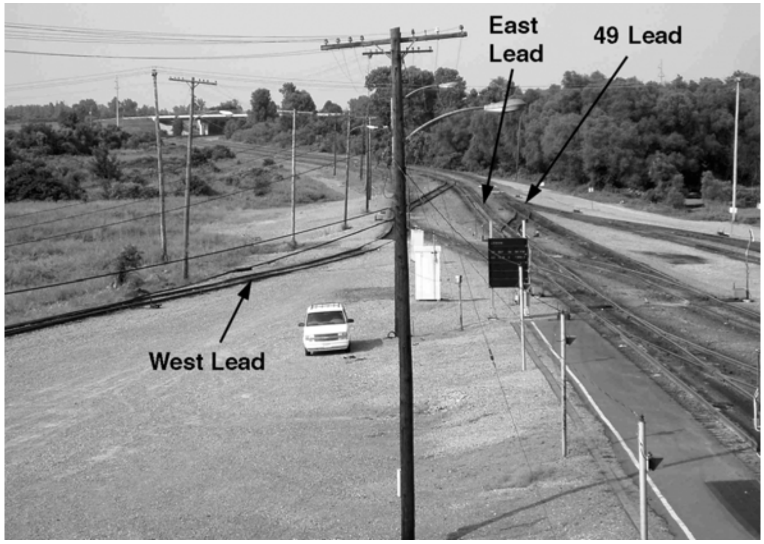

Figure 32. RCL3 view of crossovers east of hump

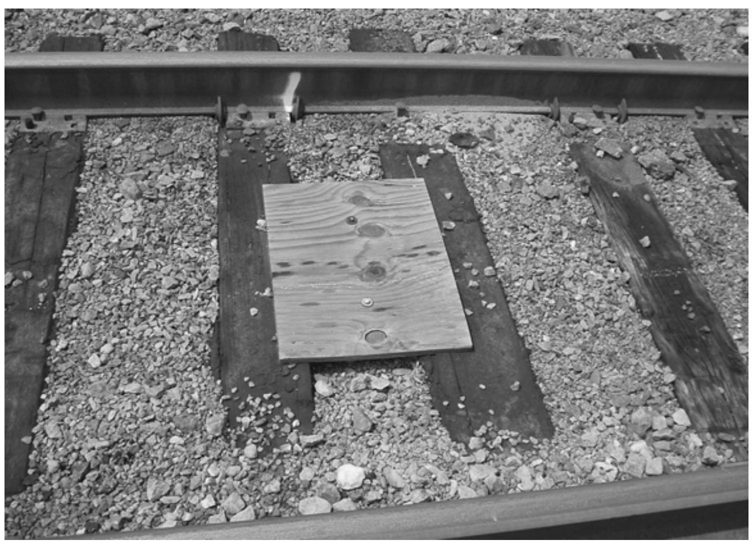

Figure 33. RCL3 stop transponder embedded under plywood in east lead track

6.2.5 Preceding Events

The crew began their shift at 11:59 p.m. the evening before the collision. The crew had a student RCO (trainee) attached to its assignment. Several hours into the shift, the hump yardmaster instructed the RCL crew to pull a cut of 106 cars, 6599 ft, eastward out of (receiving and departure) track 48 to the east lead, to hump the cars. He informed the crew that the cut was too long to pull past the switch needed to clear (to access the west lead to hump), without overriding the pullback protection system, so he instructed the crew to override the pullback protection system. The cut of cars was 6599 ft, and the segment of track protected by the pullback protection system was about 5950 ft. The foreman told his helper that he would pull the cut out, and the helper should line the switches for the eastward move. The helper and student, located near the hump, then lined the crossover switches, while the foreman, in control of the move (A operator), rode the RCL down track 48, coupled up to the cut of cars, and began his eastward pull move. The foreman stopped near the hump, dismounted the RCL, and then initiated movement again. The cut of cars then traveled eastward along the east pullback-protected lead track, unmanned, and stopped as commanded at the last stop transponder. The rear of the cut had not cleared the switch needed to reverse the move to the hump, as expected. A second crew, operating light power, was on the 49 lead track waiting on the east side of the crossover, near the hump. The second crew was waiting for the cut to clear the crossover before proceeding westward into track 48.

The foreman radioed to his helper and instructed his helper to pick him up in a scooter, which was parked at the hump tower, and take him out to the RCL to override the automatic pullback protection. The foreman also asked the crew waiting for his cut to clear to radio him to let him know when the rear of the cut had cleared the switch. The RCO foreman and helper then rode the scooter out to the RCL, where the foreman instructed his helper to turn the scooter around (toward the hump) while he boarded the RCL and overrode the automatic pullback protection system. The trainee remained at the hump during this time.

Meanwhile, a freight train with 80 cars had been waiting on the main track, just across the river, for clearance from the dispatcher to progress farther westward on the main track and enter the yard farther west. The crew received clearance to proceed, initiated the move, and began traveling westward along the main track.

6.3 The Collision

The foreman then initiated movement eastward and set the RCL speed to 7 mph, boarded the scooter, and began riding westward back to the hump (as a passenger) with his back to the move. Twenty-six seconds later he increased the speed to 10 mph and 75 s after that reduced the speed to coast. While still riding, the foreman received word from the second crew that their cut had cleared the switch. The foreman then placed the RCD speed selector to stop. Less than 1 min after, the RCL crew received a communication loss display on their RCDs. The crew asked a more experienced RCO at the hump what to do to fix the communication loss. The RCO suggested turning the RCDs off and back on again to reset the system. The RCL crew turned their RCDs off and back on, but they were unsuccessful at recovering their RCL. The crew then decided to ride back to the RCL to try to relink their RCDs when they discovered the collision. The trainee remained at the hump the entire time.

The cut of cars had traveled eastward, beyond the absolute red signal, and collided with the road train traveling westward along the main track. The road train was traveling about 20 mph at the time of impact, and the cut of cars was traveling approximately 5 mph at the time of impact.

6.3.1 RCL Event Recorder-Based Timeline

Table 8 provides a timeline of information from the RCL OCC event recorder download.

Table 8. RCL3 OCC event recorder download data

Time	Event	Additional details
3:32:22 a.m.	RCT A Speed Sel = 7, RCR speed = 0.0 mph.	Foreman initiates movement by adjusting the RCD speed selector (RCT A Speed Sel) from stop to 7 mph.
3:32:48 a.m.	RCT A Speed Sel = 10, RCR speed = 1.2 mph.	Foreman increases speed by moving the speed selector from 7 mph to 10 mph. Current speed (RCR speed) is 1.2 mph.
3:34:03 a.m.	RCT A Speed Sel = Coast, RCR speed = 10.4 mph.	Foreman moves the speed selector from 10 mph down to Coast. Speed is 10.4 mph.
3:34:16 a.m.	RCT A Speed Sel = Stop, RCR speed = 9.8 mph.	Foreman commands the RCL to stop. Speed is 9.8 mph.
3:34:17 to 3:35:00 a.m.		Speed continually decreases.
3:35:01 a.m.	RCR BP PSI = 92, RCR speed = 5.4 mph.	Speed is 5.4 mph. Brake pipe pressure (RCR BP PSI) is fully charged at 92 psi and has remained that way since movement was initiated.
3:35:02 a.m.	RCR BP PSI = 31, PCS = open, RCR speed = 5.1 mph.	Brake pipe pressure is suddenly reduced to 31 psi. Pneumatic control switch (PCS) is triggered/opened due to sudden loss of air pressure in air line.
3:35:04 a.m.	RCR AB Over = Full, RCR speed = 0.1 mph.	Automatic brakes (RCR AB Over, the automatic brake override) automatically and fully apply.
3:35:05 a.m.	Loss of data (- - lines replace event values).	RCL crew receives communication loss message.

6.3.2 Injuries

No injuries occurred.

6.3.3 Damage

The lead RCL sideswiped the 9th and 10th cars behind the locomotives of the westward train and derailed the next 8 cars (see Figure 34 and Figure 35). The lead RCL derailed and toppled over on its side (see Figure 36), while the trailing RCL and first car derailed but remained upright. No injuries occurred. Damages were estimated to range from $500,000 to $1,000,000.

Figure 34. RCL3 derailed hopper car of inbound road train

Figure 35. RCL3 spilled plastic pellets from derailed hopper car

Figure 36. RCL3 view of damaged sheared left side of lead RCL

6.3.4 Train Information

The westward train traveling on the main track consisted of 5 locomotives and 80 cars (5337 trailing tons). The length of the consist (excluding the 5 locomotives) was 5383 ft. The RCL job consisted of 2 RCLs pulling a cut of 106 cars (8027 trailing tons). The length of the cut of cars was 6599 ft.

6.3.5 Actions of Crewmembers

<u>RCL Crew</u>

After the RCL stopped at the stop transponder, the foreman and the helper used a motorized scooter to ride down to the RCL to override the pullback protection system and to move the cut further eastward, in order to clear a switch at the rear of the cut. The foreman also asked a crew of another job to notify him when the rear of the cut had cleared the switch. After overriding the system, the foreman initiated eastward movement by setting the speed selector to 7 mph, boarded the scooter, and rode back to the hump, with his back to the move, and adjusted the speed selector from 7 mph up to 10 mph, then down to coast, and finally to stop upon receiving notification from the other crew waiting at the hump that the rear of his cut had cleared the switch. The trainee remained at the hump the entire time.

Hump Yardmaster

The yardmaster gave initial instructions to the crew to pull a cut of cars out of track 48 and up the east lead to hump. He informed the crew that the cut was too long to pull past the switch needed to hump, without overriding the pullback protection system, so he instructed the crew to override the system. This was the first time that the yardmaster had ever instructed a crew to override the pullback protection system. After this instruction, the yardmaster tended to other duties.

Inbound Train Crew

The road crew had received clearance to proceed westward along the main track and initiated movement. Shortly after, the conductor called the yardmaster to inform him that their train had gone into emergency and that they could not recover. The conductor dismounted the locomotive and walked the train to diagnose the problem when he discovered the collision.

6.4 Analysis

The analysis section is organized into two sections. The first section identifies exclusions—those factors that were examined but not considered to be a contributing factor. The second section presents and discusses the HFACS-RR analysis.

6.4.1 Exclusions

The investigation team considered the following exclusions and factors, dismissing them as contributing factors. They are included here for completeness.

- Neither crewmember nor the yardmaster appeared to be sick.
- Meteorological conditions suggest that inclement weather was not a factor.
- Neither crewmember was in a hurry to complete the move.

6.4.2 Analysis of Accident

The RCL crew was not adequately prepared to work the RCL hump job the evening the collision occurred. They lacked sufficient training and knowledge of, and experience with, yard switching and RCL operations. This lack of training, experience, and knowledge facilitated a loss of RCO situation awareness that enabled the RCL to travel eastward up the lead, pass an absolute red signal, and strike a train on the main track. The remainder of this section provides a human factors analysis of the factors that contributed to the collision.

Loss of RCO Situation Awareness

Due to the excessive length of the cut of cars and RCLs, it was necessary for the crew to override the pullback protection system to clear the switches near the hump. The need to override the pullback protection system set up a chain of events that led to the collision. After disabling the pullback protection, the foreman initiated movement further eastward and then boarded the scooter, and both RCOs traveled westward to the hump with their back to the move. The choice not to stay with the RCL to protect the point of movement after the pullback protection system had been overridden reduced crewmembers' situation awareness and limited their ability to make a safe eastward move. This is discussed below.

HFACS-RR analysis:

- Poor choice by RCOs not to protect the point of the movement after overriding the pullback protection system. Neither crewmember remained with the RCL once it began its eastward move beyond the pullback protection to ensure that their path was free of any fouling equipment or people. Instead, both RCOs rode back to the hump with their backs to the move, preventing them from seeing anything in front of the RCL. Operating the RCD on the scooter further reduced the crew's situation awareness by requiring the helper to pay attention to operating the vehicle rather than allowing him to monitor the RCL and cut of cars. *Operator acts/decision error/poor choice.* **Probable contributing factor.**

- Foreman's alertness was likely compromised at the time of the collision. Using FAST, a predicted effectiveness schedule based on work schedule data and self-reported sleep habits was constructed for the foreman. The collision occurred near the circadian nadir (lowest point) at 3:35 a.m. when effectiveness was predicted to be about 71 percent and lapse likelihood would be about five times that of a well-rested person. As a reference, 70 percent effectiveness equates to the amount of degradation expected of a person with a blood alcohol level of 0.08 BAC, which is legally intoxicated in many states. Two fatigue factors account for this low level of effectiveness. The foreman may have had an accumulated sleep debt of about 7.5 h, which is close to the margin of concern of 8 h debt. That would combine with the fact that the collision occurred during the circadian nadir to yield the predicted value. An acute sleep debt would not have existed if this person followed his routine of taking a nap before a night work shift. With the nap, this person would have had 8 h of sleep in the prior 24 h. *Preconditions for operator acts/operator conditions/adverse physiological state.* **Possible contributing factor.**

- Inadequate procedure to address overriding pullback protection. At the time of the collision no operating or safety rule existed that specified that point protection was necessary or that the RCZ was no longer in effect, when an RCO overrides the pullback protection system within an RCZ on the east or west lead tracks. The RCZ extends for 500 ft beyond the end of the pullback protection system. Given the presence of the RCZ for an additional 500 ft beyond the last pullback protection transponder, it is reasonable that an RCO may believe that he could pull a cut further down the track, still within the RCZ, without the need to provide point protection. *Organizational factors/organizational process/ organizational practices and procedures.* **Probable contributing factor.**

- Inadequate practice (bulletin) specifying maximum length of a cut of cars to be switched using pullback-protected track. Contributing to the need to override the pullback protection was a superintendent bulletin that specifies the maximum length of a cut of cars to be switched using the pullback-protected tracks.

According to the bulletin, the maximum length for a cut of cars is 6700 ft. This length corresponds to the distance between the clearance point of the last switch needed to clear near the hump to the west and the last pullback protection (stop) transponder to the east. However, the bulletin only addresses the cut of cars and not the RCLs making the move. Thus, in this case, although the length of the cut of cars being moved was 6600 ft (under the maximum length of 6700 ft), the actual length of the entire cut of cars and (two) RCLs was approximately 6760 ft. This assumes each RCL was 80 ft. Thus, it is possible that cuts of cars that are within the maximum length specified by the bulletin may require the pullback protection system to be overridden due to the additional length added to the cut by the RCLs. *Organizational factors/organizational process/organizational practices and procedures.* **Probable contributing factor.**

Inadequately Prepared RCOs

Both crewmembers lacked important procedural (knowing how to do something) and declarative (knowing that something is) knowledge necessary to work safely the night the collision occurred. The combination of inadequate training, unstructured on-the-job training (OJT), and lack of train-the-trainer training for OJT mentors all contributed to inconsistent and insufficient RCO training that created the situation whereby both crewmembers lacked some critical knowledge necessary to working safely. These factors are discussed below.

HFACS-RR analysis:

- <u>Inadequate RCO training</u>. At the time of the collision, neither crewmember was familiar with the part of the yard where the collision occurred. The foreman had never physically set foot in this part of the yard, and the helper had only been there once or twice in training while using a track that was not equipped with the pullback protection system. Neither crewmember knew that a signal was at that end of the yard, and neither crewmember knew that the lead track entered the main track at this end of the yard. Neither crewmember was aware that he needed to protect his move after overriding the pullback protection system. Neither employee knew that there existed a system special instruction that prohibits operating the RCD from a motorized vehicle[14]. Both RCOs were new hire employees with no previous railroad operating experience. Although trained in separate classes, their training each consisted of a total of 14 wk of classroom and OJT training. The first 3 wk involved brakeman-in-training (BIT) classroom instruction, which included general rules instruction and 6 d of RCO-specific

[14] The contravention of the system special instruction is discussed here rather than being called out as its own contributing factor to the incident since the contravention was not intentional. The HFACS classification system includes intentional contraventions as a distinct category but does not explicitly address unintentional contraventions. Intentional contraventions are often a result of poor oversight or poor organizational practices or procedures (e.g., a rule or instruction may be contravened if it is not considered to be helpful or is considered to be problematic), while unintentional contraventions suggest inadequate (rules) training or inadequate organizational procedures to distribute the rules that lead to a lack of employee awareness of the rules.

training, such as on the mechanics of RCD operation. Training, however, did not explicitly address overriding the pullback protection system. Each student then received 7 wk of OJT in the yard. Each workday, students were assigned to a working two-person crew. The railroad ensures students are assigned to both hump and trim jobs (the two primary RCL jobs in the yard) through the use of a computer spreadsheet. The OJT was otherwise unstructured, however, and the railroad did not provide any train-the-trainer training to crews that the students were assigned to. The railroad provided each student with a small map of the yard, but students were not provided or afforded any additional yard familiarization training, instruction, or aids. After their 7 wk of OJT, the helper immediately qualified as a yard switchman and RCO, returned to conductor school for 4 wk of classroom and OJT, and began to work as an RCO, while the foreman went immediately to conductor school following his 7 wk of switchman/RCO OJT and qualified as an RCO. To qualify as an RCO, each student participated in a 3.5–4 h check-ride in the yard with a local officer (trainmaster or road foreman of engines). The officers performing the check-rides are qualified RCOs. Check-rides consisted of (1) confirmation of proper linking up and initial RCD testing, (2) verification of RCO knowledge of daily locomotive inspection procedures, and (3) unstructured observation of the RCO operating the RCD while making moves. The foreman's check-ride included limited testing of his knowledge of tracks (e.g., the supervisor would point to a track and ask "what track is that?") but was neither systematic nor complete. The helper's check-ride did not contain any such testing of track knowledge. The check-rides were otherwise unstructured and did not specifically address a student's knowledge of, or familiarity with, the section of yard east of the hump (including pullback tracks), how to override the pullback protection system, or what to do in case this was necessary. *Supervisory factors/inadequate supervision (inadequate training).* **Probable contributing factor.**

- <u>Inadequate RCO OJT</u>. RCO OJT is completely unstructured other than that student RCOs are assigned to both RCL jobs (hump and trim). RCO mentors—those RCOs that are also responsible for training a student RCO during a work shift—do not receive any train-the-trainer training. OJT does not ensure that student RCOs gain experience with, or exposure to, any particular operating practice or procedure and does not ensure that student RCOs will be exposed to all parts of the yard or that they will have adequate hands-on experience using the RCD to move different cuts of cars. While working as student RCOs on the hump jobs during their 7 wk of OJT, often the two crewmembers involved in the collision either pulled pins at the hump or watched the other crewmembers work, similar to what the student RCO was doing at the time of the collision. According to crewmembers, some of the more experienced RCOs were impatient and wanted an early quit, so the experienced and qualified RCOs would do the work themselves and not provide an opportunity for the student RCOs to operate the RCD. As a consequence, their hands-on experience was limited. In other cases, the RCOs to whom the student RCOs were assigned were very inexperienced themselves and did not have much knowledge to share. As a consequence of their inadequate OJT, the two RCOs involved in the collision had minimal direct exposure to that part of yard—one had never set foot there, and the second had only been back there once or twice on an adjacent track—and neither knew that (1) a red signal was at the east end of the east lead, (2) the east lead connected to the main track at that point, and (3) they had to protect their movement after overriding the pullback protection system. Thus, inadequate OJT contributed to inadequate familiarity and exposure to that part of the yard, as well as incomplete knowledge of important procedures and rules. *Supervisory factors/inadequate supervision (training).* **Probable contributing factor.**

- Inadequate RCO train-the-trainer training for OJT mentors. While the BIT and conductor classroom trainers come from the railroad's training department and receive train-the-trainer training, OJT mentors do not receive any such training. The RCOs involved in the collision noted they received inconsistent OJT. Sometimes they trained with very experienced RCOs; other times RCOs were very inexperienced. Some RCOs provided enough opportunity to learn, while other times the RCOs would not let the student RCOs operate the RCD, or the student RCO did not feel comfortable asking the RCOs questions. This lack of train-the-trainer training likely contributed to inconsistent and insufficient student RCO training. *Supervisory factors/inadequate supervision (training).* **Probable contributing factor.**
- Allowing early quits may reduce OJT opportunities for student RCOs. The organizational practice of allowing early quits, where a crew is informed that they may go home after completing a certain number of moves in their shift, may encourage RCOs to rush to complete their moves to go home early. The motivation to leave work early, however, may take opportunities to obtain hands-on practice and experience operating the RCD away from student RCOs attached to these crews. This is because student RCOs undoubtedly work more slowly than the more experienced crews and thus may cause a delay in leaving work. Both RCOs reported that their OJT was affected by some crews who wanted an early quit or who felt that they were not going fast enough when operating the RCD, and this consequently did not give the RCOs opportunities to operate the RCD during these shifts. The opportunity to go home early might motivate some crews to do the work themselves (faster) rather than letting the student RCO gain the experience (but complete the work more slowly). *Organizational factors/organizational process/organizational operations.* **Possible contributing factor.**

Inadequately Experienced Crew

The combined railroad experience of both crewmembers was less than 5 mo. Furthermore, the foreman had only four previous starts at the hump, all as a helper, and the helper only had two previous starts (both as a helper). Two major factors likely contributed to this situation: a failure by the railroad to anticipate adequate staffing needs and the resultant practice of pairing two inexperienced RCOs on a crew. The pairing of two very inexperienced crewmembers created a situation where the crewmembers had an incomplete knowledge and understanding of railroad operations, including familiarity with the yard (e.g., presence of signal, access to main track) and RCL operations (e.g., when to protect the point). That is, between the two crewmembers, insufficient procedural and declarative knowledge of yard and RCL operations existed. Failure to anticipate adequate staffing and poor crew pairing are each discussed in greater detail below.

HFACS-RR analysis:

- Inadequate staffing. Over the last 2 yr, most of the railroad industry, including the railroad involved in the collision, has been affected by two major economic impacts: a large number of employees, especially those from the operating crafts, have retired; and an unanticipated increase in business, especially in 2004. One indication of railroad retirement is the number of employees who began their railroad pension or annuity in a given year. According to Railroad Retirement Board (RRB) data, the number of retired railroad employees increased sharply in 2002 (RRB, n.d.), almost doubling the 2001 retirement figure (see Table 9). In terms of increased business in the railroad industry as a whole, the AAR reported that for the first 28 wk of 2004, which covered the time period in which the collision occurred, both total carloads originated and ton-miles are up (3.7 percent and 4.9 percent, respectively) compared to the same period in 2003 (AAR, 2004). More specifically, while the number of cars originated on the particular RCL3 railroad system increased steadily each year from 2000-2003, the volume of cars switched at the yard where the collision occurred first decreased between 2000-2002 and then jumped up in 2003, likely corresponding to a surge in business (see Table 10).

Table 9. U.S. railroad employee retirement data 1997-2003

Year	Number of retired U.S. railroad employees
1997	7,422
1998	6,756
1999	6,846
2000	7,186
2001	6,285
2002	11,127
2003	8,261

SOURCE: RRB Retirement and Survivor Benefits Table B-2, www.rrb.gov.

Table 10. RCL3 car loads originated and switched 2000-2003

Year	System car loads originated	Cars switched at RCL3 yard
2000	8,901,283	543,941
2001	8,916,060	526,439
2002	9,131,348	506,013
2003	9,238,831	527,108

The combination of increased retirements and increased business has led to shortages in train crews to operate an increased number of trains on main track and in yards throughout the RCL3 railroad system. To combat this problem, among other remedies, the railroad is in the process of hiring thousands of new train and engine (T&E) crewmembers with no prior railroad experience. This has contributed to a situation where newly hired and inexperienced operating employees are in charge of trains. At the yard where the collision occurred, a local officer estimated that they have hired 150 new T&E employees in the past 2 yr to cover road and yard service operating crews. He estimated that, while 10 yr ago the average railroad experience of operating employees was 15-20 yr, the average amount of experience now is less than 2 yr on-the-job. The 60/30 retirement law that went into effect January 01, 2002, allows railroad employees with 30 or more yr of experience to retire at age 60, rather than the previous minimum requirement of 62. Although the railroad industry helped to create this law, the industry, including this railroad, may have failed to fully anticipate the large number of employees who chose to retire when this law went into effect (see Table 9). The railroad also failed to fully anticipate the rebound in the economy and consequent increase in demand for business (and cars switched) that it is now experiencing. The result is greater demand in moving cars with a less experienced crew base. *Organizational factors/resource management/human resources*. **Probable contributing factor.**

- Poor crew pairing. The foreman had been qualified as an RCO for only 11 wk, although he had less than 11 wk of hands-on experience as an RCO since he worked non-RCL industry jobs during these 11 wk. In fact, the foreman had only worked as an RCO 31 times before the collision, and only four of these, all as a helper, were at the hump. This was his first time operating as the foreman of (and thus, responsible for) the RCL hump job. The helper had been qualified as an RCO for 6 wk, although he immediately began 4 wk of conductor training following qualification as an RCO. In fact, the helper had only four starts as an RCO, and only two of these were at the hump, both times as a helper. This was his third start on the RCL hump job (see Table 11).

Table 11. RCL3 RCO experience

	Foreman / RCO A	Helper / RCO B
Total amount of time qualified as RCO	11 wk	6 wk
Number of RCL starts	31	4
Number of hump job starts	4	2
Number of hump job starts as foreman	0	0

These two RCOs were additionally responsible for training a BIT that night. The pairing of two very inexperienced crewmembers created a situation where the crewmembers had an incomplete knowledge and understanding of railroad operations, including familiarity with the yard (e.g., presence of signal, access to main track) and RCL operations (e.g., when to protect the point). The railroad arranges its crews at this yard from a centrally located crew management system responsible for crews across the railroad system. The railroad has no written rules or guidelines regarding pairing yard crewmembers based on experience. Rather, the system is seniority-based. A local practice exists whereby a local officer at the yard speaks with crew callers during the first 2 wk after a new class of trainman (includes RCOs) has qualified to ensure that two newly qualified RCOs from the same class do not work together. This method is unreliable, however, and is limited to prohibiting the pairing of crewmembers who have less than 2 wk experience each. Nothing is in place, however, to avoid pairing crewmembers with more than 2 wk experience. Research on commercial aviation crew scheduling shows an important rule or constraint on pairing crewmembers is crew experience and the need to limit pairings to one inexperienced operator (e.g., Kohl and Karisch, 2004; Medard and Sawhney, 2004; Kharraziha, Ozana, and Spjuth, 2003). *Supervisory factors/planned inappropriate operations.* **Probable contributing factor.**

6.5 Corrective Actions

To prevent similar accidents/incidents from occurring in the future, the railroad has made, or is in the process of making, the following yard-specific corrective actions since the accident occurred:

1. The railroad is in the process of coaching all RCOs on what to do if and when pullback protection is overridden. RCOs are explicitly instructed to provide point protection when the pullback protection system is overridden.
2. A system general order is being developed to provide written instructions regarding the need to protect the point of a movement when pullback protection is overridden.
3. Training materials are being reviewed to see if a new section is needed to address overriding pullback protection.
4. As part of a systemwide review into RCL operations, the railroad will look at how point protection and RCZs, including pullback protection, are used; how much understanding RCOs and managers have of these aspects of RCL operations; and will develop systemwide standards based on best practices gleaned from RCL operations across the system.

7. Case Study 4

7.1 Summary

At approximately 8:30 p.m. local time, a two-man RCL crew was shoving cars into track 23 to couple with a standing cut of cars. The foreman (B operator), riding a gondola at the point, requested a safety stop before coupling to the standing cut. After the cut of cars stopped, the foreman began to dismount the side ladder when his RCD struck a ladder rung and was forced up into his face, knocking his eyeglasses off, obstructing his view, and causing him to lose his balance as he dismounted. The foreman's foot missed the sill step, and he fell to the ground, where he landed on a combination of large and small ballast. The foreman suffered a torn rotator cuff and back sprain.

7.2 Circumstances Before the Injury

7.2.1 Meteorological Conditions

At the time of the injury, conditions were partly cloudy, with 10 miles of visibility, calm winds, and a temperature of 67° F.

7.2.2 Personnel

RCL Crew

The RCL crew went on duty at 3:30 p.m. local time. The injury occurred 5 h into their shift.

- *Helper/A Operator*

  The helper was 35 yr old. He had been qualified as a conductor for 2 mo and as an RCO for 6 wk. He had not yet qualified as a yard foreman. The helper had had, and passed, four efficiency tests; none were related to RCL operations. The helper had been off duty for 16 h and 45 min prior to the start of his shift.

- *Foreman/B Operator*

  The foreman was 30 yr old. The foreman had been qualified as a conductor for 4 mo, as an RCO for 3.5 mo, and as a yard foreman for 2 mo[15]. He passed his last rules exam 14 wk before the injury. The foreman had had nine efficiency tests, three of which were related to RCL operations. He passed eight out of nine tests. The one failed test related to proper lining of switches. The foreman had been off duty 16 h and 45 min prior to the start of his shift.

[15] At this location, a trainman is qualified as a conductor first, which includes qualification as a yard helper. He or she is then eligible to qualify as an RCO. However, he or she must have 30 starts before he or she can qualify as a yard foreman.

7.2.3 Yard Layout

This flat switching yard consists of two primary switch lead tracks on the north side of the yard (the side relevant to the injury), an east lead and a west lead. Traffic runs north-south on these two leads. The east lead feeds into a ladder track and a number of classification tracks, while the west lead runs into a second ladder track and a number of additional classification tracks. Classification track numbers increase west-to-east (see Figure 38).

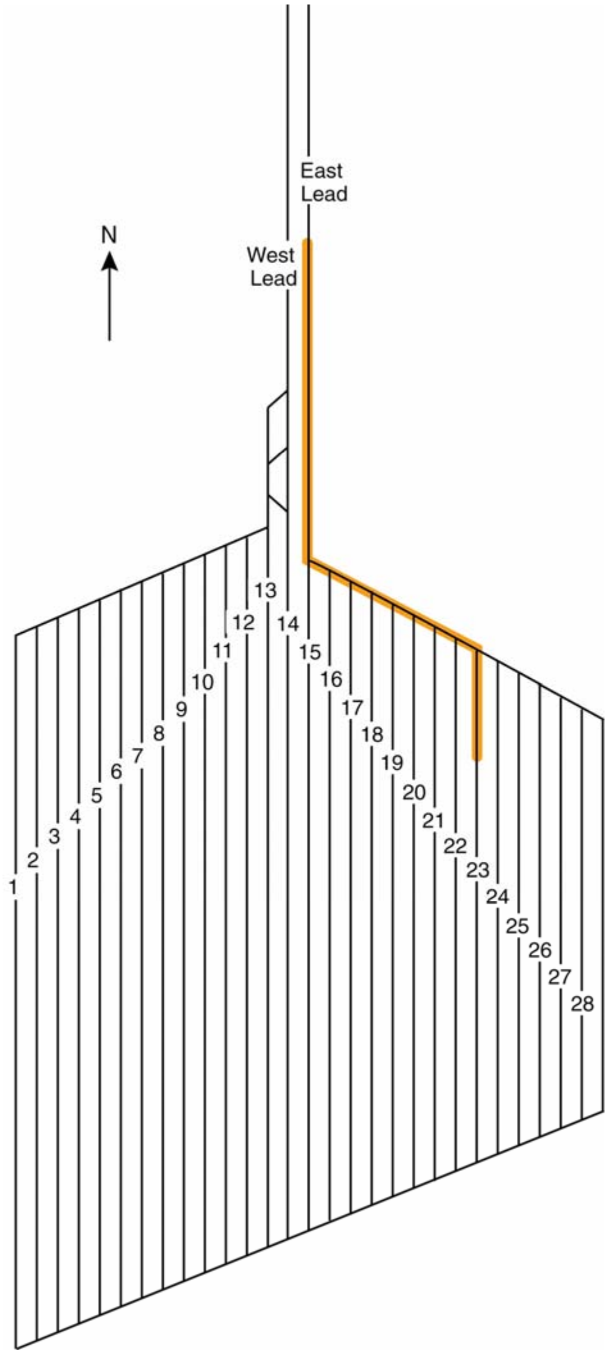

Figure 37. RCL4 yard diagram with path of RCL path highlighted

7.2.4 Preceding Events

Both crewmembers began duty at 3:30 p.m. local time. The trainmaster conducted a safety briefing with the RCL crew, and the yardmaster gave the RCL crew their first set of switching instructions. The crew then departed the yard office and performed all the necessary remote control tests and began switching cars.

Before the injury, the crew was building a train in track 23. The next move on their switch list was to pull a cut of cars northward out of track 17 and shove into track 23. The helper rode on the RCL to provide point protection,[16] while the foreman rode out on the second to rear car, a gondola[17]. The crew pulled the cut of cars out of track 17 using the east lead. After they pulled out of track 17 and cleared the switch, the foreman dismounted the car and relined the switch for movement on the ladder track. The track 23 switch was already lined for the shove move southward into 23. The foreman mounted the gondola, and they shoved along the ladder track and entered track 23 (see Figure 38). The helper was still in control of the move, and the foreman was riding the trailing end of the gondola car on the outside (north) of the ladder track.

Figure 38. RCL4 view of ladder and track 23

[16] Part of the lead track the RCL crew was using was an RCZ. Since the RCL crew was not sure whether or not their cut would extend beyond the far limit of the RCZ, however, they chose to protect the point during the pull.

[17] The rear car was a flat car that did not have a ladder for the foreman to ride on, so the foreman rode the next car, which was the gondola car.

7.3 The Injury

The foreman instructed his helper to make a safety stop before coupling to the standing cut of cars in track 23. His intent was to receive the pitch from his helper and control the move from the vantage point at the coupling from the ground. After the cut had stopped, the foreman began to dismount the side ladder when his RCD struck a ladder rung. The RCD fastened on the RCO's vest at the lower and middle sets of clasps[18], lifted up, knocked his eyeglasses off, obstructed his view of the ladder and ground, and caused the foreman to lose his balance as he was lowering himself. The foreman's foot missed the sill step, and he fell to the ground and landed on a combination of large and small ballast (see Figure 39).

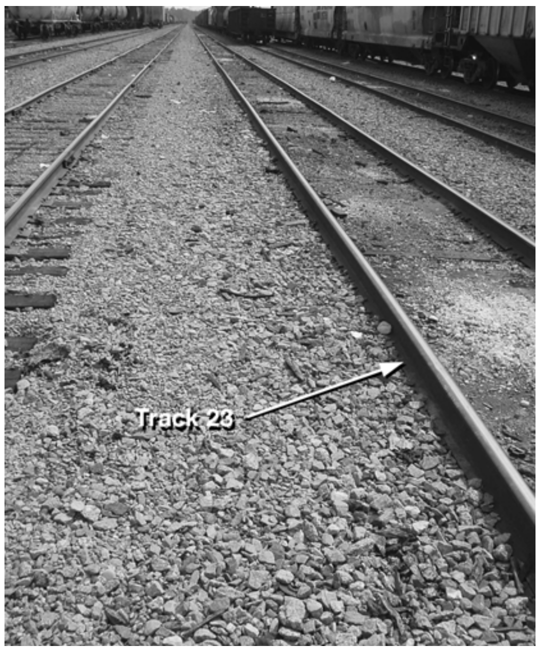

Figure 39. RCL4 approximate location of fall

7.3.1 Injuries

The foreman suffered a torn rotator cuff in his shoulder and sprained his back.

7.3.2 Damage

No damage to any equipment occurred.

7.3.3 Train Information

The car the foreman rode was a 57 ft, 34 ton gondola car (see Figure 40). It was the second car from the front; the lead car was a flat car that contained a load of steel. In

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[18] RCO vests are equipped with 3 sets of clasps—bottom, middle, and upper. An RCD must be attached at all four corners to the vest, fastened to either the bottom and middle sets of clasps, or the middle and upper sets of clasps. Either configuration is acceptable.

addition to a ladder on each end of the car, each side has two ladders—one near the B, or brake, end and one near the A, or non-brake, end. The left side of the B end and the right side of the A end each have ladder configurations that contain a sill step and four rungs to allow a person to climb to the top of the gondola car (see Figure 41). These ladders also afford the RCO the option of standing on the sill step or one rung above the sill step while riding the car. The rung above the sill step is referred to as a double drop rung. It is designed to prevent an RCO's feet from sliding off the rung horizontally as he or she swings around from the end of the car to the side of the car[19]. Above the double drop rung are three more rungs. Generally, an RCO stands in either the sill step or the first rung above it. The RCO ordinarily holds onto the second or third rung, whichever is more comfortable. The ladders on the other two corner sides each have a sill step and two rungs (see Figure 42). These ladders are designed to allow the RCO to stand in the sill step and hold onto either of the ladder rungs. The spacing of the rungs does not permit an RCO to stand on them.

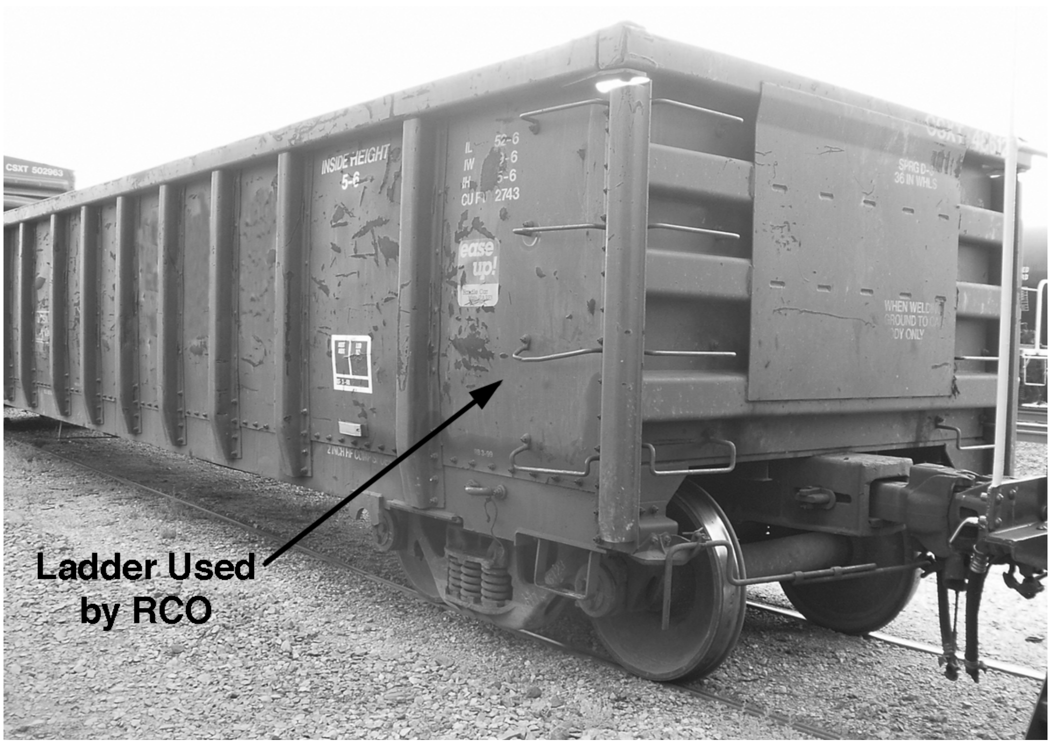

Figure 40. RCL4 gondola car and ladder where foreman was riding

[19] The sill step and rungs are designed, more generally, for any person riding or standing on the equipment. For the report, though, reference is specific to the RCO.

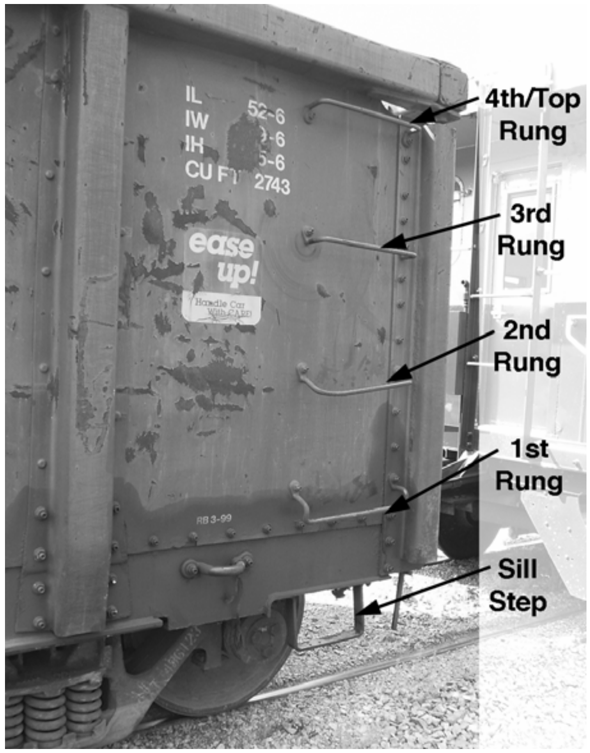

Figure 41. RCL4 A end ladder used by RCO foreman

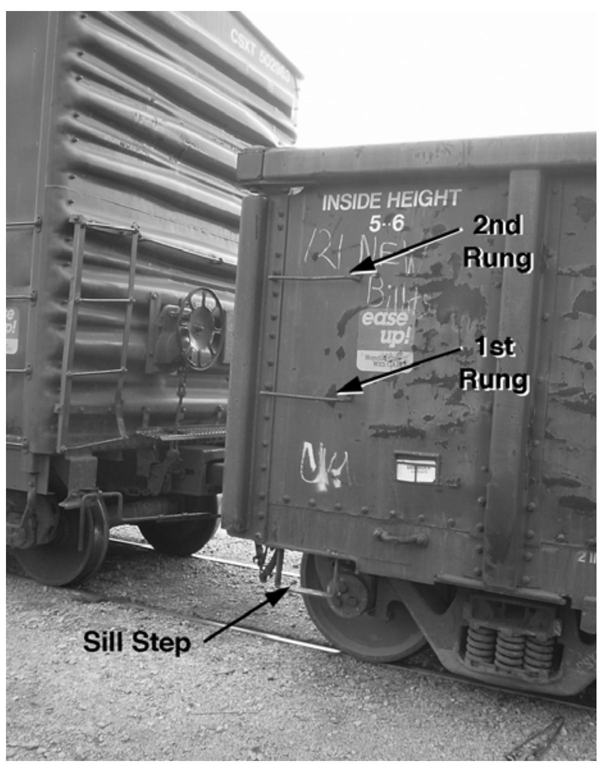

Figure 42. RCL4 B end ladder not used by RCO foreman

7.3.4 Actions of RCL Crewmembers

RCL Foreman

The foreman rode the gondola car because the lead car—a flat car carrying a flat load of steel—had no place for the foreman to ride. The RCO was still able to protect the point from this position. The foreman rode the outside, or north side, of the gondola car because the switch handles (to line movement into the classification tracks) were located on the north side of the ladder track. Another reason he rode this side is because it is safer to ride on the north side since a potential exists for cars in the classification tracks to foul the ladder track on the south side of the ladder track and strike a switchman riding that side of a cut of cars along the ladder track.

The foreman rode the trailing, A end of the gondola car because of a preference to stand on the first ladder rung above the sill step. The ladder on the north side, leading end of the gondola only, contained a sill step to stand on and several ladder rungs to hold onto (see Figure 42). This configuration forces the rider to stand on the sill step. Because the sill step is recessed compared to the rest of the ladder rungs and side of the car (see Figure 43 and Figure 44), it can cause a rider's upper body to hang out, making it potentially dangerous when riding on a track with a narrow clearance[20] or if equipment is fouling the path. It may also be uncomfortable to some riders. In fact, the clearance between tracks 23 and 24 was considered narrow, although at the time of the injury, track 24 was empty. To avoid riding the sill step, the foreman rode the trailing end of the gondola car. There he was able to place his feet in the first ladder rung above the sill step and his hands on the top rung in order to pull himself, and ride, closer to the body of the car.

As the cut of cars approached the standing cut of cars in track 23, the foreman instructed his helper to stop before making the coupling. After the stop, the foreman began to dismount the car to get into position to receive the pitch from his helper and control the move at the coupling. At the time of the stop, the foreman's hands were on the top ladder rung, and his feet were on the first rung above the sill step. As he began to dismount, the foreman removed one foot from the ladder rung and tried to place it in on the sill step. As he lowered himself, his RCD struck a ladder rung and was shoved into his face, knocking his eyeglasses off, obstructing his view, and causing him to lose his balance. As a result, the foreman missed the sill step with his foot, lost his grip on the ladder, and fell to the ground.

[20] Clearance refers to the space, or more specifically the walking path, between two tracks. When tracks contain equipment on them, this situation can create a narrow passage between the two tracks since the equipment is wider than the rail gauge.

Figure 43. RCL4 front view of recessed sill step

Figure 44. RCL4 side view of recessed sill step

7.4 Analysis

The analysis section is organized into two sections. The first section identifies exclusions—those factors that were examined but not considered to be a contributing factor. The second section presents and discusses the HFACS-RR analysis.

7.4.1 Exclusions

The investigation team considered the following exclusions and factors, dismissing them as contributing factors. They are included here for completeness.

- The foreman did not appear to be ill.
- Weather conditions were moderate and dry and did not appear to play a factor in the injury.
- Workload was considered average the night the injury occurred.
- Maintenance records indicate that the gondola car from which the foreman fell had been repaired four times over the last 12 mo, but none of the work was related to the sill step or ladder. No exceptions were noted of the condition of the sill step or ladder. Based on observation and photographs, the sill step and ladder rungs appear to comply with Federal regulations (49 CFR 231, Railroad Safety Appliance Standards).
- The foreman was fitted for his vest during RCO training and noted that the vest fit well.
- The RCD was attached to the vest at all four points, as required by the carrier.
- Training on mounting and dismounting equipment (without an RCD) is addressed in initial conductor classroom and field training. The need for additional awareness when mounting and dismounting equipment due to the size and location of the RCD was discussed in RCL classroom training according to one instructor. Furthermore, mounting and dismounting equipment is an item on a checklist to be covered by a supervisor during an RCO's check-ride. Neither crewmember, however, recalled any additional training on mounting and dismounting equipment with the RCD during his RCL training. Given that the procedure for mounting and dismounting equipment while wearing the RCD is no different than that for ordinary conductors and switchmen in general, and given the self-evident fact that the RCD adds extra dimensions to the RCO when he or she is wearing the RCD, training is not considered to be a contributory factor in the injury.
- The RCO's alertness did not appear to contribute to this injury. The foreman was on a regular assignment with start times that were either 11:30 p.m. or 3:30 p.m. For several days before the accident, the foreman had start times of 3:30 p.m. and was off duty between 10:45 p.m. and 11:30 p.m. Based on the self-reported sleep habits, the foreman would have gone to bed between 12:30-2:30 a.m. and slept for at least 6 h. On the day prior to the injury, the person went to bed at 12:30 a.m. and slept until 10 a.m., about 9.5 h. He came to work again at 3:30 p.m., and the

injury occurred at 8:30 p.m. with an estimated effectiveness at the time of the injury of 100 percent, since this time is approximately the time of the circadian peak for someone working this type of schedule. His lapse index was less than the average well-rested person. Although the foreman was carrying a small sleep debt of about 4 h, this had minimal impact on the expected cognitive alertness. No basis exists for expecting that the helper was fatigued at the time of the injury based on the sleep history provided.

7.4.2 Analysis of Accident

The primary element that led to the foreman's fall from the gondola car was an attention failure by the foreman because of a physical distraction caused by the RCD shoving into the foreman's face, knocking his eyeglasses off, and obstructing his view of the sill step and ground. The remainder of this section provides a human factors analysis of the factors that contributed to the injury.

Loss of Crewmember Attention

The foreman failed to attend to dismounting the gondola car when his RCD struck a ladder rung and raised up into his face. The foreman subsequently missed stepping onto the sill step and lost his balance and fell to the ground. Loss of crewmember attention can be broken down into two contributing factors. They are discussed below.

HFACS-RR analysis:

- <u>Temporary distraction</u>. The foreman was temporarily distracted as he was dismounting the car when his RCD caught a ladder rung as he began to lower himself. The RCD raised up into the foreman's face, knocked his eyeglasses off, and obstructed his view of the sill step and ground beneath. *Operator acts/skill-based error/attention failure.* **Probable contributing factor.**
- <u>Size, shape, and location of the RCD</u>. The size and shape of the RCD, and its location worn on the foreman's chest (see Figure 45[21]), enabled the RCD to catch on a ladder rung and raise up into the foreman's face as the foreman dismounted the gondola. The RCD is 10 inch (in) long by 3.5 in wide by 4.5 in high (Cattron-Theimeg, 2002). In fact, it is common knowledge among RCOs that RCDs occasionally strike, or catch, railroad equipment (e.g., locomotive cab door). In this instance, the RCD got caught on a ladder rung as the foreman lowered himself. *Preconditions for operator acts/environmental factors/technological environment.* **Probable contributing factor.**

[21] The individual shown in the picture was not the RCO involved in the injury.

Figure 45. RCL4 side view of RCD involved in injury

7.5 Corrective Actions

To prevent similar accidents/incidents from occurring in the future, the railroad has made, or is in the process of making, the following yard-specific corrective action since the accident occurred. RCL crews on all shifts were briefed on the injury during job briefings for a period of time immediately after the injury. As part of the briefings, crews were given awareness training regarding the RCD's extra dimensions. Rules associated with getting on and off equipment were also reviewed.

8. Case Study 5

8.1 Summary

At approximately 3:15 p.m. local time, an RCL trim job shoving southward on the trim 2 track entered an industrial lead around 7 mph and derailed off the end of the track, destroying part of an industry building and coming to rest on a city street. Both cars leading the move derailed, and the first sustained damages from the impact with the building. Costs associated with the damaged building and rolling equipment were estimated to be at least $200,000.

8.2 Circumstances Before the Derailment

8.2.1 Meteorological Conditions

At the time of the collision, the temperature was around 81° F with thunderstorms in the area, though no precipitation occurred at the time. Winds were west-south-west around 7 mph, and visibility was 10 miles.

8.2.2 Personnel

<u>RCL Crew</u>

The RCL crew went on duty at 2:00 p.m. local time.

- *Brakeman/A Operator*

  The brakeman was 43 yr old. He had been qualified as a switchman/brakeman/conductor for19 mo and had been qualified as an RCO for just under 12 mo. This job was an extra board assignment. The railroad had conducted 46 efficiency tests on this brakeman in the last 9 mo[22]. Of these, 21 were RCL-related. The brakeman passed all but two (neither was RCL-related) tests. His most recent efficiency test was 2 wk before the collision. His most recent annual performance monitoring observation was 11 mo and 9 d before the derailment. His last biannual rule examination was 19 mo before the derailment. The brakeman had been off 25 h 44 min prior to going on duty.

- *Conductor/B Operator*

  The conductor was 35 yr old. He had been qualified as a switchman/brakeman/conductor for 17 mo and had been qualified as an RCO for 11 mo 1 wk prior to the derailment. This was his regular job. The railroad had conducted 79 efficiency tests on this brakeman in the last 9 mo[23]. Of these, 47 were RCL-related. The brakeman passed all efficiency tests. His most recent

[22] Data were provided for only 9 mo.

[23] Data were provided for only 9 mo.

efficiency test was 3 d before the collision. His most recent annual performance monitoring observation test was 6 d before the derailment. His last biannual rule examination was 17 mo prior to the collision. The conductor had been off 63 h 30 min before going on duty.

8.2.3 Yard Layout

The yard is laid out in a north-south direction. The hump, bowl, and storage tracks are all located toward the north end, while several trim, or pullback, tracks are located to the south (see Figure 46). Cars are humped into bowl tracks, and then cuts of cars are pulled southward out of the south end of the bowl track using trim tracks 1 and 2, and shoved back northward into the storage tracks. An industry also feeds into the trim 1 track south of the storage tracks using a curved industrial lead track (see Figure 47). At the end of the industrial lead, a bumping post denotes the end-of-track and prevents cars from rolling off the end-of-track.

In addition, one track—track 214—is used to store long cuts of cars, among other uses (see Figure 48). Track 214 is located in the eastern part of the yard and runs southward and then westward, serving as a ladder track for the southern part of the bowl tracks. Track 214 then continues southward, serves as a ladder track for the storage tracks, and eventually feeds into the trim 2 track. Just south of the track 214 switch, an RCZ begins and runs southward along trim 1 and trim 2 tracks (see Figure 49).

8.2.4 Automatic Pullback Protection System

Trim 2 track is equipped with an automatic pullback protection system to provide PSP. The pullback protection system consists of an antenna underneath the RCL that searches for and reads passive track transponders embedded between the rails (see Figure 50 for an example). These passive transponders communicate speed directive information to the antenna as an RCL encounters the transponders. The antenna, in turn, communicates the information to the RCL to control the speed of the RCL. The first set of transponders communicates to the RCL that it is entering the pullback protection system and communicates a maximum prescribed speed for the RCL as it begins to travel down the pullback-protected track. Subsequent transponders communicate lower and lower speed information, so that the RCL is instructed to stop at designated location along the track based on two stop transponders. The start of the pullback protection system, as indicated by the location of the first track transponder, is just south of the track 214 switch and just north of the industrial lead turnout.

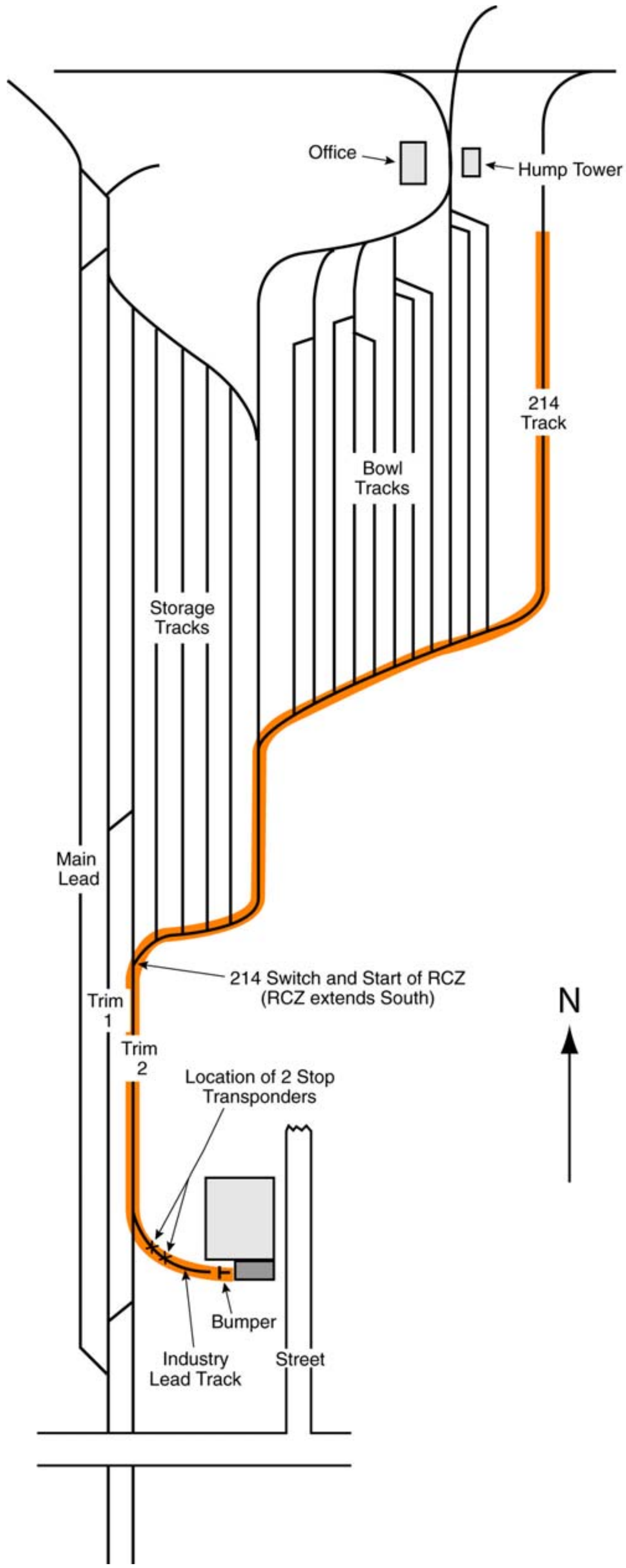

Figure 46. RCL5 yard layout with RCL path highlighted

Figure 47. RCL5 southward view of industrial lead track

Figure 48. RCL5 southward view of bowl tracks and 214 track from hump tower

The industrial lead track is also equipped with two stop transponders that were installed by the industry that owns the track. The intent is to require the RCL to stop as it approaches the industry and require a manual override of the pullback protection system so that an RCO will be in control of the move when he or she spots cars at the industry.

Figure 49. RCL5 southward view of 214 switch and start of RCZ along trim 2 track

Figure 50. RCL5 passive track transponder

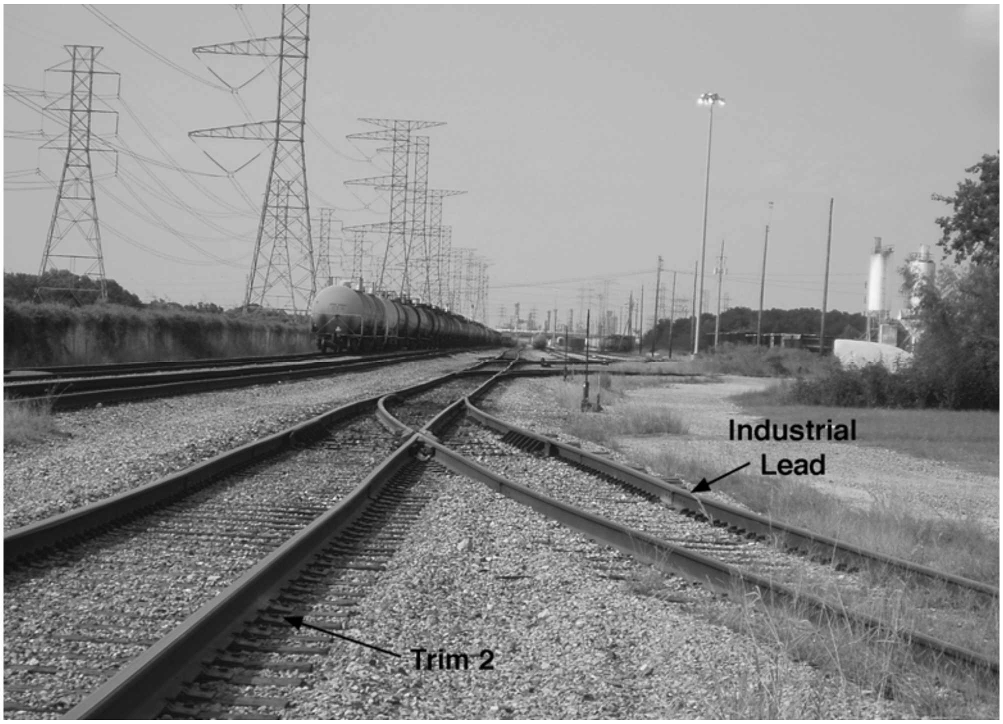

Figure 51. RCL5 northward view of trim 2 and industrial lead tracks

8.2.5 Preceding Events

The RCL crew came on duty at around 2 p.m. They were one of two jobs scheduled to work that afternoon. The other hump job had not begun. The conductor of the trim job had to wait for the hump job to classify a cut of cars from a train that had not arrived in the yard yet before he could begin to build his first outbound train. The trim job conductor suggested that they go ahead and service a local industry, a routine task at the yard whereby existing, empty rail cars are removed and new cars are placed, or spotted, at the facility. The three cars that needed to be spotted at the local industry were currently sitting in track 214. Cars in track 214 were supposed to have been classified via the hump, but the previous hump job crew had not been able to classify these cars before going off duty, and the next hump job crew had not begun their shift. The conductor received a switch list for cars in track 214 from the yardmaster. The conductor reviewed the switch list, which listed the cars he needed at the bottom of the list.

The conductor expected these cars to be located on the south end of track 214 since the switch list for the trim job is prepared so that the southern-most cars—the cars the trim job will pull out first—are located at the bottom of the list. Trim crews read and work the switch list from bottom to top. Yardmasters prepare switch lists for the hump job on the north end of the yard so that the southern-most cars—the cars to be humped (southward) first—are listed at the top, and the crew reads and works the switch list from top to bottom. The conductor walked over to track 214 on the south end of the track to locate the cars and soon realized that the cars he needed were on the north end of the cut. The switch list that was provided to the trim job had probably been prepared for the hump job in preparation for humping the cut of cars in track 214. The ordering of the cars on the switch list, thus, was the opposite as that which was initially expected by the conductor.

Since the cars to be spotted at the local industry were located at the far (north) end of track 214, the conductor decided to go ahead and run their light RCLs over to the industry, pick up two empty cars first, then return to the yard to pick up the three cars out of track 214, and spot the cars at the local industry. The conductor's plan was to couple up the RCLs to the cut of 67 cars on track 214 and shove[24] southward until they found the three cars they needed. The crew would then shove the three cars into a bowl track, cut them off, return the remaining cars back into track 214, and run northward around the yard with the two original cars so that they could then travel southward along the empty bowl track to couple up their two cars to the three cars they needed to spot. This process would position the three cars on the south end of the cut, so that the crew could easily shove them down trim 2 and spot them at the industry.

The crew took their two light RCLs, traveled southward along trim 2, and entered the industrial lead to pick up two empty cars. The track transponders stopped their move as they entered the industry track. The brakeman, operating the RCD, overrode the pullback protection system, resumed movement into the industry, and coupled up to the cars. They then pulled out of the industry track back onto trim 2. At this point, the brakeman asked the conductor if they should line the industrial track back for trim 2. The conductor told the brakeman to leave it lined for the industry since they were coming right back. The crew pulled their cars northward and coupled up their RCLs to the south end of the cut of cars in track 214. They began to shove southward. As the crew began to shove southward, they were standing on the ground near the track 214 switch, looking out for their three cars. The start of this southward movement occurred at 3:09:35 p.m.

8.3 The Derailment

The brakeman, in control of the move, continued to shove the cut southward out of track 214 while looking for the cars they wanted to spot. At approximately 3:17:05 p.m., the RCL encountered the first industry pullback protection stop transponder (see Figure 50). The cut was presumed[25] to be traveling approximately 7.4 mph when it encountered this stop transponder. The RCL initiated a stop[26] as a result of encountering the stop transponder. Approximately 9 s later the cut derailed off the end-of-track and struck the building; it was traveling 6.3 mph at the time of derailment. Twenty-one seconds later the cut came to a stop. The crew received several warnings on their RCD as a result of the RCL encountering the track transponder, wheel slip, and subsequent derailment. The crew was unsure what had happened and drove their vehicle to the industry to investigate,

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[24] Technically, the RCLs were shoving the cut of cars out of track 214, instead of pulling, because the two empty cars they had picked up were coupled up to the south (lead) end of the RCLs.

[25] Data came from the locomotive event recorder rather than the RCL event recorder. Consequently, events are presumed based on matching knowledge of the track and derailment with characteristics of locomotive outputs, such as sudden application of the brakes and a change in throttle.

[26] It cannot be determined from the locomotive event recorder whether the stop was a full service brake application or an emergency brake application.

where they discovered the derailment.

8.3.1 Locomotive Event Recorder-Based Timeline

Table 7 provides a timeline of information from the locomotive[27] event recorder download.

Table 12. RCL5 locomotive event recorder download data

Time	TMC (Amps)	Throttle	Brake pipe (psi)	Brake cylinder (psi)	Speed (mph)	Reverser	Additional details
3:09:35 p.m.	35	0	89	30	1	Forward	Southward movement initiated as RCL crew looks for their three cars.
3:17:05 p.m.	1066	8	89	0	7.4	Forward	RCL encounters first stop transponder on industrial lead track.
3:17:06 p.m.	544	0	89	8	7.4	Neutral	One second after encountering stop transponder, the RCL initiates a stop.
3:17:15 p.m.	0	0	45	76	6.3	Neutral	Presumed impact with building.
3:17:36 p.m.	0	0	0	90+	0-1	Neutral	RCL comes to a final resting point on street.

8.3.2 Injuries

No injuries occurred.

8.3.3 Damage

A conference room extending off the main industry building and located just beyond the end-of-track was destroyed (see Figure 52 and Figure 53). Both cars (the original two cars pulled out from the industry) on the point of the movement derailed. The first sustained damages from the impact with the building structure. Damages to the building and cars were estimated to be at least $200,000.

[27] Event recorder data from other case studies came from RCL OCC event recorders; however, for this derailment, the RCL OCC event recorder data was not recovered before it was recorded over with newer data. The locomotive involved in the derailment was equipped, however, with an event recorder; these data were used.

Figure 52. RCL5 damaged bumper post and industry building conference room

Figure 53. RCL5 damaged industry building conference room

8.3.4 Train Information

The cut consisted of 2 cars at the point of the movement, 2 RCLs, and 67 trailing cars.

8.3.5 Actions of RCL Crewmembers

<u>Brakeman/A Operator</u>

The brakeman controlled the RCL movement as they traveled southward toward the industry. At some point the brakeman dismounted the RCL and, using the conductor's switch key, lined the industry switch for movement into the industry. The brakeman controlled the move as it entered the industry lead. Upon entering the industry track, the track transponders stopped the RCLs. The brakeman overrode the pullback protection system and continued his movement into the industry lead to pick up two empty cars. After coupling with the two cars, he pulled the two cars out of the industry lead. As they left the industry track, the brakeman asked the conductor if they should stop to reline the switch back for trim 2. The conductor told the brakeman to leave it lined for the industry since they were coming right back.

The cut continued northward. They entered track 214 on the south end and coupled up to the southern-most car in track 214. The brakeman was in control of the move the entire time. He then reversed direction and began shoving southward. At some point before or early in the move, the brakeman dismounted the RCL and was operating the RCL from the ground near the conductor and track 214 switch, where track 214 joins the trim 2 lead track. The brakeman and conductor were watching for the cars they needed to set out and spot. Several minutes into the move, the brakeman received several warnings on his RCD, including a track transponder message and a wheel slip message. Once the brakeman realized what had happened, he placed the RCL into emergency to stop the cut. Shortly after he and the conductor drove over to the industry to see what had happened.

<u>Conductor/B Operator</u>

Before beginning the shift, the conductor pulled up his initial paperwork to get an idea of what to expect for the shift. Once the brakeman arrived, the two crewmembers retrieved their RCDs, installed batteries, drove to the RCLs, linked up, and did their initial RCL tests. The conductor the walked over to track 214 to line switches for the bowl tracks, while the brakeman checked their switches to establish their RCZ.

Shortly after, the yardmaster called to inform the crew that they could not begin building their first train since they were waiting on cars from an inbound train that had not arrived yet. At this time the conductor suggested that they go ahead and service the local industry. The conductor checked his switch list and looked for the cars in track 214 that he needed to set out to spot at the industry. Rather than first setting out the three cars from track 214, the conductor decided to go down and pick up the two empty cars from the industry, bring them back, and then find and set out the three cars from track 214 that needed to go to the industry.

The conductor rode the rear RCL as they traveled southward. He gave the brakeman his switch key to unlock the industry switch. They entered the industry. The crew coupled up to the two empties and pulled them out of the industry. As they did, the brakeman asked the conductor if they should reline the switch for trim 2. The conductor told him to leave the switch lined for the industry because they would be returning to the industry shortly to drop off the three cars.

At some point as they rode into track 214, the conductor dismounted the RCL and positioned himself by the 214 switch to look for the cars they needed. The conductor and brakeman stood near the 214 switch as they pulled the cut southward out of 214. Several minutes later, the conductor received several alarms on his RCD. Soon after, the conductor drove the car down to the industry with the brakeman to determine what happened.

8.4 Analysis

The analysis section is organized into two sections. The first section identifies exclusions—those factors that were examined but not considered to be a contributing factor. The second section presents and discusses the HFACS-RR analysis.

8.4.1 Exclusions

The investigation team considered the following exclusions and factors, dismissing them as contributing factors. They are included here for completeness.

- Neither crewmember appeared to be sick at the time of the derailment.[28]
- Weather conditions did not appear to play a factor in the derailment.
- The RCL and pullback protection system appeared to work as designed. Although the RCL had entered the active RCZ, it had not reached the start of the pullback protection system on trim 2. The RCL had successfully encountered the stop transponder located in the industry track in a prior move, and it encountered the same stop transponder again just before the derailment. Locomotive event recorder data suggest that the stop transponder embedded in the industrial lead track commanded the RCL to stop; however, the RCL had too much inertia to stop short of the end-of-track. The industry stop transponders were not designed to stop this type of movement. Rather, they are designed to stop a slow-moving cut of cars to ensure that one of the crewmembers is actively controlling the move when servicing the industry.
- Workload was low at the time of the collision. The RCL crew was the only job working in the yard at the time and had to wait for another crew to begin work before they could begin building their first train. Consequently, they elected to service a local industry. This was the only activity in the yard at the time.
- The RCO's alertness did not appear to contribute to the derailment. While this brakeman was working the extra board and did not have a regular assignment, the shift involved was expected. The self-reported sleep history immediately before the derailment indicates that the person had 15 h of sleep during the 24 h immediately prior to the derailment, divided between a 2 h nap and a 13 h major sleep period. This extremely long sleep period might seem excessive; however, analysis indicates that this brakeman was carrying a 13.5 h sleep debt going into this day and may very well have been able to sleep that long. The total sleep taken between the last work period and the work period of the derailment would have reduced his sleep debt to slightly over 2 h, rising to about 4 h by the time of

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[28] The brakeman reported that he had not been suffering from any illness before the derailment. This information was not solicited from the conductor; however, he did not appear to be sick several days following the derailment, when interviewed.

the derailment, not a particularly dangerous level. The derailment occurred at 3:30 p.m. when effectiveness was estimated at about 94 percent, and his lapse index is well within the range of the well-rested person. This level is slightly depressed because of the usual afternoon dip in performance but is well within the boundaries of a well-rested person working during the day time. If the brakeman had arranged only the usual 8 h of sleep during the prior 24 h, effectiveness could have been as low as 81 percent, and lapses would have been double the normal level, even at this time of day.

8.4.2 Analysis of Accident

Several factors contributed to the derailment: (1) a poor choice to leave the industry lead switch lined for the industry, (2) a loss of situation awareness regarding the status of the mislined switch and movement of the cut of cars into the industry, and (3) contravention of a system special instruction. The remainder of this section provides a human factors analysis of the derailment.

Poor Choice to Leave the Switch Lined for Industry

As the RCL crew left the industry and traveled northward to pick up the three cars that needed to be spotted back at the industry, the brakeman asked if he should reline the switch for straight movement. The conductor instructed the brakeman to leave the switch since they would be returning shortly. This is discussed below in greater detail.

- <u>Poor choice to leave the switch lined for industry</u>. Given the nature of RCL operations and use of an RCZ (that is, the RCO can control a movement a mile or more away from the point of the movement and thus may not be able to visually detect the switch position) and given that the conductor knew where the cars they needed to spot were in track 214—on the north end, it was a poor choice by the RCOs not to reline the switch for straight trim 2 movement and reline it for the industry when they returned later with the three cars. *Operator acts/decision error/poor choice.* **Probable contributing factor.**
- <u>Inadequate knowledge of automatic pullback protection system</u>. The presence of the stop transponders in the industrial track may have given RCOs a false sense of security that the transponders would stop any movement from entering the industrial lead track. RCOs were familiar with the stop transponders in the industrial lead track since it stopped their move each time they entered the track and required the pullback protection system to be overridden before movement could commence again. These transponders are intended to stop a slow-moving cut, not the size and speed of the cut that derailed at the end-of-track. Although the RCOs were not relying on this technology to stop their move, the presence of these stop transponders may have contributed to a false sense of security that a safety net was present. *Supervisory factors/inadequate supervision (training).* **Possible contributing factor.**

Loss of RCO Situation Awareness

The use of RCL equipment, including the RCZ, reduced RCOs' situation awareness by enabling crewmembers to control their cut of cars remotely from the point of the movement. This situation eliminated their ability to detect the mislined industry switch. A number of factors contributed to this loss of situation awareness. These are discussed below.

- Failure to remember orientation of the industry switch. It is not clear whether the RCL crew forgot about the industry switch or was briefly distracted by the misordered switch list, but both crewmembers ultimately failed to remember the industry switch was lined for the industry. *Operator acts/skill-based error/memory failure.* **Probable contributing factor.**

- Reversed switch list may have created mismatched expectation of car location. The switch list that the trim job was using listed the cars they needed at the bottom of the list, which, for a trim switch list, would mean that the cars were on the south end. As it was, the cars were on the north end, and the switch list was likely created for the hump job, which works top-down starting with the southern-most car (thus, the bottom cars are at the north end of the track). Although the conductor knew where the cars were, the brakeman thought the cars were on the south end. The reversed switch list contributed to the brakeman's expectation that the cars would be located on the south end. This could have briefly distracted the brakeman from thinking about the industry switch. *Preconditions for operator acts/environment/technological environment.* **Possible contributing factor.**

- Inadequate communication between crewmembers may have contributed to at least one crewmember's loss of situation awareness. The conductor knew that the cars they needed to pull out were on the north end of track 214, but the brakeman did not know and was expecting the cars to be located on the south end. This discrepancy in crewmember understanding of the move they needed to make suggests that inadequate communication occurred between the conductor and brakeman, which may have contributed to at least one crewmember's loss of situation awareness. *Preconditions for operator acts/personnel factors/crew resource management.* **Possible contributing factor.**

- RCL technology enabled the RCO to control his movement from a distance and thereby reduced RCO situation awareness. The use of RCL equipment, including RCZs and automatic pullback protection, enabled the RCOs to control cuts of cars at a significant distance away from the point of the movement. The presence of this technology enabled the RCOs to operate at a distance far enough away from the point of the movement where they could not visually detect the mislined switch or feel the movement of the cars and RCLs when they entered the industry turnout. Had an RCO been riding the point of the movement or had he been in a position further south to watch the point of the movement, this RCO likely would have noticed the industrial lead switch target indicating movement into the industry lead (see Figure 54). The crewmembers also would have noticed once the lead cars began to enter the industrial lead. By its very nature, the RCL technology reduced RCOs' situation awareness by enabling them to operate the move remotely from the point of movement. *Preconditions for operator acts/environment/technological environment.* **Probable contributing factor.**

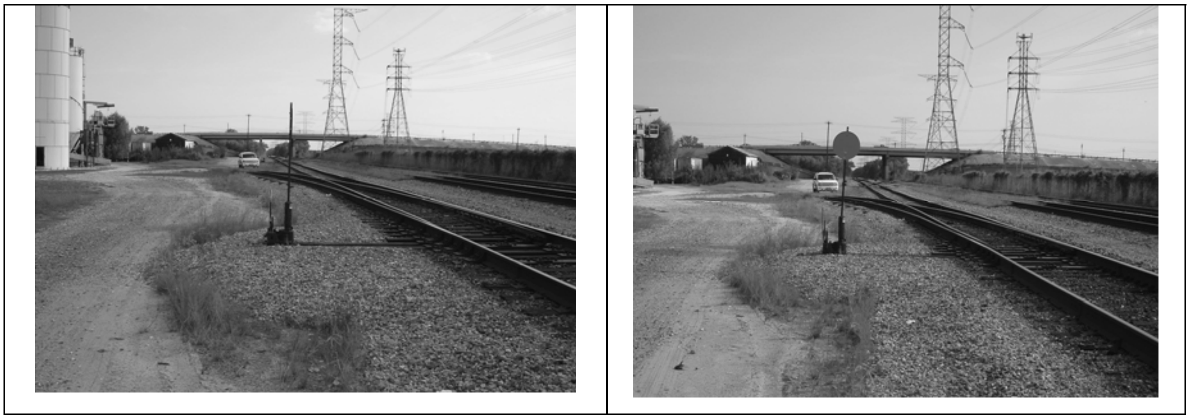

Figure 54. RCL5 industrial lead switch target communicating straight (trim 2) track movement (left) and industrial lead movement (right)

Contravention of System Special Instruction

At the start of the shift, the RCL crew activated their RCZ, which included the trim 2 lead track southward to the industry lead (and beyond). A system special instruction (SSI) related to activated RCZs reads (*italics* are authors' emphasis),

> When a remote control zone is activated, the RCO must ascertain that *switches/derails are properly lined* and track(s) within the zone are clear of trains, engines, and cars and men or equipment fouling track. The RCO is then relieved of point protection and the requirement to stop in one half the range of vision for pull out movements with *locomotive on the leading end only*.

As the RCL crew was shoving their cut southward out of track 214, however, they did not have the industry lead switch properly lined for straight movement along the trim 2 track, and they operated with cars on the point of the movement. Both of these conditions trigger a de-activation of the RCZ and create a situation where point protection is required to stop short of hazards. At a minimum, the conductor knew that the cars they needed were on the north end of the cut, and thus they were going to have to pull the cut southward a significant distance and would likely enter the RCZ on the north end of the trim 2 track. Both crewmembers elected to stand at the 214 switch and look for the three cars rather than delegating one crewmember to protect the point while they shoved southward. This is discussed below.

- <u>Contravention of SSI</u>. The RCL crew opted to leave the industry switch lined for the industry when they should have lined it back for straight movement, given their dependence on the RCZ as they shoved their cut southward out of 214. The crew opted to leave the switch lined for the industry to save time since they knew they were coming right back, even though at least one crewmember knew that they would have to pull several thousand feet of cars southward out of track 214 shortly. Further, the crew was operating with two cars on the south end of the two RCLs. According to one crewmember, the yardmaster instructed the crew to hold onto the two cars as no place existed to put them at the time. Since these two cars were at the point of the movement, one of the crewmembers should have protected the point according to the SSI in effect. Yet, neither crewmember protected the point, and instead both remained with the car at the 214 switch and watched for the cars they needed. Further exploration revealed that, even though the SSI requires point protection to be provided when the RCL is not at the leading end of the movement (in such cases, the RCZ is no longer active), occasionally an RCO may not protect the point under similar circumstances (e.g., a short movement with cars on the leading end in a recently active RCZ) since it will save the crew time by not having to ride on the lead car or not having to walk further southward along the 214 track and trim 2 lead track to protect the point. *Operator acts/contravention/routine contravention.* **Probable contributing factor.**

- Organizational culture may encourage corner cutting. Exploration of the organizational culture at this yard suggests that a culture of "hurry up" exists where crews are encouraged to get their work done as quickly as possible and, thus, to take shortcuts when expedient. This organizational culture may have facilitated the situation where the RCL crew decided to leave the industry switch lined for the industry and to shove their cut southward with cars on the lead without protecting the point. *Organizational factors/organizational climate/organizational culture.* **Possible contributing factor.**

8.5 Corrective Actions

To prevent similar accidents/incidents from occurring in the future, the railroad has made, or is in the process of making, the following yard-specific corrective actions since the accident occurred:

1. The railroad briefed all yard crews in safety meetings about the necessity of protecting the point in the RCZ when the RCLs are not at the leading end of the movement.
2. The crew involved in the derailment was given the opportunity to improve performance after more training and 5 d off.

9. Case Study 6

9.1 Summary

At 2:06 a.m. local time, a one-person remote control job, with 2 locomotives and 37 cars, weighing 2928 tons, ran off of the end of the west pullback track and derailed up an embankment, causing approximately $23,000 in damage to the lead and trailing locomotives. No injuries occurred.

9.2 Circumstances Before the Derailment

9.2.1 Meteorological Conditions

At the time of the derailment, conditions were clear. Winds were eastward at 8 mph, visibility was 10 miles, and the temperature was approximately 65° F.

9.2.2 Personnel

The accident involved a cut of cars operated by a one-person RCO crew.

<u>RCO</u>

The RCO started the shift at 11 p.m. the evening before the derailment and was approximately 3 h into the shift when derailment occurred. The RCO had been off duty for over 15 h before going on duty the evening before. The operator was 35 yr old. He had been qualified as a conductor and switchman for 12 mo, all of which was in yard service, and had been qualified as an RCO for just under 7 wk. Fifty-four RCL-related efficiency tests had been conducted on the individual since he qualified as an RCO, all of which he passed. The last efficiency test was performed 6 d before the accident.

9.2.3 Yard Layout

Running approximately south to north, the yard consists of a number of receiving tracks, followed by a hump, a number of classification tracks, and two pullback tracks—an east and a west (see Figure 55). The pullback tracks each end at the lower portion of an embankment (see Figure 56). To the east and west of the classification tracks are a number of departure or forwarding tracks. A number of run-around, repair-in-place (RIP), and other service tracks are throughout the yard. Two towers exist—a hump tower positioned at the hump and a north end tower located at the juncture of the northern part of the classification tracks and the pullback tracks.

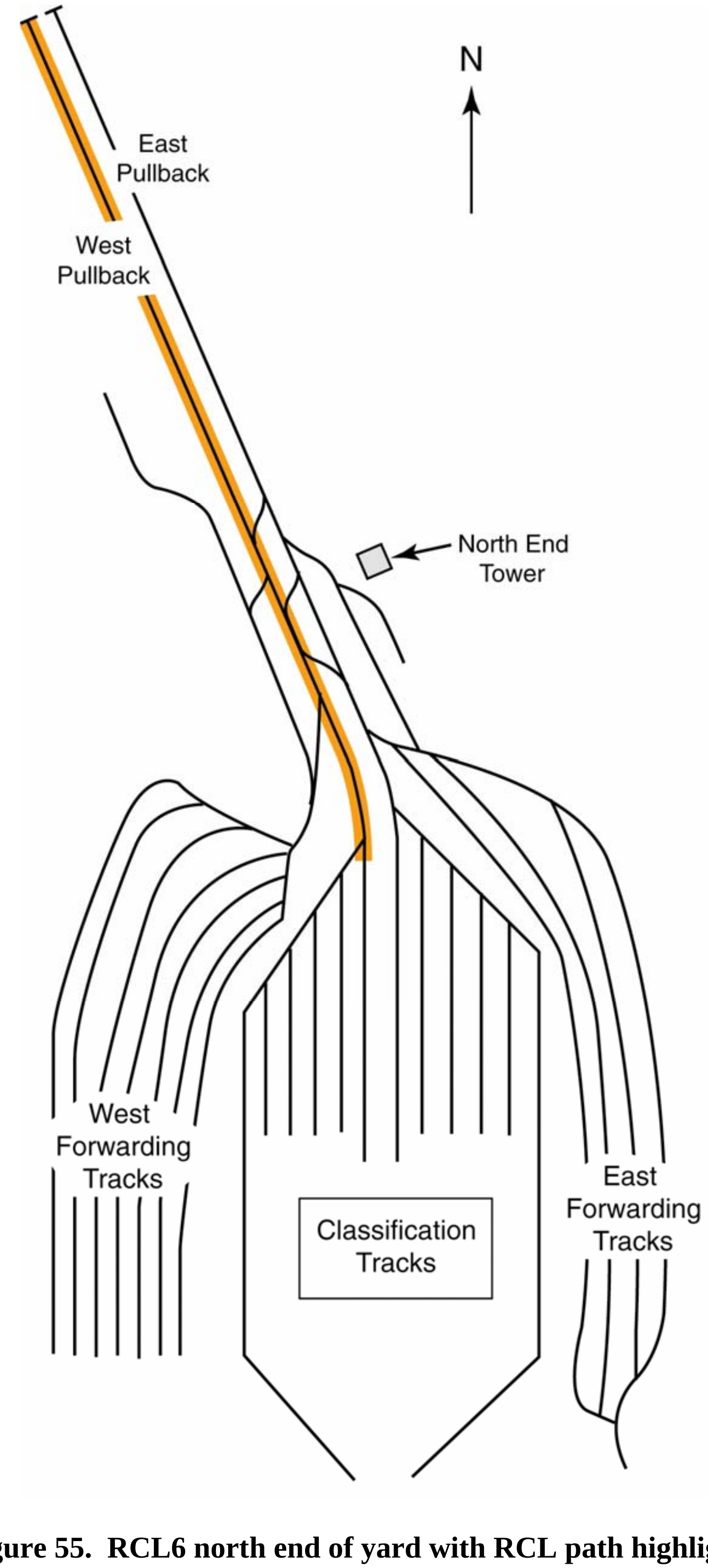

Figure 55. RCL6 north end of yard with RCL path highlighted

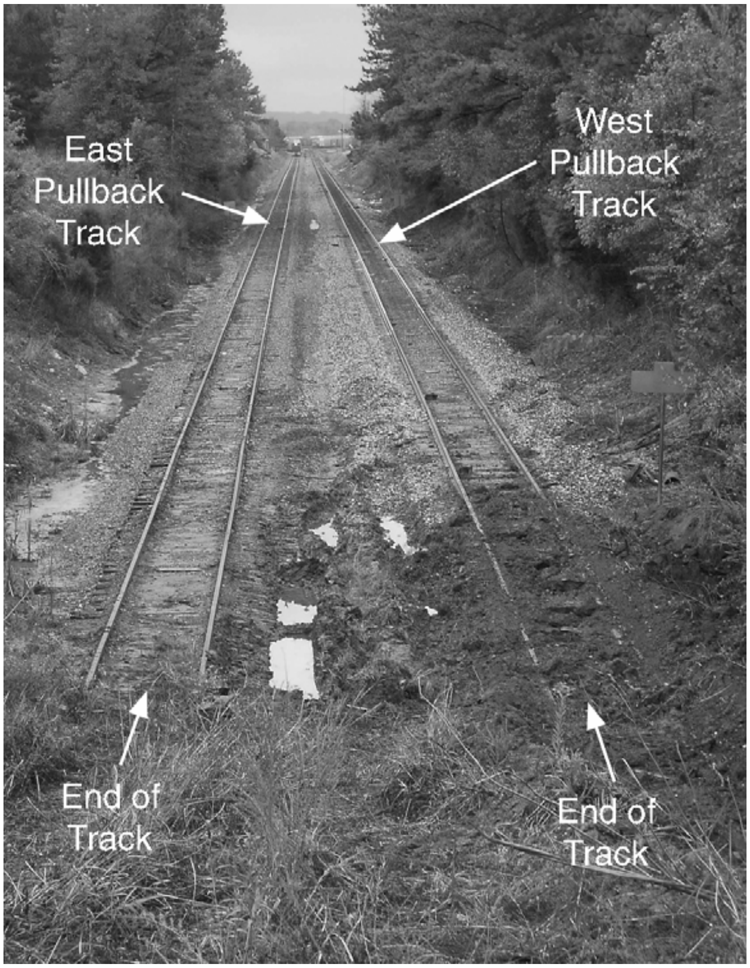

Figure 56. RCL6 southward view (from embankment) of east and west pullback tracks toward classification tracks and other parts of yard

9.2.4 Automatic Pullback Protection System

The east and west pullback tracks are each equipped with an automated pullback protection system that provide PSP. The pullback protection system is designed to ensure that the RCL does not run off of the end of the track by providing an automated overlay (i.e., a secondary) system that augments the RCO's control of the RCL. That is, where in other case studies RCOs hand over control of the cut of cars to the pullback protection system to move the cut, at this railroad, RCOs do not hand off control to the system. Rather, the system is supposed to be used only as a safety net.

Each pullback track contains 16 passive transponders (see Figure 57) embedded in the track to communicate with appropriately equipped RCLs. The distance between the first and last transponders is 3190 ft. The first three transponders, located just north of the switch points at the south end of the pullback track, communicate to the RCL that it is entering pullback-enabled track and permit the RCL to travel at a prescribed speed. Subsequent transponders are located further north in each track and communicate to the RCL other, slower, prescribed speeds. At the end of the track two stop transponders instruct the RCL to stop. The last stop transponder is located approximately 110 ft from the end of the track (see Figure 58). The accident occurred on the west pullback track.

Figure 57. RCL6 automatic pullback protection system transponder mounted under plywood (visible) and embedded in track

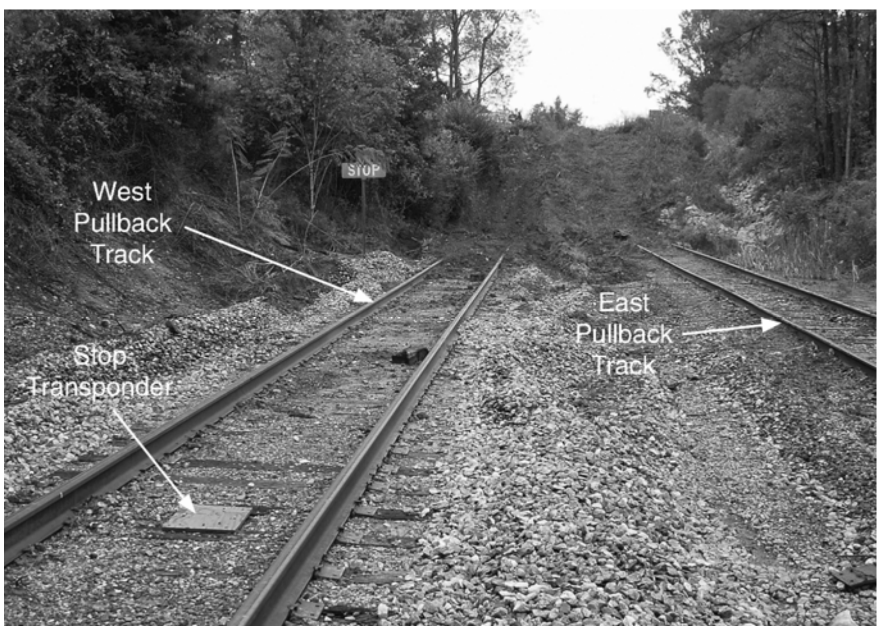

Figure 58. RCL6 northward view of east and west pullback tracks with view of embankment and pullback protection system transponder embedded in track

Each RCL is equipped with a special RF antenna (see Figure 59) mounted beneath, and toward the front of, the RCL. As the antenna passes over a transponder, it energizes the transponder. The transponder, in turn, then transmits limited information about itself (identification) to the antenna, which receives this RF information. This information is communicated to a reader and OCC located in the RCL cab through two interconnected cables—an antenna cable and an antenna extension cable. The antenna cable connects the antenna to the antenna extension cable, and the antenna extension cable connects the antenna cable to the reader in the RCL cab. The reader is connected to the OCC through another cable. The RCL OCC directly interfaces with the engine subsystems to control the RCL.

In addition, a test transponder (see Figure 60) is mounted above the RF antenna to test the health of the RF antenna. The RF antenna polls the test transponder several times per minute to ensure the antenna is functioning (i.e., that it can read transponder information). If the antenna does not receive information from the test transponder, the pullback protection system is designed stop the RCL. Figure 61 shows a diagram of the pullback protection system.

Figure 59. RCL6 pullback protection system RF antenna mounted beneath locomotive

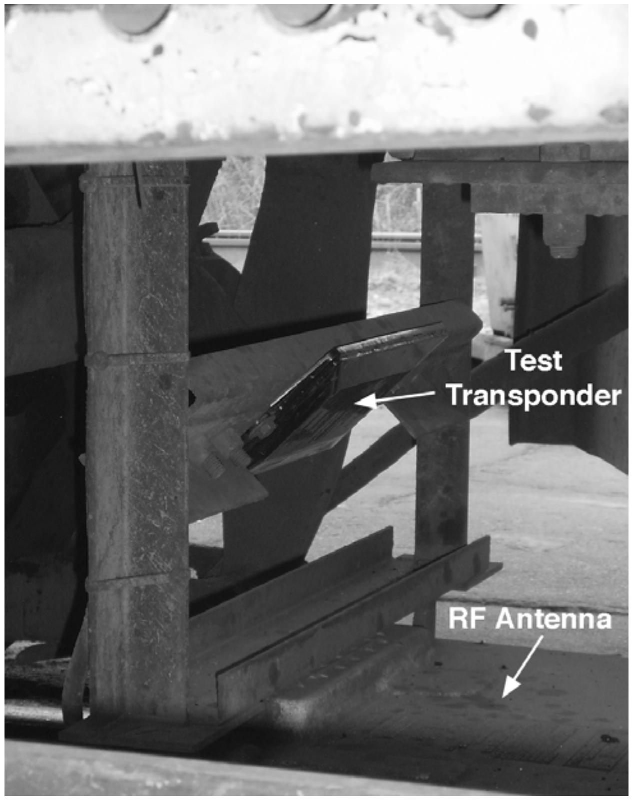

Figure 60. RCL6 pullback protection system test transponder mounted above and at an angle from RF antenna

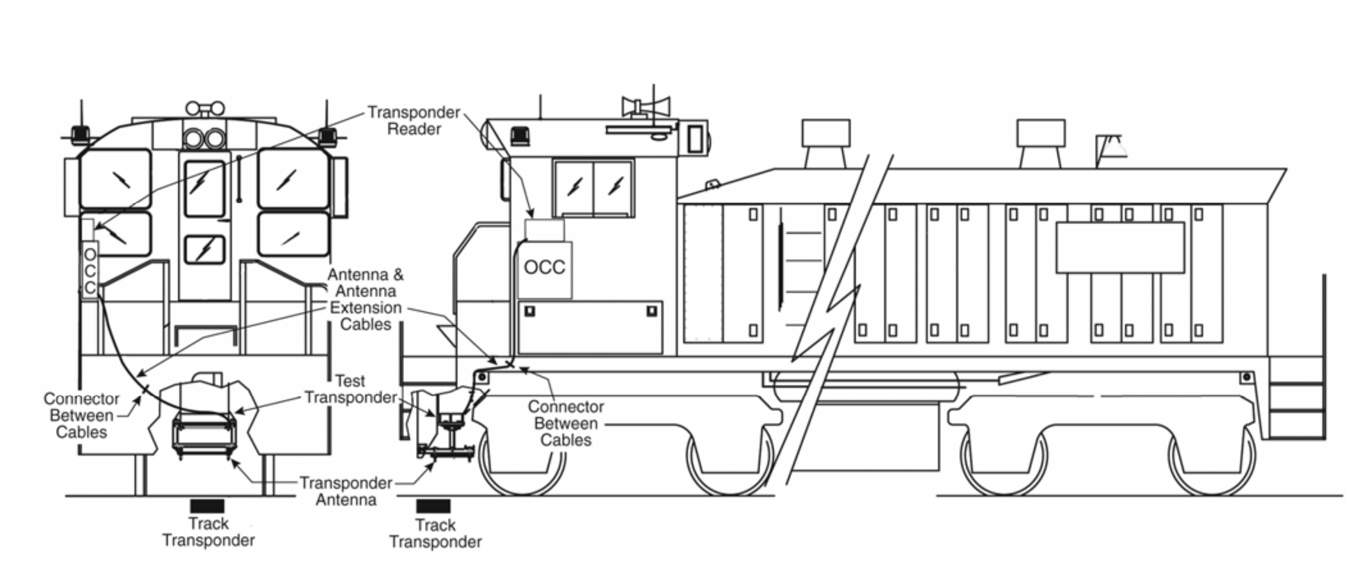

Figure 61. RCL6 pullback protection system schematic
(modified and reprinted with the written consent of BELTPACK Corporation)

9.2.5 Power Switch Control System

In addition to the pullback protection system, this railroad has installed a power switch control system located at the south end of the pullback tracks. The power switch control system consists of a number of power switches to control crossovers located at the beginning of the pullback tracks, to enable cuts of cars to be pulled and shoved into and out of the pullback tracks, classification tracks, and forwarding tracks (see Figure 62). The north end yardmaster controls the power switches.

The tracks are divided into small sections by means of insulated joints between rails (see Figure 63). The system senses when a cut of cars occupies a particular section of track or block, using a low voltage electrical current passed through the rails. As cars pass over the rail and enter a block, the wheels interrupt, or shunt, the current passing through the rails, informing the system that a car or locomotive is now occupying that block. This information is conveyed to the yardmaster by means of a graphical display on a computer, similar to how main track centralized traffic control displays block occupancy to a train dispatcher. The power switch control system also broadcasts two sequential messages to the RCO via radio: first, that a cut of cars is approaching clear (of the crossover) for either the west or east pullback track, and second, once the last car has cleared the crossover (see Figure 64), another broadcast is made announcing to the RCO that the west or east pullback track is clear.

The RCO uses the information from the power switch control system when pulling a cut of cars down the pullback track, to know when he or she is clear of the switch points. Once clear of the switch points, the RCO can stop and reverse his or her move to shove back into a designated track. The pullback protection system is used as an additional protective measure to ensure the RCL does not run off the north end of the track.

Figure 62. RCL6 view of crossovers at the south end of pullback tracks near yardmaster office

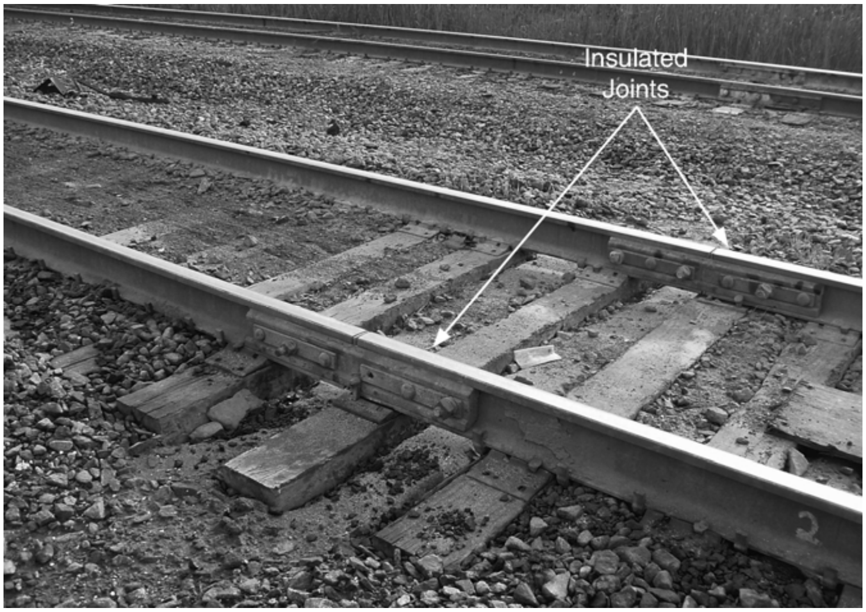

Figure 63. RCL6 insulated joints connecting rails

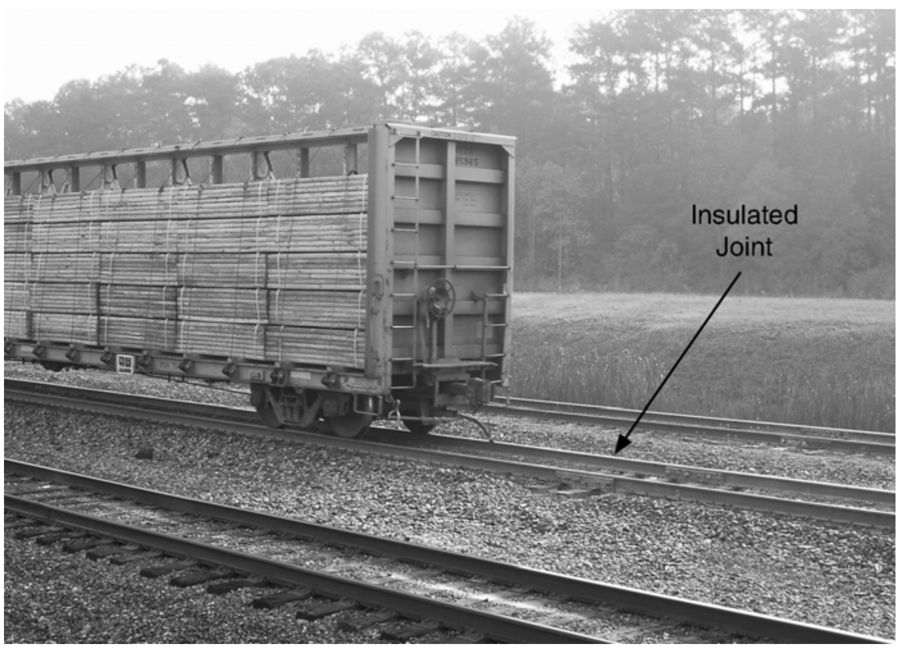

Figure 64. RCL6 view of car passing by insulated joint and track circuit

9.2.6 Preceding Events

Table 13 presents a timeline of events leading up to the shift in which the accident occurred. Events are traced back starting approximately 6 mo before the derailment, when the RCL involved in the current derailment was involved in another collision.

Dates are referenced in terms of days, weeks, or months prior to the collision and are approximate.

Table 13. RCL6 timeline of preceding events

Time period before derailment	Time (local)	Event
6.5 mo	10:50 p.m.	RCL involved in a collision. Damage was sustained to the cab, pilot, and RCL equipment.
6.5 mo–10 d		The RCL was sent to, and repaired at, one of the railroad's major diesel shops. Repairs were done to the engine, and new RCL equipment was installed by shop employees. After making the repairs, shop employees tested the RCL equipment to make sure it was functioning. Shop employees were unable, however, to recover the RCL from emergency. The RCL equipment manufacturer was contacted to troubleshoot. The equipment manufacturer determined that the RCL was missing the RF antenna and test transponder needed for the automatic pullback protection system[29]. Shop employees examined another RCL from the same yard that was in the shop to determine where they should mount the antenna and test transponder on this RCL. Shop employees mounted the antenna and test transponder.
10 d		The RCL is released from the diesel shop and returns to the yard for remote control service.
7 d–6d		The RCL is put back into RCL service. Over the next 2 d, the RCL experiences intermittent test transponder failures, causing the RCL to immediately stop and go into emergency. The railroad cannot diagnose the problem.
5 d		The railroad requests an RCL supplier field service technician (FST) to come to the yard to diagnose the test transponder problem with the RCL and, more generally, the track transponders in the east and west pullback tracks, since RCLs were having intermittent problems reading some of the track transponders.
5 d		The RCL is pulled out of RCL service and used in conventional operations until the problem with the test transponder can be fixed.
3 d		An FST arrives at the yard. The FST determines that the test transponder underneath the RCL is mounted in the wrong position.
2 d–1 d		Local shop employees remount the test transponder according to instructions given to them by the FST.
1 d	9:45 p.m.	During the second shift, about 4.5 h before the derailment, the RCL re-enters service, replacing another RCL that is pulled out of service.

[29] Shop employees had worked on other RCLs, but only RCLs from this particular yard were equipped with the pullback protection system. Shop employees had never seen an RCL that contained these extra components required for pullback protection—chiefly, the RF antenna and test transponder.

The RCO began his shift at 11 p.m. the night before the derailment occurred. The RCO relieved the second shift RCO and started by doing his RCL tests. Before commencing with his first move, however, the yardmaster called to tell him to stop while the RCL supplier updated the software on the RCL to reflect the new locations of some of the track transponders in the pullback tracks. The software was upgraded at 12:13 a.m. Afterward, the RCO began his work. He made five moves using the pullback tracks, and all were without derailment.

9.3 The Derailment

Shortly before 2 a.m., the RCO was instructed, for his sixth move, to pull a cut of 37 cars north out of classification track number 20 using the west pullback track and then shove back south into one of the forwarding tracks. The RCO went to the classification tracks with his RCL to retrieve his cut. Once the RCO received permission to continue with his move to the west pullback track, he instructed the RCL to send his cut to the west pullback track. He initiated a stop of his cut about 5 min later after clearing the switch needed for the reverse move. The track circuit system broadcast two messages—"approaching west pullback clear" and "west pullback clear." However, the antenna beneath the RCL never read any of the track transponders embedded in the west pullback track, and consequently, the RCL never broadcast that pullback protection had been enabled. A short time after the RCO stopped his cut, the yardmaster contacted the RCO to instruct the RCO to set his cars out in one west (track). The RCO repeated the instruction to confirm. The RCO then requested a status check from the RCL. The RCL broadcast, "[locomotive call sign]…consist ready, pull back protection disabled, out." Instead of reversing the move to make his shove move into one west, however, the RCO set the RCL speed selector to 10 mph and resumed northward movement (i.e., he did not change the reverser setting). The RCLs and cut of cars traveled another 1 min 5 s northward, derailed off the end of the track, climbed up the embankment, and came to a rest. Both engines, the leading RCL and trailing locomotive, derailed but remained upright. The lead RCL traveled up the embankment approximately 100 ft (see Figure 65 and Figure 66).

Figure 65. RCL6 view of locomotives derailed up embankment at end of track
(modified and reprinted with permission of the railroad)

Figure 66. RCL6 view of lead (RCL) locomotive derailed up embankment
(modified and reprinted with permission of the railroad)

9.3.1 RCL Event Recorder-Based Timeline

Table 14 provides a timeline of information from the RCL OCC event recorder download, beginning with the RCO's move north to the pullback track.

Table 14. RCL6 OCC event recorder download data

Time	Event	Additional details
1:58:38 a.m.	Op Reverser Command	RCO initiates movement north to pullback track by adjusting reverser from Neutral to Reverse position. Speed is 0.0 mph.
1:58:42 a.m.	Op Speed Command	RCO adjusts speed selector from Stop to Coast. Speed is 0.0 mph.
1:58:43 a.m.	Op Speed Command	RCO adjusts speed selector from Coast to 4 mph. Speed is 0.0 mph.
1:58:59 a.m.	Op Speed Command	RCO adjusts speed selector from 4 to 7 mph. Speed is 2.5 mph.
1:59:12 a.m.	Op Speed Command	RCO adjusts speed selector from 7 to 10 mph. Speed is 5.9 mph.
2:03:40 a.m.	Op Speed Command	RCO initiates a stop by adjusting speed selector from 10 mph to Stop. Speed is 10.04 mph.
2:04:32 a.m.	Locomotive Stopped	RCL and cut of cars are stopped. Speed is 0.0 mph.
2:05:00 a.m.	Oper. Status Request A	RCO requests status information. Speed is 0.0 mph.
2:05:00 a.m.	Talker Msg Sent by MCU	Status information sent from OCC. Speed is 0.0 mph.
2:05:00 a.m.	Talker Msg Broadcast	Status information broadcast over radio. Speed is 0.0 mph.
2:05:06 a.m.	Op Speed Command	RCO adjusts speed selector from Stop to 10 mph. Speed is 0.0 mph.
2:05:22–2:06:05 a.m.	Wheel Slip	Wheel Slip recorded eight different times as RCL gains speed. Speed increases from 2.18 to 9.11 mph[30].
2:06:06 a.m.	Sand Output ON	RCL applies sand. Speed is 10.11 mph.
2:06:11 a.m.	Stopped Flag Event	Two speed sensors are on the RCL. One speed sensor determined that the RCL was stopped, and the other speed sensor on the RCL determined that the RCL was in motion. This discrepancy triggered a Stopped Flag Event. This discrepancy and the much lower speed reported at this time (5.92 mph) suggest that the RCL experienced a significant deceleration and probably reflects the point of derailment.
2:06:12 a.m.	Low Pipe Pressure Event	RCL detects significant reduction in independent air brake pressure. Speed is 5.17 mph.
2:06:14 a.m.	Low Pipe Pressure Fault	RCL operating mode changes from Normal to Emergency. RCL has stopped; speed is 0.0 mph.

[30] RCL speed is based on axle generator information which can be falsely influenced by wheel slip. Specifically, if wheel slip exists/occurs, the axles will rotate, suggesting an increase in speed, but the wheel rotations do not correspond with the true movement of the RCL. In this situation, it is likely that the significant amount of wheel slip caused the RCL to believe it was going faster than it was in reality. This is based on the fact that the RCLs and trailing 2928 tons traveled 1 min and 5 s before derailing, and it could not have attained a speed of 10 mph in that short of a time period. RCL speed readings are thus suspect after 2:05:22 a.m.

9.3.2 Injuries

No injuries occurred.

9.3.3 Damage

The accident resulted in minor damage to both locomotives, with an estimated cost of around $23,000 (see Figure 20 and Figure 68).

Figure 67. RCL6 damage to trailing locomotive

9.3.4 Train Information

The train consisted of 22 loads and 15 empties, weighed 2928 tons, and was 2144 ft long.

9.3.5 Actions of RCL Crewmember

After making five uneventful moves earlier in the shift, the RCO obtains a cut of cars from the classification tracks and sends the cars northward from a classification track to the west pullback track in preparation to shove back to a forwarding track. The RCO initiated a stop of his cut approximately 5 min later, after the track circuit system broadcast that the cut was clear. After receiving instructions from the yardmaster regarding which track to shove his cut into and repeating the instruction, the RCO requested a status check from the RCL. Instead of reversing his move to shove into one west (track), however, the RCO resumed his northward movement by adjusting the speed selector from Stop to the 10 mph setting. That was the last RCO input before the derailment.

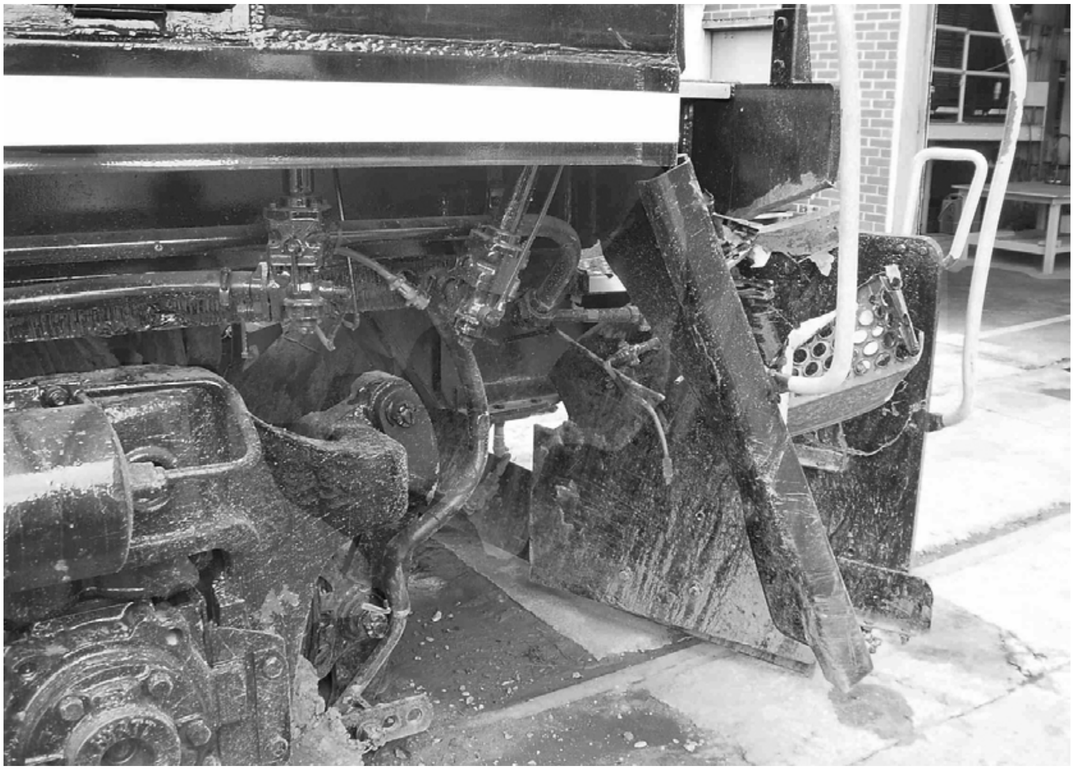

Figure 68. RCL6 damage to leading RCL

9.4 Analysis

The analysis section is organized into two sections. The first section identifies exclusions—those factors that were examined but not considered to be a contributing factor. The second section presents and discusses the HFACS-RR analysis.

9.4.1 Exclusions

The investigation team considered the following exclusions and factors, dismissing them as contributing factors. They are included here for completeness.

- Drug and alcohol tests were not performed after this accident.
- The RCO was familiar with all parts of the yard, including the pullback tracks.
- The RCO was not sick at the time of the derailment.
- Weather did not appear to play a role in the derailment.
- The RCO's alertness did not appear to contribute to the derailment. The RCO had a regularly assigned nighttime assignment from about 11:00 p.m. to 7:00 a.m. Based on his self-reported sleep habits, he normally sleeps during the day between 10:00 a.m. and 7:00 p.m. for a total sleep of about 9 h per day. This may

be interrupted by time to pick up the children from school between 2:30 p.m. and 3:30 p.m. and for church on Sundays. The RCO' sleep history was modeled two ways: (1) assuming a sleep history that conforms to this pattern on all days, including off duty days and (2) assuming a sleep history in which the RCO follows this pattern on duty days but sleeps at night on off duty days. Interestingly, the predicted effectiveness is about the same in either case, which is 94-95 percent, and the lapse index is well within the range of the well-rested person in both cases. The accident occurred at 2:30 a.m. This would be near the usual person's circadian nadir, but for the RCO, who has adapted to a night work schedule, this time is actually during the RCO's circadian high. While it is unusual for a person to be this well adapted to a night work schedule, it is assumed that the self-reported sleep history is accurate. Thus, no analytic evidence exists that this person would be expected to have been impaired by fatigue at the time of the derailment.

9.4.2 Analysis of Accident

Analysis of the accident centers around (1) the RCO's loss of situation awareness regarding the location and direction of his cut of cars and the status of the pullback protection system; (2) the failure of the pullback protection system itself; and (3) the absence of the Global Positioning System (GPS)-based safety overlay subsystem of the pullback protection system. The remainder of this section provides a human factors analysis of the derailment.

Loss of RCO Situation Awareness

The RCO lost situation awareness regarding the direction of his movement after he was instructed to shove back into one west (track). Three factors contributed to this loss of awareness: (1) an initial failure to reverse the move, (2) a failure to attend the cut, and (3) the ability to operate remotely from the cut that enabled the RCO to fail to realize that the movement was moving in the wrong direction.

Furthermore, the RCO did not realize at any time during his shift that the pullback protection system was not functional. In all of his moves to the pullback tracks that night, the RCO had successfully stopped his cut short of the end of track even though the RCO never received an unsolicited broadcast by the pullback protection system that the system had ever been engaged. The pullback protection system, when functioning reliably, announces over the air in an unsolicited message that it is enabled when it passes over the first set of track transponders. The pullback protection system will announce, "[locomotive call sign]…pullback protection on, out." Once enabled, the pullback protection system relieves the RCO of protecting the point on the east and west pullback tracks. The RCO's lack of awareness of the status of the pullback protection system may have been because the RCO may not rely on this information, and it may therefore have fallen below the radar. Another possibility is that successful use of the equipment in the past, even when the equipment was unreliable, created an illusion that the equipment was working at the time. A third factor that likely contributed to the lack of situation awareness regarding the non-operational status of the pullback protection system was the RCO's training in the use of the pullback protection system. A fourth and final factor to be considered was the procedure governing use of the pullback protection system. The remainder of this section discusses the myriad of factors that contributed to the loss of RCO situation awareness.

- Failure to remember to reverse move. After stopping the cut once it cleared the west pullback switch and receiving instructions from the yardmaster regarding which track to shove the cars into, the RCO failed to move his reverser before resuming movement. One minute and 5 s later, the RCLs derailed off the end of the track at the north end. After stopping his movement north of the switch he needed to clear, the RCO failed to move the reverser from reverse to forward.[31] At some point before the RCO commenced his movement, he requested a status check. An RCO can determine that his cut has stopped by requesting a status check. If the message says, "consist ready," the cut is stopped, and the RCO can move the reverser to change directions. It is likely that the RCO requested a status check to verify that his cut had stopped movement before reversing direction. In fact, the RCL broadcast consist ready as part of its message. The RCO, however, forgot to move the reverser before resuming his movement, though it is unclear precisely why the RCO forgot. *Operator acts/skill-based error/memory failure.* **Probable contributing factor.**

- Failure to attend cut. The RCO was in the west forwarding tracks lining switches for the move into one west track when his RCL went off the end-of-track. It is unclear precisely why the RCO lost awareness of his cut—the cut may not have been within view, or the RCO may have been attending to something else, such as lining his switches. Regardless, the RCO failed to attend to his cut of cars as they traveled northward away from him instead of southward toward him. *Operator acts/skill-based error/attention failure.* **Probable contributing factor.**

- RCL technology enabled the RCO to control his movement from a distance and thereby reduced RCO situation awareness. Use of RCL technology, including the pullback protection system, enabled the RCO to control his cut of cars from a distance sufficiently far away from the point of the movement that he may not have been able to visually detect the errant northward direction of movement of his cut of cars. Furthermore, because the RCL equipment enables the RCO to operate from the ground, the RCO lost any type of kinesthetic feedback felt when riding the RCL or a car that would indicate the northward direction of movement. By its very nature, the RCL technology reduced the RCO's situation awareness by enabling him to operate the move remotely from the point of movement and the part of the pullback track on which the move was being made. *Preconditions for operator acts/environmental factors/technological environment.* **Probable contributing factor.**

- RCO failed to notice the non-operational status of the pullback protection system before the derailment. The RCO used the pullback tracks to make a number of moves the night the derailment occurred and at no time did he receive a message that the pullback protection system had been enabled. It is not clear why the RCO

[31] Reverse direction was northward toward the pullback track.

did not notice the lack of message each time he used the pullback track, but it is possible that, because RCOs use the pullback tracks so frequently and because RCOs often listen for the track circuit messages, the lack of pullback protection-related information was not significant. That is, the RCO was not relying on this information that night, and the absence of pullback protection information at the pullback track, therefore, did not automatically catch the RCO's attention. *Operator acts/skill-based error/attention failure.* **Probable contributing factor.**

- The RCO's successful use of unreliable equipment in the past may have fostered an illusion of reliable equipment. RCOs reported experiencing intermittent problems with RCLs reading pullback protection track transponders, leading to unsolicited RCL stops. This would occasionally also occur outside pullback protected track—the RCL would believe it should have seen a transponder but did not and stops (by design). In addition, RCOs reported occasionally not hearing one, or both, of the track circuit broadcasts announcing that a cut was approaching clear and clear. Most of the time, though, RCOs are sufficiently aware of where their cuts are relative to switches and the end-of-track to operate safely. Successful operation with unreliable technology at the pullback tracks in the past may have led the RCO to assume the pullback protection system was working and reduced his vigilance with regard to expecting to hear the announcement at the beginning of each move to a pullback track, as well as not attending to the announcement that the pullback protection system was disabled after initiating a status request just before the derailment. *Preconditions for operator acts/environmental factors/technological environment.* **Possible contributing factor.**
- Inadequate coverage of the pullback protection system in RCO training. Use of the pullback protection system is not explicitly covered during RCO training, although it may be addressed informally and in an unstructured manner during the student RCO's second week of OJT. The extent to which the pullback protection system is covered, and the actual content, depends on the interaction between the student RCO and the working RCO mentor. Thus, complete knowledge of the pullback protection system, including what to do when the pullback protection system is not engaged when it should be, may not be explicitly addressed by the RCO's training. *Supervisory factors/inadequate supervision (training).* **Probable contributing factor.**
- Inadequate procedure specifying and governing the use of the pullback protection system. At the time of the derailment, a Terminal Bulletin (#1) described the pullback protection system and its use. An excerpt from the bulletin reads,

> East and West pullback tracks have been equipped with transponders that will communicate with properly equipped Remote Control Locomotives to prevent those locomotives from traveling beyond the end of the track. When pulling back into the East or West pullback tracks, a properly equipped Remote Control Locomotive will issue a radio message, 'Pullback protection established.' Once this message is issued, the on-board system will prevent the locomotive from traveling beyond the end of the

track regardless of speed selector setting or tonnage being handled.

The bulletin, however, did not specifically and explicitly address what to do if and when the pullback protection radio message is not received. Furthermore, the procedure requires a passive response to the message, rather than, say, requiring the RCO to somehow acknowledge the message or else the pullback protection system shuts down the RCL. *Organizational factors/organizational process/organizational practices and procedures.* **Probable contributing factor.**

Acute Failure of the Pullback Protection System

The pullback protection system failed to make any unsolicited broadcasts regarding engagement (and, thus, successful operation) of the pullback protection system at any time during the RCO's shift that night. In fact, the pullback protection system contained a broken wire in one of the cables connecting the antenna to the reader and OCC. As a result, the RF antenna was reading the track transponders but was unable to communicate this information to the reader and OCC. Thus, the RCL system believed that it never encountered any track transponders. Just as the RCO did not detect that the pullback protection system was not working, the pullback protection system itself never detected (and thus never communicated) this fault. The remainder of this section discusses the failure of the pullback protection system.

- The wire that communicates the presence of track transponders to the RCL OCC was broken. Investigation by the RCL, pullback protection system supplier, and railroad revealed that one of the wires in the antenna cable was broken at the connector pin solder joint (see Figure 69 and Figure 70). The result was that track transponder information was not being relayed from the antenna to the reader and OCC. Analysis by the supplier, however, found that the test transponder was being read. The design of the pullback protection system requires the antenna to periodically (several times per minute) poll the test transponder to ensure proper functioning of the antenna. If a failure occurs in reading the test transponder, then the pullback protection system is designed to stop the RCL. However, the night of the derailment no such problems occurred with the test transponder. Subsequent testing by the supplier revealed that the likely reason the OCC was receiving positive information about the presence of the test transponder but not receiving information regarding the presence of any track transponders, was because the information from the test transponder was being directly communicated to the antenna extension cable, above the point where the wire that communicates transponder presence and information was broken. It is suspected that the low power generated around the antenna, including the test transponder and cabling, enabled the antenna extension cable to act as a low power antenna, and consequently it attracted test transponder information directly from the test transponder to the wire within the antenna extension cable that communicates transponder-related information (see Figure 71). In doing so, the information skipped the antenna. However, the reader still received the test transponder information and thus believed the antenna to be working. The OCC believed that the antenna was functioning, and it had not encountered any track transponders. It is not clear when, at some point before the collision, the wire broke off at the solder joint, nor why and how it broke. The wire was probably held loosely in position by the heat-shrink tubing that surrounded the wire-solder joint (see Figure 69), causing intermittent functioning and intermittent failures, of the pullback protection system, during the days before the derailment occurred. The cause of the broken wire connection is beyond the scope of this research. *Preconditions for operator acts/environmental factors/technological environment.* **Probable contributing factor.**

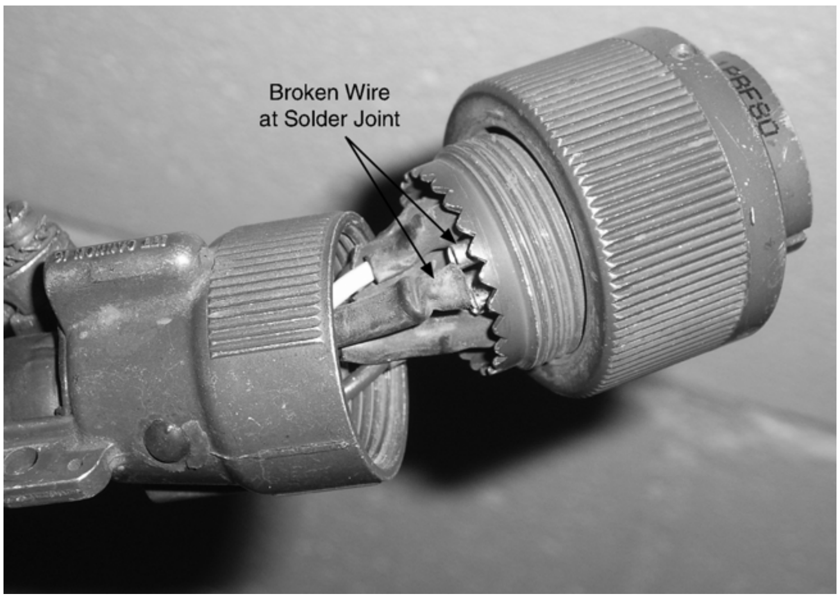

Figure 69. RCL6 view of disconnected wire at connector solder joint

Figure 70. RCL6 view of antenna cable pins and connector

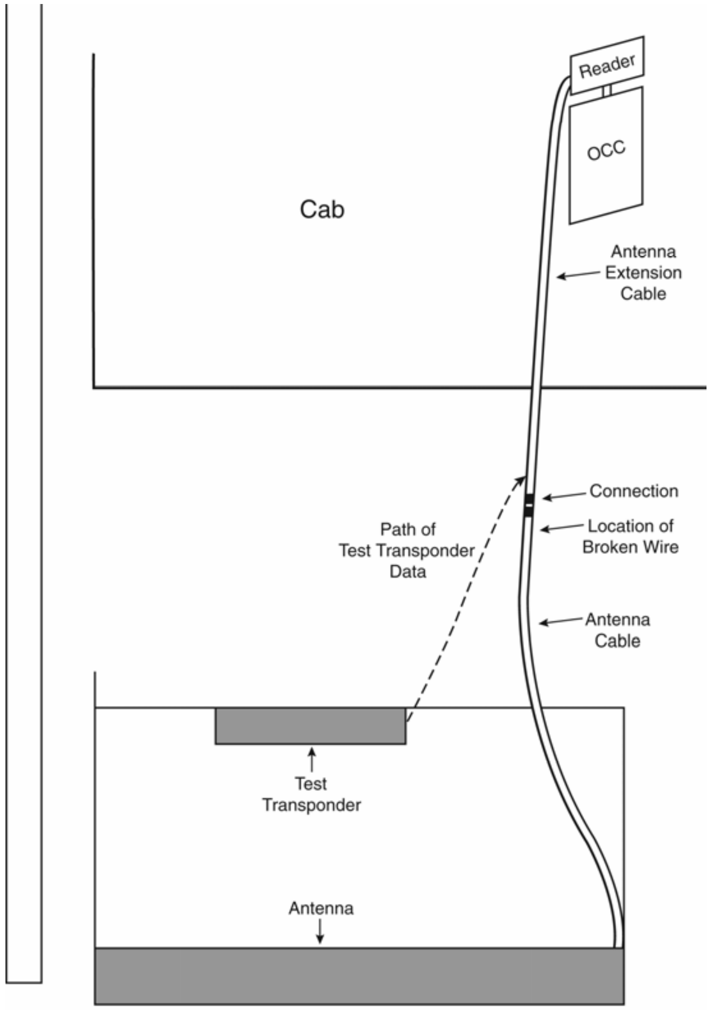

Figure 71. RCL6 presumed path of test transponder information

- Pullback protection system cables not properly installed/mounted. Further inspection revealed that the antenna and antenna extension cables were not installed on the RCL per supplier specification, which called for a metal flex conduit to house, protect, and shield the cables. The metal flex tubing would have provided physical protection to the cables and may have prevented a wire break or, at a minimum, prevented RF information from bypassing the RF antenna and jumping directly to the antenna extension cable wire. If test transponder information had not bypassed the antenna, the reader and RCL would not have received any information about the test transponder and would have caused the RCL to shut down, as it is designed to do. *Preconditions for operator acts/environmental factors/technological environment.* **Probable contributing factor.**

- Failure of pullback protection system technology to fail-safe or otherwise inform the user (RCO) of a communication problem between the RF antenna and OCC. The design of the pullback protection system—in particular the cable and software—allowed the wire failure to go unchecked, giving a false impression that the pullback protection system was reliable. The pullback protection system employs a test transponder above the antenna that is intended to verify the health and functioning of the antenna and its ability to read track transponder information. However, the system did not contain any type of verification or check of the health of the wires. In the case of the derailment, test transponder data were able to be relayed to the antenna extension cable above the section that was broken; yet track transponder data were communicated through the intended and as-designed path through the antenna and antenna cable and not able to be relayed to the reader due to the broken wire. A self-diagnostic of all communication paths, including wires, would likely have prevented the derailment by identifying the broken wire. *Preconditions for operator acts/environmental factors/technological environment.* **Probable contributing factor.**

- Poor communication between shop employees and supplier field service technician. The FST who oversaw the remounting of the test transponder bracket left the yard the afternoon before the RCO's shift began and before remounting of the test transponder was complete. The FST was under the impression that the job would not be completed until the next day, at which time he would do his testing before he signed off on the work. However, the shop employees completed the remounting of the test transponder, and the RCL was released back into service before the FST had an opportunity to test the pullback protection system. Though the FST was going to test out the pullback protection system to ensure that the test transponder was being read successfully, he may have tested the RCL on the pullback tracks, given that the FST was there to troubleshoot problems with the track transponders more generally. Had the FST been notified of the work completion, he may have been able to test the pullback protection system with the RCL and determined that a problem did exist in reading the track transponders. *Preconditions for operator acts/personnel factors/crew resource management.* **Possible contributing factor.**

GPS Subsystem not Installed at the Time of Derailment

At the time the pullback protection system was purchased and installed, an additional GPS safety overlay was being developed by the supplier, but was not yet ready for production. The GPS subsystem was designed to add a layer of safety by determining where the RCL is relative to each transponder in a pullback protection-enabled track and comparing RCL speed with that prescribed by the track transponder over which an RCL passes. A GPS-equipped RCL would place the RCL into emergency to stop it if the RCL's speed is in excess of that specified by a particular track transponder. The RCL supplier recommended installing the GPS subsystem at the same time as the rest of the pullback protection system. Instead of waiting to install the pullback protection system with the GPS safety overlay, however, the railroad elected to install and use the pullback protection system without the GPS subsystem and then retrofit the RCLs with GPS once the GPS kits were made available. The GPS kits were subsequently purchased when they were available but had not been installed in any of the RCLs at the time of the derailment.

The remainder of this section discusses the failure to install the GPS subsystem.

- Pullback protection system initially installed without the GPS safety overlay subsystem. At the time that the pullback protection system was installed, the GPS overlay subsystem was not available for purchase. Rather than waiting to install the pullback protection system with the GPS overlay subsystem, however, as recommended by the RCL supplier, and delaying the implementation of RCL operations at this yard, the railroad elected to go ahead and implement the pullback protection system as is, without the GPS overlay. The GPS subsystem likely would have prevented the derailment by determining immediately that the RCL's speed was in excess of the track transponder-prescribed speed. Once aware of this discrepancy, the RCL would have been placed into emergency to stop before it reached the end of the track. *Organizational factors/resource management/equipment and facility resources.* **Probable contributing factor.**
- Inadequate number of locomotives available to meet operational demands and receive GPS upgrades resulted in a delay in GPS safety overlay subsystem installation. Due to (1) an industrywide increase in railroad business and traffic, (2) periodic locomotive failures, (3) the need to shop RCL-equipped locomotives for FRA-required testing, and (4) the fact that the RCL involved in the derailment had been in a diesel shop for 6 mo while it was being repaired from a previous collision, the yard had only a limited number of locomotives, including RCLs, to meet operational demands. The railroad had, in fact, purchased and had ownership of the GPS kits at the time of the derailment, and it had arranged for an outside shop to retrofit the RCLs, but the railroad was unable to afford to take any RCLs out of service to equip them with the GPS subsystem. The railroad failed to anticipate the number of locomotives necessary to keep up with operational demands and take RCLs out of service temporarily to have the GPS kits installed. The shortage of locomotives contributed to a delay in retrofitting the RCLs with the GPS kits. *Organizational factors/resource management/equipment and facility resources.* **Probable contributing factor.**

9.5 Corrective Actions

To prevent similar accidents/incidents from occurring in the future, the railroad has made, or is in the process of making, the following yard-specific corrective actions since the accident occurred:

1. Conduct contact sessions to brief all employees on the procedure that should be followed at the pullback tracks.
2. Issue a new (written) bulletin explicitly describing the procedure at the pullback tracks, including what to do if an RCO does not receive confirmation that pullback protection has been enabled.
3. Install GPS overlay kits on all RCLs.
4. Update the classroom portion of RCL training to describe how pullback protection works and what to do if an RCO does not receive confirmation that pullback protection has been enabled. The railroad will also review and update, if necessary, an RCL video used in the classroom portion of the training to discuss this procedure.

5. Add questions to the RCL physical characteristics written test to address proper use of the pullback protection system and tracks.
6. Put out instructions to all Mechanical Department employees to contact the RCL supplier if any RCL component of a locomotive is damaged.
7. Provide all Mechanical Department employees with 8 h of training on RCL equipment.
8. Update the operating plan to clarify that transponders should not be used to stop an RCL or cut of cars.

To prevent similar accidents/incidents from occurring in the future, the RCL supplier has made, or is in the process of making, the following corrective actions:

1. Provide additional instructions regarding use of flex conduit housing for antenna cables.
2. Conduct testing to try to repeat the path of RF information from the test transponder directly to the antenna extension cable to learn more about what happened and why.

10. Analysis of RCL Case Study Results

Two analyses were conducted on the results of the six RCL accident/incident case studies. The first analysis focused on the HFACS-RR categories, while the second analysis focused on the contributing factors themselves (content analysis). Each is presented below.

10.1 Analysis of HFACS-RR Categories

Analysis of the HFACS-RR categories associated with the contributing factors focused on the 23 unique categories depicted in the HFACS-RR taxonomy (see Figure 8). For those contributing factors that are further classified in the case study (e.g., an attention failure), the higher-level unique category is used instead (in the previous example, the contributing factor would simply be treated as a skill-based error). Figure 72 presents the HFACS-RR classification of all 46 probable and possible contributing factors for all six RCL accidents/incidents. Figure 73 presents the HFACS-RR classification of just the 36 probable contributing factors for all six RCL accidents/incidents.

Table 15 presents a side-by-side comparison and breakdown of HFACS-RR categories associated with all contributing factors and probable contributing factors only. In both cases, the same six HFACS-RR unique categories (in **bold**) are associated with a majority of the contributing factors and are listed below:

- The technological environment
- Skill-based errors
- Inadequate supervision
- Organizational process
- Decision errors
- Resource management

Although beyond the scope of the present study, the HFACS-RR analysis can also help in identifying corrective actions since certain types of corrective actions will be more appropriate to certain HFACS-RR categories of contributing factors. For example, corrective actions focused on training may address skill-based errors and decision errors, while design changes and operating practice changes may be more suitable to address contributing factors associated with the technological environment.

Interestingly, these six categories are equally distributed across four of the five top-level HFACS-RR categories, providing support to a systems approach to accident/incident contribution. That is, for each accident/incident, multiple factors, at different levels of a system, appear to contribute to the accident/incident.

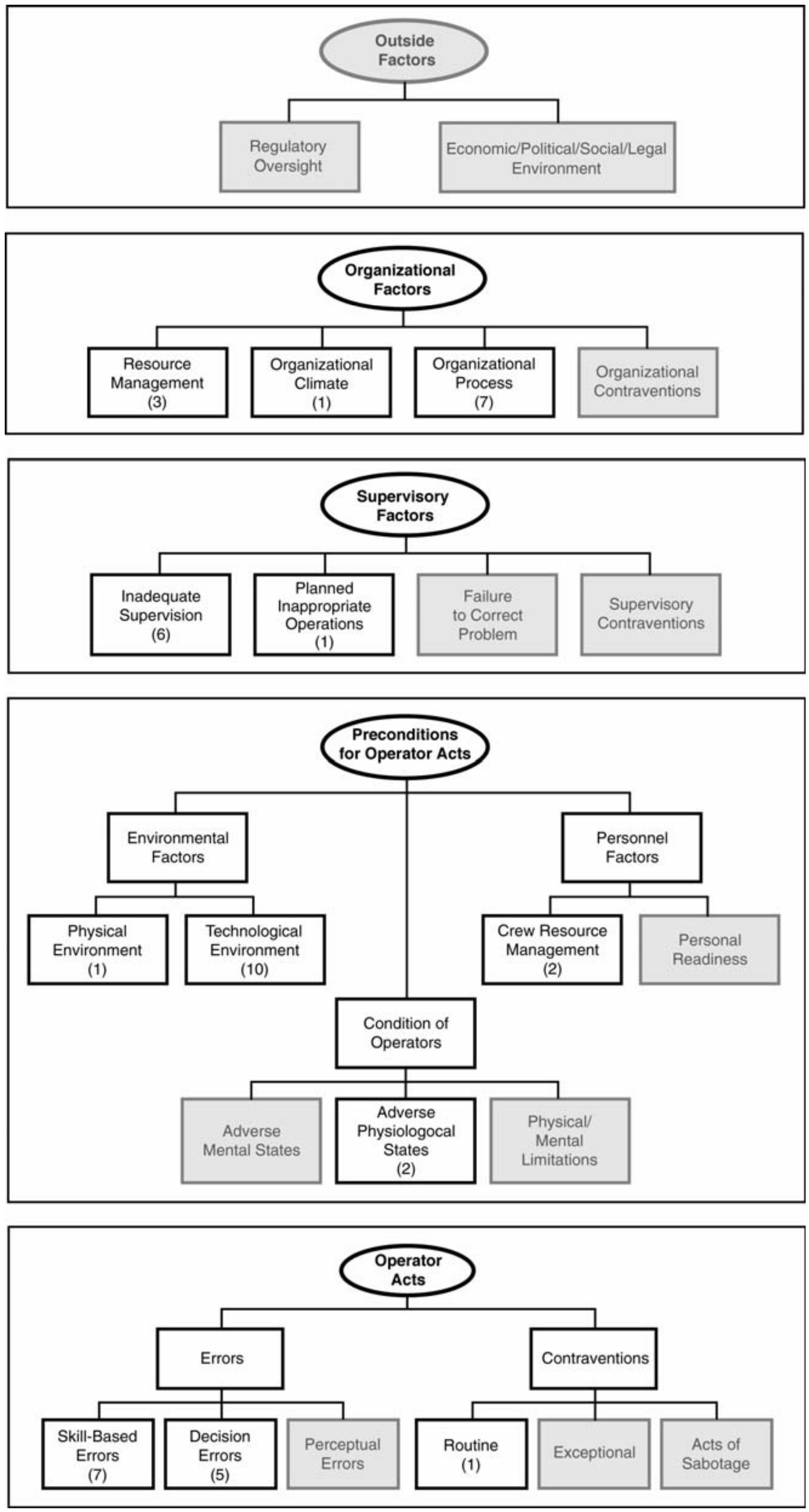

Figure 72. HFACS-RR classification of possible and probable contributing factors

Figure 73. HFACS-RR classification of probable contributing factors only

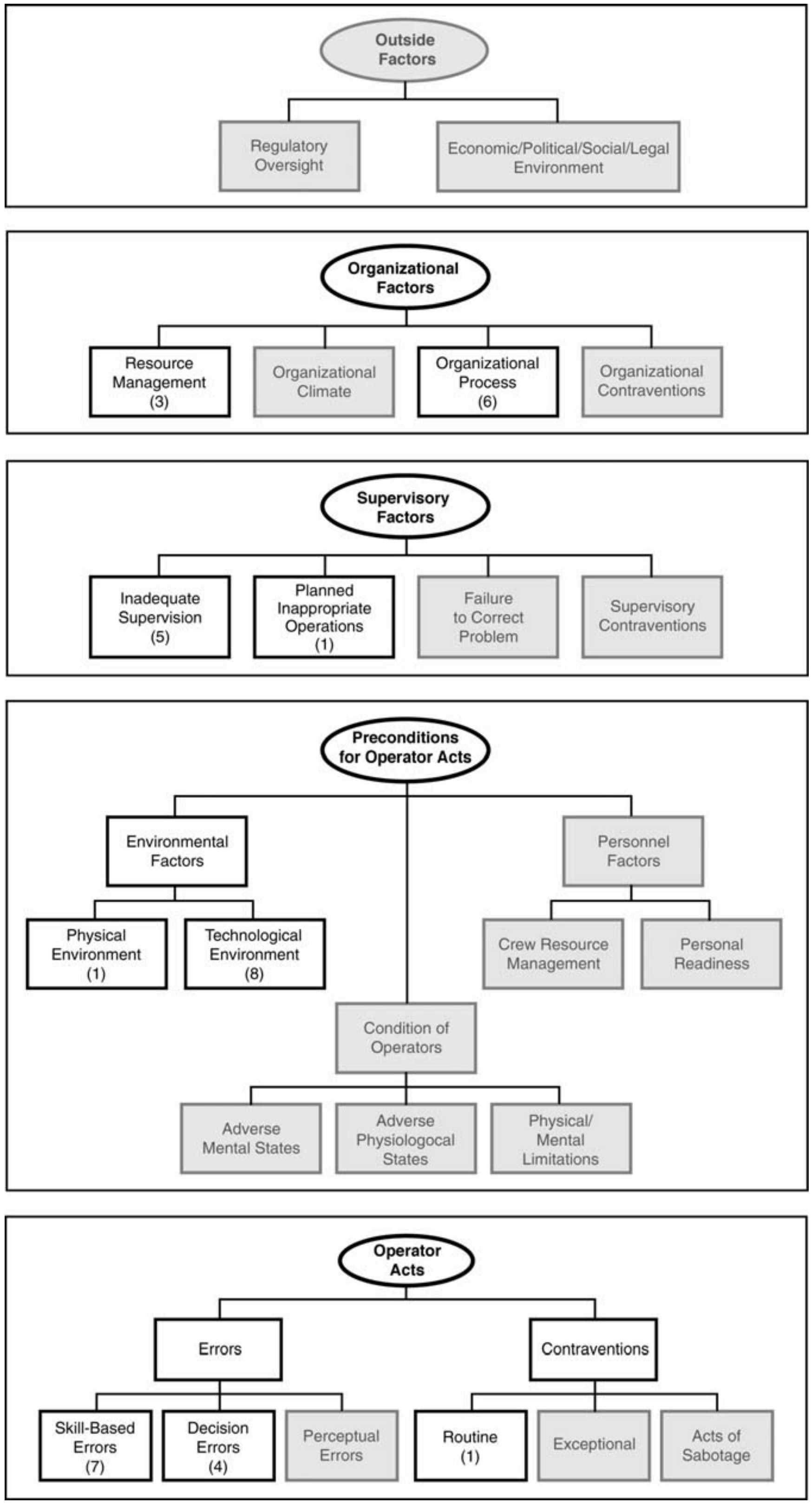

Table 15. Analysis of HFACS-RR categories associated with accident/incident contributing factors

Top-level HFACS-RR category	Specific HFACS-RR category	All contributing factors	Probable contributing factors only
Organizational factors	**Organizational process**	**7**	**6**
	Resource management	**3**	**3**
	Organizational climate	1	0
Supervisory factors	**Inadequate supervision**	**6**	**5**
	Planned inappropriate operations	1	1
Preconditions for operator acts	**Technological environment**	**10**	**8**
	Adverse physiological state	2	0
	Crew resource management	2	0
	Physical environment	1	1
Operator acts	**Skill-based errors**	**7**	**7**
	Decision errors	**5**	**4**
	Routine contraventions	1	1
TOTAL		46	36

10.2 Analysis of Contributing Factors

Table 16 presents the overall contributing factors for all six RCA case studies. One to three overall contributing factors were identified for each accident/incident. The overall contributing factors were intended to provide an organization to the more specific probable and possible contributing factors. Analysis of these overall contributing factors suggest that a loss of situation awareness was a major factor in five of the six accidents/incidents studied (RCL1, RCL2, RCL3, RCL5, and RCL6). Further analysis reveals that RCL technology facilitated this loss of situation awareness by enabling RCOs to control their cuts of cars away (i.e., remotely) from the point of movement in four of these five accidents/incidents. The physical properties of the RCD contributed to the loss of crewmember attention in one accident/incident (RCL4). A lack of RCO training and experience contributed to one of the accidents/incidents (RCL3). Failure of the pullback protection system, which is part of the overall RCL technology, contributed to one of the six accidents/incidents (RCL6).

Table 16. Overall RCL accident/incident contributing factors

Accident/Incident	Overall accident/incident contributing factor
RCL1	Loss of RCO situation awareness Double crossover to unintended track
RCL2	Loss of RCO situation awareness
RCL3	Loss of RCO situation awareness Inadequately prepared RCOs Inadequately experienced crew
RCL4	Loss of crewmember attention
RCL5	Poor choice to leave switch lined for industry Loss of RCO situation awareness Contravention of system special instruction
RCL6	Loss of RCO situation awareness Acute failure of the pullback protection system GPS subsystem not installed at the time of the derailment

Next, the individual contributing factors associated with the six accidents/incidents were examined. A total of 46 contributing factors were identified. Of these, 36 were probable contributing factors (78 percent). For each accident/incident, 2 to 13 contributing factors were identified. For completeness, Table 17 presents all of the contributing factors that were identified for the six RCL accidents/incidents that were further studied, the HFACS-RR categories, and confidence ratings.

Table 17. Contributing factors, HFACS-RR categories, and confidence ratings for all six RCL accidents/incidents

Contributing Factor	HFACS-RR Category	Confidence Rating
RCL1		
Helper failed to attend to (notice) cars fouling path.	Operator acts/skill-based error/attention failure	Probable
Helper's alertness was likely compromised at the time of the collision.	Preconditions for operator acts/operator conditions/adverse physiological state	Possible
Operating practice allowed the foreman to control the move at the rear, which likely reduced the helper's situation awareness by making point protection task passive.	Organizational factors/organizational process/organizational practices and procedures	Probable

Contributing Factor	HFACS-RR Category	Confidence Rating
Poor RCO decision not to inform others of errant move to unintended track.	Operator acts/decision error/poor choice	Probable
Loss of yardmaster situation awareness.	Supervisory factors/inadequate supervision	Probable
RCL2		
Failure to correctly recall previous movement.	Operator acts/skill-based error/memory failure	Probable
Poor choice to initiate movement without being able to see the cut of cars.	Operator acts/decision error/poor choice	Probable
Misapplication of a good rule.	Operator acts/decision error/procedural error	Possible
Inability to determine or verify locomotive's F orientation.	Preconditions for operator acts/environmental factors/technological environment	Probable
No feedback to indicate the true direction of RCL movement.	Preconditions for operator acts/environmental factors/technological environment	Probable
Unsafe operating practice permitting RCOs to initiate movement of a cut of cars without line-of-sight to the cut.	Organizational factors/organizational process/organizational practices and procedures	Probable
Inadequate lighting.	Preconditions for operator acts/environmental factors/physical environment	Probable
Inadequate procedure for use of west side camera to monitor west end movements.	Organizational factors/organizational process/organizational practices and procedures	Probable
RCL3		
Poor choice by RCOs not to protect the point of the movement after overriding the pullback protection system.	Operator acts/decision error/poor choice	Probable
Foreman's alertness was likely compromised at the time of the collision.	Preconditions for operator acts/operator conditions/adverse physiological state	Possible
Inadequate procedure to address overriding pullback protection.	Organizational factors/organizational process/ organizational practices and procedures	Probable
Inadequate practice (bulletin) specifying maximum length of a cut of cars to be switched using pullback-protected track.	Organizational factors/organizational process/ organizational practices and procedures	Probable
Inadequate RCO training.	Supervisory factors/inadequate supervision (inadequate training)	Probable
Inadequate RCO OJT.	Supervisory factors/inadequate supervision (training)	Probable

Contributing Factor	HFACS-RR Category	Confidence Rating
Inadequate RCO train-the-trainer training for OJT mentors.	Supervisory factors/inadequate supervision (training)	Probable
Allowing early quits may reduce OJT opportunities for student RCOs.	Organizational factors/organizational process/organizational operations	Possible
Inadequate staffing.	Organizational factors/resource management/human resources	Probable
Poor crew pairing.	Supervisory factors/planned inappropriate operations	Probable
RCL4		
Temporary distraction.	Operator acts/skill-based error/attention failure	Probable
Size, shape, and location of the RCD.	Preconditions for operator acts/environmental factors/technological environment	Probable
RCL5		
Poor choice to leave the switch lined for industry.	Operator acts/decision error/poor choice	Probable
Inadequate knowledge of automatic pullback protection system.	Supervisory factors/inadequate supervision (training)	Possible
Failure to remember orientation of industry switch.	Operator acts/skill-based error/memory failure	Probable
Reversed switch list may have created mismatched expectation of car location.	Preconditions for operator acts/environment/technological environment	Possible
Inadequate communication between crewmembers may have contributed to at least one crewmember's loss of situation awareness.	Preconditions for operator acts/personnel factors/crew resource management	Possible
RCL technology enabled the RCO to control his movement from a distance and thereby reduced RCO situation awareness.	Preconditions for operator acts/environment/technological environment	Probable
Contravention of SSI.	Operator acts/contravention/routine contravention	Probable
Organizational culture may encourage corner cutting.	Organizational factors/organizational climate/organizational culture	Possible
RCL6		
Failure to remember to reverse move.	Operator acts/skill-based error/memory failure	Probable
Failure to attend cut.	Operator acts/skill-based error/attention failure	Probable

Contributing Factor	HFACS-RR Category	Confidence Rating
RCL technology enabled the RCO to control his movement from a distance and thereby reduced RCO situation awareness.	Preconditions for operator acts/environmental factors/technological environment	Probable
RCO failed to notice the non-operational status of the pullback protection system prior to the derailment.	Operator acts/skill-based error/attention failure	Probable
The RCO's successful use of unreliable equipment in the past may have fostered an illusion of reliable equipment.	Preconditions for operator acts/environmental factors/technological environment	Possible
Inadequate coverage of the pullback protection system in RCO training.	Supervisory factors/Inadequate supervision (training)	Probable
Inadequate procedure specifying and governing the use of the pullback protection system.	Organizational factors/organizational process/organizational practices and procedures	Probable
The wire that communicates the presence of track transponders to the RCL OCC was broken.	Preconditions for operator acts/environmental factors/technological environment	Probable
Pullback protection system cables not properly installed/mounted.	Preconditions for operator acts/environmental factors/technological environment	Probable
Failure of pullback protection system technology to fail-safe or otherwise inform the user (RCO) of a communication problem between the RF antenna and OCC.	Preconditions for operator acts/environmental factors/technological environment	Probable
Poor communication between shop employees and supplier field service technician.	Preconditions for operator acts/personnel factors/crew resource management	Possible
Pullback protection system initially installed without the GPS safety overlay subsystem.	Organizational factors/resource management/equipment and facility resources	Probable
Inadequate number of locomotives available to meet operational demands and receive GPS upgrades resulted in a delay in GPS safety overlay subsystem installation.	Organizational factors/resource management/equipment and facility resources	Probable

Content analysis focused on the 36 probable contributing factors since they are the most reliable. Thirty-three of the 36 probable contributing factors (92 percent) were concentrated among 6 HFACS-RR categories. The following subsections present the analysis of the 36 probable contributing factors, starting with the HFACS-RR category with the greatest number of probable contributing factors.

10.2.1 Technological Environment

Eight probable contributing factors associated with the technological environment were identified, which are:

- Inability to determine or verify locomotive's F orientation
- No feedback to indicate the true direction of RCL movement
- Size, shape, and location of the RCD
- RCL technology enabled the RCO to control his movement from a distance and thereby reduced RCO situation awareness (2)
- The wire that communicates the presence of pullback protection system track transponders to the RCL OCC was broken
- Pullback protection system cables not properly installed/mounted
- Failure of pullback protection system technology to fail-safe or otherwise inform the user (RCO) of a communication problem between the RF antenna and OCC

Four of the eight contributing factors (related to two of the six accidents/incidents) were related to one or more RCO's control of a movement from a physical location away from the RCL and/or cut of cars. Three contributing factors (all were associated with one accident/incident) focused on the failure of the pullback protection technology as part of the overall RCL system. One contributing factor was associated with the physical characteristics of the RCD itself.

10.2.2 Skill-Based Errors

Seven skill-based errors, all attentional or memory failures, were identified among the 36 probable contributing factors, which are:

- Failure to attend to (notice) cars fouling path
- Failure to correctly recall previous movement
- Temporary distraction
- Failure to remember orientation of the industry switch
- Failure to remember to reverse move
- Failure to attend cut
- Failure to notice the non-operational status of the pullback protection system before the derailment

10.2.3 Organizational Process

Organizational process was identified 6 times among the 36 probable contributing factors, which are:

- Operating practice allowed the foreman to control the move at the rear, which likely reduced the helper's situation awareness by making point protection task passive

- Unsafe operating practice permitting RCOs to initiate movement of a cut of cars without line-of-sight to the cut
- Inadequate procedure for use of west side camera to monitor west end movements
- Inadequate procedure to address overriding the pullback protection system
- Inadequate practice (bulletin) specifying maximum length of a cut of cars to be switched using pullback-protected track
- Inadequate procedure specifying and governing the use of the pullback protection system

All six of these contributing factors address inadequate practices and procedures governing RCL operations and the use of the RCL technology, including the pullback protection system.

10.2.4 Inadequate Supervision

Inadequate supervision was identified 5 times among the 36 probable contributing factors, which are:

- Loss of yardmaster situation awareness
- Inadequate RCO training
- Inadequate RCO OJT
- Inadequate RCO train-the-trainer training for OJT mentors
- Inadequate coverage of the pullback protection system in RCO training

Four of the five contributing factors are related to some aspect of RCO training.

10.2.5 Decision Errors

Four decision errors were counted among the 36 probable contributing factors, which are:

- Poor RCO decision not to inform others of errant move to unintended track
- Poor choice to initiate movement without being able to see the cut of cars
- Poor choice by RCOs not to protect the point of the movement after overriding the pullback protection system
- Poor choice to leave the switch lined for industry

Two of the four decision errors relate to decisions made with regard to controlling a cut of cars. The other two decisions do not directly relate to the control of a cut of cars; one is related to poor communications, while the fourth decision error, to leave an industry switch lined for the industry, was likely driven by a desire to save time and effort.

10.2.6 Resource Management

Three contributing factors were associated with resource management:

- Inadequate staffing
- Pullback protection system initially installed without the GPS safety overlay subsystem
- Inadequate number of locomotives available to meet operational demands and receive GPS upgrades resulted in a delay in GPS safety overlay subsystem installation

10.2.7 Planned Inappropriate Operations

One contributing factor was associated with planned inappropriate operations—poor crew pairing. Given the increase in railroad traffic, an aging workforce, and the influx of newly hired railroad employees, pairing crewmembers (rostering) without any type of safeguards to avoid pairing two inexperienced RCOs may be a significant safety issue in the future, especially when combined with inadequate staffing and inadequate training.

10.2.8 Physical Environment

One contributing factor was associated with the physical environment—inadequate lighting in the yard that made it difficult for the RCO to see his cut of cars moving early one morning.

10.2.9 Routine Contraventions

One contributing factor was associated with a routine contravention—contravention of a system special instruction that stipulated that point protection is required when cars are at the leading end of the movement. In such cases, any previously activated RCZ is de-activated or no longer in effect. This contravention, like many others, appears to be out of a desire to save time and/or effort, and was carried out at least occasionally by crewmembers at this location.

10.3 Operator Alertness

Operator alertness was analyzed for each of the six RCL accidents/incidents to either include or exclude fatigue-induced compromised alertness as a contributing factor in each accident/incident. Due to the fact that the results of the FAST analysis are predictive and based partly on estimates of sleep patterns before the accident/incident, rather than actual sleep histories, researchers treated any findings of compromised alertness as a possible contributing factor rather than probable contributing factor. Given the recognition that fatigue and operator alertness are critical areas of study in transportation safety, it was still considered important to include the results of the analyses here.

Analysis of operator alertness based on FAST suggests that two RCOs may have been working with compromised alertness (RCL1 and RCL3). In each case, the work schedule and sleep habits data that were analyzed revealed an effectiveness score below the acceptable threshold of 77.5 percent. One RCO had an effectiveness score of 67 percent, while the second had an effectiveness score of 71 percent. Though yard employees work in a fixed location and thus sleep at home, they can still have quite irregular work schedules. Although both RCOs with compromised alertness had somewhat irregular work schedules, the helper in the first accident/incident (RCL1) had an especially irregular work schedule, with varying start times from 11 p.m.-12 a.m., 7-8 a.m., and 3-4 p.m.

11. Key Findings and Recommendations

This section presents key findings from the study, as well as recommendations for future research on RCL operations safety. Section 11.1 presents the key findings and Section 11.2 presents recommendations for future research.

11.1 Key Findings

This section presents some top-level findings from the overall study. The key themes that emerged from the RCA, as well as the critical safety issues that were identified, are presented. It is important to note that, within each RCA, a host of key findings are identified (contributing factors). The contributing factors identified are all important, and the key findings discussed in this section are not intended to lessen the importance of the individual findings from each individual case study. Furthermore, only six RCAs were conducted; thus, the sample size on which these key findings are based is limited.

The overall findings from the study include the following:

- A total of 67 RCL accidents/incidents were reported from May 1–October 31, 2004.
- Of the 67 accidents/incidents, 54 were collisions or derailments, and 13 were injuries not due to a reportable collision or derailment.
- Twenty-eight (64 percent) of the 44 RCL train accidents for which train accident cause code data were provided were associated with human factors cause codes.
- Almost half of the 67 accidents/incidents, 30 (45 percent), occurred between midnight and 8 a.m.
- The largest number of accidents/incidents in any 1 month, 16 (24 percent), occurred in August.
- Of the six accidents/incidents that were further examined, three collisions, two derailments, and one employee OTJ injury occurred.
- Forty-six contributing factors were identified for the six case studies; of these, 36 were probable contributing factors and 10 were possible contributing factors.
- For each accident/incident, 2 to 13 contributing factors were identified.
- The HFACS-RR taxonomy of human errors was able to support the collection and analysis of railroad accident/incident contributing factors. Given that only minor edits were made to the original HFACS taxonomy, it appears that HFACS-RR is a valid approach to supporting railroad accident/incident investigations, and it should enable future comparisons to be made with accident/incident analyses in other industries where HFACS was also used.

Key themes that emerged from the RCL accident/incident RCA include the following:

- Loss of situation awareness was a major factor in five of the six accidents/incidents. Further analysis suggests that RCL technology facilitated this loss of situation awareness in four of these five accidents/incidents by enabling RCOs to control their cuts of cars away (i.e., remotely) from the point of movement.

- Six HFACS-RR categories (26 percent) were associated with 92 percent of the 36 probable contributing factors. They were the technological environment, skill-based errors, organizational process, inadequate supervision, decision errors, and resource management.
- Eight probable contributing factors were associated with the technological environment. Four of the eight contributing factors were related to an RCO's control of a movement from a physical location away from the RCL and/or cut of cars. Three contributing factors (all were associated with one accident/incident) focused on the failure of the pullback protection system technology as part of the overall RCL system. In addition, one contributing factor was associated with the physical characteristics of the RCD itself.
- Seven skill-based errors were identified among the 36 probable contributing factors, and included failures of attention or memory.
- Organizational process was identified 6 times among the 36 probable contributing factors, and all 6 were related to inadequate practices and procedures governing RCL operations and the use of the RCL technology, including the pullback protection system.
- Inadequate supervision was identified 5 times among the 36 probable contributing factors; 4 of the 5 were related to some aspect of RCO training.
- Four decision errors were identified among the 36 probable contributing factors; half related to decisions made with regard to controlling a cut of cars.
- Three probable contributing factors were associated with resource management issues. One was related to staffing while the other two were equipment-related.
- Two specific factors that were identified—inadequate staffing and pairing inexperienced crewmembers—may be significant RCL safety issues in the future given the increase in railroad traffic, an aging workforce, and the influx of newly hired railroad employees.

Separately, analysis of operator work schedule history and sleep habits information suggests that two RCOs may have been operating with compromised alertness; however, these were possible contributing factors rather than probable contributing factors.

Based on analysis of the 36 probable contributing factors for the six RCL accidents/incidents, the following 4 critical safety issues were identified:

- *Loss of RCO situation awareness*. Loss of RCO situation awareness was identified as a factor in five of the six RCL accidents/incidents analyzed.
- *Insufficient RCO training*. Insufficient training was identified as a contributing factor among the RCL accidents/incidents. Improved training may be able to mitigate some of the skill-based and decision errors that were identified.

- *Inadequate staffing and pairing of inexperienced crewmembers*. Though these factors were identified as contributing to only one of the six RCL accidents/incidents analyzed in the study, given the increase in railroad traffic, an aging workforce, and the influx of newly hired railroad employees, these may be significant safety issues in the future, especially when combined with insufficient training.
- *Inadequate practices and procedures governing RCL operations and the use of the RCL technology, including the pullback protection system*. Inadequate practices and procedures were identified as contributing factors in several RCL accidents/incidents. Given that operating rules and practices govern most of railroading, inadequate practices and procedures can have significant consequences.

11.2 Recommendations for Future RCL Operations Safety Research

This section presents several recommendations for future RCL operations safety research and development. The first recommendation focuses on a quantitative assessment of RCL operations, while the next three address the critical safety issues identified in the study.

11.2.1 Analysis of FRA RCL Accident and Incident Data

Railroads have been providing data on RCL-related accidents/incidents since May 1, 2003. To complement the qualitative research carried out in this study, it would be beneficial to conduct extensive quantitative analyses of RCL accidents/incidents using the FRA databases to quantify the effect RCL operations are having on railroad safety. Among other challenges, data will need to be normalized to control for exposure. For example, an RCL crew is typically comprised of one to two operators, compared to generally three crewmembers in a conventional yard switching crew. Any comparisons of accidents/incidents between RCL and conventional yard switching operations should be normalized to take this difference into consideration.

11.2.2 Development of RCO Training Best Practices

Given RCO training was implicated as a safety issue in this study, research might focus on RCO training best practices across the railroad industry. Methods may include integrating instructional design methodology with real-world railroad lessons learned to generate a set of RCO training best practices that can benefit the entire industry. Research should include examination of Canadian RCO training practices, since Canadian railroads have been using RCL operations since 1989.

11.2.3 Development of RCO Training Objectives

The FRA Office of Research and Development's Human Factors Program previously sponsored the development of training objectives, syllabi, and test designs to aid in creating more uniform railroad dispatcher training programs across the United States (Reinach, Gertler, and Kuehn, 1998). This approach was well-received by the industry as a means in which FRA can assist the railroad industry in increasing safety in a non-regulatory manner. This approach, or a similar one, might be considered to assist the railroad industry in improving RCO training and making RCL operations as safe as possible.

FRA could sponsor the development of a common set of training objectives that railroads could use to base or modify their own RCO training programs in order to ensure a minimum set of core learning objectives are satisfied. The goal of the research would be to help the railroads produce competent and adequately prepared RCOs. The research would be another non-regulatory approach to increasing safety by helping the railroads to help themselves.

The product of the research could be a document that contains training objectives and other instructional design tools and assistance that railroads could adapt for their own purposes. Much like the earlier FRA-sponsored training research, this approach would be based on input from the industry, modeled after current training practices, and non-prescriptive. Railroads would be encouraged to select and adapt those components of the training objectives that are appropriate and specific to their own operational circumstances and training needs. Development of such training aids requires knowledge of instructional design methods and RCL operations subject matter expertise.

11.2.4 Development of RCL Operations Best Practices

Similar to the development of best practices for training, the railroad industry may benefit from learning from a set of RCL operations best practices. Best practices would cover U.S. and Canadian experiences with RCL operations and technology, and these would include perspectives from railroad labor, management, and FRA. Included in these best practices might be rostering methods used successfully in other industries, such as aviation, to ensure proper crewmember pairing. Structured interviews and focus groups could be used effectively to gather best practices and lessons learned.

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Appendix A.
Interviewee Background Questions

1. Name: ____

2. Position/Title: ____

3. Railroad: ____

4. Accident/Incident description: ____
____
____
____

5. Involvement in accident/incident: ____

6. Age: ________________

7. Gender: Male Female

8. Total experience working in the railroad industry: ______________________________

9. Experience working in a yard: ______________________________

10. Experience as a trainman: ______________________________

11. Experience as an engineer:______________________________

12. Experience as an RCO:______________________________

13. Experience as a supervisor (______________________________) :____________________

14. Experience as other (______________________________) :____________________

15. Immediate supervisor: ______________________________

16. Telephone # for follow-up questions: ______________________W H M

17. Second Tel. #: ______________________________ W H M

18. Best time to contact: ______________________________

Appendix B.
Operator Interview Questions

Starter questions

1. Take yourself back to the accident/incident. Get a picture in your mind. [Think about the following:] Where were you? What did you see? How did you feel? What did you smell? What did you hear? When you're ready I'd like to hear the whole story, at your pace, from the beginning. I want to hear all the details, even if they seem unimportant or you're not completely sure. [Try to be as specific as possible regarding times and locations/landmarks when describing the events for us.] Take your time. (Wright and Merrill, 2001)
2. Who else was nearby or was involved? Where were they located? What were they doing?
3. Describe the workday leading up to the accident/incident. Did you have any rest breaks the day of the accident/incident?

<u>Operator Acts</u>

1. Was your task during the time of the accident routine to you? Did you have prior experience with this task? (HFACS)
2. When do you use pitch-and-catch operations? Are there any rules that govern when and how you use it? Were you trained in pitch-and-catch operations?
3. Is there more than one way you could have completed the task? What are they?
4. Were there any distractions at the time of the accident? (H-15)
5. Were there any explicit operating and safety rules that governed your activity leading up to the accident/incident? What were they? How helpful are they? Did you take any short-cuts? Is this common?

<u>Preconditions for operator acts</u>

1. When did you work during the previous 3 days? What were your other activities during this period?
2. When did you go to sleep each of the previous 3 nights? When did you wake up? Did you feel well rested?
3. [If operator did not work any of the last 3 days…] When was the last time you worked before the accident?
4. What is your work schedule? When are your days off? When was your last vacation?
5. Were you working an unusual schedule the day the accident/incident occurred?

6. How was your workload on the day of the accident? Were there any time pressures or incentives to work faster? Was this your last move of the day?
7. What was the condition of the equipment when you began your shift? Did you have any problems with the *remote control equipment, locomotive, rolling stock, radio, yard, track, or switches*? Did you or other operators ever complain about the condition of the equipment to supervisors?
8. Describe the operating environment the day of the accident/incident—what was the weather like, temperature, noise, visibility, etc.
9. What was the mood of the other crewmember(s) before the accident?
10. Did you hold a job briefing at the beginning of the shift? What did it address? Do you hold a job briefing every day? (HFACS)
11. More generally, how would you describe the communication among you and your other crewmember the day of the accident/incident? What about communication with other crews operating in the area, and you and the yardmaster?
12. In the past year:
    a. Have you had major changes in your health (good or bad)?
    b. Have there been major changes in your financial situation (good or bad)?
    c. Have there been major changes in your personal life (e.g., separation, divorce, birth, death, changes in the health of immediate family/close friends)?

<u>Supervisory factors</u>

1. How were RCL operations introduced and implemented in your yard?
2. What was your training like? Please be as specific as you can. Was it sufficient? Who trained you? How much experience did they have?
3. Do you feel you were adequately prepared to operate remote controlled locomotives in switching yards?
4. Did you receive training in crew resource management or any other type of communication and coordination with other crewmembers?
5. Has this sort of accident/incident or problem happened before? Was it reported? Was something done to correct it?
6. How would you describe your supervision?
7. Have you ever been encouraged by a supervisor to cut corners or bend rules?
    a. Have you heard of others being encouraged to cut corners or bend rules?
    b. If rule bending occurs, is your supervisor aware of it?
8. Are you aware of your supervisor ever cutting corners, or disregarding a rule, procedure, or policy, to get something done on time, or for any other reason?

Organizational factors

1. Do you feel that staffing at this yard is adequate?
2. Has workload level recently increased in the yard? To what do you attribute this? (HFACS).
3. How is safety communicated to you?
4. How would you describe the safety culture at your railroad?
5. How do you report safety-related problems or recommendations? Are your comments received well? Is there a way for you to bring up safety-related issues without fear of retribution, such as through a safety hotline? Do you find this effective?
6. Are there any barriers to you communicating with the people above you who influence your job?
7. What contact is there between top management and yourself or other employees.
8. How would you describe labor/management relations at this yard?

Sleep and Work History Questions

1. Call Predictability: [*It is helpful to know if the call for the work shift involved in the event was expected or not*.] Was the call to report to work expected or were you called early and by how many hours? Were you called and then delayed until the actual work start?
2. Immediate Sleep History: [*It is also very helpful to know what sleep was taken during the 24 h immediately prior to the accident, as well as can be remembered. This must be obtained from the operator or the family immediately after the event.]* When did you last sleep prior to the work shift? When did you go to bed and when did you get up? If this was just a nap, did you have another major sleep period earlier on that day? When was that and for how long?
3. Other Sleep History: [*Other sleep going back before the day of the event would be helpful but probably hard to obtain.*] Do you remember how much sleep you were able to get on the previous day? Were there any unusual events that prevented or limited sleep during the day or two prior to the event (illness, family event or crisis, unusual delays in transportation to or from work, recreational activities or personal obligations, etc.)?

Sleep Habits Questions for Operator

1. Sleep on Work Days: When do you ordinarily go to bed during your work-days? When do you wake up? In other words, how long do you usually sleep during work days, and when do you sleep?

2. Sleep on Days Off: When do you ordinarily go to bed on your days off? When do you wake up? Put another way, generally how long do you sleep on your days off? Do you try to make up sleep on your days off?
3. Naps: Do you ordinarily take naps? If so, when and for how long? What is the shortest nap you take?
4. Transition time: Generally how long does it take you from the time you wake up to the time you get to work?
5. Designated non-sleep period: Do you have a set time in the day that you reserve for personal or family time, such as errands, housework, family activities or exercise? When, and how much time?

Appendix C.
Local Railroad Officer/Supervisor Interview Questions

Operator Acts

1. What should the operator(s) have done? Typically what would have happened?
2. What operating/safety/other rules, notices, special instructions, etc., govern the operator's activities just prior to the accident/incident? Can we obtain a copy of all relevant operating/safety rules, general notices, special instructions, bulletins, etc. that are relevant?
3. Did the operator violate a practice, rule or procedure? Which ones? Could you describe?
4. Is there more than one way the RCO could have completed his task? What are they?

Preconditions for operator acts

1. Describe how the RCL equipment is maintained. Are there any known problems with RCL equipment or parts?
2. Had the crewmembers worked together before?
3. Did the crewmembers get along personally?
4. How did the crewmembers get along with other crews working at the time?
5. Did anyone ever complain about working with this *RCO*?

Supervisory factors

1. When and how were RCL operations introduced at this location?
2. Are supervisors (trainmasters, superintendents, road foremen) required to be current on all RCL-related operating rules and procedures?
3. Have you ever been trained to use RCL equipment? How many local officers are RCO qualified?
4. Please describe RCO training. Who trains the RCOs? What is their background/experience with RCL operations? What is the classroom portion like? What is the OJT like? Any structure to OJT? What is involved in the check-ride to deem the RCO qualified, i.e., how do you determine when someone is qualified? Any formal checklists or other aids?
5. Do you provide crew resource management or any type of communications training to RCOs?
6. How do you track operator performance?
7. What is the performance record of the operator(s) involved in the accident? Has the employee been involved in any previous accidents?

8. Who investigates accidents/incidents, and what is involved (i.e., what is the process)?
9. How many similar accidents/incidents have happened at this yard since RCL operations were introduced? What has been done to correct the situation?

Organizational factors

1. How does the railroad communicate safety information to employees (e.g., newsletters, videos)?
2. How would you describe the safety culture at your railroad?
3. How much overtime is there at this yard? How does overtime work?
4. How would you describe labor/management relations at this yard?
5. How would you describe communication between you and your management?
6. Have you ever received pressure or encouragement from above to bend rules or cut corners?
7. Has there been a large increase or decrease in staffing or workload recently? Can you describe? To what do you attribute this increase or decrease?
   a. How many yard employees have retired in the last _____years?
   b. How many new hires have you trained in the last _____years?

Outside factors

1. How much communication do you have with the FRA? What is the nature of this communication? How often are FRA inspectors on-site?

Appendix D.
Upper Management Interview Questions

Organizational factors

1. In the past several years, has the railroad undergone a significant expansion or reduction of its operations? To what do you attribute this? Was this increase/decrease in staff or workload anticipated?
2. How would you describe labor-management relations?
3. What contact is there between carrier headquarters and yard officers?
4. Do you have a corporate safety office? What are its activities? [Who does it report to?]
5. How does the company communicate safety information to its employees (e.g., newsletters, videos)?
6. How are accidents/incidents investigated? Is there accident/incident reporting and investigation? How and to whom are accidents/incidents reported?
7. Describe the railroads safety program and management methods.
8. How does the company examine trends (good and bad) in operations and maintenance?
9. Does the company provide training in crew resource management (CRM)? What does it consist of? How many hours are devoted to it?
10. Are you aware of similar accidents/incidents in other parts of your system?

Outside factors

1. How much interaction does your RR have with FRA?

Appendix E.
Railroad Materials Checklist

The following is a checklist of railroad-provided records, reports and data that supported data collection for each RCA. Researchers used the checklist to identify relevant materials they wanted to collect; not all items on the checklist were relevant to each accident/incident that was studied.

Checklist:

- Crewmember information:
    - Time crewmembers went on-duty before accident/incident
    - HOS/work schedule records (previous 30 days) for crewmembers involved in accident/incident:
        - Date and time of call
        - Date and time on-duty
        - Date and time off-duty
    - Qualification dates for switchman (brakeman/conductor/yard foreman), hostler (if applicable), engineer (if applicable), yardmaster (if applicable), RCO, etc.—for all crewmembers involved in accident/incident
    - Dates and performance information on prior RCO training and most recent rules test for RCL crewmembers
    - Number of efficiency tests performed in last 12 months, and of these how many were related to RCL operations. What were the outcomes (# passed and failed out of total for last 12 mo, etc.)?
        - Date and outcome of most recent efficiency test? Related to RCL operations?
    - Information on any prior infractions, discipline record, and commendations
- Railroad information
    - All relevant operating and safety rules that were in effect at the time of the accident/incident
    - Copies of any Special Instructions, General Notices, General Orders, General Bulletins, Superintendent Instructions, Division special orders and instructions, etc. that supersede or augment timetable and rulebook authority, that were in effect at the time of the accident/incident. Please point out those that are particularly applicable to accident/incident
    - Copy of yard track diagram
    - Information on corrective actions taken, or that will be taken, as a result of the accident/incident

    - Overview of RCO training program received by involved crewmembers
- Accident/Incident information
    - Copy of crewmember statements and carrier report
        - Initial FRA .97 or .54 report?
    - Copy of photographs of accident/incident
    - Copy of switch list
    - Copy of RCL event recorder download
    - Review of yard surveillance video, if available
    - Equipment inspection and maintenance logs and record books
    - Equipment operating instruction manuals/guides

Abbreviations and Acronyms

AAR	Association of American Railroads
BAC	blood alcohol content
BIT	brakeman-in-training
BLET	Brotherhood of Locomotive Engineers and Trainmen
BNSF	Burlington Northern and Santa Fe Railway
BRS	Brotherhood of Railroad Signalmen
CN	Canadian National Railroad
CP	Canadian Pacific Railway
CSX	CSX Transportation
d	day
FECR	Florida East Coast Railroad
FRA	Federal Railroad Administration
FST	field service technician
ft	feet
GPS	Global Positioning System
h	hour
HFACS	Human Factors Analysis and Classification System
HFACS-RR	Human Factors Analysis and Classification System Railroad
IBEW	International Brotherhood of Electrical Workers
KCS	Kansas City Southern Railroad
min	minute
mo	month
mph	miles per hour
MRL	Montana Rail Link
MU	multiple (locomotive) units
NS	Norfolk Southern Railroad
NTSB	National Transportation Safety Board
OCC	onboard control computer
OJT	on-the-job training
PCS	pneumatic control switch

PSP	positive stop protection
RCA	root cause analysis
RCD	remote control device
RCL	remote control locomotive
RCO	remote control operator
RCZ	remote control zone
RD	receiving and departure (tracks)
RF	radio frequency
RIP	repair-in-place (track)
RRB	Railroad Retirement Board
SSI	system special instruction
T&E	train and engine
UPRR	Union Pacific Railroad
UTU	United Transportation Union
wk	week
yr	year